

20ICCC  
20GIS

8<sup>th</sup>

International  
Conference on  
Cartography & GIS

2020, Nessebar, Bulgaria



PROCEEDINGS  
VOL.1



INTERNATIONAL CARTOGRAPHIC ASSOCIATION  
BULGARIAN CARTOGRAPHIC ASSOCIATION  
UNIVERSITY OF ARCHITECTURE, CIVIL ENGINEERING AND GEODESY

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International Cartographic Association

Bulgarian Cartographic Association

University of Architecture,  
Civil Engineering and Geodesy

# 8<sup>th</sup> INTERNATIONAL CONFERENCE ON CARTOGRAPHY AND GIS

Nessebar, Bulgaria

2020

## PROCEEDINGS Vol. 1

**Editors:** Temenoujka Bandrova, Milan Konečný, Silvia Marinova

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## **8<sup>th</sup> International Conference on Cartography and GIS**

Proceedings Vol. 1  
2020, Nessebar, Bulgaria

© Editors: Temenoujka Bandrova, Milan Konečný, Silvia Marinova

© Publisher: Bulgarian Cartographic Association  
1, Chr. Smirnenski Blvd.  
Sofia, Bulgaria, 2020

**ISSN: 1314-0604**

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## INTRODUCTION

Dear colleagues,

Welcome to the 8th edition of the International Conference on Cartography and GIS in Bulgaria. The Conference is organized for the second time under the patronage of the President of the National Assembly of Bulgaria Mrs. Tsveta Karayancheva. The previous events took place in Borovets (2006, 2008), Nessebar (2010), Albena (2012, 2016), Varna-Riviera (2014) and Sozopol (2018). The conference is organized by Bulgarian Cartographic Association and University of Architecture, Civil Engineering and Geodesy (UACEG) in Sofia. Co-organizer is Military Geographic Service. The event is organized with the support of the Bulgarian Science Fund. This year, 2020 the World Health Organization announced COVID-19 outbreak as a pandemic and this was a reason that the conference was postponed to June 2021. Nevertheless, the organizing committee decided Proceedings Vol. 1 to be published in 2020 and Vol. 2 in 2021. The ancient seaside town of Nessebar, a world cultural heritage city, will welcome the participants from 14 to 19 June 2021 for the second time of the Conference's history. It is one of the major seaside resorts on the southern Bulgarian Black Sea Coast. Due to the city's abundance of historic buildings, UNESCO included Nessebar in its list of World Heritage Sites in 1983.

The organizers' aim is to collect knowledge and share experience about the latest achievements in the field of cartography and GIS with special accents for the region of the Balkan Peninsula, Europe and global aspects. Another goal is to discover and offer decisions for satisfaction of the ever increasing demands for analyses, handling and visualization of geo-spatial data in the area of science, economy, management, ecology, early warning and crises situations in smart ways coming in modern times at a national, regional and global scale.

The main topics of the conference and the Proceedings are:

- 3D Cartographic Modelling
- Cartographic Concepts in Big Data Environment
- Cartographic Visualization
- Cartography and GIS in Education
- Geoinformation for Smart Cities
- Geospatial Analysis and Data Mining
- Geospatial Information Semantics
- Geospatial Information Ontology
- GIS for Geology, Natural Sciences and Ecosystems
- GIS Technologies and Related Disciplines
- GNSS Technologies in Cartography
- Map Design and Production
- Map Projections and Geodetic Coordinate Systems
- Remote Sensing Technologies for Cartographic Purposes
- UAV Applications and New Trends
- Volunteered Geographic Information
- Web Cartography and Digital Atlases
- Seminar on Disaster Risk Reduction – Solutions and Innovations

In these years, marked by pandemic, social and natural crisis, these topics allow us to outline the hunger of our users for cartography achievements. They also show the need of businessmen, government representatives and scientists for real time cartographic representations and better SDI, GPS and GIS solutions. To deliver them, we need support and cooperation of domain specialists in different branches of the Earth sciences.

During the conference, five ICA commissions will have their annual meetings:

- Commission on Cartography in Early Warning and Crisis Management
- Commission on Cartography and Children
- Commission on Geospatial Semantics
- Commission on Map Projections
- Commission on Maps and the Internet

A two-day Seminar on Disaster Risk Reduction – Solutions and Innovations is organized by Prof. Dr. Milan Konecny, vice-chair of the Commission on Cartography on Early Warning and Crisis Management and ICA President (former) and with co-organizer Faculty of Science, Masaryk University, Brno, Czech Republic.

Special ISDE Plenary Session is organized and supported by International Society for Digital Earth.

The conference is supported by different ministries and government institutions that expect significant results to be achieved and many new projects to be started during the event. As NATO member since 2004, EU member since 2007, Bulgaria welcomes all ideas for collaboration in the field of Earth sciences. An example for such cooperation is the above-mentioned Seminar that has acquired EU dimension built around the Bulgarian and Czech combined efforts. Among the members of the Local Organizing Committee, numerous universities that specialize in the field of Cartography and GIS can be distinguished. The organizers are proud to announce that ESRI as a leader company in geo-informatics and cartography domains participate as a platinum sponsor of the event.

8ICCGIS media partners are GeoConnection, Coordinates, Remote Sensing Journal, and International Journal of Geo-Information.

World-famous scientists are invited to present keynote speeches:



Tim Trainor – President of International Cartographic Association, USA

*Beyond the SDI, the new UN Integrated Geospatial Information Framework and the Role of Cartography*



Dr. Alessandro Annoni – President of International Society for Digital Earth, Italy



Prof. Dr. Dr. h.c. Georg Gartner – Technical University Vienna, Former President of ICA, Austria

*Location-based Services: Evolution and Development*

The main international organizer of ICCGIS is the International Cartographic Association (ICA) with the exclusive supports of the President of ICA Mr. Tim Trainor, Vice-Presidents and many chairs of ICA commissions. This cooperation arouses interest among 365 authors from 30 countries.

We would like to wish all colleagues successful work, inspiring ideas for future projects about present issues and many new opportunities for improvement and collaboration in the near future.

**Prof. Dr. Temenoujka Bandrova and Dr. Silvia Marinova**

8<sup>th</sup> International Conference on Cartography and GIS

**PROCEEDINGS**  
**VOLUME 1**

# APPLICATION OF ENTITIES METHODOLOGY AND RULES FOR DESIGNING OF ANIMATED CARTOGRAPHIC ANAMORPHOSES

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## **Abstract**

*The authors analysed currently distinguished types of animated cartographic anamorphoses and proposed its classification based on 7 criteria: mathematical bases, transformed object, methods of transformation, continuity, graphic presentation, grid transformation and location of the main distortion point. The analysis of possibilities of usage of static and dynamic visual variables during process of designing of main types of animated cartographic anamorphoses allowed to formulate the tables of rules, inspired by research on entities methodology for designing spatiotemporal maps (Dukaczewski 2019). The analyses of properties of distinguished types of anamorphoses and other methods of cartographic presentation allowed to propose the rules of its potential combined usage. The authors proposed the method facilitating the design of animated cartographic anamorphoses. The analysis on utility of these maps, employing the statistical solutions and coefficients (Markowska 2018), allowed to carry out an evaluation of its effectiveness of transfer of information and utility for didactic purposes.*

**Keywords:** *Animated cartographic anamorphoses, Entities methodology of designing of spatiotemporal maps, cartographic anamorphoses classification, Static and dynamic visual variables*

## **INTRODUCTION**

Although first animated cartographic anamorphoses have appeared in the middle of the eighties of the XX century (Dukaczewski 2019), the majority of them was created during the last decade. In this period the first complex animated cartographic anamorphoses (employing more than one cartographic presentation method) were published. The number of animated cartographic anamorphoses, available at different websites is growing dramatically, but part of them made by non-cartographers is full of errors. There is no doubt, that designing the animated cartographic anamorphoses is a complex process, demanding very good knowledge of cartographic methodology. In the case of these maps the methodology has still some gaps. Despite the growing interest in producing static or dynamic cartographic anamorphoses and unquestioned methodological development, it should be stressed that till now there is no common terminology and coherent classification of these maps (Monmonier 2015, Markowska 2019). This situation makes hard to analyze and discuss the properties of different types of anamorphoses, the possibilities and limitations of application of static and dynamic visual variables during process of its designing, as well as potentialities of its combined usage with others methods of cartographic presentation. Thus, it is relatively difficult to assess the effectiveness of transfer of information by these maps. This situation implies the need for an attempt to complete the identified gaps in methodology, to propose a method facilitating the design of animated cartographic anamorphoses and to analyse the utility of these maps, employing the statistical solutions and coefficients.

## OBJECTIVES, APPROACH AND METHODS

The first aim of this research was to analyse and to synthesize the currently distinguished types of animated cartographic anamorphoses and to propose its classification. The next stage was an analysis of possibilities of usage of static and dynamic visual variables during process of designing of distinguished main types of animated cartographic anamorphoses. This allowed achieve the second aim of research - to formulate the tables of rules, inspired by author's research on entities methodology for designing spatiotemporal maps (Dukaczewski 2019). The analyses of properties of distinguished main types of anamorphoses and other methods of cartographic presentation allowed to propose the rules of its potential combined usage. Thus, it was possible to formulate the proposition of method facilitating the design of animated cartographic anamorphoses. The analysis on utility of these maps, employing the statistical solutions and coefficients, inspired by research on static cartographic anamorphoses (Markowska 2018), allowed to carry out an evaluation of its effectiveness of transfer of information and utility for didactic purposes.

## RESULTS

In English, Japanese, Korean terminology cartographic anamorphoses are called 'cartograms', while in most of the European languages the similar terms are employed for method called in English 'choropleth map'<sup>1</sup>. Till now there is no common terminology and consistent classification of anamorphoses. According to general definition in the case of these maps one feature – area or distance is distorted proportionately to the value of a given phenomenon (Faliszewska 2011). Many authors distinguish distance cartograms and area cartograms. In the sixth volume of *The history of cartography...* (Monmonier 2015) other terms for area cartograms are mentioned: 'anamorphosis', 'diagramic maps', 'map-like diagrams', 'varivalent projections', 'density equalized maps', 'isodensity maps', 'mass-distributing (pynomirastic) map projections'. Terms of many area cartograms (anamorphoses) contain the name of the algorithm or method used in their preparation. When W. Tobler (2004) wrote about computer elaboration of area cartograms, he mentioned J. Dougenik, N. Chrisman and D. Niemeyer (Continuous Area Algorithm made with Rubber Sheet Distortion method, 1985) or Gastner-Newman (Diffusion-based Method, 2004) algorithms. It is possible to find other names related to algorithms used to generate these maps (A. Markowska, J. Korycka-Skorupa 2015), e.g.: W. Tobler algorithms (Rubber-map Method of 1973 and Pseudo-cartogram of 1986), D. Dorling (Cellular Automata Algorithm, 1990; Circular cartogram, 1996), D. House and C. Kocmoud algorithm (Continuous Area Cartogram Using the Constraint-based Method, 1988). It is to mention also solutions of J. Olson (Projector method, 1976), N. Kadmon, E. Shlomi (Polyfocal projection, 1978), S. Selvin, D.W. Merrill and E.R. Close (DEMP - Radial Expansion method, 1984), C. Cauvin, F. Escobar, A. Serradj (Piezopleth maps, 1989), J. Torguson (Interactive polygon zipping method, 1990), V.S. Tikunov, S. Gusein-Zade (Line Integral method, 1993), M. Sarkar, M. Brown (Graphical fisheye views, 1997), H. Edelsbrunner, R. Waupotitsch (Combinatorial-based approach, 1997), D. Keim, S. North (Panse CartoDraw, 2001), G. Sluga (Lastna tehnika za izdelavo anamorfoz, 2004), M. Van Kreveld, B. Speckmann (Rectangular Cartogram, 2004), R. Heilmann, D. Keim, C. Panse, M. Sips (RecMap, 2004), D. Keim, C. Panse, S. North (Medial-axis-based cartograms, 2005), R. Henriques, F. Bação, V. Lobo (Carto-SOM, 2009), S. Sun (Opti-DCN and Carto3F, 2013), B. S. Daya Sagar (Mathematical Morphology-Based Cartograms, 2014), M.T. Gastner; V. Seguy; P. More (Fast Flow-Based Method, 2018). Some authors use new terms e.g. 'gridded cartogram' (B.D. Henning 2011), 'circular-arc cartogram', 'rectilinear cartogram', 'table cartogram or mosaic cartogram' (S. Nusrat, S. Koborov 2016).

For the purposes of this research authors proposed classification of anamorphoses based on 7 criteria: mathematical bases, transformed object, methods of transformation, continuity, graphic presentation, grid transformation and location of the main distortion point. The criteria are divided depending on which map class they can be referenced:

- Cartographic anamorphoses:

- A) mathematical basis,
- B) transformed object,
- C) transformed method;

- Area cartograms:

- D) graphic continuity;
- E) graphic presentation;

- Anamorphical projections:

- F) grid transformation;

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<sup>1</sup> Probably the first usage of 'continental' term cartogram was these of C.J. Minard '*cartogramme à foyer diagraphiques*' in 1851 (Friis 1974)

- Distance cartograms:
- G) the main distortion point's location.

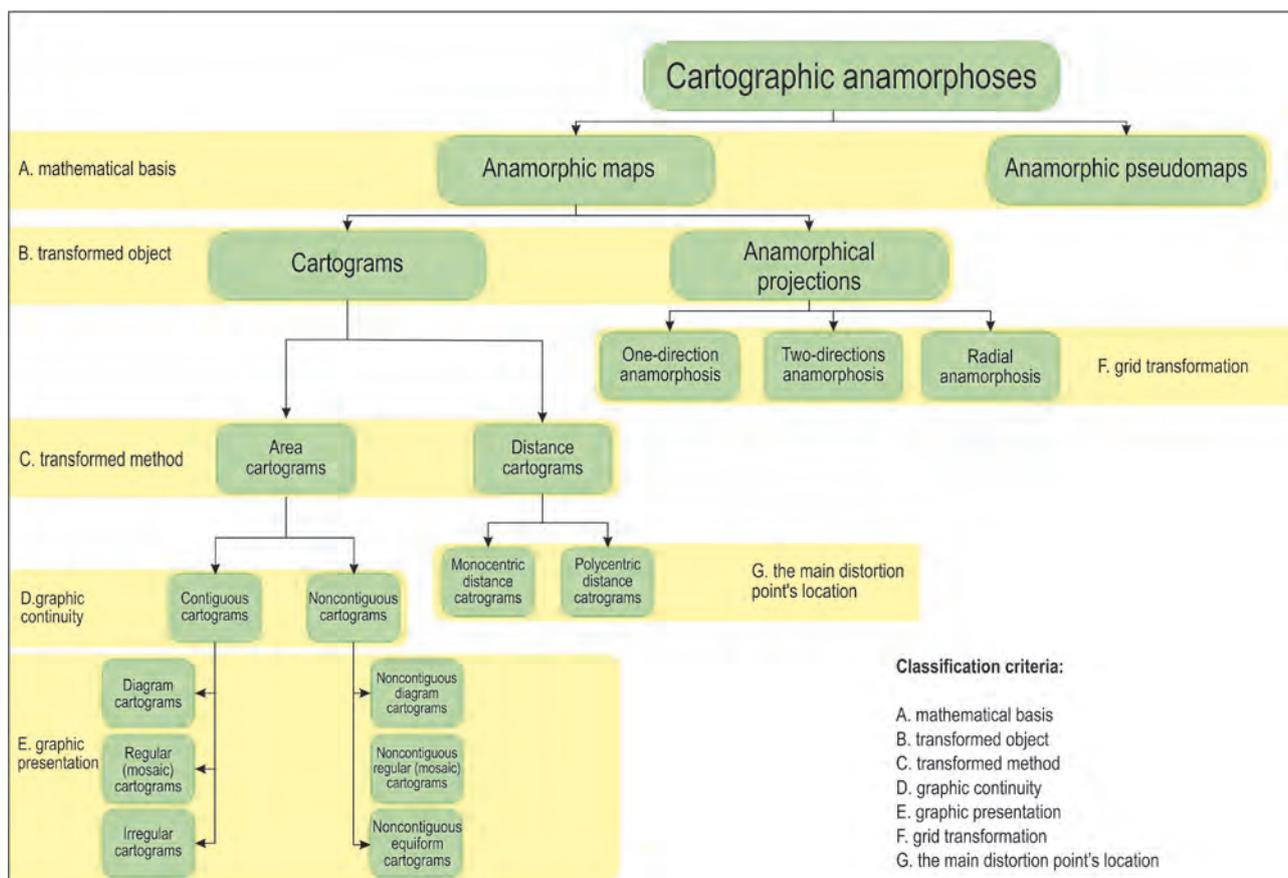


Figure 1. Classification of anamorphoses

The criterion of mathematical basis (A) - mathematical accuracy of transformation was employed according to the proposition of Z. Mudrych (1976). The term 'cartographic anamorphosis' includes all presentations having certain anamorphic features, though they may not be drawn up according to strict mathematical rules or may not maintain spatial relations. It is possible to distinguish:

- anamorphic maps (**AM**) – presentations which have been made according to mathematical and spatial rules;
- anamorphic pseudomaps (**APM**) – graphically close to anamorphic maps, but elaborated in a One of the more arbitrary way, often without clearly determined mathematical rules or rules connected to spatial relations.

The second criterion of classification – transformed objects (B) concerns the solutions of application of the anamorphic transformation applied to the cartographical grid or to the thematic contents of the map. According to this criterion it is possible to distinguish:

- cartograms (**CA**) – anamorphic maps showing the value of the thematic phenomenon employing the area of individual units (area cartogram) or the distance between selected points (distance cartogram).
- anamorphical projections (**AP**) – anamorphic maps resulting from a transformation of cartographical grid (Korycka-Skorupa, et al. 2015).

Anamorphical projections are a type of distortion projections in which cartographical grid is distorted (S. Grabarczyk-Walus 2007). In this case it is possible to distinguish:

- one-direction anamorphoses (distortion along one axis of the rectangular coordinate system) (**AP1**),
- two-direction anamorphoses (distortion along two axes) (**AP2**),
- radial anamorphoses (distortion in radial directions from a given central point) (**APR**).

Taking into the consideration the criterion of transformed method (C) it is possible to distinguish anamorphoses in which the changes in the area of base units or distances between selected points can be introduced (Olson 1976). This way two classes of cartograms can be proposed:

- area cartograms (**CAA**) – maps on which the area of individual spatial units is changed depending on the value of a phenomenon;
- distance cartograms (**CAD**) – maps on which the distance between selected points is changed depending on the value of a phenomenon.

In the case of distance cartograms, according to the location of the main points of distortion it is possible to distinguish:

- monocentric distance cartograms (**CADm**) – maps on which the thematic information is shown by the distance between the central point and given points (point 4a, figure 2a);
- polycentric distance cartograms (**CADp**) – maps on which the value of phenomenon is shown by distance between a subsequent pair of points in a given network (point 4b, figure 2a).

Using spatial continuity(D) as a criterion of classification of area cartograms two classes can be proposed:

- contiguous cartograms (**CAAC**) – area cartograms on which spatial continuity is preserved, which means that base units have not been separated (points 5a–7, figure 2a, 2b);
- noncontiguous cartograms (**CAAN**) – area cartograms on which spatial continuity is broken, which means that base units have been separated (points 8 – 10, figure 2b).

The last criterion of classification refers to the shape of base units (E). This aspect can be considered in both contiguous and noncontiguous cartograms. Looking at the shape of base units contiguous cartograms could be divided into:

- contiguous diagram cartograms (**CAACD**) in which units of reference have been substituted by simple geometric figures, e.g. squares, rectangles, circles (e.g. Dorling cartogram, 5c, figure 2b);
- contiguous regular (mosaic) cartograms (**CAACR**) (point 6, figure 2b) in which base units correspond in shape to spatial units, but their borders are geometrized, most often build of segments;
- contiguous irregular cartograms (**CAACIR**) (point 7, figure 2b) in which base units correspond to the shape of statistical units, their borders are not geometrized, the shape of units depends on the distortion algorithm applied.

In the case of noncontiguous cartograms it is possible to distinguish:

- noncontiguous equiform cartograms (**CAANE**) (point 10, figure 2b) which preserve the shape of spatial units;
- noncontiguous diagram cartograms (**CAAND**) (point 8, figure 2b) non preserving the shape of spatial units;
- noncontiguous regular cartograms (**CAANR**) (point 9, figure 2b), in the case of which the shape of base units corresponds to spatial units, but their borders are geometrized, often built of segments.

The next stage was an analysis of possibilities of usage of static and dynamic visual variables during process of designing of distinguished main types of animated cartographic anamorphoses. Authors have employed the results of previous research on evaluation of the combined application of static and visual variables, sound variables and related methods of cartographic presentation for 8 age group of users<sup>2</sup> (Dukaczewski 2019, 2016). The result was table of rules, including information on employed combination of static visual variables (and dynamized static visual variables), dynamic variables and sound variables, related methods of presentation as well as potential usefulness of these combinations for different groups of users. This table of rules is available as appendix 1 at [http://www.igik.edu.pl/upload/File/dr-dariusz-dukaczewski/20\\_Appendix1.pdf](http://www.igik.edu.pl/upload/File/dr-dariusz-dukaczewski/20_Appendix1.pdf).

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<sup>2</sup> 4-6, 7-9, 10-15, 16-19, 20-30, 31-60, 61-80, over 80 years

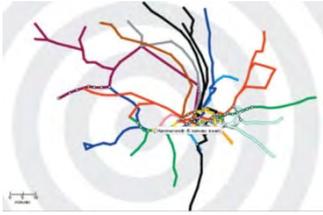
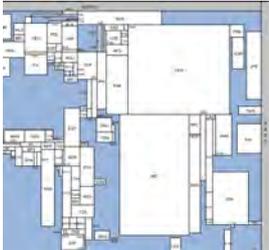
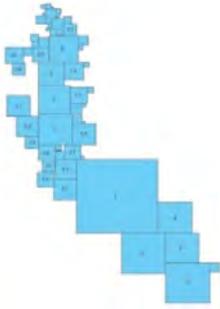
No	Cartographic anamorphoses	Example	Information and source
1.	<i>Anamorphic maps (AM)</i>		
2.	<i>Anamorphic pseudomaps (APM)</i>		
3.	<i>Anamorphical projections</i>		Topographic map with two points of anamorphical projection (Grabarczyk-Walus 2007).
<i>Cartographic anamorphoses / Cartograms (CA)</i>			
<i>Distance anamorphoses / Distance cartograms (CAD)</i>			
4a	<i>Monocentric distance anamorphoses / Monocentric distance cartograms (CADm)</i>		London tube (time scale) <a href="http://www.tom-carden.co.uk/p5/tube_map_travel_times/applet">http://www.tom-carden.co.uk/p5/tube_map_travel_times/applet</a>
4b	<i>Policentric distance anamorphoses / Policentric distance cartograms (CADp)</i>		Distances between Warsaw metro stations expressed in travel time (fragment) (Korycka-Skorupa et al. 2015)
<i>Area anamorphoses / Area cartograms (CAA)</i>			
<i>Contiguous anamorphoses / Contiguous cartograms (CAAC)</i>			
<i>Anamorphic diagrams / Diagram cartograms (CAACD)</i>			
5a	<i>Rectangular anamorphic cartodiagrams / Rectangular cartograms (CAACDr)</i>		World population in 2006 (fragment) <a href="https://www.win.tue.nl/~speckman/Cartograms/WorldCarto.html">https://www.win.tue.nl/~speckman/Cartograms/WorldCarto.html</a>
5b	<i>Square anamorphic cartodiagrams / Square cartograms (CAACDs)</i>		Population of the counties of the state of California <a href="http://www.ncgia.ucsb.edu/projects/Cartogram_Central/types.html">http://www.ncgia.ucsb.edu/projects/Cartogram_Central/types.html</a>

Figure 2a. Examples of cartographic anamorphoses (part 1)

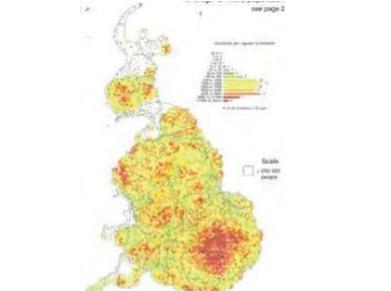
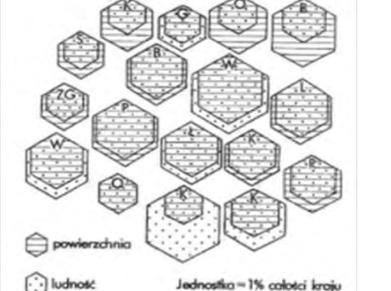
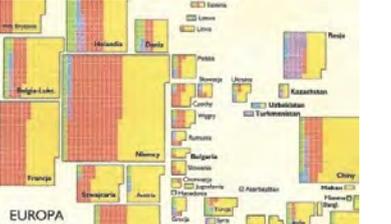
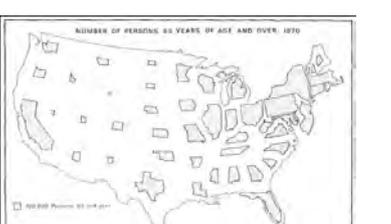
No	Cartographic anamorphoses	Example	Information and source
5c	<i>Dorling cartograms (CAACDd)</i>		Population of counties of Britain (Dorling 1995) <i>A new social atlas of Britain</i> , Wiley, Chichester
6.	<i>Regular anamorphoses / Regular cartograms (CAACR)</i>		Infant mortality in North Carolina in 1991. The area of counties is the number of births (Meade, Earickson 2005) <i>Medical Geography</i> , New York: The Guilford Press
7.	<i>Irregular anamorphoses / Irregular cartodiagrams (CAACIR)</i>		World population in 1500. Regions of the World are distinguished by colors. <a href="http://www.worldmapper.org">www.worldmapper.org</a>
<i>Noncontiguous anamorphoses / Noncontiguous cartograms (CAAN)</i>			
8.	<i>Noncontiguous anamorphic cartodiagrams / Noncontiguous diagram cartograms (CAAND)</i>		The area of hexagons is proportional to the population and area of voivodeships in Poland in 1969 (Ratajski 1989), <i>Metodyka kartografii społeczno-gospodarczej</i> , Wydanie II, PPWK, Warszawa – Wrocław
9.	<i>Noncontiguous regular anamorphoses / Noncontiguous regular cartograms (CAANR)</i>		Export of goods (fragments) <i>Nowy atlas geograficzny. Gimnazjum</i> , 2001, Demart, Warszawa
10.	<i>Noncontiguous equiform anamorphoses / Noncontiguous equiform cartograms (CAANE)</i>		Population over 65 in the United States (Olson 1976) <i>Noncontinuous Area Cartogram</i> , The Professional Geographer, Vol. 36, no 4

Figure 2b. Examples of cartographic anamorphoses (part 2)



The advent of complex cartographic animations employing anamorphoses together with other methods of cartographic presentation, noticeable more intensely from the beginning of 2010-ties<sup>3</sup>, convinced authors to carry out an analysis on possibilities and limitations of combined usage of main cartographic anamorphoses with other main cartographic methods of presentation. The resulted table (figure 3) demonstrates the possible and conditional solutions of designing complex cartographic animations employing cartographic anamorphoses.

Using the results of previous research (A. Markowska 2018, 2019; Dukaczewski 2016, 2019) the authors have proposed the method facilitating the design of simple and complex animated cartographic anamorphoses (figure 4). The first stage is a definition of the goals of the cartographic animation, data compilation and analysis, as well as identification of the age of group of potential users (using the rules defined in five tables of the appendix 3, available at [http://www.igik.edu.pl/upload/File/dr-dariusz-dukaczewski/\\_92\\_Appendix3.pdf](http://www.igik.edu.pl/upload/File/dr-dariusz-dukaczewski/_92_Appendix3.pdf)). The next stage is a definition of the organization of type and organization of the animation. To do it it is necessary to define the organization of N sub-animation by identification of the entities, its measurement level and type, as well as to define the type of changes and to choose the type of animation, using typology of Dransch (1995), Block (1999) and Dukaczewski (2003). Then it is possible to select the combination of the method of cartographic presentation for animation or N-subanimation (and N-1 subanimation) employing typology of Korycka-Skorupa (2002), Dukaczewski (2003) and figures 2a, 2b. Verification of this choice can be done with table of rules of Dukaczewski (2009) and figure 3. The next stage is a choice and verification of static visual variables (including dynamized variables, employed for presentation of dynamic processes). This allow to choose the graphic form for the dynamized visual variable(s), definition of their relations with dynamic visualisation variables (& optional sound variables), as well as to select the method of cartographic presentation. These tasks can be carried out employing the appendix 1 available at [http://www.igik.edu.pl/upload/File/dr-dariusz-dukaczewski/\\_20\\_Appendix1.pdf](http://www.igik.edu.pl/upload/File/dr-dariusz-dukaczewski/_20_Appendix1.pdf). The verification of the correctness of the choice of dynamized visual variable(s), other static visual variables and dynamic & sound variables, as well as verification of the correctness of selected method(s) of cartographic presentation should be carried out using the tables of rules at [http://www.igik.edu.pl/upload/File/dr-dariusz-dukaczewski/\\_92\\_Appendix2.pdf](http://www.igik.edu.pl/upload/File/dr-dariusz-dukaczewski/_92_Appendix2.pdf). These actions should allow to realization phase of the animation (or N –subanimation in the case of complex animation).

Due to the specificity of perception of cartographic anamorphoses the vital problem is the utility of these maps for users from different age and education groups. Authors are preparing the research concerning perception of simple and complex animated cartographic anamorphoses. A. Markowska has carried out the research on utility of static area anamorphoses / area cartograms for educational purposes in secondary schools in Poland (Markowska 2018, 2019a, 2019b). The tests made in different types of secondary schools, taking into the consideration the groups of pupils of different level and profile allowed to formulate hypotheses, verified employing the logistic regression of dichotomous data, one-way analyses of variance (one-way ANOVA) and chi-squared test ( $\chi^2$  test). These research has proved that regular anamorphoses / regular cartograms were the most useful for presentation of socio-economical phenomena in school geography. The time of lecture of these maps is similar like in the case of traditional maps and the level of correctness of lecture is better in the case of pupils of better geographical knowledge. The tests have proved that regular anamorphoses / regular cartograms and anamorphic diagrams / diagram cartograms were more comprehensible than irregular anamorphoses / irregular cartodiagrams, especially for less geographically skilled pupils.

## CONCLUSION

The aim of this research was the following to contribute to the discussion about the possibilities for (and limitations on) the design of animated maps that are better adapted to the needs of users belonging to different age groups, through the application of solutions based on the choice of variables specifically tailored to a given user age group. Another objective was to further advance the cartographic animation methodology itself, especially concerning the usage of animated anamorphoses. The analysis allowed to distinguish the main types of animated cartographic anamorphoses and to propose its classification. The analysis of possibilities of usage of static and dynamic visual variables for building the distinguished main types of animated cartographic anamorphoses allowed to formulate the tables of rules, which can be employed during the process of designing of animated cartographic anamorphoses. The analyses of properties of different types of anamorphoses and other methods of cartographic presentation allowed to propose the rules of its potential combined usage. Employing the proposed tables of rules and results of previous research it was possible to formulate the proposition of method facilitating the design of animated cartographic anamorphoses. The analysis on utility of static anamorphoses, carried out by A. Markowska (2018, 2019a, 2019b) has proved that these maps (especially regular

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<sup>3</sup> One of the first such animations were: *East Asia Internet Users 1993 – 2008*, Han-Teng Liao, 2010; *General Election 2005 – 2010*, B. D. Hennig (SASI Group, University of Sheffield), 2010; *The changing colors of America 1960 – 2000. Election results by county*, M. Gastner, C. Stalizi, M. Newshaw (University of Michigan), 2010; *Global Annual Precipitation [per month] 1950 – 2000*, B. D. Hennig (University of Sheffield), 2011

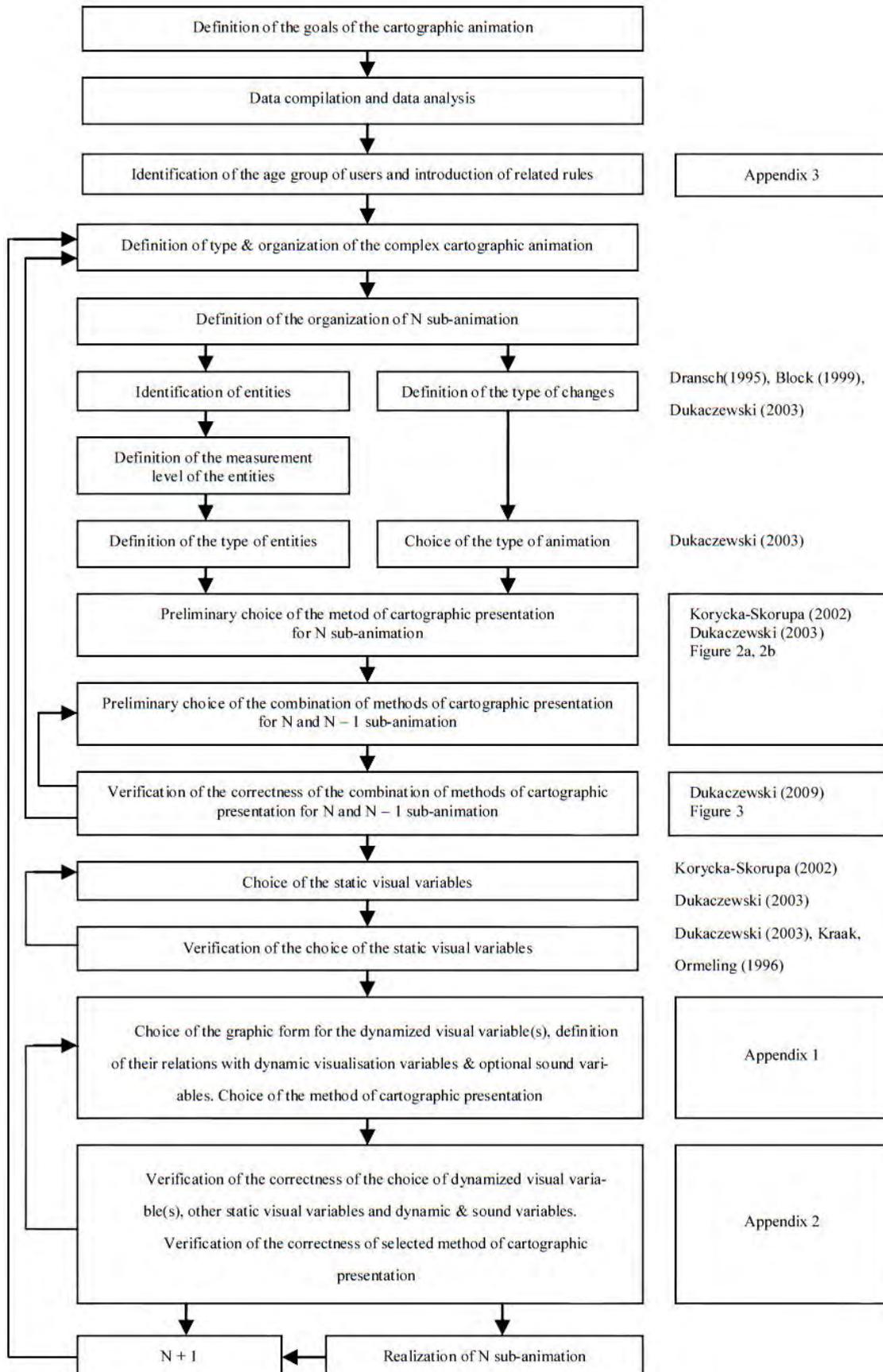


Figure 5. Entities – polystaimic method of design of complex animated maps employing cartographic anamorphoses

anamorphoses / regular cartograms) are useful for educational processes in geography, as well as other methods of cartographic presentation. It should be emphasized, that due to the specificity of animated cartographic anamorphoses it is necessary to carry out the research on perception of these maps by users of different age groups.

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## DIGITAL RECONSTRUCTION OF A UNIQUE, GIANT GLOBE

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### **Abstract**

*The 127.5 cm diameter manuscript globe (1 : 10 million) of Perczel from 1862 is among the largest ones from Central Europe. This sphere suffered severe damage during the wars of the 20th century. A restoration was carried out in the 1970s, but due to improper solutions it lost further information. The recent reconstruction project included: creating a digital facsimile of this globe to archive its present state; finding the possible sources that were used for compiling the globe; reconstructing the globe in digital form based on the digital facsimile globe, original source materials and contemporary descriptions; creating a renewed copy of the globe. In 2019, the Department of Cartography and Geoinformatics of Eötvös Loránd University continued the research and production to re-create Perczel's globe in a half-year project. The last phase of the project included the considerable redaction of the 72 half-gores of the globe-map, especially the place-names and linear features.*

**Keywords:** *contemporaneous facsimile; digital virtual reconstruction; globe*

### **ANTECEDENTS**

The manuscript globe made by the Hungarian László Perczel in 1862 was a unique product concerning its size, delicate drawing, and richness of place names. Although its former beauty can be imagined, but its present state – due to the physical damage and the darkening of the protecting lacquer coat – does not show its original values. Therefore, the globe cannot be exhibited for the public and is only known by few professionals even in Hungary.

Right after the establishment of the Virtual Globes Museum (VGM) in 2007 (<http://terkeptar.elte.hu/vgm>) was born the plan (Márton 2008a) to register the actual state of the globe for the VGM (Márton 2008b) and make the *contemporaneous copy of the globe* in digital form by 2012, which would celebrate the 150th anniversary of the giant globe made by László Perczel in 1862. This project was undertaken by the staff and students of the Department of Cartography and Geoinformatics at Eötvös Loránd University (ELTE).

In May 2008, nearly 900 high-resolution photographs were taken of the original globe kept in the Map Room of the National Széchenyi Library (OSZK). After processing these photos, the 3D model showing the present state was made for the VGM. In this way, *the digital copy registering the actual state* of Perczel's globe was completed (VGM ID 76). At the same time, the photos made it possible to make high-resolution spherical segments (gores) in open jpg format.

These gores were processed by students, and the *restored, digital contentual copy* of the globe was born by 2012 (VGM ID 110). József Sziládi, a map editor of the one-time Cartographia Company was unselfish to use these segments to make the shaded relief for almost the whole area of the globe (without any financial compensation!).

Altogether, five master theses and six BSc theses were made on the processing of the globe. Five papers were published in Hungarian or English (Gede M., Márton M., Ungvári Zs. 2011), some of which (Márton 2012b) were also presented at conferences (Gede M., Márton M., Ungvári Zs. 2010; Márton M., Gercsák G. 2011).



Figure 1. A vision in 2012: the state of today (left) and the dream (middle) using the completed digital contentual copy (VGM ID 110) and the reconstructed copy in 2019

## FACSIMILE OR COPY

In cartography, a *facsimile* is generally considered a new edition of a cartographic document (manuscript, colour-printed or subsequently coloured map, atlas, terrestrial or celestial globe, etc.) published in the past, which shows the actual state of the reproduced object *in the time of the new edition* and includes all those changes – wears, tears or other damage, discolouration, etc. – that the object had suffered from its publication until its reproduction. There are several ways of making a facsimile. The most usual and fastest method is taking photographs of the original and, after colour separation, the object is re-printed (*traditional facsimile*). It is also possible to scan the document at high resolution, which (*digital facsimile*) then can be studied in print or on the screen. In this case, we can remove the damage or discolouration (*digital restoration*) particularly when several copies of the original publication are available. Another way is reconstructing the state of the object as it was in the time of its making, for instance by recreating the object by using the original technology of making (*technological facsimile*). However, it is not necessary to reproduce the damage that happened to the object during the times! Using computer technology, it is possible to redraw and recolour the document and to rewrite the place names with modern fonts. In this case, the product is “only” a *digital contentual facsimile*. The *facsimiles* of the same document made by various methods may not always be identical (Gercsák–Márton 2010).

A *facsimile that registered the state* of Perczel’s globe was made in 2008. Its lower-resolution copy was placed in the VGM to make it available for the public on internet. Up to 2012, the Department worked on making a *contemporaneous facsimile* to reproduce the supposed state of the globe at the time of its making. The main source of this work was a detailed description of the globe by Zoltán Ambrus-Fallenbüchl (1963), when the “unrestored” globe was one hundred years old.

In 1962, the hundred-year old globe – according to Ambrus-Fallenbüchl – had “fine lacquer coating”. However, after an unprofessional “restoration” in the 1970s, when a protecting lacquer layer was added, the coating became so much yellow and brown that the originally red settlement symbols and place names almost completely faded, many of them became illegible.

## THE CONTINUATION

There was no substantial advance in project in the years after 2012. However, in 2015, talks started with a possible sponsor to continue and complete the project. The negotiations speeded up in 2018 and the parties arrived at an

agreement, though the sponsor did not cover itself. Finally, Mátyás Márton was charged to carry out the cartographic tasks to prepare the task for physically recreating Perczel's globe.

The contract included the following tasks:

- Preparation of 10-degree wide half-gores printable on A0 sheets for the northern and southern hemispheres.
- The inclusion of the high-resolution photos of the original globe transformed into projection in the files of the gores.
- Inclusion of the shaded relief made by József Sziládi in 2008–2012 and changing the shaded relief into shades of grey.
- Exporting the cdr files of the above elements into pdf, their transfer to a graphic artist named by the firm.
- Replacing, digital restoration and partial reconstruction of the damaged parts (linear and areal map elements, place names) of the 132 cm-diameter globe.

In short, the task was the digital restoration and digital reconstruction of the globe. Already at the beginning of the work, the original photos of the globe had to be handed over to the graphic artist to design the fonts that should be the same as that of the handwriting of Perczel. There came further tasks too, such as generating additional files that included the labelling of scattered names fitted on curves, arranging the amendments of graphic and name elements in separate files.

A uniform sheet system had to be established at the beginning to guarantee quick information exchange and referencing. The 10-degree wide sheets are identified in the Ferro system:  $-180 - 0 + 180$  degrees, marked by 01N, ..., 36N, and 01S, ..., 36S (Márton 2019)

## PREPARATION OF THE RESTORED, DIGITAL, CONTENTUAL FACSIMILE

In this case, *digital restoration* meant that the linear and areal elements covered by thick “protecting” lacquer coat that faded to yellow and brown had to be redrawn according to the original colours. The place names, which were handwritten, had to be spelled out and registered according to their original form. The geographical names and inscriptions are written by characters standing very close to Perczel's handwriting.

During restoration, it is forbidden to “find out” illegible names or any other graphic elements. These can only be completed if contemporaneous source maps justify our idea. This will lead to a *contentual facsimile*, the colours and graphical picture of which are like the image formed after Ambrus-Fallenbüchl's description. However, the illegible elements are still missing or only partly displayed. For instance, the illegible characters in place names are shown by question marks.

The major part of the digital restoration had already been completed by 2012. The next step was to check and correct the work done until this date. Let us take two examples of errors:

- The gore showing the coastline of Antarctica (sheet 28S) created by assembling the high-resolution photos taken of the original Perczel's globe was incorrect, because the same photo was mounted to each other. That is, the same area was shown twice. The student working on this area “solved” the problem: simply and literally “cut” the Gordian knot by fitting the coastline of the joining sheet and “found out” how the coastline had looked drawn by Perczel in 1862 (Figure 2).

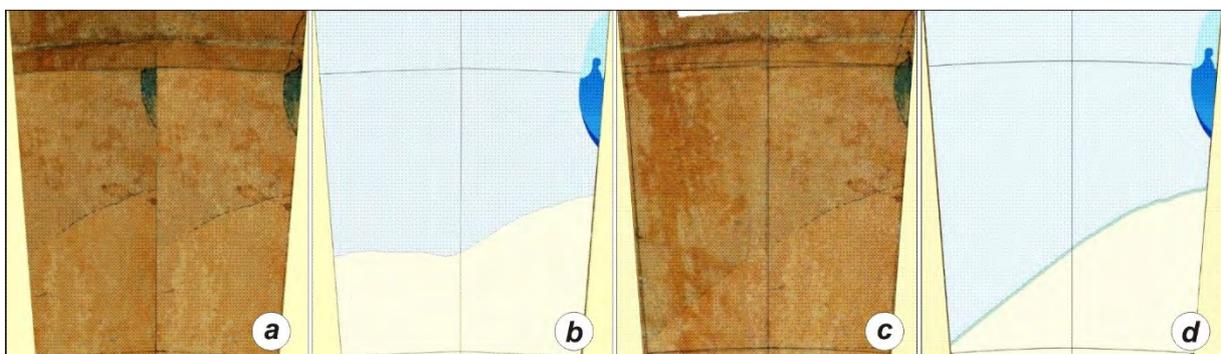


Figure 2. Error of the coastline on Antarctica: a) Wrong assemblage; b) Graphical element of the student's inventiveness; c) Corrected assemblage; d) The new coastline

- We could not open the file of an archived sheet (34N) of Asia. We managed to make the graphical content based on interim materials; the place names were relatively quickly supplemented with the help of a bitmap extracted from the restored, digital content facsimile placed in the VGM in 2012 (Figure 3).

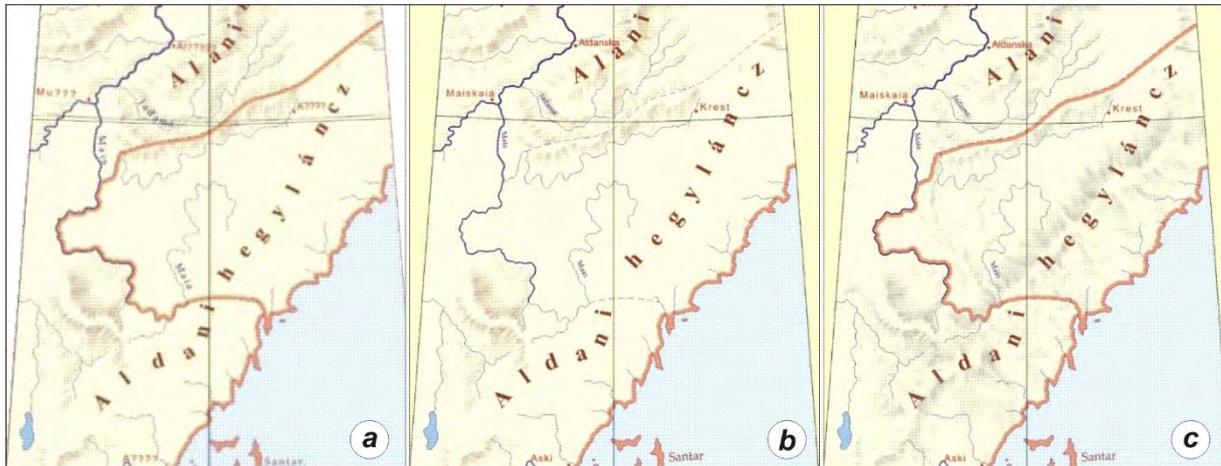


Figure 3. An extract of sheet 34N: a) State of the area in the VGM in 2012; b) Recovery; c) Completion with hill shading (on the area of Aldani hegylancz)

## DIGITAL RECONSTRUCTION

Usually, in the case of printed maps or globes, reconstruction means that the damaged parts are completed by using photographs taken of an existing copy of the same edition. However, Perczel's globe is manuscript product in one copy only, this method was not available for us.

Large parts of the surface of the sphere are not only worn, but they are also physically damaged. This is particularly true for a 5 to 10-degree wide stripe along the Equator. Probably, the blast of explosions during bombings in the second world war caused the serious defects along the Equator: the globe was almost torn into two, into a northern and a southern part. Similar defects are also observable in the western regions of Africa or in smaller areas such as in the third of the western part of Kamchatka or parts in the western and north-eastern regions of South America. In addition to the mentioned defects mainly on the continents, there are large damaged areas also on maritime regions, for instance around the Indian Ocean (Figure 4).

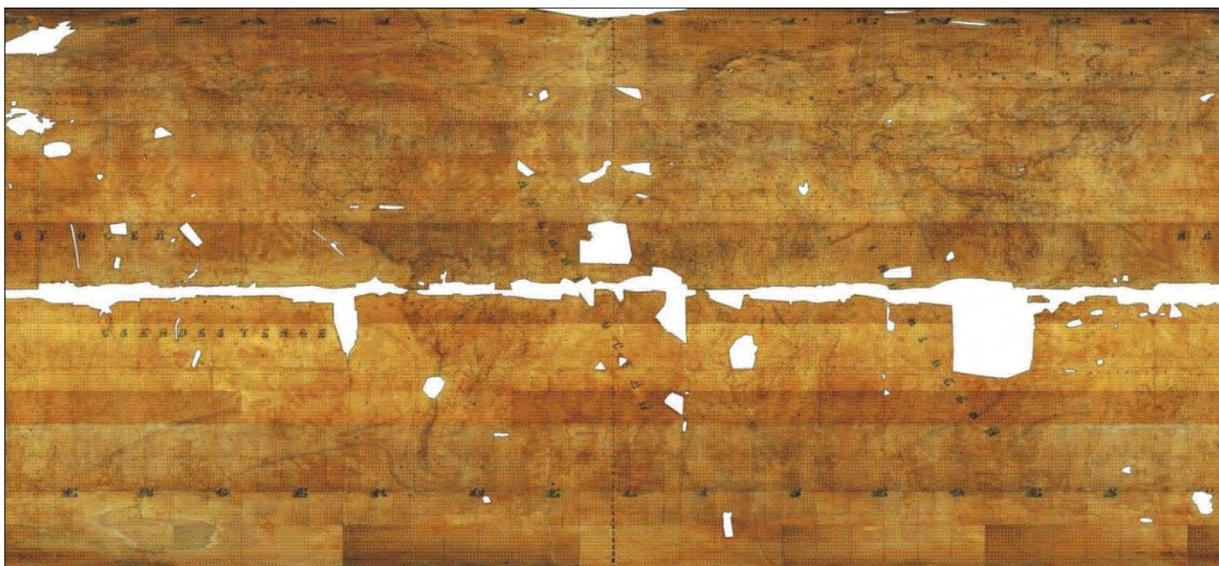


Figure 4. Highlighted defects on the map of the globe in Mercator's projection

Digital reconstruction means the recreation of the content of the damaged parts, where no or only fragmentary map elements can be seen. During the "restoration" in the 1970s, the seriously damaged parts were only indicated by completing the graticule without any map content. This is true for the continents and the oceans too.

József Sziládi, who generously and excellently made the professional hill shading of relief between 2008 and 2012, could not take upon himself the task of completing the remaining parts in 2019 due to the deterioration of his eyesight. This task had to be carried out “in the house” (Figure 3c).

## SOME IMPORTANT SOURCES USED FOR RECONSTRUCTION

Due to the short of time, it was not possible to carry out an in-depth investigation and study of sources that were supposed to have been used by Perczel. We had to work with the materials (atlases) available in the Map Collection of the Department of Cartography and Geoinformatics of ELTE. The following atlases published in the time of Perczel were of great help:

*Universal-Handatlas (Heinrich Berghaus). Glogau, 1859 (A/61)*. Perczel surely used the atlas maps for designing his globe. This statement is justified by many agreements in the graphics, and almost complete take-over of geographical names from some map sheets (often retaining the German spelling). It can be said with absolute certainty that this was one of the essential sources. Naturally, it is also possible that he used a former edition of this atlas! For instance, the “fünfte Auflage” from 1857 or even an earlier edition.

*Atlas complet du précis de la géographie universelle. Paris, 1812 (A/275)*. It can also be established that Perczel used this atlas or rather the map sheets of one of its later editions. This atlas was of great help when discussing the geographical names of Africa and the archipelago in the South Pacific Ocean.

*Galetti Egyetemi Világrajza (Falk Miksa). Pesten, 1857 (A/177)*. This atlas was published not only in the time when Perczel made his globe but – this is very important – in Hungarian. Perczel himself aimed at the Hungarian usage of geographical names. The atlas is a geography book of the world richly illustrated with maps. It would deserve a special study of comparing the geographical names in the text and in the maps with the names shown on Perczel’s globe.

In addition to the works briefly described above, naturally there were several contemporaneous and modern atlases that helped our work.

## THE CALENDAR FRAME

The calendar frame was also processed in 2019: the high-resolution photos were taken by Zoltán Nemes, the digital assemblage was done by Mátyás Gede (Figure 5).



Figure 5. The assembled calendar frame or horizon ring (a) and an extract (b)

The calendar frame was as damaged as the globe. Perczel indicated 32 points of the compass on it. The Hungarian language usually names the four cardinal points (N, E, S, W), the halving second-order directions (NE, SE, SW, NW) and by further halving the third-order directions (NNE, ENE, etc.). However, Perczel indicated the fourth-order directions too. The modern Hungarian language does not use them. It would be interesting to know how these directions were named in Hungarian.

## IS 132 CM 132 CM?

In the Hungarian literature, one can often read after Ferenc Fodor’s book on Hungarian map making that “Perczel’s globe is of 1 million scale and 132 cm diameter”. (All authors have noticed and corrected the mistake, because the scale is 1 : 10 million.) However, all Hungarian and foreign authors writing about Perczel’s globe repeat the 132 cm diameter. Perczel was a student of the military academy (K. K. Militärtechnische Hochschule) in Vienna between 1841 and 1845 (Ambrus-Fallenbüchl 1963), where he certainly had learnt the data of Bessel’s ellipsoid in the courses on

surveying (Timár 2018): from this ellipsoid it comes that the equatorial diameter of the 1 : 10 million scale globe must be 127.5 cm (the polar diameter is 127.1 cm). Indeed, recent measurements show that the diameter of the globe is 127.5 cm!

## RESULTS OF THE CARTOGRAPHIC PROCESSING IN 2019

Study of the 72 segments in cdr format one by one meant their comparison with the bitmaps compiled from the photographs taken of Perczel's globe and transformed into spherical projection, that is the correction and completion of graphical elements and geographical names (Figure 6). Altogether, 2872 graphical elements and 3252 place names were completed and amended. New files containing the hill shading were created: 35 files for the northern hemisphere and 25 for the southern hemisphere. (Some of these files of hill shading are composed of two parts for the segments on both hemispheres.) Finally, 77 hill-shaded areas were converted to grey and fitted in the above files; further, hill shading was added to 318 areas mostly on the damaged parts of the globe (Márton 2019).

These results were used to create the third version of the virtual facsimile series of Perczel's globe, namely the *reconstructed, digital, contentual facsimile* (VGM ID 153).



*Figure 6. Working on the cartographic part-project with Archiflex Studio's machines set up by Béla Kovács, assistant professor of the Department, 2019*

## THE PHYSICAL REBIRTH OF PERCZEL'S GLOBE IN 2019

Two major tasks were executed to create a facsimile copy of the object:

- The maps of the globe had to follow the original manuscript as accurately as only possible, which was achieved by using and processing 72 half-segments that were digitally restored and reconstructed at the Department (Figure 7);

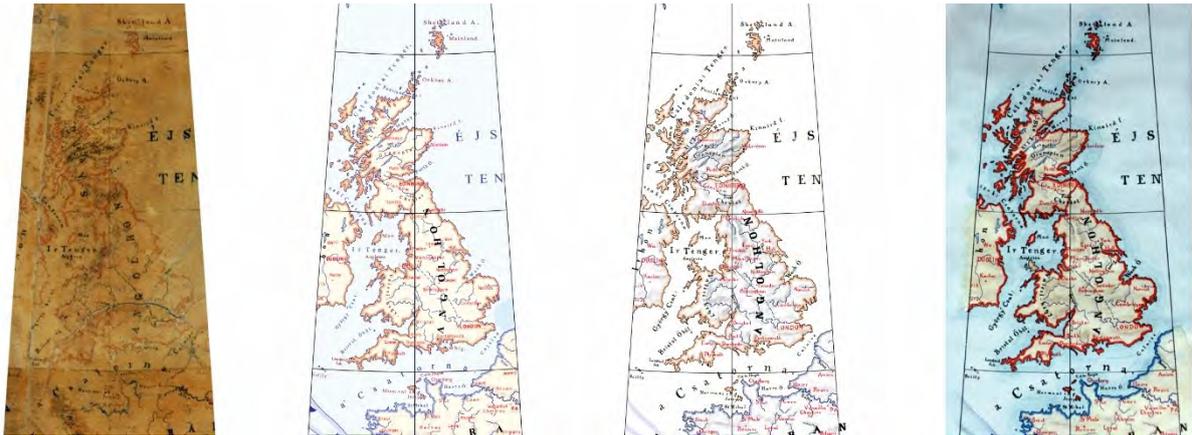


Figure 7. Steps of making the maps of the globe: a) Extract from the original globe; b) Contentual facsimile at ELTE; c) Print after typographic and graphical processing; d) Testing the manual colouring

- In addition to manufacturing the large ball in its original size (127.5 cm diameter!), the true copy of the original wooden stand of the globe had to be fabricated together with the calendar frame and the hand-wrought and engraved copper meridian.

Fortunately, the participants – who represented various disciplines – in this complex project cooperated in perfect harmony. The somewhat longer than half-year joint work was organized by András Lente, a member of the Archiflex Studio. The artistic leader was Zsuzsanna Lente, a certified restorer of objects. Barbara Kecskés design-graphic artist carried out the graphic supplementary work on the digital cartographic tasks, which were coordinated by Mátyás Márton, professor emeritus. The printing was done by MPB Hungary Kft., the professional paperwork (manual colouring, mounting, lacquering) was also done by Zsuzsanna Lente. The ball was manufactured by model builders, Géza Csizmazia and Károly Takács. Metal-working on the copper meridian ring was done by István Fóris, ornament-smith, the engraving by András Nagy. The wood-work of the ball was made by Gyula Bodnár, certified wood-restorer.

## MAKING THE MAP OF THE GLOBE AND THE DRAWING OF THE CALENDAR FRAME

The original character of the manuscript had to be reflected on the print by the writing of the place names and handwriting of the lines, broken lines, and arrows.

Handwriting is irregular, and there is no font that could reproduce this irregularity of characters: the printing fonts are always regular even if they imitate handwriting. After studying the existing letters on the original globe, it turned out that four font types can be used to reconstruct the original way of writing fairly well.

After four letter types were graved and converted for computer use, all textual elements in the digital material (altogether 72 half-segments) had to be changed and replaced by the appropriate font.

Much time was spent on searching the paper and printing technology that would comply with all the requirements. The following aspects had to be considered: the paper had to be free of acids, not too smooth, hygroscopic, relatively light, cross-fibred, resistant to pressure and endure aquarelle colouring. The print had to be durable, with sharp contours, light should make it bind faster, and water-colour painting should not solve it. Considering all these and checking numerous proofs the decision was to use UV printing and 110 g/m<sup>2</sup> paper made of cotton fibre.

After the first proofs it became clear that the prints should have black, blue, and red colours (the settlement names were written in red by Perczel). The colour of the boundaries should be reduced to 30–50% just to make it visible, and everything else should be manually coloured. Before the final printing started, we had to determine to what extent the stretching of the paper would influence the print after mounting. This percentage value was used for the deformation of the material to be printed and for deciding the size of the prints.

The aim was to paint the area colours by hand. The unique manual painting gave spirit to the surface of the print.

The water surfaces (oceans and seas) were painted in aquarelle when the maps were in flattened state so that this large, more than 3.5 m<sup>2</sup> surface look real. For this, the description of the globe by Zoltán Ambrus-Fallenbüchl in 1963 was taken as basis. We also used the digitally cleaned photos taken of the original globe, which brought out the bright blue colour of seas at some places. The colours of the lands were also painted before mounting the maps.

The mounting of gores required meticulous, precise fitting due to the stretching of the paper (Figure 8). This was followed by painting the boundaries, which job again required special attention (Figure 9).



Figure 8. Mounting of gores



Figure 9. A phase of manual colouring

When painting, we always worked considered the pictures taken of the original globe. We tried to interpret and determine the original colours of those areas that faded to yellow or dark. This was an especially great task with the several hundred small islands. Dense aquarelle ink and very thin brush were used for painting and following the intricate drawing of coastlines and boundaries. Wide and impetuous strokes of the brush were used to paint the sea currents as probably drawn on the original.

After painting, the globe was coated with UV- and time-resistant lacquer in several layers.

The calendar frame with fine colours and drawn on parchment paper by Perczel was so much defected that only faint marks of the zodiac remained. These and the splits were reconstructed (Figure 10). The print was assembled from 12 pieces, then painted and lacquered (Lente–Kecskés 2020).



Figure 10. Part of the globe in the reconstructed calendar frame

## THE BALL AND STAND

The globe was made of modern, durable composite of plastics. It turns round on a metal rod. The diameter of the ball is 127.5 cm. Due to its large size, manufacturing the globe was a serious job.

The beautiful stand of the globe was made with traditional method following the original technology. The four legs and the stiffening parts are hand-carved and made of nut-wood, the fifth leg is a turned one (Figure 11).



Figure 11. Making of the calendar-framed stand

The kernel of the calendar ring is pine-wood covered with sawn plywood of nut-wood. The size of the stand is as follows: 153 cm wide and 94 cm high. The surface is beautiful hand-polished lacquer.

The solid meridian ring (with a cross-section of 10 x 30 cm) was made of yellow brass, manually bended and fitted by riveting by an ornament-smith. The holds and the polar caps were made of yellow brass. The lines, inscriptions and the graduation on the copper ring were added by the engraver (Lente–Kecskés 2020).

One of the three artistic copies can be seen on 6th floor of the Buda Castle, in the National Széchényi Library in Budapest. The original globe of Perczel can also be seen here, in the Map Room on the 7th floor.

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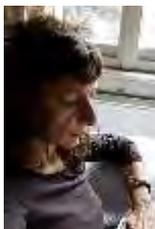
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Graduated from The Hungarian University of Fine Arts, in 1992, as conservationist, worked as paper conservationist for 20+ years in the National Széchényi Library of Hungary. Restored numerous books, maps, works of art on paper, codices, including Corvinas. Working as a private conservationist Since 2007. Having considerable practical experience in conserving Globes and a commitment to the highest standards and performance.



Barbara KECSKÉS

Graduated from The Hungarian University of Fine Arts, in 2005, as graphic artist, Barbara works as freelance graphic designer and artist. Her most important works are image building, branding, logo design (as 41ST Hungarian Film Week; Korda Filmpark – Hungary; Fact Consultants; Eddh 70eme Anniversaire de la Déclaration Universelle des Droits de l’Homme – France), book design (as From Art to Life / Hungarian at the Bauhaus – catalogue of a great Bauhaus Exhibition and SPACE\_PUBLIC – a huge album that focuses on the investments and their architectural concepts of Pécs2010 European Capital of Culture – Pécs 2010, co-works with Zsolt Czakó; Derkovits / The artist and his age – exhibition album of the famous hungarian painter – for Hungarian National Galery, 2014), exhibition design (as the permanent exhibition at Korda Filmpark – 2019, Etyek; Years of Disarray / Avantgardes in Central Europe – 2020, Pécs). Between 2009–2014 she has been teaching graphic design and typography.



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# AN EYE-TRACKING ANALYSIS OF VISUAL SEARCH TASK ON CARTOGRAPHIC STIMULI

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## **Abstract**

*The theoretical research in cartography was recently boosted mostly by technological development, which enables the comfortable usage of various new and even traditional methodological approaches. For example, the Eye-tracking method can possibly provide deep insight into the process of map reading, especially in the case of simple tasks. The visual search is one of the basic tasks when users are dealing with cartographic stimuli. For the presented study, the symbol set was designed in order to create a logical system, varying in different graphic variables (shape, hue, etc.). The designed symbol set was used for the creation of experimental stimuli simulating large-scale maps. The stimuli were used for the test battery administered to twenty four participants using an eye-tracking device. The influence of the point symbol design (various graphic variables), the position of the point symbol in the map field, and also the properties of the map background on the visual search task was investigated.*

**Keywords:** Visual Search, Cartographic Stimuli, Eye Tracking

## **1. INTRODUCTION**

The theoretical foundations of cartography can be tracked down back to the second half of the twentieth century when the work of e.g., J. Bertin (Bertin, 1983), A. Kolačný (Koláčny, 1969), A.M. Maceachren (Maceachren, 1995), and others were published (Montello, 2002). The foundations were based mostly on scientific studies from other fields of science and only on the limited number of empirical studies in cartography. The development of technology enables the extension of available methods and the introduction of novel approaches to cartographic research. For example, the Eye-Tracking method can provide detailed objective information about the user's eyes gazes (Ooms, Dupont, Lapon, & Popelka, 2015). A combination with other methodological approaches can provide deep information about the nature of the map reading process and contribute to the level of understanding of this process.

Map reading is a complex process that can be divided into various levels of complexity. One of the most basic tasks performed on the map is a visual search when the participant needs to identify the required target (Nelson, Dow, Lukinbeal, & Farley, 1997). The maps are in general complex mosaics of graphic layers. Especially the thematic maps consist of topographic background and thematic information. Usage of different graphic variables can enable various visual effects caused by the used colors, objects, collisions, etc. E.g., the 'pop-out' is documented if the target differs to other objects. (Lloyd, 1997). Another important issue is the position of target within the map field (Lloyd, 1997).

## 2. EXPERIMENTAL STUDY

The aim of the study is the detailed investigation of the visual search task performed on the designed set of point symbols. The main focus will be on the influence of the pop-out effect and the relative position of the target within the map field.

### 2.1 Participants and Apparatus

Twenty four volunteer participants joined the study in total. Participants were university students of Masaryk University, Brno, Czech Republic. The participants were students of the social sciences or humanities (average age – 21,8, M/F – 5/19).

The data were be collected within the HUME Lab research infrastructure. The Hypothesis software was used for the time, and correctness recording (Šašínska, Morong, & Stachoň, 2017)and the SMI RED-m eye-tracking device was used for the eye movement collection.

### 2.2 Stimuli and design

The unique set of point symbols (divided into the three main thematic categories: Blue – transportation objects, Yellow - cultural objects, and BW – other objects) on the topographic background was used as a stimulus for the study (see selected examples on figure 1). Two particular exceptions were a single red sign for hospital and green for the Apotheke.



Figure 1. The selected examples of used symbol set. (The transport - blue (left), cultural - yellow (middle) and the other category- BW (right)).

The set of sixty map compositions (see figure 2) was created and presented to the participants using on the LCD 22” display screen. The respondents are instructed to locate and select (by mouse click) the given map sign as quickly as possible. The target map sign presented on the left side of the screen needs to be identified in the map field presented on the right side of the screen. There was no time limit.

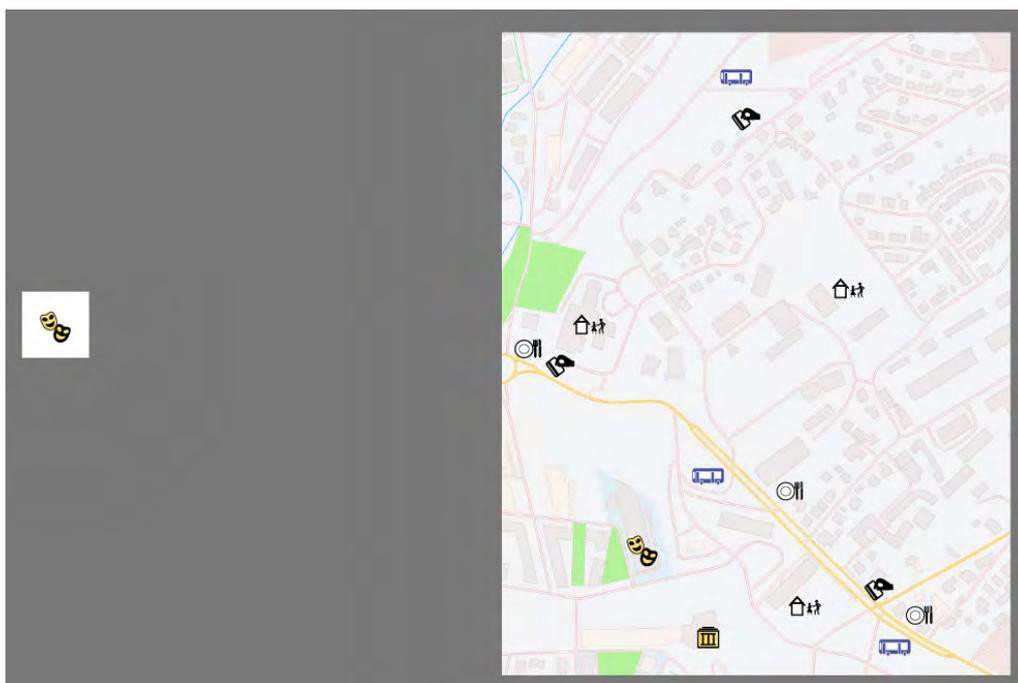


Figure 2. The example of used stimulus (the target - left, map field - right).

The main research questions are:

- Are the colored categories of symbols inducing the pop-out effect in comparison to BW symbols?
- Are the central positions of symbols advantage for the visual search task?
- Is the red color the most prominent? Will the red symbol (hospital) score the lowest time?

## 2.3 Results

The data were collected on several levels. The time, correctness, and eye-tracking data were recorded and analyzed. The correctness was 100% in all of the collected datasets. Therefore it is not reported below.

### 2.3.1 Time

The average time necessary to fulfill the visual search task differs from 1,3 s. to 1,5 s. The differences are documented in the figure 3.

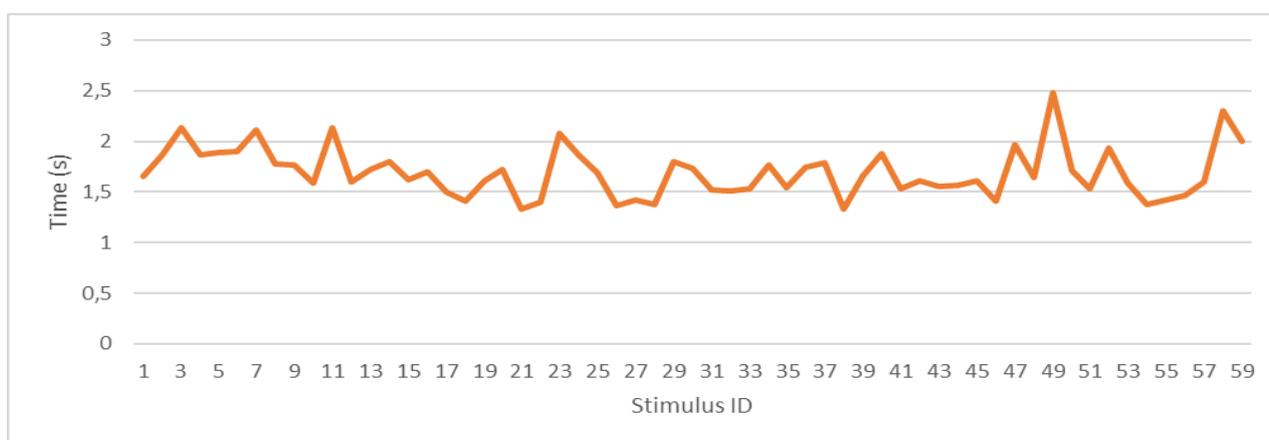


Figure 3. The average time (s) necessary fo fulfill the visual search task.

The more in-depth insight revealed that there were only colored symbols (no BW symbol) within twelve fastest identified symbols. Also, there were ten BW symbols within the twelve slowest identified symbols. This finding strongly supports the evidence of the pop-out effect.

If we focus on the difference between the symbol groups (blue, yellow, etc. – see figure 1), we can observe the difference between the average time for each symbol category. The fastest, the participants identified the red symbol (hospital) followed by the blue and yellow symbol category.

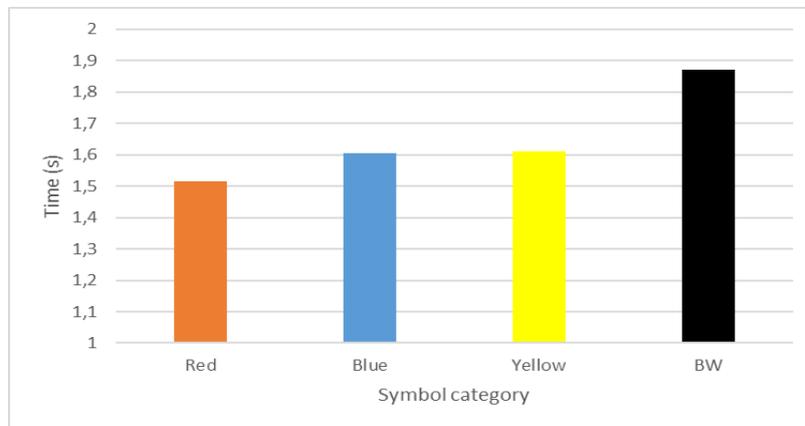


Figure 4. The average time necessary to fulfill the visual search task for symbol categories.

We can also focus on the relative position of the map symbol within the map field. The map field was divided into the nine sectors (see figure 5), which were evaluated separately. The results proved the advantage of the symbols situated in sectors 2 and 5. It supports the idea of the advantageous central position of the map symbol except for sector number eight.

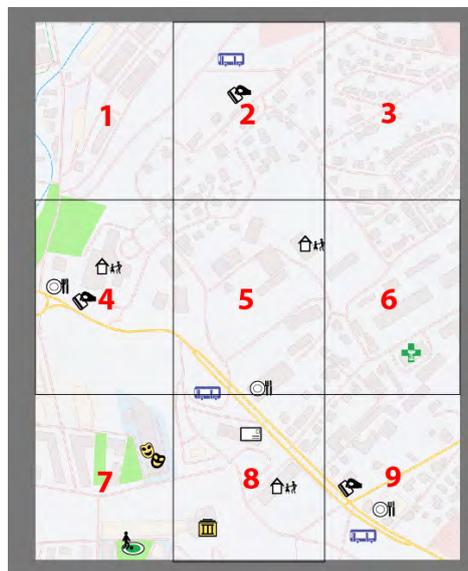


Figure 5. Nine sectors defined in the map field.

### 2.3.2 Eye-tracking data

The more in-depth insight into the visual search process was provided by the eye-tracking data. The primary focus was devoted to the most time-consuming stimuli. Namely, the stimulus ID 49 (vending machine, sector 8) and the stimulus ID 7 (restaurant sector 9)). The detailed trajectories are displayed in figure 6. There can be identified two different strategies.

1. In the case of stimulus number 49, the participant started the search on the target, then continued to the sectors 5, 2, and 8 where the target was identified. The identification was followed by the final check to the target area.
2. In the case of stimulus number 7, the participant started in the middle of the map field, followed by the search for the target and the search of the sectors 5, 2, 1, 4, and 9 where the target was identified.

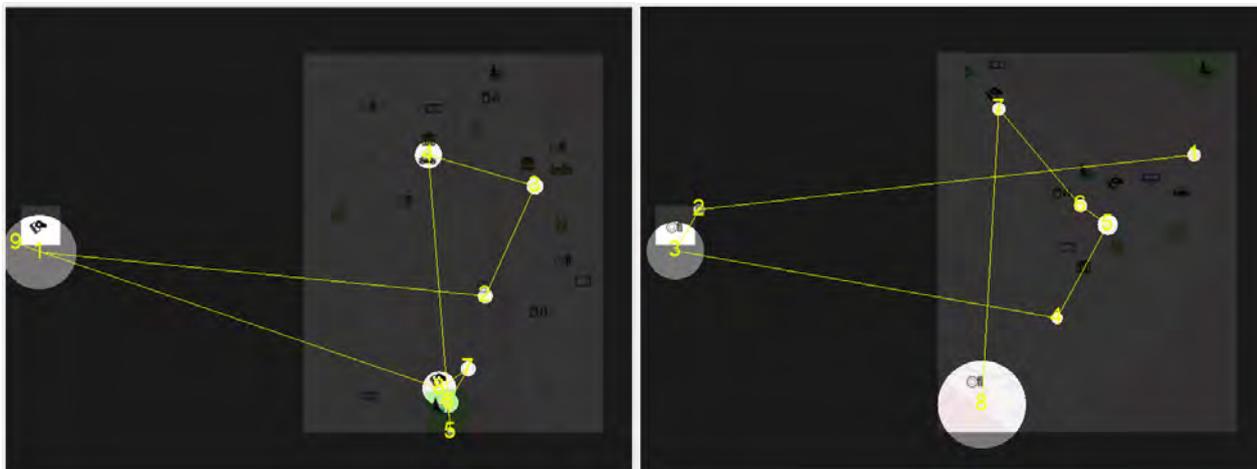


Figure 6. Eye-tracking data from the task number 49 (left) and task number 7 (right).

### 3. DISSCUSSION AND CONCLUSIONS

The presented study focused on the visual search tasks using the cartographic material as a stimulus bring reveal the potential of eye-tracking data in cartographic research. The designed symbol set varying in different graphic variables (e.g., shape, hue) was used as an experimental stimulus simulating large-scale maps. The results confirm the findings of previous studies, e.g. (Lloyd, 1997):

1. The strong evidence of the pop-out effect, if the target stimulus visually differs from the topographic background and other symbols.
2. The prominence of red color.
3. The strong influence of the relative position of the target symbol. The symbols located in the sectors 5 (centre of the map) and the sector 2 (centre of the upper part of the map field) are identified faster to other sectors.

The more in-depth insight into this effect was enabled by the available eye-tracking data. The various sequences of eye movements were identified. The results provide ques for a deeper understanding of the visual search in the process of map reading and reveal the influence of the graphic variables and the relative position of the target on the strategies used for the visual search task.

Future possible extension of the study can be a focus on other variables as for example, the cultural background of the participants. Especially the effect of the different ordering of writing systems can bring different visual search strategies or the different roles of colors.

### ACKNOWLEDGMENT

This publication was supported by the Czech Science Foundation (GC19-09265J: The influence of socio-cultural factors and writing system on perception and cognition of complex visual stimuli).

Preparation of related experiments was made available by the research infrastructure of Virtual Geographic Environments Lab, Department of Geography, Faculty of Science, Masaryk University, and HUME Lab Experimental Humanities Laboratory, Faculty of Arts, Masaryk University.

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# COMPARISON OF THE EXTRINSIC AND INTRINSIC VISUALIZATION METHODS: EXPLORATIVE EYE-TRACKING ANALYSIS

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## **Abstract**

*The aim of the study is to identify the differences between the cognitive processes underlying different map-reading tasks. An eye-tracking study was designed based on our previous research. We hypothesized that significant differences may occur when utilizing two different methods of presenting two phenomena in one map (i.e. bivariate scales). Specifically, the extrinsic and intrinsic methods will be compared using two different types of tasks: The participants will be presented with maps that provide information on soil moisture and soil depth, and will be asked to identify the areas that meet the required conditions (e.g. area with the highest soil moisture and low soil depth). The research sample will consist of university students of humanities and social sciences, for it is our intention to focus on the people with no significant cartographic experience. In order to explore the collected eye-tracking data, an explorative analysis will be used. The main objective of the analysis will be to find out whether either of the bivariate scales requires more saccades to accomplish the task, requires more direct transitions between the legend and the map, and whether the different visualization types induce different cognitive processing methods. Our results will shed some light on the topic of computational (non)equivalence of the extrinsic and intrinsic visualization methods. The presented study will provide a basis for the upcoming cross-cultural research. The paper presents the suggested experimental design of the research and the means of analysis.*

## **1 INTRODUCTION**

Empirical investigation of visual stimuli plays an important role among cartographical research methods (Juřík et al., 2020, Herman et al., 2018; Juřík et al., 2017, Kubiček et al, 2014, Kubiček et al, 2017, Svatoňová and Kolejka, 2017). The aim of this paper is to present the design of an experiment comparing the impact of extrinsic and intrinsic

visualization using bivariate maps (Elmer, 2013, Nelson, 1999, Nelson, 2000, Nelson, 2002), and to suggest suitable methods of analysis. In order to meet the requirement for objectivity, we suggest using the eye-tracking technology which can provide a deep insight into the cognitive processes and strategies employed by the participants when performing map-related tasks (Alaçam et al., 2009, Çöltekin et al., 2009, Herman et al., 2017, Opach et al., 2017, Popelka and Brychtová, 2013). The presented experimental study is a direct follow-up to the work by Kunz (Kunz, 2011, Kunz and Hurni, 2011), who created bivariate maps quantifying the avalanche risk (along with the degree of uncertainty of the risk). The methods employed by Kunz were empirically tested by Šašinka et al. (2019), whose results indicated, inter alia, that the familiarity of the map content to the participants plays such an important role that its impact may override the effect of the phenomena under investigation (Alexander et al., 1994). Therefore, relatively simple and widely understandable topics were selected for our study: soil moisture and soil depth. The presented study will employ a broader design that will allow us to examine not only the participants' individual cognitive style, but also the role of cross-cultural differences in perception. We consider bivariate maps to be highly suitable for the above type of experiment (Šašinková et al., 2020).

We suggest using the technology of eye-tracking for our study because it provides a unique possibility to investigate the differences in the participants' cognitive processing; thanks to eye-tracking, we can study the very process of task-solving in addition to the results of the participants' cognitive activity. The oculomotor data can be used to reveal if the same or different cognitive styles are used for the different types of visualizations (of identical data).

## 2 STIMULI AND EXPERIMENTAL DESIGN

The stimuli and the types of tasks will be the same for all the groups of participants. The instructions will be displayed in the upper part of the screen; the map legend will be shown on the right side, the map field on the left and the button bar with 4 buttons (used to indicate the correct answer) will be shown in the bottom part of the screen (see Fig. 1 and 2). The identical design of the stimuli will provide for full control of the experimental environment. The participants will be familiarized with the type of the visual stimuli prior to the experiment in order to ensure that any differences in the participants' performance are visualization- or type of task-related.

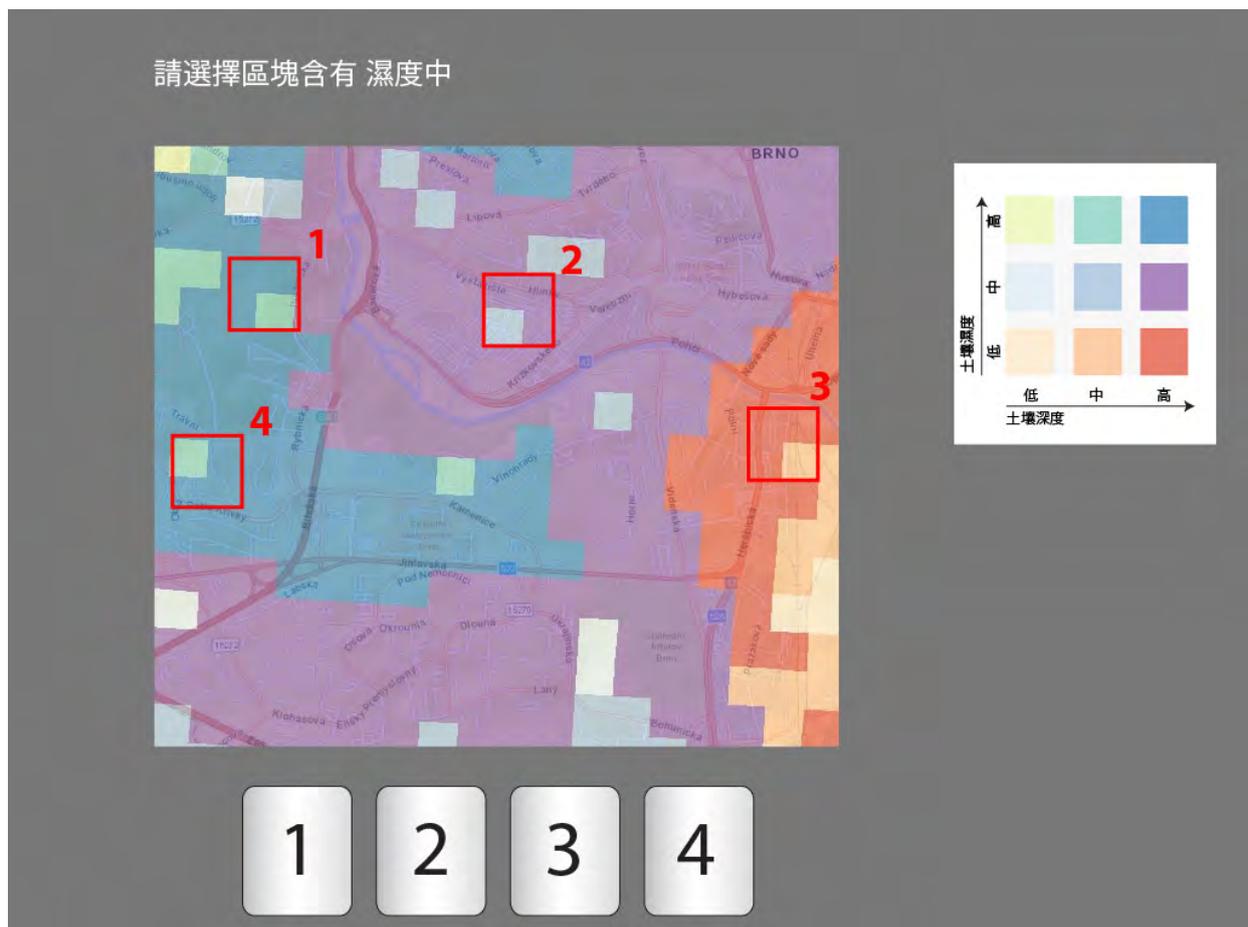


Figure 1 Example of an intrinsic visualization, subtest 1 (analysing wider areas consisting of 4 units), one variable is in question here.

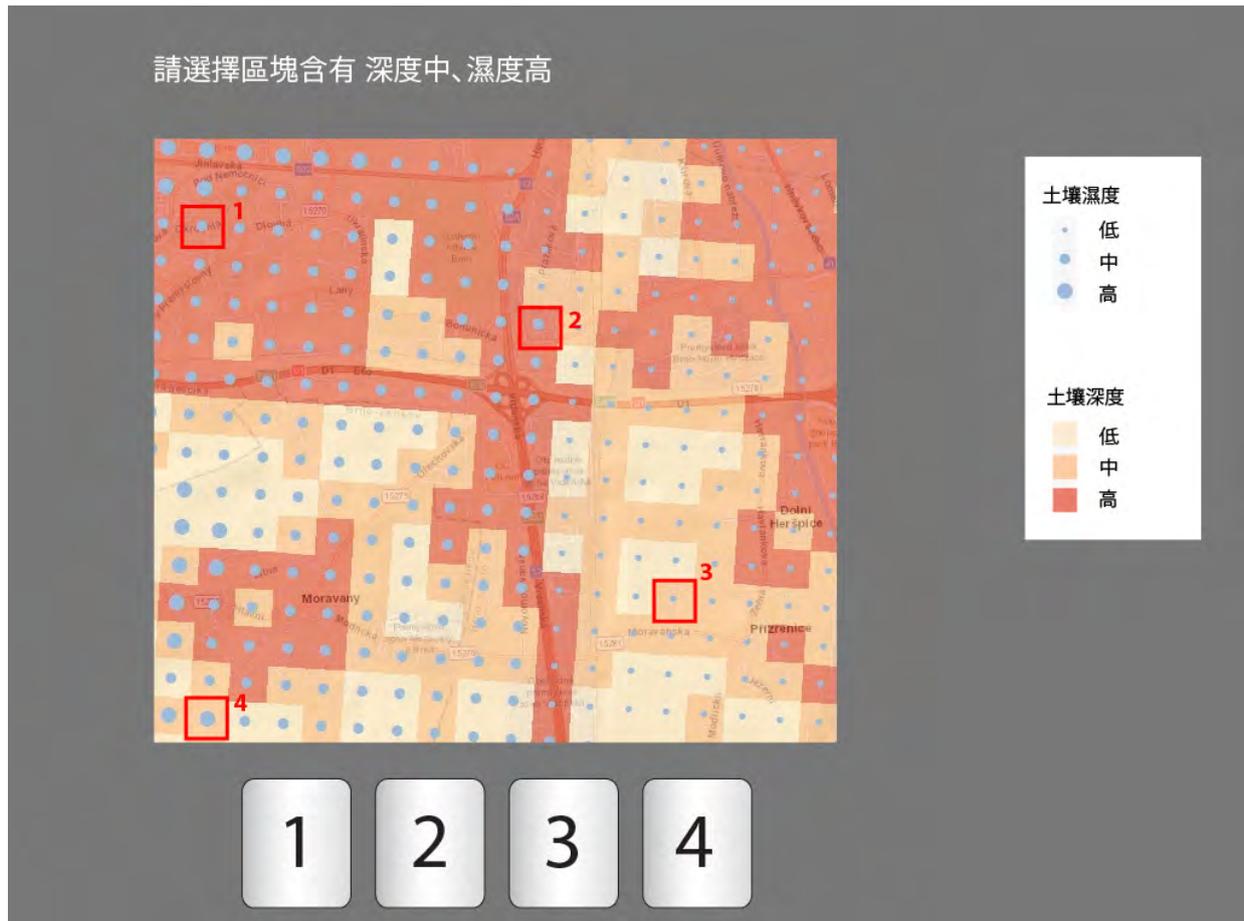


Figure 2 Example of an extrinsic visualization, subtest 1 (analysing only isolated units), two variables are in question here

The study will include two subtests, each consisting of 15 items. The participants will be presented with bivariate maps divided into small square units. For each item, four areas are marked either with a single square (in the subtest No. 2) or with 4 squares (in the subtest No. 1). The participants will be asked to choose the area that fits the criteria defined in the instructions (e.g. “Select the area with low soil moisture AND high soil depth”). Some items will require only one condition to be considered (e.g. “Select the area with low soil depth”), others will require two conditions to be met (such as the above-mentioned example).

It needs to be stressed that the study was designed in such a way that the impact of practice and the type of task could be controlled and assessed. We consider it necessary to use a between-subject design in order to be able to compare the data related to the two types of visualizations. If a within-subject design were used (that is, the participants would be presented both extrinsic and intrinsic visualizations), the users' experience with the first task would significantly affect their performance in the subsequent tasks. A disadvantage of the between-subject design consists in that a larger sample of participants needs to be used. Because the test contains several different types of tasks (a single-square vs. multiple-square area, one variable vs. two variables), the participants will be divided into four groups (Counterbalanced Measures Design). To the third and the fourth groups the tasks will be presented in a reverse order (single-unit areas are presented before the four-unit areas). In this way we will be able to counterbalance the effect of experience (resulting e.g. in shorter response times).

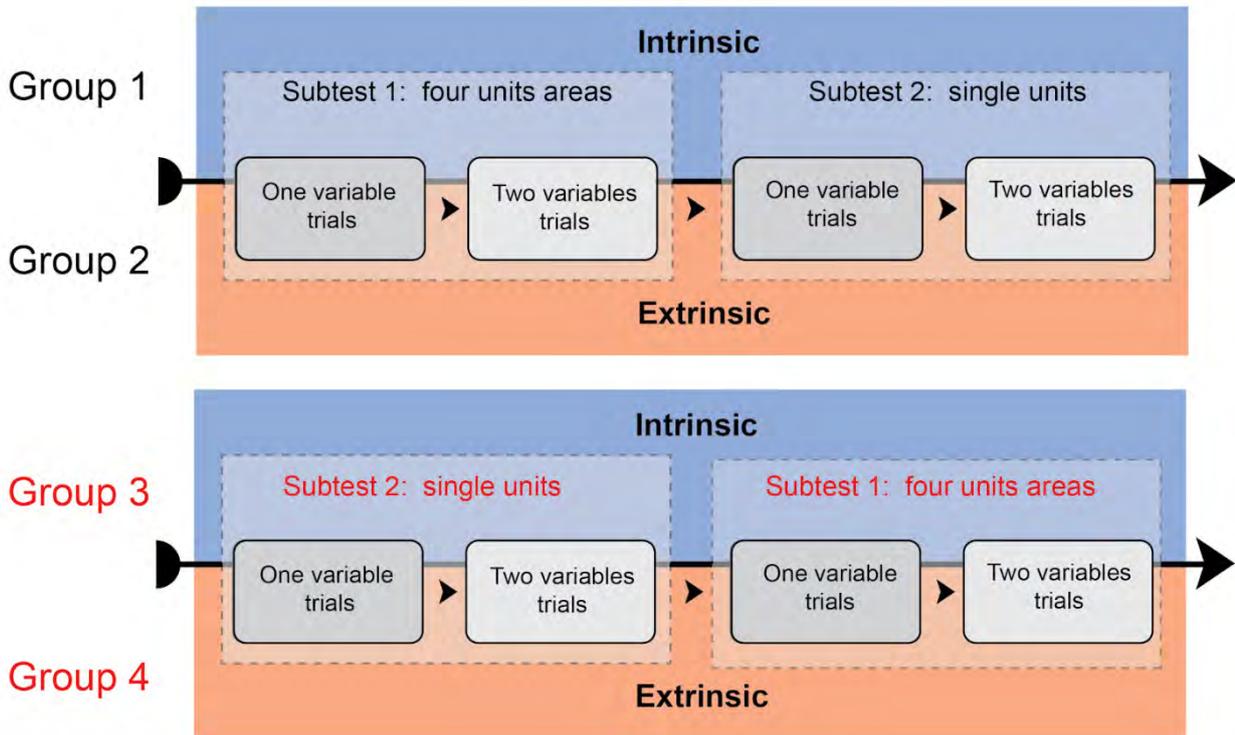


Figure 3 Experimental design: comparing intrinsic and extrinsic visualizations in two subtests, presenting two types of items (considering one or two variables at a time).

## 2.1 Apparatus

Data collection will be done in the HUME Lab using an SMI RED-m eye-tracking device. The eye-tracker will be connected to an external screen on which the tests will be presented to the participants. The experiment will be administered via the Hypothesis software (Šašinka et al., 2017) and the eye-tracking data will be recorded using the Experiment Center 3.7 software, with the frequency set at 250 Hz. Ogama software (Voßkühler et al., 2008) will be used for data analysis and the data will be transferred to Ogama via the HypoGama application (Popelka et al, 2016).

## 2.2 Participants

The participants will be university students of humanities and social sciences. It is essential that the participants have no expertise in maps because previous knowledge would likely distort the data. Participation will be rewarded financially. Due to the expected high discard rate, the number of participants needs to be overestimated

## 3 Data Analysis

The analysis of the collected data will be a two-level one, the first level consisting of the analysis of the oculomotor data and the second level of the analysis of the behavioral phenomena. The behavioral data include response time and correctness. Because of the complexity of the experimental design, several complex statistical models will need to be used to investigate the behavioral phenomena. Even the basic version of the design involves several factors (culture x visualization x type of task; see Tab. 1); therefore, a mixed-factor ANOVA will be considered, which makes it possible to investigate the interactions between the factors involved. Another factor can consist in whether the user looks for a single variable or both variables at a time.

Table 1 Main factors in the research design

Culture	Visualization	
	Extrinsic	Intrinsic

East x West	Type of task		Type of task	
	Unit	Area	Unit	Area

The main goal of the explorative analysis of the collected oculomotor data will be to identify the possible differences in visual scanning of the map during task-solving. The analysis will employ two types of eye-tracking metrics: 1) transitions (saccades between AOIs) and 2) AOI dwell time.

Several Areas of Interest (AOI) will be created: the area of instructions, the legend, the visualization field (i.e. the map itself) and the buttons (Figs. 4 and 5). We will be interested in the total duration of the fixations on the selected AOIs (point No. 2; see Fig. 5). The information about the total dwell time will make it possible to determine the amount of attention allocated to the various parts of the task at hand. The AOIs representing the visualized areas (possible responses) will be used to establish which distractors were considered by the users to be the most probable before they made the final decision.

The transitions metrics (point No. 1; Fig. 5) provides more detailed information about the dynamics of the task-solving process. The main question is: How many direct saccades out of the defined AOIs were made and in what direction? The following two attention-shift directions are particularly important: the “map-legend” shift and the “legend-map” shift. A high number of map-legend transitions indicates that the user needs to repeatedly check the correctness of their choice.

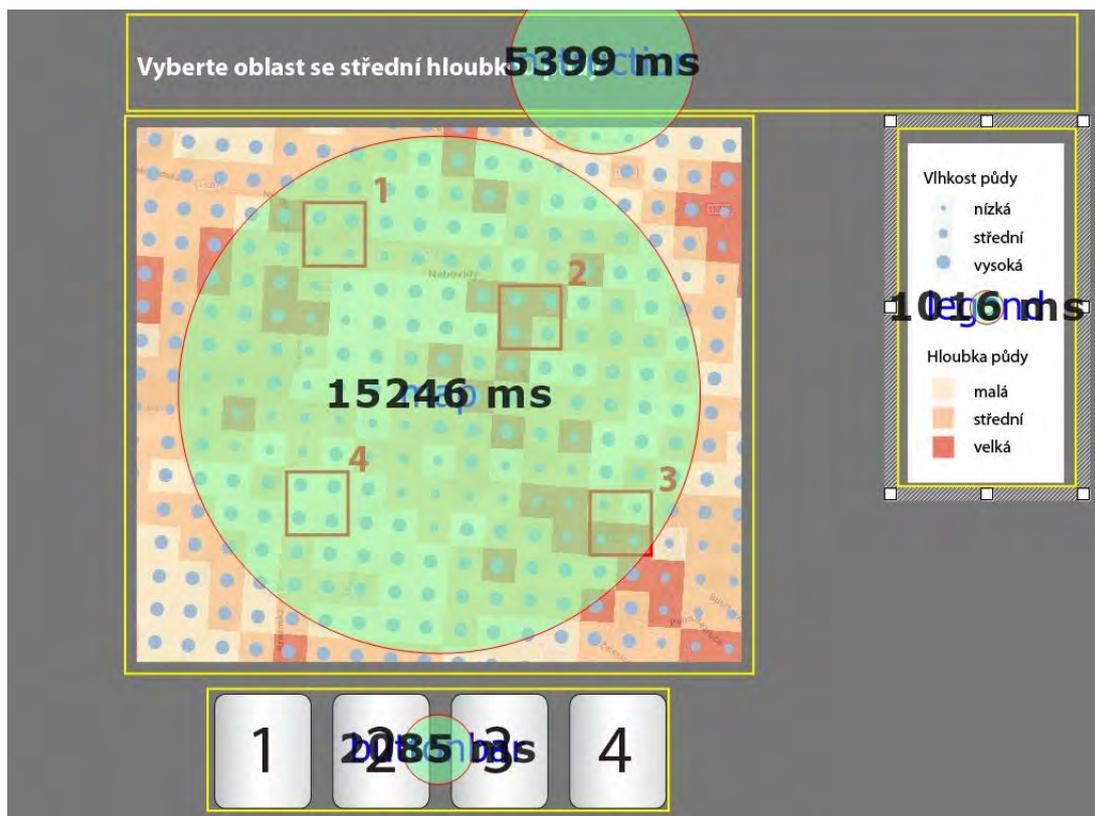


Figure 4 AOI dwell time assessment

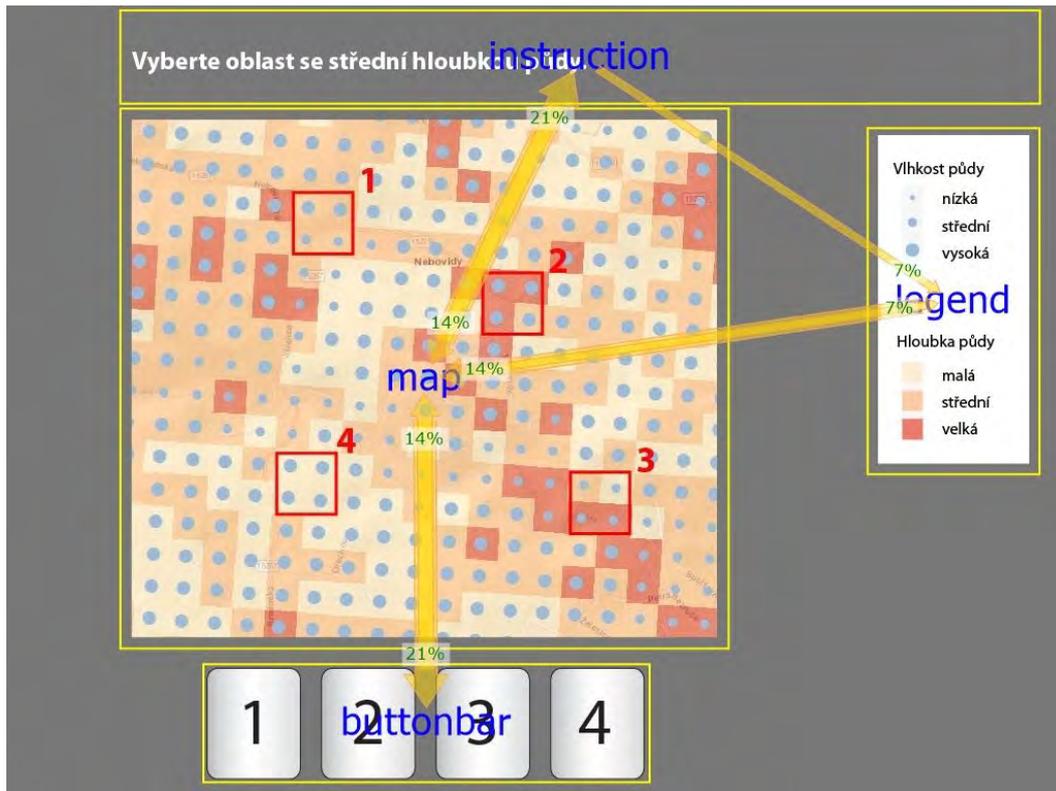


Figure 5 Example of direct saccades (transitions) between AOIs

## 4 Discussion

Based on the pilot testing as well as on our previous studies, the intrinsic map legend is considered less intuitive, and thus is expected to take more time to decode than the extrinsic legend. However, it remains to be answered how the efficiency of the users' task-solving is affected by practice, and also if the intrinsic legend can induce better results with some tasks than the extrinsic legend. Other topics to be investigated include the impact of the users' cultural background and of their individual preferences for one or the other type of visualization.

## ACKNOWLEDGEMENT

This publication was supported by the Czech Science Foundation (GC19-09265J: The influence of socio-cultural factors and writing system on perception and cognition of complex visual stimuli).

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# DIFFERENT PRACTICES OF MAP USE IN EARTH SCIENCES

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## **Abstract**

*Thematic cartography is a major tool for earth sciences to present research results about various spatial characteristics. When used correctly, maps enrich the content of publications. This study focuses on the quality of map use in geoscientific publications. Maps of geology, geography, geophysics, meteorology and cartography were assessed from Hungarian and international journals and posters. We measure the means of 1) quality of visual representation, 2) presence of map accessorial and 3) quantity of topographic and thematic content with an objective system of criteria. Statistical evaluation of the items reflects the map use habits of each field and common mistakes in map representations are also revealed. Comparison of the Hungarian vs. international practice was primarily aimed, but the results reflect the spatial variability of scientific mapmaking. This database and analysis draw attention to the objective criteria of proper map use in scientific communication and may help authors to improve their maps' quality.*

**Keywords:** geosciences, map use, thematic cartography

## **THE ROLE OF THEMATIC CARTOGRAPHY IN GEOSCIENCES**

Maps in geosciences have been fundamental tools of communicating spatial information for a long time. Through maps scientists use cartographic visualization, which can be considered as geographic research and/or tool of spatial analysis (Philbrick 1953, DiBiase 1990). The proposal framework of DiBiase (1990) considers maps as accessories of scientific work: they are used when exploring the subject of a research, during the formulation of theories and conclusions, and for final representation of the results. This makes a clear distinction between private visual thinking at the early phase of a research and public visual communication when publishing. Although there are various views about emphasizing different aspects of visualization authors agree that it is built up by a visual thinking and a communication-presentation component (MacEachren 1994).

These theories were completed by the definition of (Cartography)<sup>3</sup> that shows an expressive three-dimensional connection between human-map interaction, presenting knowns/unknowns, private/public map use and visualization/communication (*Figure 1*, MacEachren 1994). According to Kraak (2002) this process of geovisualization and cartographic design have to be reviewed for usability, as these maps may be used for further analyses, generating hypotheses or solve further problems.

DiBiase et al. (1992) and DiBiase et al. (1994) deals with visualization methods of Earth System Sciences built on this foundation. Geoscience data visualization and interpretation have been hard in the past decades. The accelerating changes in our global environment force geoscientists to search for new mapping methods to process the growing amount of quantitative information. Sometimes the purpose of geoscientific thematic maps also changes, e.g. the original aim of geological maps has been to gather information for mining industry, but nowadays the emerging and growing sector of geotourism also widely uses these kinds of thematic maps (Albert 2019). Due to the geographical context earth sciences has always needed thematic maps when presenting spatial information about research results. The correct visualization of these spatial characteristics is inevitable to reach the third dimension of the cartographic cube – (Cartography)<sup>3</sup> – that means information-sharing public presentation (MacEachren 1994).

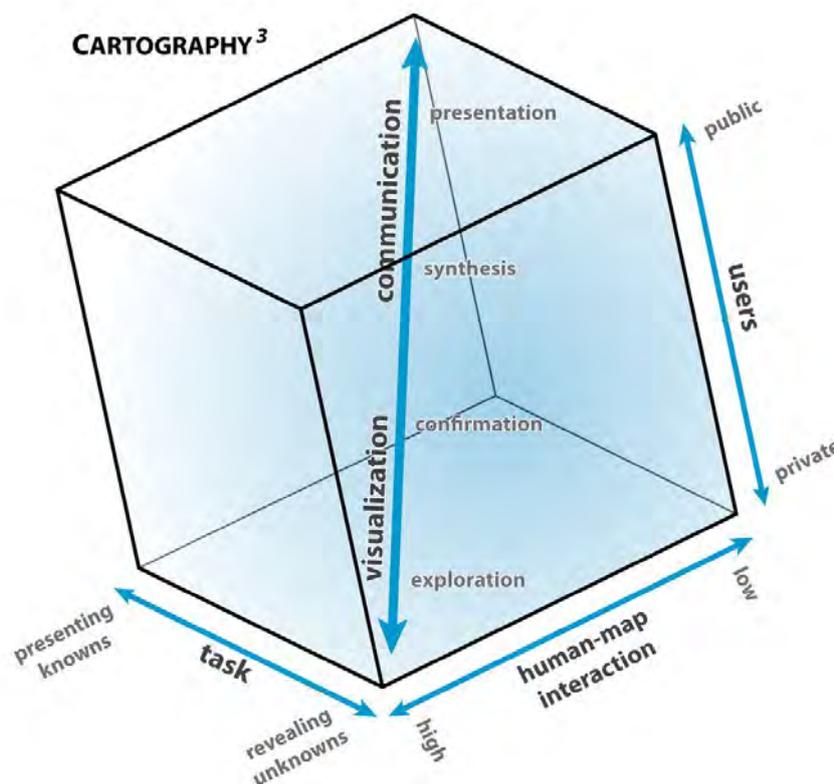


Figure 1. The cartographic cube (MacEachren 1994). Thematic cartography in geosciences follow its principles: a complete research includes all steps described in it

A map, when used in scientific publication, should thematically fit in the textual content, and should enrich it. It is an extra task for scientist to take basic cartographic and visual rules into consideration. With correct and understandable maps, their publications can earn multiple benefits, such as increased readership and wider dissemination. Measuring the goodness of maps is not easy, since the map is considered good in many different ways. However, we can check certain elements on a map (e.g.: scale, or a scale bar), which can help the reader to understand the map if exist, and if not, the understanding of the map is harder. Although it seems obvious to include elements on a map such as coordinates, title, legend and scale, we can see scientific publications sometimes presenting “maps” without them. The preludes of this research have been taken place in the XXth Congress of the Carpathian-Balkan Geological Association in Tirana, Albania, 2014. The idea of the evaluation system was established by Gáspár Albert attending the poster section of this conference, and the initial set of data were also collected here concentration on geological maps. It was aimed to find the most occurring phenomena that make maps less understandable.

This study aims to examine the maps of different geoscience branches focusing on these visual rules and map elements rooting from cartographic rules. The classification of geoscientific maps declared by the ICA Commission on Thematic Cartography in the 1970s (led by Emil Meynen) distinguish seven categories (Klinghammer and Papp-Váry 1983): 1) morphometric, 2) geophysical, 3) geological, 4) pedological, 5) geomorphological, 6) hydrological and 7) meteorological (climate) maps. Elements of this system refer to an individual science branch in geosciences, but some are more, others are less represented in contemporary scientific journals. To evaluate, how different science branches manage maps, we have chosen journals and conference posters from the field of cartography, geography, geophysics, geology and meteorology to check, how they applied the universal rules of thematic cartography in them. The spatial variability of map use was also supposed – there might be remarkable differences between each countries’ map design solutions. We especially focused on the differences between Hungarian and international scientific literature.

## METHODOLOGY OF THE EVALUATION

### Map evaluation system

Table 1. Criteria of the map evaluation system

<p><b>A) Visualization</b></p> <ul style="list-style-type: none"> <li>• <b>Excellent:</b> The map is designed to its purpose. The symbols are unique or appropriately selected to the topic. The base map and the thematic content are in harmony. The printing quality matches with the resolution of the map.</li> <li>• <b>Medium:</b> The content is readable, but the symbols are not designed to the purpose of the map (e.g. usage of default colours, line types). Base map and thematic coverages are compiled differently. The printing quality matches with the resolution of the map.</li> <li>• <b>Poor:</b> The content is hardly readable due to inappropriate symbols (in vector-based maps), rough resolution (in raster-type maps) or the bad quality of printing.</li> </ul>
<p><b>B) Type</b></p> <ul style="list-style-type: none"> <li>• <b>Overview:</b> The map is for showing the location of the study area. It is a small-scale map, which can be solitary, or in pairs with a main map.</li> <li>• <b>Main:</b> The map shows the results of the research subject. It can be solitary, or in pairs with a main-, or a detail map.</li> <li>• <b>Detail:</b> The map shows the results of the research subject in large scale. It is always in pairs with a main map.</li> <li>• *: in case of mixed types, use the * sign for the inferred, and "1" for the dominant type.</li> </ul>
<p><b>C) Accessorial (coordinates, orientation, scale, legend, name/title)</b></p> <ul style="list-style-type: none"> <li>• When doing survey, put a checkmark in the proper column if the accessorial type exists on the map (consider the captions of figures as names/titles in some cases).</li> </ul>
<p><b>D) Topographic content</b> (put a checkmark in the proper column if the accessorial type exists on the map)</p> <ul style="list-style-type: none"> <li>• <b>Hypsography:</b> contours, shaded relief, graded hypsometry, etc.</li> <li>• <b>Hydrography:</b> water courses, lakes, rivers, channels, springs, wells, marshes.</li> <li>• <b>Road network:</b> roads, trails, streets, etc. (manmade structures).</li> <li>• <b>Boundaries:</b> delineator signs of administrative territories.</li> <li>• <b>Settlements:</b> signs of human build structures/administrational units (i.e. cities, villages, farms).</li> <li>• <b>Names:</b> geographical names (of natural and manmade objects).</li> </ul>
<p><b>E) Thematic content:</b> in this criterion all existing map type from the evaluated set should be written. In our case:</p> <ul style="list-style-type: none"> <li>• Geological, geophysical, geographical, geomorphological, meteorological, cartographical, ethnographical or general, if there is no thematic content.</li> </ul>
<p><b>F) Base map type:</b></p> <ul style="list-style-type: none"> <li>• <b>Copy unreferenced:</b> scanned raster from an existing map without citation.</li> <li>• <b>Copy referenced:</b> scanned raster from an existing map with citation.</li> <li>• <b>Edited:</b> edited topography/thematic base map content with references to the source of data.</li> <li>• <b>Vector:</b> the base map seems to be edited but the data source is not indicated.</li> <li>• <b>No data:</b> the base map exists, but there is no information about it.</li> <li>• <b>No base map</b></li> </ul>
<p><b>G) The nationality of the article's first author</b></p>

Geoscientific map representations sometimes lack important marks that help the reader to understand the information. When using cartographic methods, we need to find the balance between precision, quality of visual representation and quantity of thematic data. Our method focuses on the quality of cartographic visualization in geosciences, measuring these marks with the help of an objective system of criteria (*Table 1*). These included the quality of visualization, map type, map accessorial, topographic content, coverage type and copyright rules. We also noted the nationality of the first author of the publication to examine spatial variability. Using this system, we could give grades for each map for each criterion.

## Map sources

Table 2. Journal data from the database of SCImago Journal & Country Rank (SCImago 2020)

C A R T O G R A P H Y	<b>The Cartographic Journal</b>	Country: <b>United Kingdom</b> Current H index <sup>1</sup> : <b>25</b> Current quartile <sup>2</sup> : <b>Q2</b> Total cites in 2018: <b>132</b>
	<b>Geodézia és Kartográfia</b> ( <i>Geodesy and Cartography</i> )	Country: <b>Hungary</b> Current H index: <b>7</b> Current quartile: <b>Q4</b> Total cites in 2018: <b>2</b>
G E O G R A P H Y	<b>Geoheritage</b>	Country: <b>Germany</b> Current H index: <b>21</b> Current quartile: <b>Q2</b> Total cites in 2018: <b>264</b>
	<b>Földrajzi Közlemények</b> ( <i>Geographical Review</i> )	Country: <b>Hungary</b> Current H index: <b>10</b> Current quartile: <b>Q2</b> Total cites in 2018: <b>102</b>
G E O P H Y S I C S	<b>Earth &amp; Planetary Science Letters</b>	Country: <b>The Netherlands</b> Current H index: <b>215</b> Current quartile: <b>Q1</b> Total cites in 2018: <b>8720</b>
	<b>Magyar Geofizika</b> ( <i>Hungarian Geophysics</i> )	Country: <b>Hungary</b> Current H index: <b>7</b> Current quartile: <b>Q4</b> Total cites in 2018: <b>1</b>
G E O L O G Y	<b>Geology</b>	Country: <b>United States</b> Current H index: <b>189</b> Current quartile: <b>Q1</b> Total cites in 2018: <b>4256</b>
	<b>Földtani Közlöny</b> ( <i>Bulletin of the Hungarian Geological Society</i> )	Country: <b>Hungary</b> Current H index: <b>9</b> Current quartile: <b>Q3</b> Total cites in 2018: <b>21</b>
M	<b>Quarterly Journal of the</b>	Country: <b>United States</b>

<sup>1</sup> An entity has an H index value of y if the entity has y publications that have all been cited at least y times (Hodge and Lacasse 2011).

<sup>2</sup> The set of journals have been ranked according to their SCImago Journal Ranking and divided into four equal groups, four quartiles. Q1 comprises the quarter of the journals with the highest values, Q2 the second highest values, Q3 the third highest values and Q4 the lowest values (SCImago 2020).

E T E O R O L O G Y	<b>Royal Meteorological Society</b>	Current H index: <b>125</b> Current quartile: <b>Q1</b> Total cites in 2018: <b>2843</b>
	<b>Időjárás</b> (Weather)	Country: <b>Hungary</b> Current H index: <b>13</b> Current quartile: <b>Q3</b> Total cites in 2018: <b>59</b>

The main data sources for the project were scientific journals of the five chosen geoscience branches. One Hungarian and one international journal from each field were chosen. We used the last available issues and followed the articles back in time until we reached nearly 300 maps per each periodical. We also assessed more than 100 maps from posters. These were photographed either at the university or during attending conferences.

We have tried to reach balance between the fields of geoscience, so nearly 300 maps of each branch were assessed, 1509 in total. In *Table 2*, data about map source journals are available.

### Evaluation process

Each journal issue was searched for maps. These were saved as files with a code name that helped the identification later. If the papers were available online, print screens, if not, photographs were made. Each periodical got its own folder with the figures waiting to be evaluated.

The assessment process was carried out by MS Excel software. Each science branch got two individual tables. In the first, authors, the title, the name of the journal and the date of issue were noted for easier further identification. Assessment records were stored in the second table. According to the evaluation system, the visualization, type, accessorial, topographic content, thematic content, base map type and the nationality of the first author were examined. All criteria (except the nationality) deals with the presence or the absence of a certain map feature, so presences were marked with a '1' sign.

When finishing the evaluation, the marks were summed, and each geoscience field got its statistics. These numbers were separated then with the help of the 'nationality' column to produce data showing the trends of each.

## RESULTS

After the investigation, the results can be separated into two groups: the map use habits of different geoscience branches and the geographical differences between them.

### Map use habits of the different geoscience branches

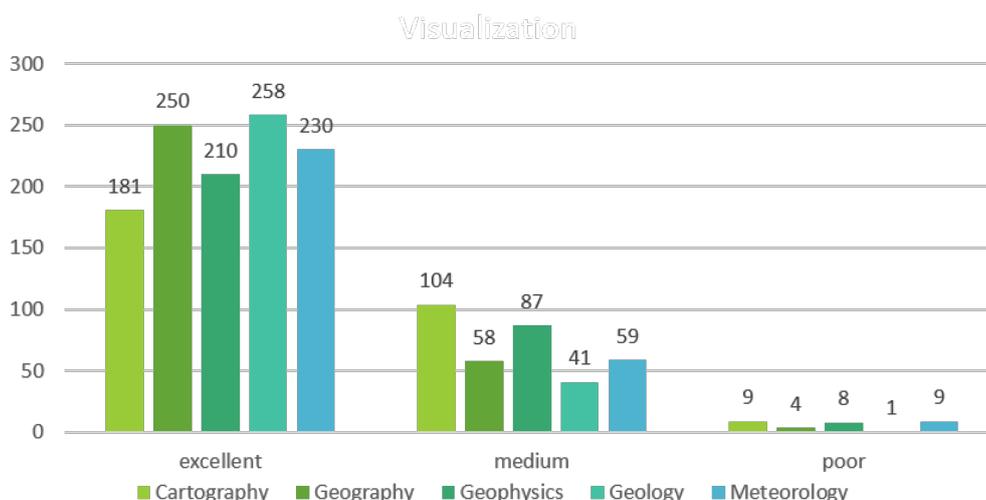
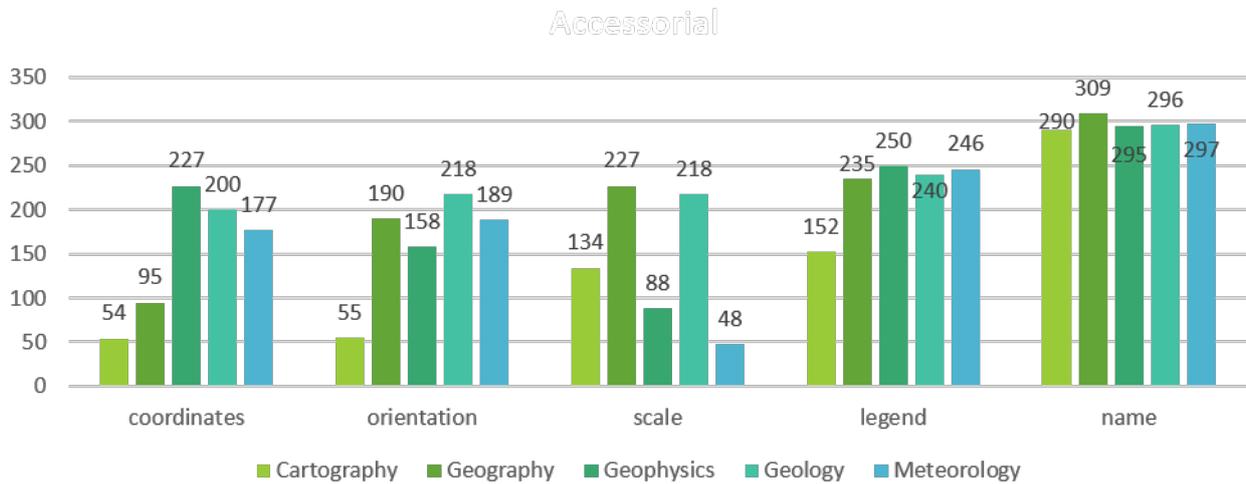
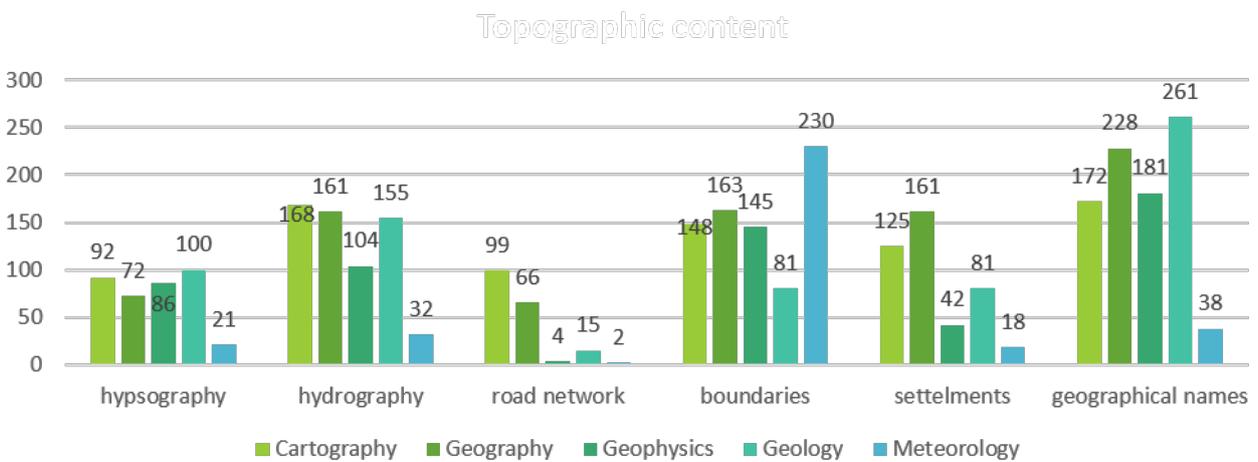


Figure 2. Results of map visualization criteria category

In this section, we give an overview about the most interesting data of the evaluation. Our results showed that the quality of visualization is nearly balanced. Surprisingly, maps from cartographic journals got the lowest, while maps from geological journals got the highest excellent score (*Figure 2*). The quantity of accessorial and topographic content show that these criteria and map elements are varying by the branch of geoscience and the applied thematic map type (*Figure 3 and 4*). We can state that every science field use the basic map accessories and topographic elements wisely to help the reader. The map types are also in a connection with the branches: e.g. while geology uses the most of overview maps, it uses the leas main maps and vice versa for cartography (*Figure 5*).



*Figure 3. Results of map accessorial criteria category*



*Figure 4. Results of topographic content criteria category*

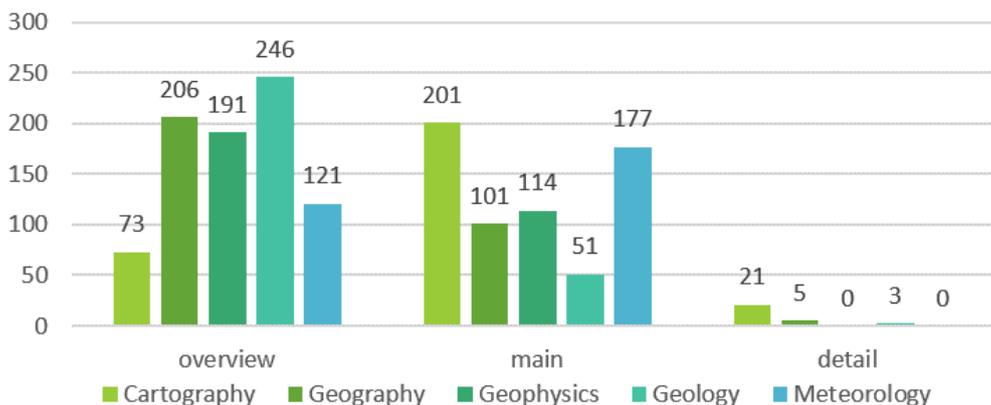


Figure 5. Results of map type criteria category

### Spatial variability of map use habits

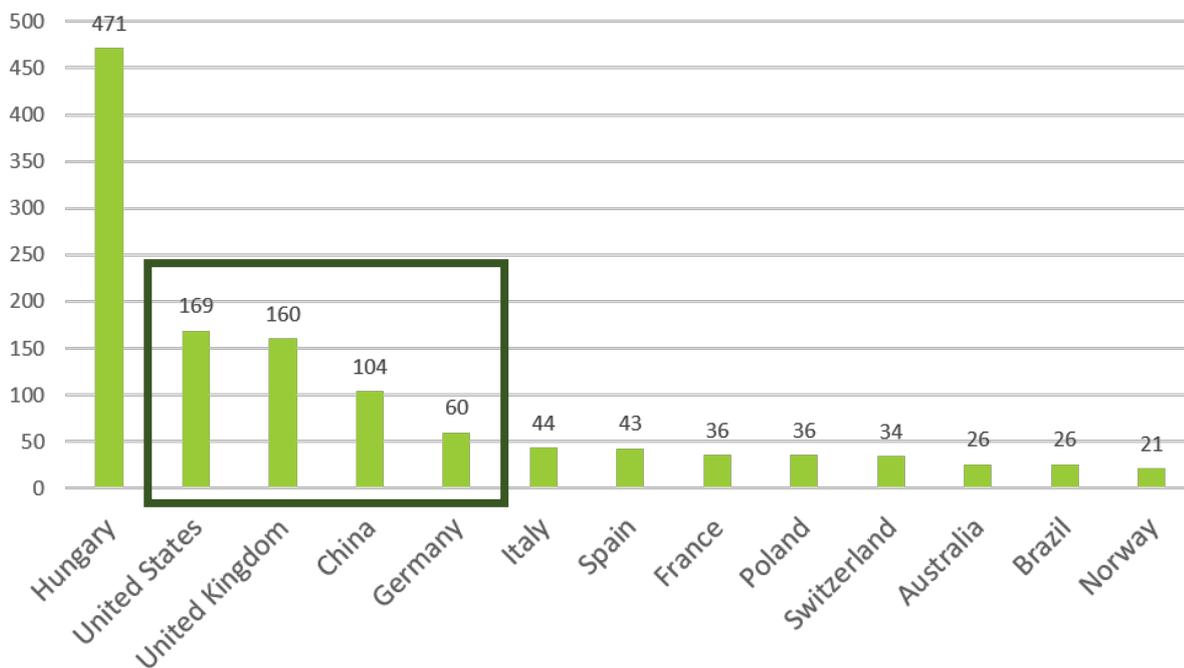


Figure 6. The most common countries with first authorship with more than 20 maps evaluated. The four countries in Figure 7 are highlighted

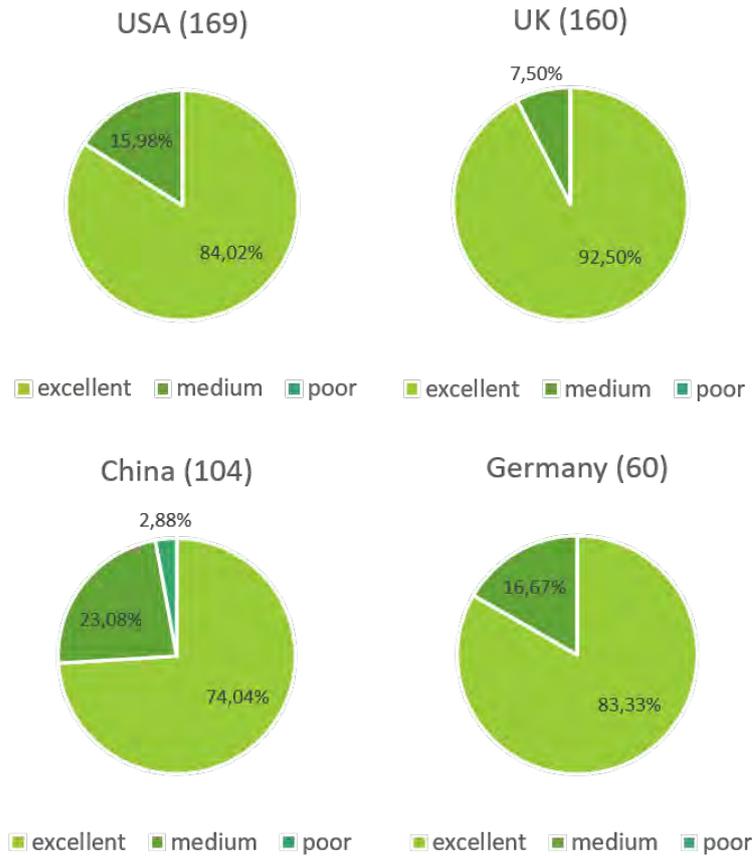


Figure 7. The four countries with the most evaluated maps (number of maps in parentheses)

Countries with 20 or more evaluated maps are shown on Figure 6. The large number of Hungarian elements is caused by the Hungarian journal per each branch. We have found that there is a large spatial variability in the map use habits of different countries and cultures (Figure 7). This can either mean specific but correct ways of visualization or solutions that make the map hard to understand and should not be followed.

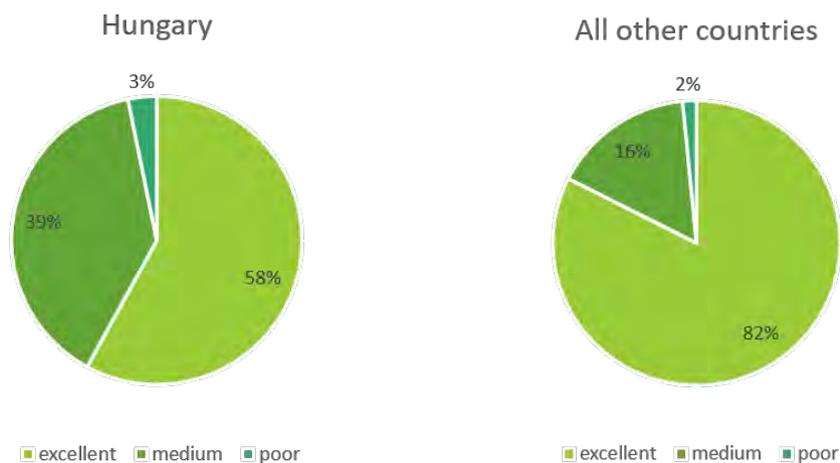


Figure 8. The visual quality of maps from Hungary and all other examined countries

The quality differences between maps with Hungarian first authors and international authors are depicted in Figure 8 in percentages. The visual quality of maps with Hungarian authors (in the Hungarian periodicals) is much worse, than the maps of other countries' authors (in international journals). This usually mean bad resolution images, bad colour chooses, missing map elements and other negative effects that worsen the interpretability of the map.

## CONCLUSION AND DISCUSSION

We can state that most of the examined science branches have their typical thematic map type – or at least a typical set of data that is presented. All map accessories, map types and thematic contents are in a relation with this specific theme. The visual quality of geoscience maps is nearly balanced. Geological and geographical journals have the largest H index values – it is reflected by the maps too: a larger H index may mean stricter editorial rules and better map quality.

Countries with developed scientific life publish better maps. There are lots of articles and figures from developing countries, but the tradition of scientific publication is weak. Because of this, some visualization methods do not meet the requirements of “excellent” quality. In the case of Hungary this is also valid. Despite being in Central Europe, especially national earth scientific journals have less strict editorial rules – this leads to worse visual quality and missing elements of maps. The trends in the H indices of journals is nearly the same as internationally – higher values are also connected to better map quality.

By analysing these statistics, the examined geoscience branches can draw their own conclusions: what are their common mistakes, how can they develop their map communication skills. It is also true for each countries or cultures. Everyone can use this methodology to enhance self-assessment too. By applying this evaluation model, one can examine his/her own map before publishing. As the dual aim of scientific publications to bring science closer to professionals and laics too, we need to keep visual and cartographical norms to succeed.

## ACKNOWLEDGEMENT

The project is supported by the ÚNKP-19-3 New National Excellence Program of the Ministry for Innovation and Technology.

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# TOWARDS A SEMANTIC-BASED VISUALIZATION PORTAL OF INTERNATIONAL RELATIONS OF THE VIENNA UNIVERSITY OF TECHNOLOGY

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## **Abstract**

*Internationalisation plays a key role for universities. International cooperations amongst researchers, departments and universities contribute to the capacity, output and reputation of academic institutions. Many universities have programs to strengthen and enable international relations on all scales. However, in order to understand the success of such programmes it is needed to define internationalisation through indicators, which can be measured and monitored.*

*In this paper possible indicators for measuring internationalisation of universities will be discussed, a selected set for TU Wien analysed and a semantic model for defining processes related to internationalisation at a university will be presented. Such a model is a key underpinning element for visualising international relations of academic institutions through cartographic representations and visualisation portals*

## **1. INTERNATIONAL RELATIONS OF ACADEMIC INSTITUTIONS**

Higher education systems, such as universities, are confronted with ever increasing demands to improve their reputation, attractiveness and quality in the context of the globalisation of knowledge, which leads to an increased competition at national and international level. Internationalisation is one of the most important criterias that must be taken into account when it comes to the performance and position of universities in rankings (Bas, Boquera & Carot, 2017).

In a very general sense International relations represent a multidisciplinary field that generally can include aspects of political economy, foreign policy analysis, development studies, environment, international security and much more (Department of International Relations, San Francisco State University, 2019). When focusing on the international relations of a university the areas of concern are especially the international activities of the academic staff and students, both in respect to research and teaching.

According to Brandenburg and Federkeil, internationality is the current status of an institution at a given point in time with regard to international activities. In contrast, internationalization is a process in which an institution changes from an actual status of internationality at time X to a modified status of internationality at time X+N. The result is the difference between the actual status of internationality and the desired status at the end of a period (Brandenburg & Federkeil, 2007). According to Polak the following activities form the basis of a university's internationalisation process (Polak, 2017).

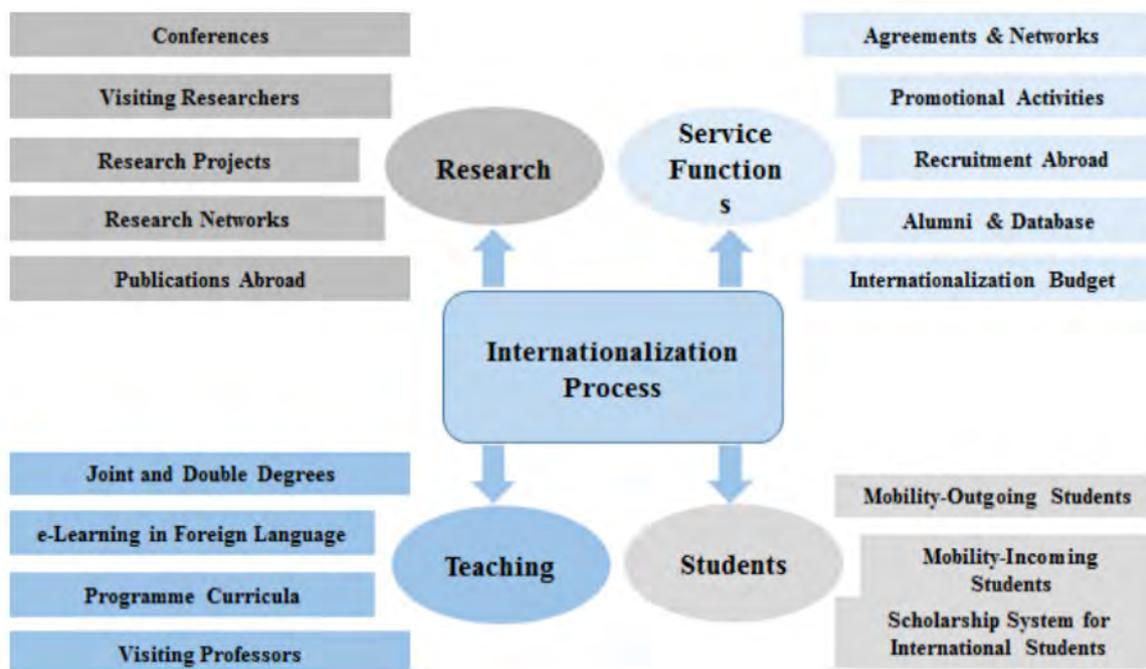


Figure 1 Common International University Activities

It is also important to differentiate, that international relations can be measured at different entity levels such as institutional (faculty and university staff), sectoral (technical universities), national, regional or even global (Sanderson, 2007).

In order to compare the internationality and internationalisation of different universities, a standardised approach for measuring these aspects must be developed. For such a standardized approach the use of representative indicators of the phenomena are desirable. A comprehensive list of potential universities was introduced by Brandenburg & Federkeil (2007). The most commonly used methods for data collection are surveys and institutional data. The institutions themselves play the most important roles in the collection of data, thus ensuring a precise assessment of internationalisation activities (Beerkens, Brandenburg, Evers, van Gaalen, Leichsenring & Zimmermann, 2010).

There are two categories of sources on which an indicator set can be based. In the first case, indicators are based on expert assessments and knowledge about internationalization, because theory and practice show that these indicators are important for measuring the internationalization of institutions. In the second case, the universities themselves must judge whether an indicator is useful for analysing the internationalization and whether the necessary data should be collected (Brandenburg & Federkeil, 2007). Whatsoever, the main aspect remains, that the selected indicators describe both internationality at the current point in time and the process of internationalization within a certain time span. In this way, a development of the measured values can be statistically measured, such as growth or decrease in numbers within a certain period.

## 2. INTERNATIONAL RELATIONS OF TU VIENNA

### 2.1 Selection of indicators

The selection of indicators which are representing the International Relations of TU Vienna should be inline with the broader internationalization goals of TU Vienna. As a starting point of the selectioning the “Development plan 2013+” of TU Vienna was analysed, where the strategic guidelines of TU Vienna were defined. Indicators were chosen from the IMPI-Toolbox (Indicators for mapping & profiling internationalization) and the CHE-Toolbox (Centre for higher education development), because their indicators are among the best known. The international activities of TU Vienna were split into 3 sections: “Students”, “Staff and research” and “Education and studies”. A total of 21 indicators were selected.

Student mobility is important for measuring internationality and internationalisation because of the correlation with the perceived quality of the study programmes. In the project "TU Vienna Global Strategy 2013+" it was emphasised that TU Vienna promotes the mobility of TU master and doctoral students. According to Polak, mobility of "incoming and

outgoing students" contributes to the internationalisation process of a university (Polak, 2017). For this reason, indicators have to be selected that take into account the incoming and outgoing exchange students:

#### **Students- 6 indicators**

- Study abroad – 3 indicators
- International students – 3 indicators

Example for indicator from the section “Students”:

*What proportion of students from the unit participate in outgoing exchange or mobility programmes in a given year?*

The mobility strategy of the Vienna University of Technology is intended above all to enable young researchers to gain international and scientific experience and establish contacts (Vienna University of Technology - TU Vienna, 2014). It can be noted that the following international activities of an academic staff member play a significant role in the formation of international relations: Participation in international research projects and publications, lectures at universities abroad, participation in conferences, stays at foreign universities as visiting professor, visiting researcher or guest lecturer (Polak, 2017). Therefore the section “Staff and research”, covering the international activities of the academic staff of Vienna University of Technology, include the following indicators:

#### **Staff and research – 12 indicators**

- International mobility of academic staff – 6 indicators
- Research projects – 1 indicator
- Publications – 3 indicators
- Patents – 1 indicator
- Partnerships – 1 indicator

Example for indicator from the section “Staff and research”:

*Proportion of professors who have spent at least 1 semester abroad relative to the total number of professors*

When assessing internationality and internationalisation a final section of concern is "Education and studies". As part of this the overall policy of TU Vienna is promote mobility abroad as "securing language courses as well as the courses on Transferable Skills in the soft skills catalogue for all students" (Vienna University of Technology - TU Vienna, 2014). A suitable indicator must be selected for this objective formulated by the Vienna University of Technology:

#### **Education and studies – 3 indicators**

Example for indicator from the section “Education and studies”:

*Out of all courses offered by the unit in a given year, what is the proportion of courses taught in a foreign language?*

## **2.2 Data collection for the indicators**

All indicators need reliable, up-to-date and comprehensive data. There are several sources of data which can be used and it became clear during the research, that further efforts need to be taken to harmonize and streamline data acquisition and modelling for enabling the sought analysis and reasoning towards internationalisation. The following sources have been identified:

- Public statistics at the website of TU Vienna
- Research database of TU Vienna
- Individual websites of the faculties
- Publication database of the TU Vienna
- Citation database “Web of Science”
- Section “International Office” at the website of TU Vienna
- Internal Information and administration database of TU Vienna

It should be mentioned that only TU Vienna has access to the larger part of the data, thus most of the data is not publicly available.

### 3. SEMANTIC DATA MODEL

A semantic data model is a method for structuring data in order to present it in a certain logical way. It is a conceptual data model that contains semantic information that adds fundamental meaning to data and relationships. An entity relationship model is used as the basis for database design. Before using "SQL" language to set tables and relationships, the ER model must be planned, which describes how the database structure can be built. The basic elements of any entity relationship model are: entities, relationships and attributes.

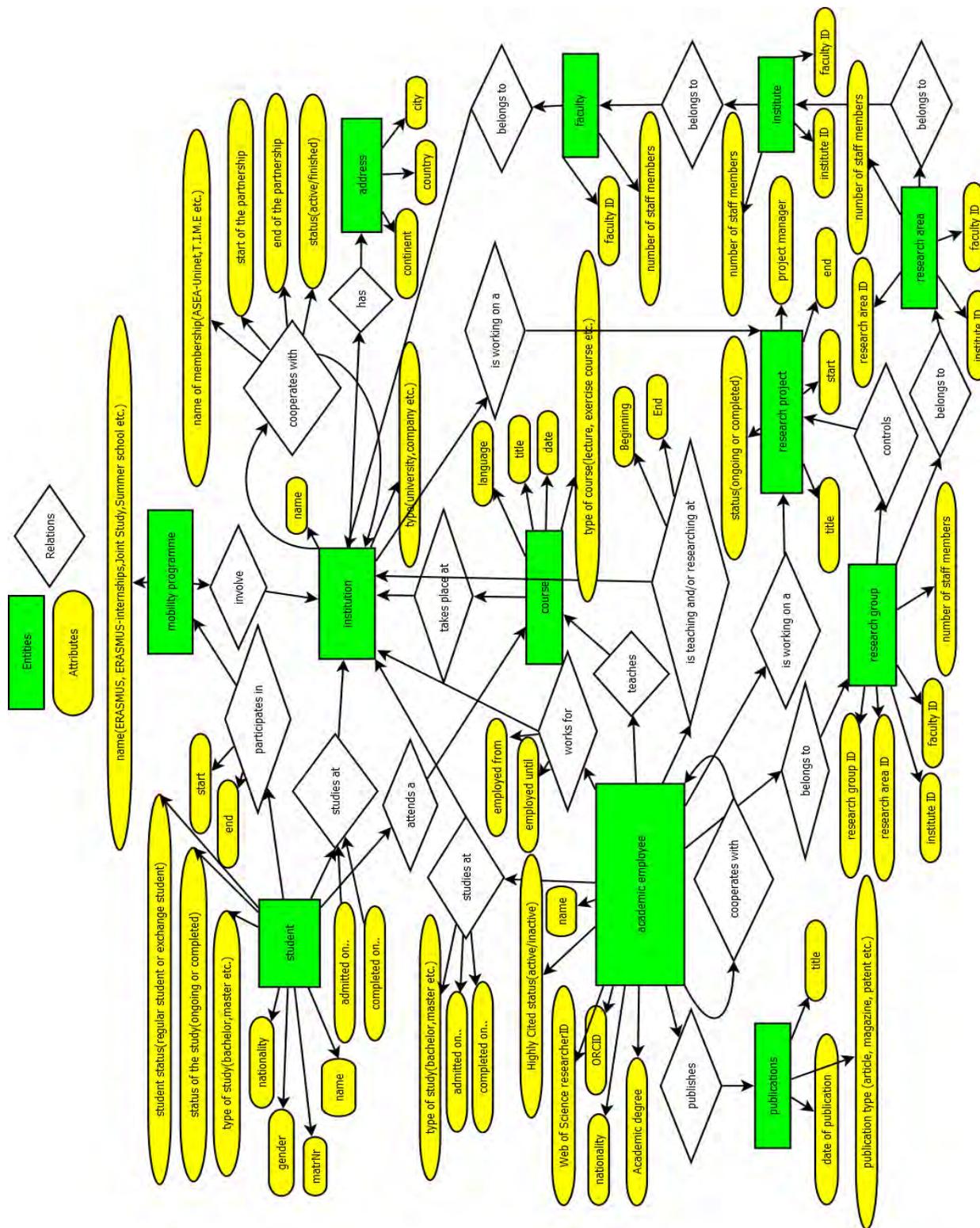


Figure 2 Entity-Relationship Model of International Relations of TU Vienna

An entity is understood here as a single and uniquely identifiable information object. Attributes and relationships can be assigned to entities or other information objects. The entities can be used to model complex data sets clearly (Luber, 2019). For example, the individual researchers and professors of TU Vienna should be stored as entities. The attributes can be different, e.g. researcherID, first and last name or nationality. The attribute values represent the actual information, e.g. attribute = "Web of Science researcherID", attribute value = "AC-5507-2019".

A list for all twenty-one indicators was then created describing how the selected indicators can be calculated based on the semantic relationships of the entities. Such an example of the above described indicator 01-003 can be:

- Entity-“students”(attributes: student status=“ordinary student”), who study at the institution with name=“Technical University Vienna” and participate in mobility programs in a certain year/ Entity-“students”(attributes: student status=“ordinary student”), who study at the institution with name=“Technical University Vienna”.

#### **4. METHODS FOR VISUALIZATION OF INTERNATIONAL RELATIONS**

Based on the semantic data model of international relations several visualization approaches could be applied to present the international relations.

##### **4.1 Approaches for visualizing semantics**

There are different approaches for visualizing semantic information which focus on presenting different aspects of semantic structure and attributes. As showed in the ER-Diagram, the semantics may contain various levels of information. Existing approaches utilize various graphical representation techniques from visual computing, visual analytics and information visualization.

The most frequently used approaches for visualizing semantic data are categorized into:

- Hierarchical semantics visualization
- Relational semantics visualizations
- Entity-based semantics visualization

The first approach is focused on visualizing hierarchical aspects of semantic information. Hierarchies provide the opportunity to categorize domain-specific resources in inherited concepts and allow a topic-related access to the modeled domain knowledge. Users are able to locate a search topic in the hierarchical structure and get thereby a starting point to abstract his query by querying the parent node or precise his search by choosing a sub-node. Hierarchies can be visualized in various ways: nested, treemap, indented, or top-down and left-right structures intuitively as hierarchies (Nazemi, Burkhardt, Ginters & Kohlhammer, 2015).

Relational visualizations play an essential role in visualizing semantics. The natural structure of semantics is predestinated for visualizing semantic relationships and thereby a structural view on the domain of given knowledge. A relational view on semantics is important, due to the ability to get an overview of the entire knowledge space or see the relations of resources to interact and browse for a knowledge path (Nazemi, Burkhardt, Ginters & Kohlhammer, 2015).

Entity-based semantics visualization is designed for search tasks. The above mentioned approaches for graphically representing the relationships or hierarchies are secondary and are frequently used to support the search process. The entity-based visualizations are aimed at giving a kind of interactive “picture” on the entities that builds the content of the underlying visualized data. This kind of visualizations are useful for mapping the entity to a certain contextual information, e.g. time, location, or semantic similarity (Nazemi, Burkhardt, Ginters & Kohlhammer, 2015).

##### **4.2 Visualization options**

Aiming for a web-based portal of visualising a semantic model of international relations of a university requires a basemap, thematic cartographic methodology, interactivity functionality and dynamic mapping due to contemporary standards. Some of the most frequent used visualization options are column diagrams, circle diagrams, line diagrams, scatter diagrams and bubble charts. Since the focus here is visualization of International Relations, diagrams can be combined with world maps. The following options can be used for such purpose:

- Bubble Chart Map: A combination of a bubble chart and a map. It can be used to visualize places and proportions in a simple way. The size of the bubbles can represent different indicators

- Connection – Map: Displaying a network in combination with geographical data by combining color or pattern to the lines or inserting another type of illustration (e.g. bar chart or pie chart)

Those visualisation options need to be embedded in an interactive framework allowing for exploring the attributes of every entity (e.g. researcher, department, faculty), every attribute (e.g. number of publications, time of employment etc) and relations (collaborations, travels, visits, joined activities etc), thus a model for a selection menu was created regarding the different aspects of internationalization, allowing a user to analyse internationalization at different levels. A specific visualization option is selected for each indicator. The most of the indicators can be represented with a single number in percent. *What proportion of students from the unit participates in outgoing exchange or mobility programmes in a given year?*

For in-depth analysis of a certain aspect the user should receive more information. For example, the aspect “Study abroad” contains three indicators: the first measures the proportion of students from the unit that participates in outgoing exchange or mobility programmes and the other two measure the proportion of graduates that have completed an internship or a semester abroad. The user should get additionally the following information:

- The user should be able to limit the search to a certain period of time and as a result a web page opens with data on the indicators and two interactive web maps.
- The first visualizes the completed semesters abroad, the second – the completed internships abroad.
- In addition to the web map, a bar chart with x-axis target country and y-axis number of students who have visited the target country can be created.
- In order to measure the internationalization process, a line chart can also be produced, which visualizes the change in the values of the indicators.

## 5. SUMMARY

International Relations become crucially important for universities. In order to be able to communicate those it becomes necessary to define the underpinning processes and indicators, representing these international relations, and to model them accordingly. By this an overall reflection on the relevance and importance of internationalization can contribute to a clearer understanding and awareness. In this paper a semantic approach for defining and modelling related processes of activities in relation to internationalization of a university is proposed, which can underpin visualisation portals aiming for depicting and exploring international relations.

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# MANIFOLD LEARNING–BASED MAP COLOR TRANSFER

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## **Abstract**

*Map colors are indispensable in map visual communication and thinking. However, creating a good color design is challenging for experts as well as novices. Recently, a new idea, color transfer, has drawn considerable attention in cartography and computer graphics; it aims to transfer colors from one or more reference images to a target image while preserving the color appearance of the reference image. However, existing methods in computer graphics have limited consideration of cross-regional, legibility, and cartographic color design rules, such as conventional and semantic rules. This paper proposes a vector-based map color transfer method that treats map color transfer as a multiconstraint optimization problem. The manifold learning technique is introduced to organize discrete colors from a reference image. The proposed method is implemented with four reference images. Compared with FastPhotoStyle from NVIDIA, our method achieves better results in terms of legibility and graphical quality.*

**Keywords:** Map color design, Color transfer, Manifold learning, Multiconstraint optimization

## **1 INTRODUCTION**

In the era of so-called ubiquitous mapping, anyone can be a cartographer (Wood 2003, Goodchild 2007). With the development of information and communication technology (ICT), users can use maps on electronic devices anytime and anywhere (Gartner et al. 2007). Map design is no longer always performed by experts through reference maps, and the general public now shows great interest in making personal, creative thematic maps. In this context, general public-facing mapmaking techniques are now urgently needed, including map color design, which is one of the most important components of map design.

Map colors play an irreplaceable role in map visual communication and visual thinking. Color, as a visual variable, can be used to encode quantitative and qualitative information. Color can also be an esthetic element to make maps attractive. So far, a series of guidelines have been proposed for color design, such as visual variables (Bertin and Berg 1967, MacEachren 1995), legibility (Sloan and Brown 1979), conventional rules (Robinson 1995), semantic rules (Hoarau 2011), harmony (Moon and Spencer 1944), and visual contrast and hierarchy (Robinson 1995). However, these rules are often qualitatively described, and in practice, they often need to be compromised, which may be beyond the user's skills and experience. Effective color design is time consuming and labor intensive, not only for experts but also for novices. Monmonier (2018) called map color design a cartography quagmire. Supporting high-quality map colors is still challenging.

Recently, a new idea, color transfer, has drawn considerable attention in the field of cartography and computer graphic science; it aims to transfer color from one or more reference images to a target image with color appearance preservation. In cartography, some studies have aimed to transfer personalized and creative colors from artistic paintings to maps to enhance the esthetic aspects of maps. For example, to obtain Renoir painting-style maps (Feranec and Pravda 2009) and Monet painting-style maps (Friedmannová 2009) researchers summarized painters' color palettes and manually transferred them to maps; however, this method depends on the experience and knowledge of cartography and resists automation. There are also some interactive personalized mapping tools, such as Mapbox's Cartogram (Mapbox 2017), that can automatically generate four map-color styles based on a user-provided picture, but the overall

color appearance is not always harmonious. Some scholars have also tried to transfer map styles based on deep learning image style-transfer methods. For example, Bogucka and Meng (2019) used a deep learning style-transfer method to transfer map styles and evaluated the emotional quality of the transfer results. However, the transfer results are more like paintings than legible, information communication-oriented maps. Kang et al. (2019), based on a generative adversarial network (GAN), designed a tile map-based style transfer method. However, it is limited to a matched map region.

In computer graphics, Reinhard et al. (2001) proposed the first automatic image color transfer algorithm, which can transfer the color from an image to another image to enhance the visual effect of the transferred image. Then, various image color/style transfer algorithms were proposed: Chang et al. (2004) proposed a perception-based color transfer method. Colors were divided into different categories by name, and then a classification constraint was followed to generate colors from their original categories for color transfer. Neumann and Neumann (2005) introduced a nonlinear histogram-matching method based on hue, saturation, and brightness. It can transfer any color style from a source image to a target image using 3D histogram matching. Nguyen et al. (2017) used K-means clustering to construct color palettes from multiple images and transfer them to other images. Li et al. (2018) proposed a deep learning-based image transfer method, FastPhotoStyle, which can output very realistic transfer results. These methods all focus on color transfer from image to image rather than from image to map.

From the above discussion, these efforts toward color transfer show potential applications to accommodating personalized and creative mapping by providing a new way to generate an artistic color appearance. However, these methods focus on image-to-image color transfer and suffer from a common limitation: lack of consideration of essential map color design rules (e.g., conventional rules, semantic rules, harmony, etc.), making the transfer results more like paintings than maps. To fill this gap, we propose an automatic vector-based cross-scale map color transfer method. The remainder of this paper is organized as follows: Section 2 presents the model formulating the problem of map color transfer. Section 3 introduces a manifold learning-based technique to solve the problem. A heuristic algorithm based on an artificial bee colony algorithm is also shown to obtain a satisfying result. Section 4 evaluates the results of our method and of a deep learning-based color transfer method.

## 2 PROBLEM FORMULATION

We aim to perform color transfer from an image to a vector map with both scientific and artistic considerations. The references used can be paintings, fine artwork, or photographs. The target is a vector map with point, polyline, and polygon symbols and labels for any scale and region.

First, the map color should still serve as a visual variable to communicate information, and, conventional, semantic, legibility, and hierarchy principles should be considered. Then, as a representation, the color harmony and emotion of the reference should be kept. Of course, the visual appearance of the reference image should also be preserved. In this paper, the above map color transfer considerations are transformed into a multiconstraint optimization problem, the constraints of which include 1) the reference image color constraint, 2) the legibility constraint, and 3) the conventional rule constraint; the objective functions are that 1) the map color appearance should be similar between the reference and the target, and 2) the map color should be harmonious.

### 2.1 Constraints

(1) Color gamut constraint. Map colors should come from reference images. Generally, colors from reference images are discrete color points rather than a contiguous color space. In this paper, the discrete point cloud of the image colors is analyzed by the manifold learning technique. In doing so, the discrete, three-dimensional color points are dimensionally reduced in a nonlinear manner to a two-dimensional space, which can help in efficiently searching and transferring the colors (see Section 3.1 for details). The map color is searched from the image color manifold, and the map color source constraint is shown in equation (1).

$$C_{map} \subseteq Color_{manifold}, C_{map} = \{C_1, \dots, C_n\} \quad (1)$$

Where  $C_{map}$  is the map color after transfer,  $Color_{manifold}$  is the color manifold constructed from the source image, and  $n$  is the number of map layers to which the color needs to be transferred.

(2) Legibility constraint. To be legible, any two colors in the map should be distinguishable according to the perceptible color difference (just-noticeable-color-difference, JNCD) threshold (Mahy et al. 1994). In the model, the color difference between any two map colors should be greater than the threshold  $\delta$ , as shown in equation (2):

$$\forall C_i, C_j \in C_{map}, \Delta E_{ab}^*(C_i, C_j) > \delta \quad (2)$$

Where  $i$  and  $j$  are the subscripts of any two map colors in the CIELab color space.  $\Delta E_{ab}^*(C_i, C_j)$  is the color difference between two colors.  $\delta$  is the threshold for distinguishing any two map colors. The color distance can be calculated by using the Euclidean distance in the CIELab color space. In the CIELab color space,  $L$  indicates brightness (0-100),  $a^*$  ranges from green (-) to red (+),  $b^*$  ranges from blue (-) to yellow (+), and  $a, b$  usually range from -128 to +127, as shown in equation (3):

$$\Delta E_{ab}^*(C_i, C_j) = \sqrt{(L_i - L_j)^2 + (a_i^* - a_j^*)^2 + (b_i^* - b_j^*)^2} \quad (3)$$

Where  $C_i=(L_i, a_i^*, b_i^*)$  is color  $i$  and  $C_j=(L_j, a_j^*, b_j^*)$  is color  $j$ .

(3) Conventional rules. From considerable mapmaking experience, cartographers have summarized a series of conventions for map color use that can help to improve the quality of map information communication, such as using green for forests and other vegetation and blue for oceans, rivers and other water bodies. In this paper, to respect the conventional rules, the map color cannot shift too far from convention. (If no color is searched, the color with the least color difference is selected.) This is shown in equation (4):

$$\forall C_m \in C_{map}^{habit}, \Delta E_{ab}^*(C_m, C_m') < \delta \quad (4)$$

Where  $C_{map}^{habit}$  is the color set of the layers, which needs to take into account the map color convention.  $C_m'$  is the color before the transfer.  $\Delta E_{ab}^*(C_m, C_m')$  is the difference between the original color and the transferred color.  $\delta$  is the maximum color shifting threshold.

## 2.2 Objective function

(1) Similarity of color appearance. The color proportion is one of the major factors in shaping an image's color appearance, and it may vary greatly from image to image. Since the number of colors in an image is generally much larger than the number of map themes, widely used factors in current image color transfer methods, such as histogram matching, are not suitable for transferring image colors to maps. Here, the root-mean-square error (RMSE) function is used to measure the similarity of color appearance. The RMSE is a common loss function in machine learning. It represents the square root of the second sample moment of the difference between the predicted value and true value, and it can reflect the degree of deviation between the predicted value and true value. Here, we use the RMSE to indicate how close the color proportion of the transferred map is to that of the reference image. The similarity of color appearance is calculated with equation (5).

$$f_1(C) = \sqrt{\frac{1}{n} \sum_{i=1}^n (P(C_i^{map}) - P(C_j^{image}))^2}, C_i^{map} \in C_{map}', C_j^{image} \in Color_{manifold} \quad (5)$$

Where  $P(C_i^{map})$  is the color proportion of the  $i$ -th map theme,  $C_j^{image}$  is the color set of the selected image, and  $P(C_j^{image})$  is the color proportion of color  $j$ .

(2) Color harmony. Harmonious colors can enhance the beauty of maps. O'Donovan et al. (2014) captured preferences for color combinations through a collaborative filtering method on a large color palette data set and used a generalized linear model to analyze the color harmony rules; this model can be used to calculate the harmonic score of a 5-color

group. In this paper, this method was used to quantify map color harmony. Assuming that the score of the user's color preferences of a 5-color  $t_i=(1,2,\dots,5)$  group is  $\gamma(T)$ , then the objective function of the map color harmony is shown in equation (6).

$$f_2(C_{map}) = \frac{1}{M} \sum_{i=1}^M (P_i \times \gamma(T_i)) \quad (6)$$

Where  $T_i(t=0,1,\dots,M)$  is a set of  $M$  groups of color in  $C_{map}$  sorted by the color proportion,  $t_i$  is a group containing 5 map colors, and  $P_i$  is the sum of the proportion of colors in this group.

### 2.3 Multiconstraint color transfer model

Combining the above objective function and constraints, the map color transfer problem is transformed into a multiconstraint optimization problem in which the two objective functions are normalized and then combined into a single objective function by using  $\omega_1$  and  $\omega_2$  as the two weighting factors. The mathematical model of the automatic map color transfer method is shown in equation (7).

$$\begin{cases} \max F = \omega_1 \times f_1 + \omega_2 \times f_2 \\ \text{s.t.}: C \subseteq Color_{manifold}, \forall C = \{C_1, \dots, C_n\} & (C_1) \\ \forall C_i, C_j \in C_{map}, \Delta E_{ab}^*(C_i, C_j) > \delta & (C_2) \\ \forall C_m \in C_{map}^{habit}, \Delta E_{ab}^*(C_m, C_m') < \delta & (C_3) \end{cases} \quad (7)$$

Here, all the variables and symbols have the same meaning as in the previous constraints and objectives.

## 3 MODEL SOLVING

Model solving mainly consists of two parts: 1) generation of color manifolds. We translate the discrete, three-dimensional color points into two dimensions to efficiently search the image colors. 2) Heuristic search. We find a satisfying solution by a heuristic search of the color manifolds.

### 3.1 Generation of color manifolds

Manifold learning is used in this paper to organize image colors. Manifold learning can implement nonlinear dimensionality reduction expressions for high-dimensional variables, and it can implement interpolation and sampling operations that are difficult to perform in high-dimensional and nonlinear spaces (Roweis and Saul 2000). The assumption of a manifold distribution conforms to the distribution characteristics of object colors. Manifold learning has already shown advantages in efficiency and quality in automatic color recommendation and interactive color design (Nguyen et al. 2015).

At present, common methods for generating color manifolds include principal component analysis (PCA), multidimensional dimensional scaling (MDS), and self-organizing maps (SOMs) (Nguyen et al. 2015). This paper uses the SOM algorithm to generate the color manifold space of the reference image. The SOM algorithm is an unsupervised data dimensionality reduction method. As shown in Figure 1, taking Van Gogh's Starry Night as an example, a 10\*10 color manifold is generated to achieve a dimensionality reduction expression for the image color.

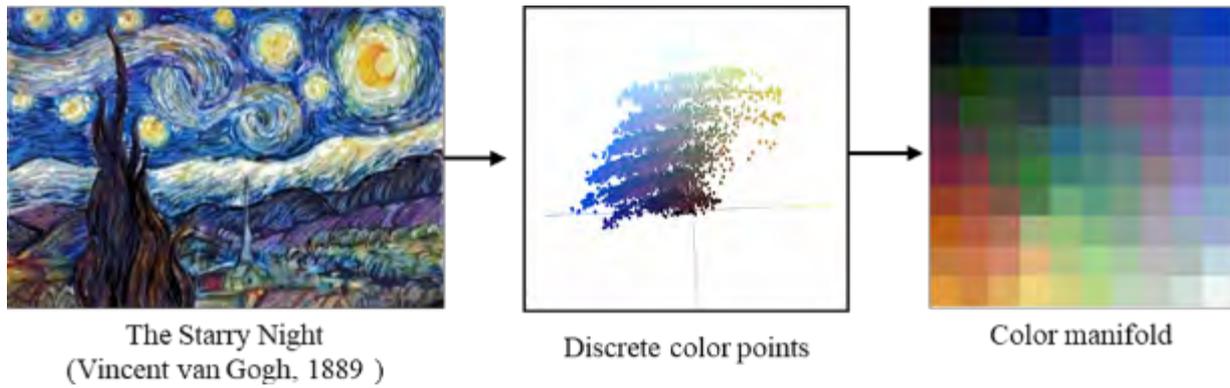


Figure 1. Example of color manifold generation

### 3.2 Heuristic search

In this paper, the map color transfer problem is regarded as a multiconstraint optimization problem. We can explore the color manifolds to solve the problem. Ideally, the global optimum can be found by traversing the color manifolds according to the constraints and the objective. However, this is too computationally expensive, as it is a typical combinatorial optimization problem whose algorithmic complexity is often exponential. We therefore choose a heuristic algorithm, the artificial bee colony (ABC) algorithm, to solve the model.

The ABC algorithm is both a local and global swarm intelligence search algorithm. It was originally proposed for numerical optimization problems and has been successfully applied to different types of optimization problem-solving tasks (Karaboga and Akay 2009). For a detailed description of the ABC algorithm, please see (Karaboga 2005). In what follows, the two major components of the ABC, initialization (which sets up a series of artificial bees to explore a space) and the fitness definition (which guides artificial bees to find a satisfying solution), are described.

(a) Initialization: Randomly generate  $SN$  (number of bee colony populations) color schemes  $C_i = \{c_{i1}, c_{i2}, \dots, c_{iD}\}$  ( $i=1, 2, \dots, SN$ ) in the search space (color manifold in this paper, such as in Figure 1). Each solution  $C_i$  is a  $D$ -dimensional color vector, where  $D$  is the number of map themes.

(b) Definition of fitness. The fitness function gives the evaluation scores of feasible solutions and guides local and global searching. As described in Section 2.3, after the normalization operation of the two objective functions, the weighting method is used to calculate the combined objective function.  $\omega_1$  and  $\omega_2$  are the weights of each objective function. In this paper, each is set to 0.5, and the fitness function is obtained as equation (8):

$$Fitness(C_i) = \begin{cases} \frac{1}{F(C_i)}, & \forall 0 < m, n < D, \Delta E_{ab}^*(c_{im}, c_{in}) > \partial, \text{ and if } c'_{im} \in C_{map}^{habit}, \Delta E_{ab}^*(c_{im}, c'_{im}) < \delta \\ 0, & \text{otherwise} \end{cases} \quad (8)$$

$F(C_i)$  is the function value calculated with the  $i$ -th feasible solution  $C_i$  of the objective function  $F$ . The smaller the function value is, the larger the fitness value.  $m$  and  $n$  are the subscripts of any two map colors in the feasible solution  $C_i$ ,  $c_{im}$  and  $c_{in}$  are the colors of any two map themes,  $c'_{im}$  is the original color of layer  $m$ , and  $\partial$  is the color of the JNCD threshold of any two layers;  $\delta$  is the maximum color difference threshold of the original color and new color.

Guided by the fitness, the artificial bees locally explore to find colors that are harmonious and visually close to those in the reference map. If a better solution than the current one cannot be found after several rounds of iteration, then the artificial bee can give up the current solution and globally try another solution until it finds a satisfying solution.

## 4 EXPERIMENT

Three artists' paintings and one photographic work are selected as the reference images (see Figure 2), and a city map from OpenStreetMap (OSM, www.openstreetmap.org) is used as the test. The test map is designed by using conventional colors, such as depicting water in blue and forests in green. Figure 2 shows the results of color transfer.

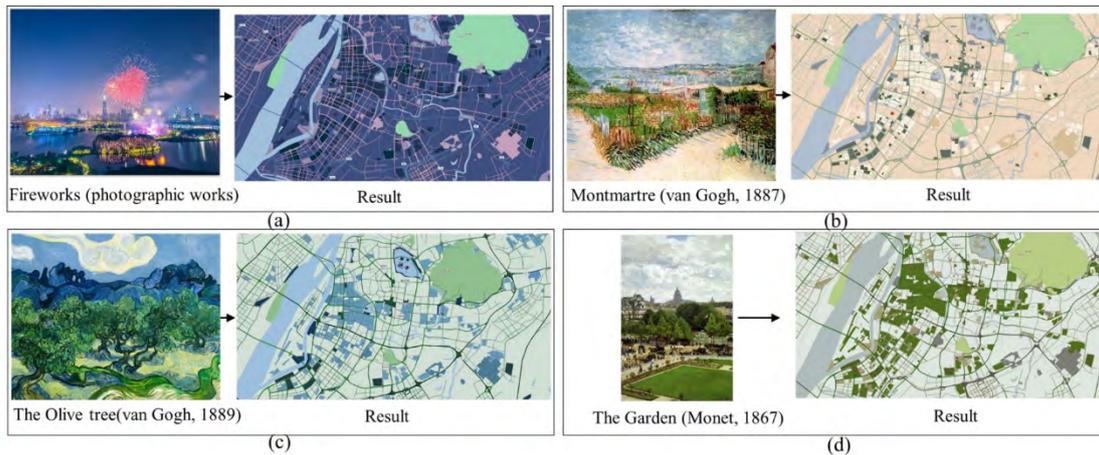


Figure 2. Example of map transfer results

Furthermore, to illustrate the advantages of our method, we compare our method with a deep learning-based method called FastPhotoStyle, which is a widely used image-to-image color transfer algorithm (Li et al. 2018). We use the OSM map as the source map and select Van Gogh's two paintings as the reference images. The results of our method and those of FastPhotoStyle are shown in Table 1.

Table 1. Comparison of the transfer results of our method and FastPhotoStyle

Test map	Reference	Our model	FastPhotoStyle

It can be clearly seen from Table 1 that the results of FastPhotoStyle are more like a painting than a map. The drawbacks are as follows: (1) the same map theme (e.g., feature A, the river layer) in the test map is transferred with different colors, which may result in misreading the feature type; (2) FastPhotoStyle introduces a blurred boundary (e.g., in feature B, the background layer); (3) FastPhotoStyle does not keep the visual hierarchy and contrast (e.g., in feature C, the road layer); and (4) FastPhotoStyle does not respect the conventional rules (e.g., in feature D, the forest layer). In contrast to FastPhotoStyle, our method can preserve conventions, visual hierarchy and contrast, can keep symbols clear and legible, and can maintain the feature classification. In addition, it can be seen from the transfer results that neither our method nor FastPhotoStyle transfers a satisfactory color for map labels, so it is necessary to optimize the method further.

## 5 CONCLUSION

To meet the general public's demand for personalized and creative map design, this paper proposes an automatic vector-based map color transfer method. Compared with an image-to-image color transfer method, our method can achieve better results in terms of legibility and cartographic graphical quality. This method can potentially be implemented as a web tool to provide personalized and creative mapping services for the general public to support the idea that anyone can be a cartographer.

In addition, there are some shortcomings that need further improvement. For example, the color transfer of map point symbols and labels cannot simply be evaluated by the similarity of color proportions, and the results need further evaluation on various map reading tasks, such as identification, location and comparison.

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# IMPROVED TECHNIQUES FOR DEPTH QUALITY INFORMATION ON NAVIGATIONAL CHARTS

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## **Abstract**

*Navigational charts contain a combination of geospatial information of varying quality collected at different times using various techniques. Bathymetric data quality is mainly encoded in electronic charts with the Category of Zones of Confidence (CATZOC). CATZOC provides information about the horizontal and vertical uncertainty of depth information, as well as the seabed coverage and feature detection. It is visualized in Electronic Chart Display and Information Systems (ECDIS) as an additional layer with glyphs using a rating system of stars: six to two stars for the best to lowest quality data and “U” for unassessed data. The current symbology creates visual clutter which is worse in areas of high quality bathymetry. Furthermore, horizontal and vertical uncertainties may not be adequately assessed by the user. This paper presents a research program aimed at the development of a method for portraying bathymetric data quality and for integrating the quantified uncertainties in ECDIS.*

**Keywords:** Spatial Data Visualization, Error-band geometry, Bathymetric Data Uncertainty, Electronic Navigational Charts ENC, Uncertainty Visualization, Visual Variables, Safety of Navigation

## **INTRODUCTION**

Bathymetry shown on nautical charts is compiled from geospatial information of varying quality, collected at different times, using various techniques. The first systematic hydrographic surveys were conducted using hand deployed lead-lines and sextants. Improved techniques in the 20<sup>th</sup> century included single-beam echo-sounders, and most recently, high resolution bathymetry is collected using multi-beam echo-sounders and airborne lidar systems. At the same time, with the use of satellite positioning systems the positional accuracy of surveys has also considerably increased. Data quality of geospatial information plays an important role in decision making in maritime navigation, and failure to take it into account can be one of the factors leading to maritime accidents [see e.g., the cases of Nova Cura (DSB, 2017) and Pazifik (BSU, 2020)].

The hydrographic community has been concerned with informing mariners about the data quality on charts since the 1919 International Hydrographic Conference in London (HMSO, 1920). The first agreed approach was with a description in the title of the chart (Pielou, 1984), which with time took the form of a chart inset either with the use of the *source diagram* introduced by Beaton (1960) or with the more complex *reliability diagram*. The simplistic nature of the former made it obsolete as it could no longer meet the needs of maritime navigation at the end of the 20<sup>th</sup> century, whereas the complexity of the latter made it difficult for cartographers to construct and for the mariners to use (Roberts & Lewis, 1992 as cited in Johnson, 2004).

In an effort to fulfill the increasing needs of contemporary navigation, in the early 1990s, the hydrographic community introduced Zones of Confidence (ZOC) for use on paper and the newly introduced Electronic Navigational Charts (ENCs). The ZOC concept was developed to provide a simple and logical means of classifying all bathymetric data in terms of quality, and displaying the confidence that a national charting authority places in it (Johnson, 2004). The ZOC diagram has served nautical charting for about three decades and, with moderate enhancements, the concept will continue to exist in the new S-101 (IHO, 2018) transfer data standard for ENCs. However, the current symbology for displaying ZOC in the Electronic Chart Display and Information System (ECDIS) has shortcomings. The most important deficiencies are associated with the star glyphs coding scheme, and that the uncertainty values provided in the ZOC categories are not fully incorporated in ECDIS analysis in route planning and execution.

This work presents research on the development of new visualization and integration methods of data quality on charts in order to support decision making on board. In the following sections, we review the limitations of the current symbology, the recent research efforts for the development of improved visualization methods, the suitability of the available visual variables for the purpose, and, lastly, we discuss a potential solution under investigation.

## ZONES OF CONFIDENCE AND QUALITY OF BATHYMETRIC DATA

The ZOC diagram formed a paradigm shift in the way the evaluation of data quality is performed by hydrographic offices in-house as part of the compilation process, replacing a system where the end-user was expected to perform the evaluation based on the provided quality indicators. For the ZOC diagram, the area of the chart is delineated into sectors (as with its predecessors) with each sector assigned one of the six ZOC categories shown in Table 1. The ZOC categories have a horizontal and vertical uncertainty associated with them, information about the seabed coverage and feature detection, as well as a short description of the typical survey characteristics [the detailed ZOC table can be found in IHO Special Publication 57 (IHO, 2014)]. With this information, mariners may more effectively interpret the seabed morphology, identify potential hazards for the vessel, and select routes that maintain under-keel clearance.

In ENCs, the ZOC categories are encoded in the attribute CATZOC (Category of ZOC) of the meta-object M\_QUAL (quality of data) which also has a number of optional attributes, e.g., SOUACC (sounding accuracy) and POSACC (positional accuracy). Currently, CATZOC is portrayed in ECDIS as an additional layer with glyphs using a rating system of stars: six to two stars for the best to lowest quality data and “U” for unassessed data (see Table 1). The layer may be activated and de-activated by mariners.

*Table 1: The six ZOC categories and the respective symbology, horizontal and vertical uncertainties, and achieved seabed coverage.*

ZOC	Symbol	THU (m)	TVU (m)	Full Seabed Coverage
A1		5	0.5 + 1%	Yes
A2		20	1 + 2%	Yes
B		50	1 + 2%	No
C		500	2 + 5%	No
D		> 500	>2 + 5%	No
U		U	U	U

As it can be seen in the examples of Figure 1, the current CATZOC symbology adds significant clutter on ECDIS screens, obscures high-quality more than low-quality data, may not be visible in small areas, is not intuitive, and dominates the screen, especially in dusk and night modes of ECDIS. Consequently, CATZOC is often not used and horizontal and vertical uncertainty may not be adequately assessed by the user, something that is confirmed by maritime accidents reports (e.g., DSB, 2017; BSU, 2020) and research (e.g., Harper et al., 2012; DQWG, 2016).

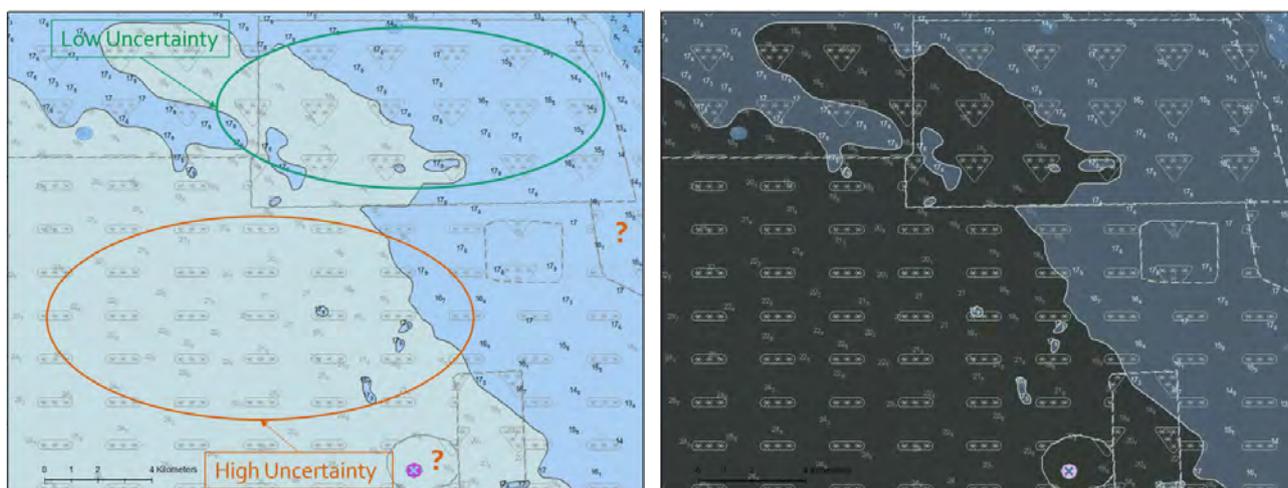


Figure 1: The visualization of CATZOC in Day (left) and Dusk (right) ECDIS modes (Kastrisios et al., 2020b)

For the S-101 standard, the CATZOC attribute is replaced by the Quality of Bathymetric Data (QoBD) in the form of a decision tree incorporated in ECDIS. The five categories of assessed data A1, A2, B, C, and D are renamed to 1, 2, 3, 4, and 5 respectively. One more category “O” (Oceanic) is provided for the areas where water depth is deeper than 200m (and, thus, does not pose a threat to surface navigation), and an attribute for the temporal variation of the seabed has been added (details in IHO S-101 Annex A). Other than that, the horizontal and vertical uncertainties and the seabed coverage criteria for each category remain unchanged. Due to the recognized deficiencies of the star symbols, the International Hydrographic Organization (IHO) Data Quality Working Group (DQWG) considers that “the current staggered pattern symbology of CATZOC should not be used in S-101” (DQWG, 2019a). The new visualization method for CATZOC and the S-101 QoBD in ECDIS has been a topic of research over the last decade, however it is yet to be selected.

## PREVIOUS RESEARCH EFFORTS

Hare et al. (2011) used a continuous color scale to represent bathymetric uncertainty in their work on modelling of bathymetric uncertainty, a technique commonly used by hydrographers for the visualization of high resolution bathymetry and the associated depth uncertainty (e.g., Bathymetry Attributed Grids). With this they demonstrated the potential uses of the new IHO S-10X product specifications (e.g., S-102) while discussing under keel-clearance and the visualization of go / no-go areas with a red-green traffic-light display.

Two other visualization techniques were proposed by the IHO DQWG and Nautical Cartography Working Group (NCWG). In the work of the former, the quality levels are visualized with line textures of varying transparency. The work of the NCWG presented the use of four different coding schemes, i.e., a ring pattern of different hues (green, yellow, red, and white), single hue with variation in color value, and two with pie charts. However, both works targeted the four quality tiers that were under consideration at the time (i.e., good, fair, low-quality, and unassessed) (see e.g., DQWG, 2015) but officially abandoned in the 10<sup>th</sup> meeting of the DQWG (DQWG, 2016). As such, the proposals are not directly applicable to the six levels of CATZOC and QoBD (seven including the oceanic). Furthermore, the DQWG identified as primary drawbacks of the NCWG proposal the ambiguity of color value and the severe display clutter of pie charts (DQWG, 2016). Furthermore, the proposed ring patterns make use of color hues that are not recommended for the application (see DQWG, 2015) as they were intended for use in under-keel clearance, and dominate the screen view in most ECDIS modes.

The most comprehensive work on the visualization of data quality in ECDIS is that by Gladisch and Ruth (2016). Therein, the authors discuss common practices in the visualization of spatial data uncertainty, record the deficiencies of the current star symbology, review the previous research efforts, and investigate the use of noise, transparency, and textures for the visualization of data quality. The grid and hexagon textures they proposed are effective in all ECDIS modes. The main deficiencies of the method are the use of the same, very dense, texture for QoBD 5 and U, and, as the DQWG points out, that it is not intuitive and adds considerable clutter in ECDIS screen (DQWG, 2019b).

Lastly, in 2017 the DQWG proposed a method using color codes (DQWG, 2017). The main idea was to combine the safety contour, safety depth, and the four shades of blue used for the color coding of depth areas in ECDIS, with the populated QoBD values into a single view. This idea was presented at the 9<sup>th</sup> meeting of the Hydrographic Services and

Standards Committee (HSSC) but raised a few concerns, and the HSSC members decided that some issues remained to be addressed and that the possible options should first mature prior to an official proposal (HSSC, 2017).

## STUDY AND PROPOSED SOLUTION

Ideally, symbology to display data quality on an ECDIS screen should:

1. Minimally interfere with the other charted information,
2. Unambiguously relate to the QoBD categories,
3. Emphasize the areas of greater uncertainty,
4. Be easy to remember, and
5. Be effective in all ECDIS modes (i.e., day bright, day whiteback, day blackback, dusk, and night).

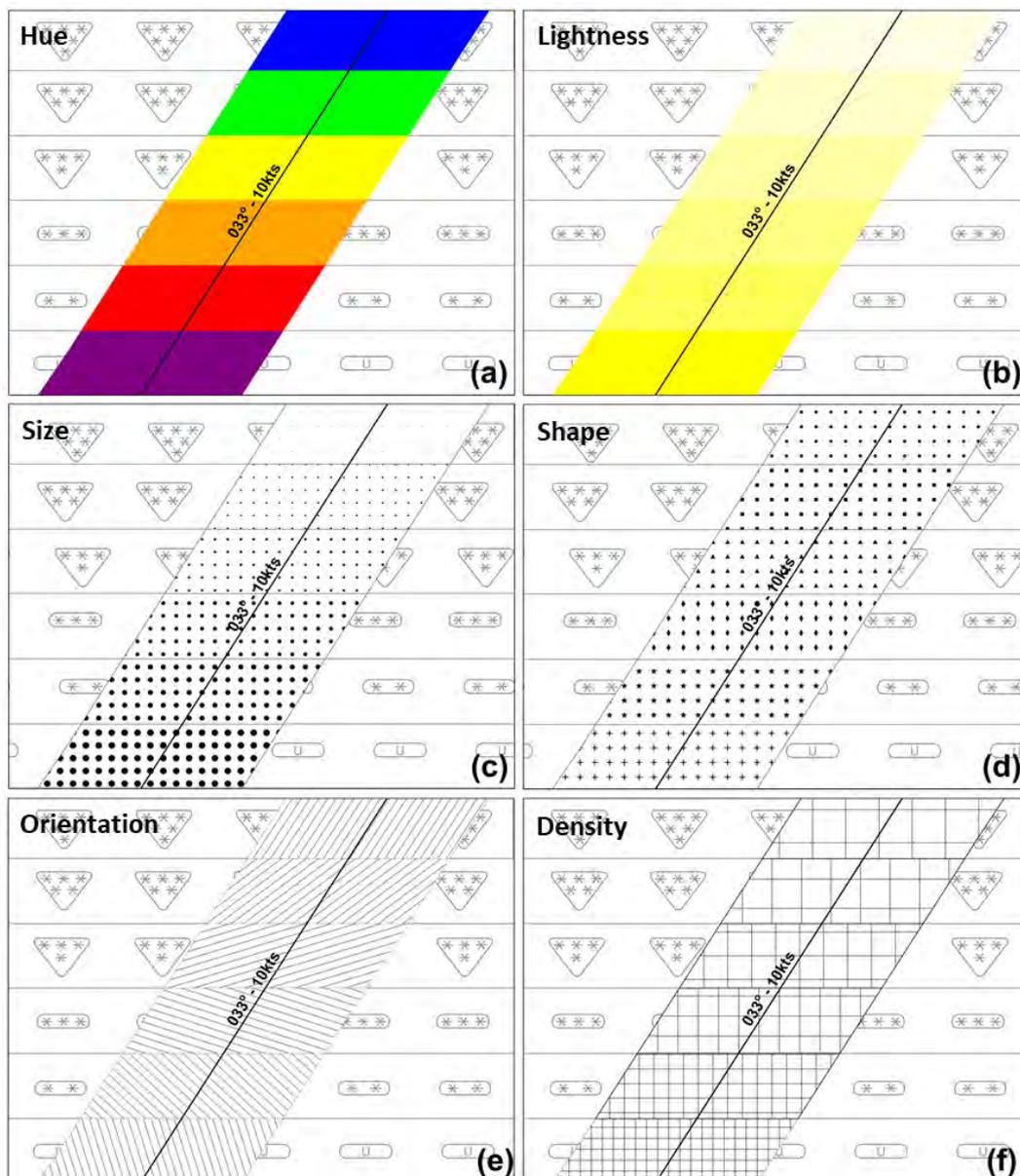


Figure 2: Examples of the utilization of the visual variables of hue (a), lightness (b), size (c), shape (d), orientation (e), and density (f) for the visualization of the six levels of ZOC on ENCs (Kastrisios et al., 2020a)

Most primary and secondary *color hues* (Figure 2a) are already reserved for other uses in the ENC/ECDIS or possibly not suitable for all ECDIS modes. In addition, the experimental results of MacEachren et al. (2012) have showed that

color hue has very low intuitiveness. *Color lightness/value* (Figure 2b) and *saturation* lead to visualizations that may obscure important underlying areal object on charts (e.g., the color coding of depth areas for shallow and deep waters). Furthermore, for all three dimensions of color the portrayed layer of data quality can become dominant in dusk and night modes. *Transparency* may alter user’s perception of the color coding of the depth areas. The visual variable of *shapes* (Figure 2d) has no intuitiveness and the decoding of ZOC categories necessitates the use of a legend. With *size*, *orientation*, and *density/grain* (Figures 2c, 2e, and 2f, respectively), the identification of the different CATZOC levels becomes ambiguous whenever only a few of the levels are displayed.

Satisfying the set of requirements for ZOC visualization with a single visual variable can be challenging. The solution that seems most promising is to use a sequence of textures created by combining two or more visual variables. The advantages of textures are that they are minimally used in current ECDIS displays, and if they consist of open meshes they are expected to minimally interfere with other chart information (unlike, e.g., opaque colors or color transparency). Each texture must be designed to be clearly distinct from the previous one so that their values can be unambiguously perceived. Each texture should be visually denser than the last, with denser textures representing greater uncertainty. Furthermore, we are suggesting a boolean strategy for distinguishing between assessed (i.e., QoBD 1, 2, 3, 4, 5, and Oceanic) and unassessed (i.e., QoBD U) data.

Table 2 shows an example of a coding scheme with textures consisting of lines. The fundamental principle is that the number of lines represent the QoBD, e.g., one solid line for QoBD 1, three lines (one single and one double) for QoBD 3, and five lines (two double and one dash lines) for QoBD 5. Oblique lines are used for assessed data (i.e., QoBD 1, 2, 3, 4, and 5), whereas vertical-horizontal lines represent the unassessed data (i.e., quality “U”). Lastly, additional information is conveyed by the single and double lines (i.e., full vs not-full seafloor coverage has been achieved).

Table 2: A sample coding scheme of textures consisting of single, double, and dashed lines. Variation in transparency and orientation of lines is also used.

ZOC	QoBD	Symbol	Texture
A1	1		
A2	2		
B	3		
C	4		
D	5		
U	U		

Figure 3 shows an example of the textures of lines presented in Table 2 superimposed on a US ENC (US4NC15M, Cape Lookout to New River, North Carolina). The texture emphasizes uncertainty while reducing visual clutter (compared to star symbols) by varying density and transparency. Increasing density and opacity of lines indicate higher uncertainty values (lower quality data). An evaluation of the illustrated solution shows that it meets the criteria outlined previously with the primary advantage of being an intuitive representation of the different QoBD categories. This and other coding schemes based on the same principles that are under consideration, along with ideas by others (e.g., DQWG, 2019a) will be evaluated in the form an on-line questionnaire which will be distributed to the mariner community. This questionnaire is designed to evaluate a set of alternative coding schemes in terms of their ability to meet the requirement set in the first paragraph of the current section.

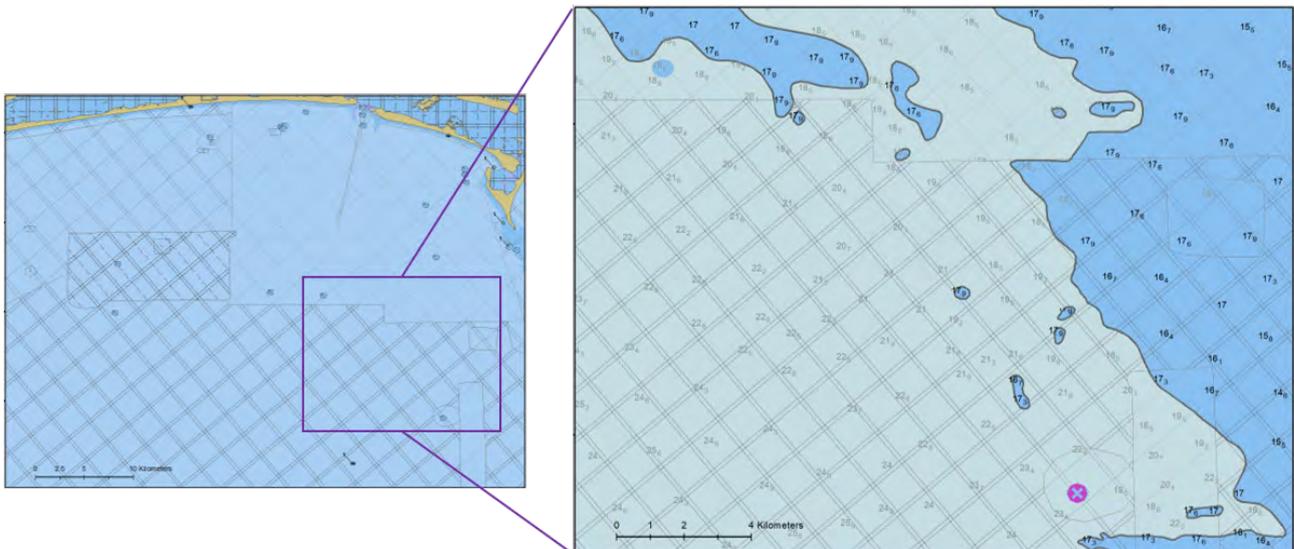


Figure 3: Visualization of ENC data quality using the textures of lines of table 2 (Kastrisios et al., 2020a)

A further aspect of the research project is the determination of the area to be visualized. Prior solutions use a layer that covers either the entire extent of the chart or a zone of fixed width around the plotted route. We are investigating the use of zone of variable width equal to the horizontal uncertainty in the area and its incorporation in the hazards appraisal performed by ECDIS. The advantage of this lies in the fact that shoals charted with high certainty (e.g., ZOC A1 / QoBD 1) not in the vicinity of the plotted route (which therefore do not pose a threat) will not be treated as a threat, but those with higher horizontal uncertainty would.

Besides the visualization of the CATZOC / QoBD sectors in ECDIS, we are also investigating the visualization of depth and positional uncertainty of individual bathymetric features (e.g., wrecks, underwater rocks, obstructions) and their incorporation in ECDIS analysis. The logical solution for their positional uncertainty is the use of an error-band geometry approach [e.g., Foy (2011)] that is already under consideration by the DQWG (2020). For the depth uncertainty, this can be incorporated in ECDIS for the adjustment of the charted depth and the consequent display of this depth value on ECDIS for the mariner's awareness whenever necessary. It is noted that the resulting error-band geometry and the depth uncertainty of features may be uniform or non-uniform in the same M\_QUAL as other quality indicator may have been encoded, e.g., POSACC and SOUACC. Cases that require special treatment, such as features in navigable channels or near the boundaries of two areas with different QoBD categories, are under consideration. Other factors include the color (e.g., magenta, black), type of line (e.g., solid, dashed, or dotted), size of font and line, location of the displayed adjusted depth (e.g., over the hazard, on the outline of the circle), and minimum visible sizes.

## CONCLUSION

This paper discusses the concept of CATZOC for bathymetric data quality in ENCs and its visualization and integration in ECDIS analysis in support of safe marine navigation. To overcome the deficiencies of the current star symbology it presents a research methodology for the development of a new coding scheme that includes the determination of application specific requirements and the evaluation of the visual variables for their suitability. It proposes the use of a sequence of textures created by combining two or more visual variables and presents an example consisting of lines with variation in the type (single, double, and dashed lines), the transparency, and the orientation of lines. The proposed solution is intuitive and unambiguous, emphasizes the areas of greater uncertainty, and is effective in all ECDIS modes. It also discusses the integration of bathymetric data uncertainty in ECDIS analysis with the use of a zone around the plotted route with width that is equal to the horizontal uncertainty encoded in CATZOC and error-band geometries around individual features. The advantage of the investigated approach is that features charted with high certainty not in the vicinity of the plotted course will not be treated as a threat (thus reducing useless alarms with a large user-defined zone width), whereas those with higher horizontal uncertainty are incorporated into the analysis (thus eliminating the risk of actual dangers that are overlooked due to a small user-defined zone width).

## ACKNOWLEDGEMENTS

The work of Christos Kastrisios, Colin Ware, Brian Calder, and Thomas Butkiewicz is supported by the National Oceanic and Atmospheric Administration grant NA15NOS4000200.

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# MAPPING STYLES FROM A PRAXIS THEORY POINT OF VIEW

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## **Abstract**

*The visual turn in social sciences left its imprints on many disciplines. The methodologies discussed in this field are a chance to adapt analysing methods to maps, when approaching them as a visual product and medium that follows other implicit rules than photographs or paintings do (following e.g. Harley 2001). In this paper, I want to present a map-interpreting methodology that is specifically compatible with a practice theory approach. The methodological base is the documentary method, proposed by the German sociologist Ralf Bohnsack. It has its root in Harold Garfinkel's ethnomethodology, Pierre Bourdieu's praxis theory and Karl Mannheim's cultural sociology, and applies techniques from art history to visual material. The paper will discuss how it can be adapted to cartographic visualizations, in order to identify the specific worldviews that different styles of map design communicate. Promising aspects as well as limitations to this approach will be discussed.*

**Keywords:** *critical cartography, cartographic theory, map studies, praxis theory, qualitative research*

## **INTRODUCTION**

While the analysis of visual material is an integral part of the social science methods playbook, the investigation of maps and cartographic images remain on its outskirts. This is not to say that there are no map studies from a social science point of view – obviously, the call of Brian Harley and others did not go unheard, and historic analyses of maps also have had a long history. But these studies remain isolated, either within the so-called critical cartography or historical studies. A look into the social science methods literature reveals that there do not exist established and specific methodologies to analyse maps the same way as they exist for interview material, for photographic imagery or for videos and which are grounded in specific theoretical and conceptual backgrounds, such as the grounded theory, objective hermeneutics, symbolic interactionism, or ethnomethodology. At the same time, within geography and – obviously, cartography – we can find a huge amount of literature on how to produce maps, representing a rather practical knowledge of how maps are communicating knowledge. Therefore, this knowledge about how to make a “good map” is still the basic ground when judging the scientific value of cartographic imagery as well as its manipulative power (Monmonier 2018).

The aim of this contribution is to put the map side by side to photographs, videos and other visual materials, and suggest a way of analysing it that takes into account the visual qualities of cartographic material. I suggest a procedure to analyse maps that offers a useful tool when conducting research that aims at understanding social meaning of cartographic documents, linking it to the nowadays widely discussed practice theory approach to the social. For this purpose, I firstly sketch some aspects of the visual turn in social sciences and social geography, in order to locate my approach in this broad field. Afterwards, I discuss the theoretical view of practice theory on maps before presenting the methodology of the documentary method, which is based on Karl Mannheim's cultural sociology of knowledge and Harold Garfinkel's ethnomethodology and links it to Pierre Bourdieu's practice theory. On this base, I suggest and discuss a procedure to analyse maps that can serve as an inspiration for research that is interested in the tacit knowledge documented in maps.

## **THE VISUAL TURN IN SOCIAL SCIENCES AND THE OVERLOOKING OF MAPS**

A rising interest in “the visual” in social sciences has been proclaimed some time ago. Already in 1994, W.J.T. Mitchell, an important representative of visual theory, observed a pictorial turn that took form of “rather a postlinguistic, postsemiotic rediscovery of the picture as a complex interplay between visibility, apparatus, institutions, discourse, bodies, and figurality” (Mitchell 1994, 16). The links to ‘postmodern’ theorists are strong and include most famously Michel Foucault's discourse theory. Brian Harley transferred this approach to maps and theorized them as a visual

product of social forces which has to be interpreted as being part of societal discourses, linked to a grit of power and to be understood in its “metaphorical and rhetorical nature” (Harley 1989, 1).

Since the beginnings of the visual turn (that has been ongoing also under the name of a pictorial or iconic turn, depending on the disciplinary background), not only has the amount of theories about “the visual” grown larger and larger, but also the analysing techniques have been refined and diversified. In every social science methods book one will find at least one section on visual methods that not only present different visual materials to be analysed such as photographs, children’s books, videos and even video games, but also different methodological approaches. Take as an example the introductory book of the geographer Gillian Rose that has been first published in 2001 and now is in its fourth edition from 2016. While including a wide range of materials, curiously (for her being a geographer, at least), maps are almost entirely excluded – as she notes herself (Rose 2016, xxii). Meanwhile, the methodological approaches she presents in deep detail are compositional interpretation, content analysis, semiology, psychoanalysis, ethnography, as well as two varieties of discourse analysis (Rose 2016, see figure 1). This illustrates the wide range of perspectives on visual material that currently exist and allows researchers interested in different modalities as well as sites to pick an appropriate procedure to analyse their material.

**TABLE 3.1 The sites, modalities and methods for interpreting found visual materials**

	modality		
	<i>technological</i>	<i>compositional</i>	<i>social</i>
<i>production</i>	ethnography	ethnography	ethnography discourse analysis I
<i>the image itself</i>	compositional analysis	compositional analysis content analysis cultural analytics semiology psychoanalysis	social semiotics discourse analysis II ethnography
<i>circulation</i>	digital methods	compositional analysis	ethnography
<i>audiening</i>	ethnography	ethnography	ethnography audience studies digital methods

Figure 1. Gillian Rose’s matrix of visual research; Rose 2016, p. 50, own markings in yellow

Researchers planning to analyse maps can therefore decide for either of them, depending on their specific theoretical background and empirical interests. Since maps are not included in the proposed procedures, though, one has to adapt it to the characteristics of maps which differ from photos, videos or other kinds of infographics. Such adaptations feed for example on historical ethnographies (which are traditionally more interested in the site of map production), semiology, discourse theory approaches as well as compositional analysis (Denil 2016). But since these are rather singular research projects, no standardised analysing procedures came out as a result of these.

The aim of my paper is to present a method to analyse maps that is based in current practice theory discussions and presents a broad variety of analytical techniques which can be adapted to specific research interests. Namely, I am using the documentary method approach to analyse maps in an ongoing postdoctoral research project which I am conducting at the Geographical Institute of the Universidad Nacional Autónoma de México. Its theoretical and conceptual frame cannot easily be placed in Rose’s overview, though. While it can be located on the site of the image itself and in part on the producer’s site, the modalities touch at the same time technological, compositional as well as social aspects (see figure 1). To make that statement more comprehensible, I will sketch basic assumptions of the documentary method in the next chapter.

## MAPPING STYLES AS AN EXPRESSION OF IMPLICIT KNOWLEDGE

The documentary method focuses on the conduct of social practices and is interested in reconstructing their implicit knowledge, which is experienced and shared amongst social groups that are structured along categories such as gender, milieu or generation (Bohnsack 2014, 222). This knowledge informs not only the structure of our theoretical knowledge but also “the way we do things” practically – the way we greet, talk or dance. It is an embodied knowledge we apprehend in the course of our socialisation (Bourdieu 1977). Societal structures and rules are inscribed into the practical conduct of everything we do, and not only in an abstract (and verbalizable) knowledge.

This view can be found in Harley’s understanding of cartographic practices, when he asks “how the ‘rules of the social order’ appear to insert themselves into the smaller codes and spaces of cartographic transcription“ (Harley 1989, 6). To conceptualize the social meaning of artefacts such as photos, interview transcripts or maps in such a way that differentiates between a theoretical, abstract and communicable knowledge on the one hand, and an embodied, practical, implicit knowledge on the other hand, which are at work at the same time, calls for the consideration of basic assumptions from the sociology of knowledge which also overcome the simplistic and outdated differentiation between a structural approach to the social that views human practice as the sole outcome of societal forces, and actor theories that exaggerate individual agency (Rossetto discusses these two poles for the field of “post-representational cartography”, 2016). One such integrating approach is to be found in the documentary method, which views different mapping styles as an expression of different worldviews which are enacted individually but refer to a broader social background.

### The methodology of the documentary method

Mapped out first by German sociologist Ralf Bohnsack in the 1980ies, the documentary method has had much impact in interpretative sociology. The regularly updated list of research that relies on the methodology (accessible on <https://www.hsu-hh.de/systpaed/dokumentarische-methode>) showcases a broad range of applications across different disciplines, including geography. Its main impact it has had on research projects interested in social differentiation by means of the differentiation of social knowledge, or as coined by Karl Mannheim, conjunctive knowledge, also named collective action orientation frames (Przyborski/Slunecko 2020, 632; Bohnsack 2014, 221).<sup>1</sup> This conceptual base frames one important line of social science research that aims at understanding more about differences in society, be it regarding cultural, economic or other categories of the “human condition”. When it comes to define knowledge, many practice theory approaches (also the documentary method) differentiate between implicit (tacit) and explicit (codified) knowledge (Przyborski/Slunecko 2020, 631), a common way to distinguish kinds of knowledge also in geography (Meusburger 2015, 93). With the dimension of implicit knowledge, Bohnsack departs from Panofsky’s and Bourdieu’s concept of the habitus, an incorporated knowledge (Bohnsack 2014, 230; Bourdieu 1977) that expresses itself not only in our rational thinking but also in *the way* we move or act. In order to analyse this kind of knowledge, the interpreter should therefore reconstruct not only *what* was communicated in the course of a specific practice, but also *how* the practice was enacted. This is the key to understand the socially shared knowledge background in which a specific conduct of a practice was been made possible.

### The formulating vs the reflecting interpretation

Any practical process of empirical analysis that follows the assumptions of the documentary method, has to take into account this differentiation between the explicit and the implicit or immanent knowledge that lies behind observable practices and artefacts – such as maps, images, videos or talks manifested in transcripts. This conceptual dualism is mirrored in a differentiation between the *what* and the *how* of any practice. Therefore, the documentary method proposes first a formulating interpretation in which the contents of a practice are being analysed (Bohnsack 2014, 225). For interview transcripts that means, for example, defining the topics that have been tackled; revising the order in which the themes came up during an interview; and reformulating the contents presented. In the case of images, it refers to analysing the figurative elements which are depicted in an image (a forest, a person, an object). This step even includes the naming of specific scenes (a wedding, a playground, a farewell scene). In order to conduct the analysis of this step properly, everything has to be described and re-formulated in all detail. This makes sure that the interpreter gets more and more estranged to the text, meaning she has to suspend her intuitive understanding of the contents. This reflects the link the documentary method has to ethnomethodological techniques (see Przyborski/Slunecko 2020, 628) such as the “Garfinkeling” which goes back to the founder of ethnomethodology Harold Garfinkel and who proposed different methods in order to lift interpretations beyond an everyday understanding of social practices – the crisis experiment being one of the most important methods in order to break with the common sense understanding of situations. And

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<sup>1</sup> This view of social differentiation was picked up in Berger and Luckmann’s classic social constructivist opus in which they state that there exists “no society known to us that does not have some division of labour and, concomitantly, some social distribution of knowledge” (Berger/Luckmann 1966, 158).

even if such methods are supposed to create a practice to be studied in itself, the idea of breaking with common sense is also behind the principal idea of the documentary method which follows Garfinkel with the idea that just as in a scientific account, also in our everyday life we are interpreting each other's practices and relate their supposed meaning to our knowledge of how the social world works. In this sense, in every practice social meaning is documented and through means of the documentary method of interpretation we understand each other (Mannheim 1921-22/1970, 137). In scientific research, though, we have to do that in a reflective manner that allows for an analytical and meta-understanding of these meanings. Also contrary to everyday life interpretations, we need techniques that allow for a proper documentation of the analysing process. Therefore, procedures have to be followed that break with our intuitive understanding procedures of everyday life – such as a very, maybe overly, detailed description of an observed practice can offer.

Only after the first step of the formulating interpretation has been concluded, the question of *how* the contents have been presented comes in. In this step, the analysing posture changes, so the habitus of the practice can be analysed. This means in the case of texts, for example, that one has to ask for the kind of texts sorts in which a specific topic has been elaborated on (narration, description, argumentation, evaluation). For images, this step means to analyse the way in which the figures and/or objects have been depicted. This touches not only the colours used, but also the geometrical arrangement or the perspective have to be looked at. Specifically in this second step, the reflecting interpretation, using comparative material is important – if not to say, essential – to the analysis. This is because if we as an interpreter think about the question of how a specific content, a specific visual scene etc. could have been presented differently, we use our own personal imagination and knowledge. In order to get more comparing horizons into play, the use of materials that are more or less similar to the one analysed should be included into the comparing step (similar meaning e.g. maps of the same topic such as population density, but from different producers). It makes sure that the interpreter's perspective is relativized. At the same time, this allows the elaboration of the orientation frames of each case, and following an analysis of different cases, a typology in which the practices conducted might not be practically the same, but are identical in its structure – and therefore the practical knowledge behind them – becomes visible (see Bohnsack 2014, 229). Cases of homologous orientation frames form groups within the socio-genetic typification (ibid.). A multi-dimensional typification can be reached when looking into social dimensions such as migration or generational background that might play into the development orientation frames (Bohnsack 2014, 229f).

### ***Specificities of analysing visual material***

While the structure with a formulating and reflecting interpretation is also to be found when it comes to the analysis of visual material, due to the different logic of images, the details of analysis need to be adapted. The most important difference between texts and images is the one between a sequential vs. a simultaneous logic. While in an interview, the meaning is unfolded in the sequential steps of the interview, the image reveals its meaning all at once, as art historian Max Imdahl states (see Bohnsack 2009, 317).<sup>2</sup> Besides the simultaneity of visual material, its characterisation as a two-dimensional object has to be taken into account. Therefore, again relying on Max Imdahl, Bohnsack proposes the analysis of three dimensions of the formal composition of the image: the planimetry which refers to the geometric composition of the image (to be explained in detail in the next chapter); the scenic choreography, referring to the spatial relation of the objects depicted to each other; and lastly the perspectivic projection that includes the relation between the objects depicted with the viewer (Bohnsack 2009, 307). These aspects of an image can only be analysed when the iconographical knowledge, the *what* of the image, is suspended (Bohnsack 2009, 305) and the interpretation moves to the question of *how* the image depicts the contents as well as itself. This is best grasped by Imdahl's differentiation between a recognising and a seeing view. While the *recognising view* relies on our communicative knowledge and recognises objects, the *seeing view* looks at the image *as* an image that presents its contents in a specific manner. This brings up ambiguities (Bohnsack 2009, 307), e. g. when a supposedly mourning person in a graveyard scene does not have the "proper look" on its face. Therefore, the image brings more to it than just the contents or the objects depicted. This transcontrariness, as Imdahl coined it (as cited in Bohnsack, 2009, 307) is another consequence of the simultaneity of images.

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<sup>2</sup> This is only one way to see it, though. There is actually a dispute between perspectives that proclaim the simultaneous logic of the images, while others claim that images are as well read the same way as texts, referring to eye-tracking studies that show in what order the elements of visuals are being watched. This has also been used in cartographic research (e.g. Xia et al. 2010). In the analysis of the documentary method, however, this aspect is only be touched in the planimetric analysis of the image or map, as will be showed in the respective chapters here.

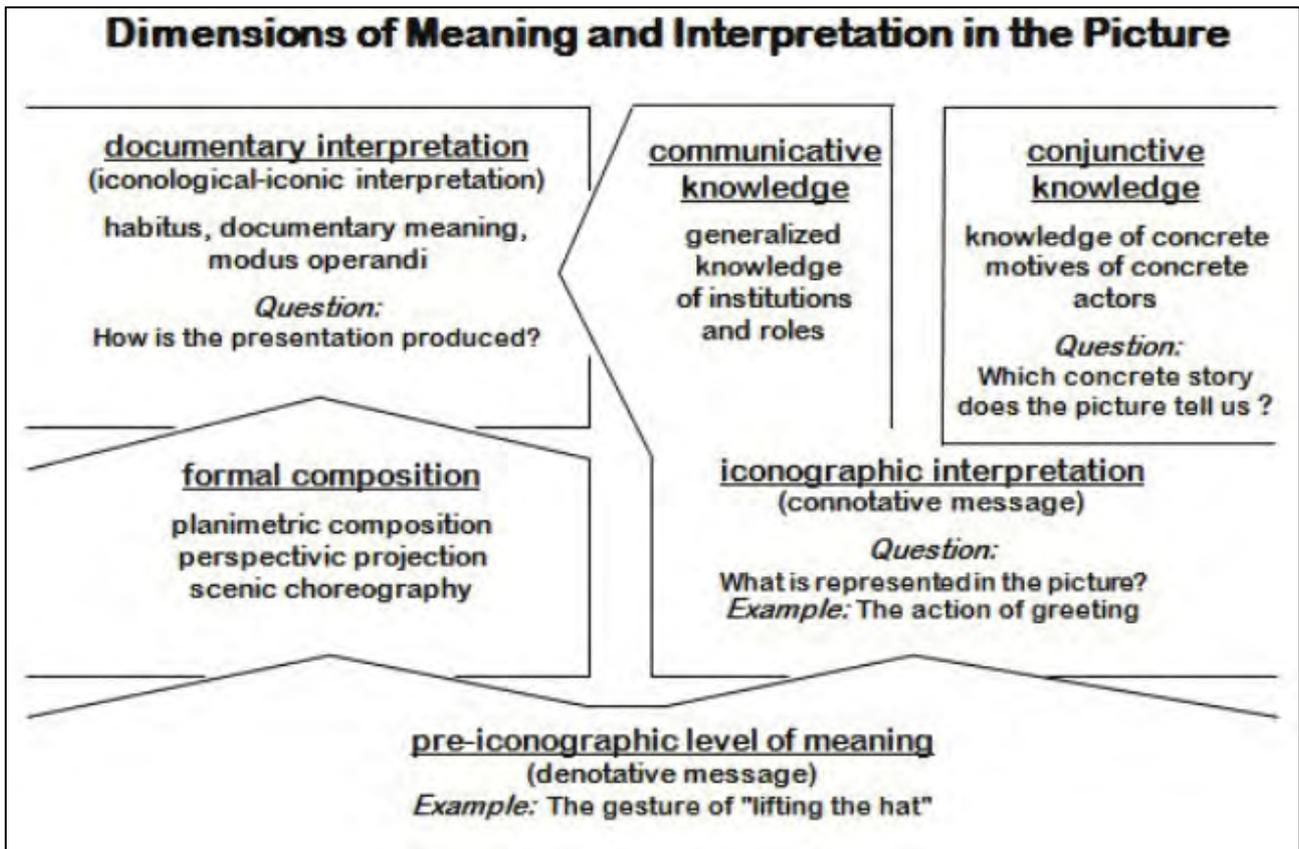


Figure 2. The dimensions of image interpretation; Bohnsack 2009, diagram 1

In order to account for the qualities of the image, Bohnsack proposes different analysis steps, as illustrated in figure 2. This procedure, however, is useful when analysing photographs or figurative paintings or other artistic, two-dimensional works. When it comes to maps, just as with images, we have to account for its specificities that are in some ways different to those of the image. While it is still a visual object, due to its nature as an infographic it usually also contains texts and data. While the above depicted image interpretation steps by Bohnsack will be used as a starting point, in the next chapter I propose adaptations to analyse maps with the documentary method.

### A documentary method approach to maps

Parallel to the documentary method perspective to images, maps can be viewed as a visual product that documents a specific practice style. However, the analysis to maps needs to be adapted to fit the specificities of the map that are a special kind of infographic which, according to Bertin, is "a 'language' for the eye" that aims at "storing, understanding, and communicating essential information" (Bertin 2011 [1983], 2). While Bertin's understanding of infographics as a monosemic system<sup>3</sup> seems problematic from a constructivist point of view, the documentary method approach offers an alternative that is located between subjectivist and objectivist approaches (Przyborski/Slunecko 2020, 630) and neither differentiates between emotions and cognition (ibid., 641). Existing procedures have to be adapted to the quality of the map which not only has some image-like qualities but also presents data and includes almost always texts. Bertin's definition of a map that he identifies "when the elements of a geographic component are arranged on a plane in the manner of their observed geographic order on the surface of the earth" (Bertin 2011 [1983], 285) clarifies that text is no necessary part of maps (but most often is to be found on them), while the "arrangement of geographic components" which refers to the geographic data and the plane which refers to the visual representation of a two-dimensional object, are integral part of them.

There exist specific conventions also regarding different types of maps which have to be taken into account when proposing a method to analyse maps. As a base to evaluate and analyse the elements of a map, the practical guide to

<sup>3</sup> Defined as „a moment for reflection during which one seeks a maximum reduction of confusion; when, for a certain domain and during a certain time, all the participants come to agree on certain meanings expressed by certain signs, and agree to discuss them no further“ (Bertin 2011 [1983], 3). This implies an objectivist thinking of map contents and appearances which are contrary to the posture taken here which sees maps as a contingent social product.

map-making of John Krygier and Denis Wood has been used that differentiates between the data, the geographic framework (scale, projection), the layout and design aspects, data generalisation and classification, symbols, words and colours (Krygier/Wood 2011). All these elements of a map will be included in the proceeding steps of the analysis which I sort into the three map dimensions of its data, its qualities as an image, and its textual elements. In the next chapter, I discuss the three dimensions more thoroughly in regard to the necessary steps to analyse them. Two maps will be used to illustrate the analysing process.

## PROCEDURE TO ANALYSE CARTOGRAPHIC IMAGERY

Analogous to the documentary method approaches for other materials, I suggest differentiating between the formulating interpretation that focuses on the “what” of the map as well the reflecting interpretation which is interested in the “how” of the map. At the same time, the texts (titles, captions,...) the data, and the image (with the symbols, colours etc.) have to be analysed separately, to be integrated in course of the interpretation later on. Two maps will be used as an analysis example. One is taken from the newspaper “El Economista” and as well as a map taken from a brochure published by CONEVAL, a public research institution. Both tackle the topic of food access in Mexico (see images 1 and 2).



Image 1. Map of the “population with a working income lower than the food basket’s cost”, *El Economista*<sup>4</sup>

<sup>4</sup> From the article “Chiapas, Guerrero y Oaxaca presentan el mayor deterioro laboral” by Ana Karen García, from 18<sup>th</sup> August 2018. <https://www.economista.com.mx/empresas/Chiapas-Guerrero-y-Oaxaca-presentan-el-mayor-deterioro-laboral-20180818-0001.html> (last accessed 19<sup>th</sup> May 2020).

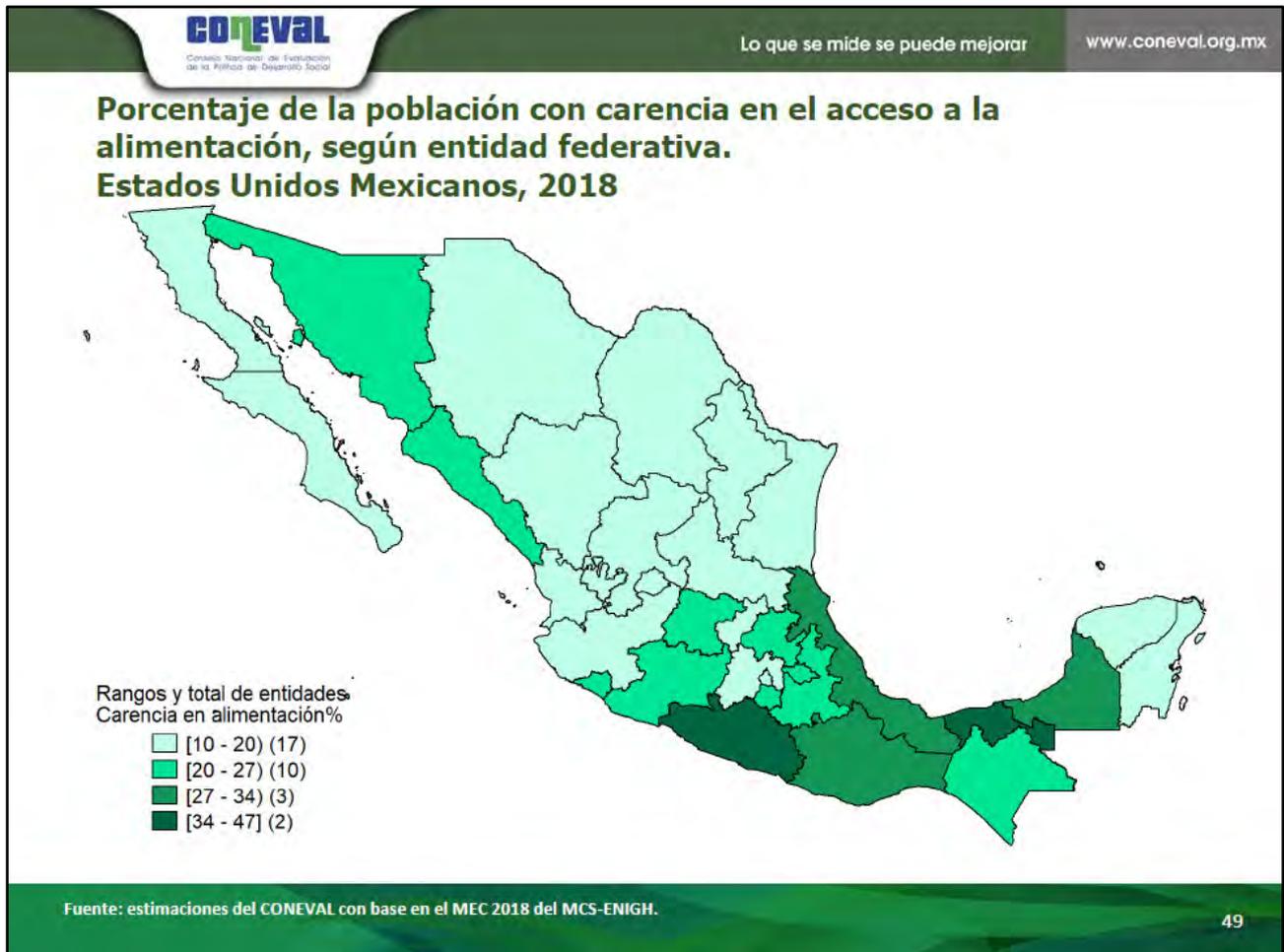


Image 2. Map of the “percentage of the population with a lack in access to food”, CONEVAL<sup>5</sup>

These maps have been undergone the procedure of analysis I will explain in detail in the following chapters. They have been chosen for dealing with a similar topic using similar data. Still, however, the styles differ very much, as a first look already reveals. To make this intuitive understanding comprehensible and to articulate it in a structured way, the following analysing steps can be useful. The aim is to open a road to criticise and socially contextualise the maps in a profound and documented manner.

### Formulating interpretation

In a first interpretation step, the “what” of the map will be analysed. The following table gives an idea of what aspects need to be considered when interpreting the map’s contents, or to put it differently, its communicative knowledge. As mentioned before, the procedure differentiates between the data used, the map as an image, and the text parts of it. The steps proposed follow Bohnsack’s approach to analyse images (2009), Arnd-Michael Nohl’s approach to analyse narrative texts (2012), and Krygier and Wood’s critical discussions of geographical data (2011).

<sup>5</sup> From the publication “Mapas de pobreza en los Estados Unidos Mexicanos, 2008 – 2018”, available at [https://www.coneval.org.mx/Medicion/MP/Documents/Pobreza\\_18/Mapas\\_pobreza\\_2018.zip](https://www.coneval.org.mx/Medicion/MP/Documents/Pobreza_18/Mapas_pobreza_2018.zip) (last accessed 18<sup>th</sup> May 2020).

Data	Image	Texts
<ul style="list-style-type: none"> <li>• <u>what phenomenon?</u></li> <li>• <u>primary/secondary source?</u></li> <li>• <u>qualitative/quantitative data?</u></li> <li>• <u>form of data:</u> <ul style="list-style-type: none"> <li>• <u>total</u></li> <li>• <u>density</u></li> <li>• <u>mean</u></li> </ul> </li> <li>• <u>spatial reference:</u> <ul style="list-style-type: none"> <li>• <u>states</u></li> <li>• <u>country</u></li> <li>• <u>...</u></li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• <u>pre-iconographic interpretation:</u> <ul style="list-style-type: none"> <li>• <u>recognizable objects? (object images, text, form with symbols etc.)</u></li> </ul> </li> <li>• <u>iconographic interpretation:</u> <ul style="list-style-type: none"> <li>• <u>form of a specific country</u></li> <li>• <u>map for education, scientific journal, newspaper</u></li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• <u>topics of text formats:</u> <ul style="list-style-type: none"> <li>• <u>caption (economy, population, ...)</u></li> <li>• <u>additional information</u></li> <li>• <u>labels</u></li> </ul> </li> <li>• <u>selection of passages/words to compare</u></li> <li>• <u>re-formulation</u></li> </ul>

Figure 3. Aspects of analysis for the formulating interpretation, own

In the following, all aspects of the table will be thoroughly discussed, using the above presented maps as illustrating examples. The design aspect as well as every aspect that relates to the “how” of the map will be suspended and rather be analysed in the interpretation part after this first one.

**What is the data about?**

Maps visualise geographical data which can be of very different qualities which has implications on the way they can be visually represented. Therefore, it is a key component to be looked at. Questions that have to be answered in this first analysing step tackle the question of the phenomenon depicted; the kind of source of the data (primary, secondary); the quality of the data (qualitative/quantitative; nominal/ordinal/interval data; total/density/mean); as well as the spatial reference (nation state, federal states, communities; singular geo-referenced data). The phenomenon depicted in the case of the El Economista map is spatial inequality, by means income and food security. The source is a mixture of secondary data as well as own calculations of the newspaper. The data is based in household interviews from a regular survey conducted by the state institution CONEVAL (Consejo Nacional de Evaluación de la Política de Desarrollo Social), titled “Encuesta Nacional de Ocupación y Empleo”, with calculations by INEGI (Instituto Nacional de Estadística y Geografía). The data is presented as the percentage of the population over 15 years in the respective federal states whose income is lower than the cost for the basic food basket (an official measurement of poverty; the basket contains the amount of food considered for a proper alimentation). Similarly, the CONEVAL map depicts estimates for the access of food in the federal states of Mexico. It uses its INEGI data from the survey “Encuesta Nacional de Ingresos y Gastos de los Hogares” together with own calculations. All this information has to be looked up, though; The El Economista map only names the institutions that provided the data, the CONEVAL map hints to the survey by means of an abbreviation. Furthermore, the El Economista map includes more detailed data since it also features the concrete percentages of various states, while the CONEVAL map only provides the aggregated data as coloured areas.

### ***What is the image depicting?***

For the visual dimension of the maps, they are analysed in two parts: in the pre-iconographic interpretation which tackles recognisable objects; and in the iconographic interpretation that asks for the known social context depicted. For the pre-iconographic interpretation, the analyst can ask questions like if there are photographs included; where are text parts; or where is a figurative symbol used. For the chosen examples, one could state in the case for the map of El Economista: We see a three-coloured map on a background in rosé. There is a box on the upper part that contains text while in the map we find also numbers linked to spots within the map. In the lower part we see text in the left corner and another box with text that frames the map below. The CONEVAL map is framed with green bars in the upper and the lower part, both contain text, partly coloured. There is a long text in the upper part and a green map below that contains parts in different green. There are also some little boxes in the different shades of green which are accompanied by text.

Only in the next step of the iconographic interpretation the form of a specific country is recognised (here in both cases Mexico with its federal states), the kind of map, and its supposed context can be named. The El Economista map for example uses colours in red and green, indicating some good or bad outcome when it comes to the phenomenon. It is an infographic as usually used in publications like newspapers, you would rather not expect the same map in a scientific publication. It pictures a legend and therefore refers to a serious source and presentation. The CONEVAL map seems rather like a scientific publication with the detailed legend and the long title. The presentation has a PowerPoint-Look and therefore seems like the map has been published in a presentation-like manner. When comparing both maps, it becomes clear that the El Economista map explains something to the reader while the CONEVAL map shows the distribution without commenting on it directly by the means of texts or numbers (such as in the case of El Economista).

### ***What is the content of the map's texts?***

The text of the maps is to be analysed in three aspects: the topic of the textual parts; a selection of passages that can be compared with other maps; and a re-formulation of all the chosen text parts. For the El Economista map that refers to its title description in which the topic of the population part with low income is presented. There is a legend explaining the data as well as a source. And there are numbers that concretise the data of several states. The CONEVAL map also includes a title, a legend and the source, but also depicts a logo and motto of the institution in the top bar. Comparable are specifically the titles (which at the same time refer to the kind of data). Both maps do not include whole sentences but rather notes that explain the data of the map.

All these steps are only shortly illustrated here and go much deeper in the course of the whole analysis. Therefore, each step of analysis produces a lot of text which has to be shortened by abstracting the outcomes of the analysis – which can be done when comparing the descriptions of the pre-iconographic analysis, for example, and concentrate on those parts that are comparable (be it by differences or similarities in the descriptions). After all of these elements are analysed in all detail and have undergone a first procedure of abstraction, the interpretation moves forward to the reflecting interpretation that is focused on the habitus that the image reveals.

### **Reflecting interpretation**

The reflecting interpretation is the aspect of analysis that is most important to the documentary method methodology, since it aims at analysing the “how” of the map: how are the contents identified before presented; which alternative depictions would have been possible; and finally, what habitus lies behind the production of the artefact analysed? Through abstraction, this step can be concluded by the development of a typology that differentiates between different orientation frames and can be considered collective practical knowledge.

Data	Image	Texts
<ul style="list-style-type: none"> <li>• <u>data representation:</u> <ul style="list-style-type: none"> <li>• <u>lines</u></li> <li>• <u>dots</u></li> <li>• <u>area</u></li> </ul> </li> <li>• <u>quantitative data: classification</u></li> <li>• <u>generalisation:</u> <ul style="list-style-type: none"> <li>• <u>dimension</u></li> <li>• <u>selection</u></li> <li>• <u>change</u></li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• <u>iconic interpretation:</u> <ul style="list-style-type: none"> <li>• <u>planimetry</u></li> <li>• <u>centralisation</u></li> <li>• <u>symbols</u></li> <li>• <u>sharpness/ blurriness</u></li> <li>• <u>colours</u></li> <li>• <u>scenic choreography</u></li> <li>• <u>projection and scale</u></li> </ul> </li> <li>• <u>iconologic-iconic interpretation</u></li> </ul>	<ul style="list-style-type: none"> <li>• <u>text sort analysis (explanation, description, narration, argument)</u></li> <li>• <u>text organisation/ comparison of sequences</u></li> <li>• <u>semantic interpretation</u></li> </ul>
<b>TYPIFICATION</b>		

Figure 4. Aspects of analysis for the reflecting interpretation, own

This chapter will discuss all the steps of the procedure as well, as presented in figure 4 by differentiating between data, image and text, and by using the same two maps to exemplify the kind of analysis.

### ***How is the data compiled?***

Regarding the data used for the map, the interpreter needs to consider the data representation. Are the data depicted as lines, dots or coloured areas? This is not only a question of scientific accuracy (Krygier/Wood 2011, 177) but also of the visual impression it leaves with the viewer. The same goes for the kind of generalisation and classification used which is not only a mathematical problem but also generates different visual impressions. In the case of the two exemplifying maps this becomes very clear. The EI Economista map uses a very intuitive classification for the colouring of the state areas of percentages above 60 percent, between 25 and 60 percent and below 25 percent. Even though another classification could have resulted in a differently coloured map, the logic behind it appears more or less comprehensible to the viewer. The CONEVAL map on the other hand uses the ranges of 10 to 20, 20 to 27, 27 to 34 and 34 to 47 percent. A rational logic behind the latter ranges are proclaimed but not made explicit, the reader or viewer has to trust the scientific reasons behind the classification. Therefore, the criteria for choosing those ranges remain unclear to the more or less uninformed viewer. So while the EI Economista is straightforward with the map being an infographic that needs explaining by even putting in more accurate numbers for some of the more extreme (or interesting) cases, the CONEVAL map rather assumes that the reader knows what is exactly behind the map – or that she trusts the producer in its accurate approach.

### ***How is the image arranged?***

Of the different aspects that are to be included in the iconic interpretation (like the centralisation, the projection and scale, the blurriness, colours, and symbols), the planimetry of the maps is one of the most important analysis steps, since it tries to understand the bi-dimensional logic of the map as an image. It was the art historian Max Imdahl that proposed the need to understand the “composition of the picture as a plane” (Bohnsack 2009, 308). And in order to do so, you have to put field lines into the image to analyse its geometrical structure, to understand how the area of the image is parted (Przyborski/Slunecko 2012, 10). Only sparsely should the lines be used. They are considered well placed when they explain to the interpreter the form in a comprehensible form. In the example here, you see two very

different planimetries. While both maps are framed by lines on the top and on the bottom, and feature rather dynamic lines, the inner part of the map is arranged quite differently. Only one line structures the El Economista map which is defined by the numbers that are put around the map and circle it. It leads the view of the reader and puts the whole of the map in the center of the image. The CONEVAL map on the other hand is structured by two lines. The more or less vertical one separates a part in which texts and numbers are to be found (a rather formal logic), while the other part includes the “main” part of the map. The second line follows the darker part of the map from north to south and visually emphasises the southern states.

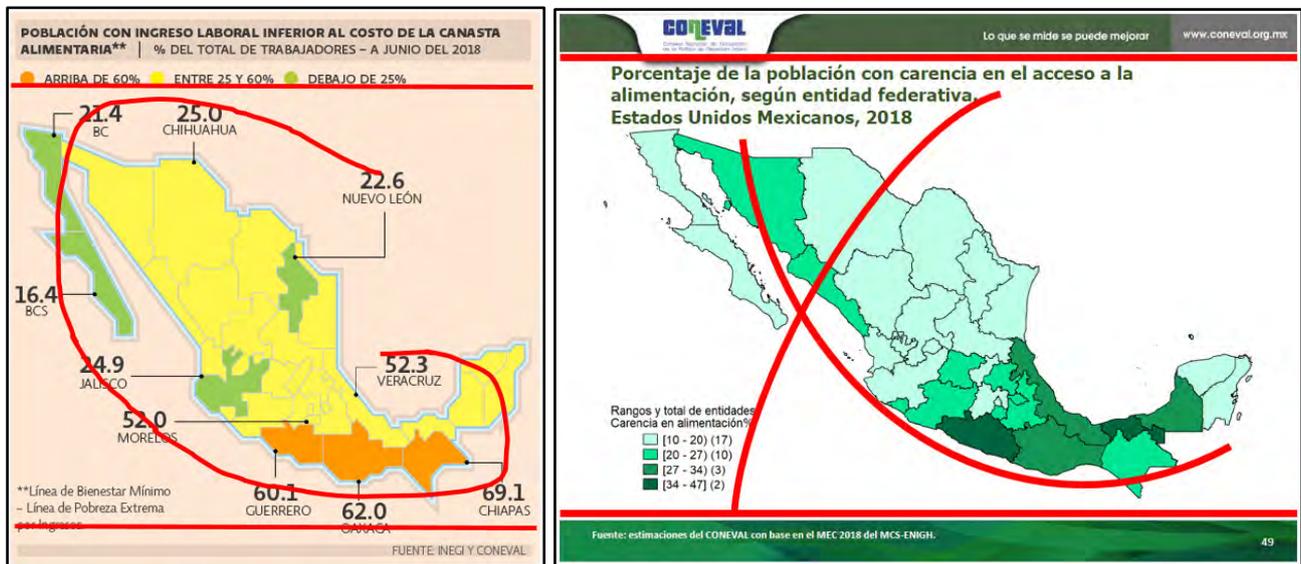


Figure 5. Planimetry of the two maps

Other analysing procedures include the centralisation and scenic choreography. The El Economista infographic puts the whole of the map in its centre while at the same time putting on the forefront the numbers who aim at explaining the colouring of the map. The colouring (green vs. orange) emphasises a logic in which a look into the phenomenon reveals states which are doing well and states which are doing badly when it comes to the problem of food access and poverty. The CONEVAL map on the other hand puts more emphasis on the texts because it features two visual gravity centres: the long title and the dark coloured south of the Mexican map (which is also emphasised through the field line). The monochromic use of colours presents the phenomenon of one that is to be observed all over Mexico, only stronger in some parts. Both maps could have been choosing the colouring of the other map, there is no intrinsic need to do as they did (only a rational argument can be made against the colouring of the El Economista map since it features gradual data with opposing colours).

### How are the texts framing the topic?

In order to understand the textual part of the map, I follow in part the suggestions of Arnd-Michael Nohl (2012) on how to analyse interviews in line with the documentary method. He proposes for the reflecting interpretation to focus on a text sort analysis that differentiates in the textual segments between argumentation, description, narration and evaluation parts; an analysis of the text organisation; and a semantic interpretation of selected text parts. In addition, I suggest having a detailed look also into the typography at this point as a major design choice (Krygier/Woods 2011, 219; it could be included in the image-part of the analysis, though). Both maps are similar in their primary use of descriptions, their classical structure with a (rather long and detailed) title, sources, and a legend. The El Economista map however does name some of the federal states while the CONEVAL map presumes their knowledge by the viewer. El Economista explains with the numbers the colours and concretises the contents, the numbers are part of the content of the map. Therefore, it can be said it is deeper in detail than the other map. In the CONEVAL map, it is the title and the legend only that explains what is to be viewed to the viewer. The content consists only of the coloured map. The semantic interpretation of the title of the map also reveals great differences between the maps. The choice of wording is undoubtedly connected to the choice of data used. In combination, it still reveals a meaningful semantic phenomenon. The El Economista map presents the “population with an income lower than the food basket”. This framing (Lakoff/Johnson 1980) is a rather visual one that triggers the image of a person, holding their money (income) in their hand, while at the same time the word “food basket” suggests an image of an actual basket, filled with food. This is a rather clear image that leaves little room to visual interpretation and imaginations. The title of the CONEVAL map on the other hand has a less visual title, “the percentage of the population with lack in access to food”. We do not imagine a

worker with their money. Food access is also a rather wide word choice, it leaves it to the reader to either imagine a shut door, someone without financial means, or maybe whole other “food access” imaginaries. The “lack” also does not trigger a specific image of “no access at all”, it is a more nuanced image – and might therefore be more “realistic” than the images brought into mind by the El Economista map. It is an abstract wording that hints to current conditions of a part of the population, while the El Economista map presents not a condition but rather a requirement to a sufficient food supply.

In conclusion (and wrapping up the iconic-iconographic interpretation): The map of El Economista presents a phenomenon of the whole country in which the federal states are presented in relation to each other: some are doing well, some are doing badly. It emphasises the responsibility of individual federal state, and insists that the content of the map needs explaining (therefore the names and numbers). The producers are the experts explaining the phenomenon to the viewer. The CONEVAL map presents a phenomenon that touches the whole country and every state, only to a different degree, it is therefore less confrontational and more egalitarian. At the same time, it depicts the south as a specific region which needs focusing and political measures, and more “help”. The map explains itself and does not need further explanation. Both, the producer as well as the reader are the experts of the phenomenon.

Obviously, with only two maps no typification can be evolved, which would be the next phase in a research project that aims at analysing in deep detail a corpus of maps collected. In the presented example, refining the characterisations of an explanatory versus a showing map could be the first step towards types of mapping styles that are expressed not through their content but rather their way of design.

## CONCLUSION

The aim of this article was to present a methodology that derives from a practice theory approach and uses formal procedures elaborated in the broad field of visual sciences that allow for the social scientific analysis of maps. Depending on the specific research interest, it can be a useful tool in order to interpret maps when touching for example the topics of ideology, visual discourses, social differentiation as expressed through maps, and other related foci in the field of critical map studies – or as Crampton and Krygier framed it for critical cartography: projects which aim at the “examination of the assumptions of a field of knowledge. Its purpose is to understand and suggest alternatives to the categories of knowledge that we use” (Crampton/Krygier 2006, 13). Furthermore, it could also be a helpful tool for cartography practitioners in order to critically evaluate their design choices. Aspects that this methodology might not be suitable to use for, on the other hand, are for example: research that is interested in the particular circumstances of the map production and its producers; the circulation practices of the map; or the individual reception and reading of these maps. And lastly, one other important field of research that I want to mention here and which needs further evaluation (and would be indeed be possible with the already existing video analysis research that uses the documentary method) are animated maps which are becoming more and more relevant nowadays, especially in news publications.

While many steps of the analysis I presented here are well established methods in visual sciences, they are never uncontested – and even more so outside of an interpretative paradigm. Since there is no methodology that can grasp every social aspect there is on the visibility of artefacts, every researcher needs to adapt already existing procedure or even develop a completely new one. Therefore, I understand the approach presented here rather as a collection and broad base of single steps to the analysis from which also researchers can pick the ones which are more affine to their study. The procedure would be needed to be adapted to specific research interests, in order to meet the needs of good and coherent qualitative research. As Tracy states: “A meaningfully coherent piece makes use of the concepts that fit their paradigm and research goals“ (2010, 848). Meanwhile, the use of a methodological approach that does not fit in all aspects the theoretical approach of the research is possible, but the researcher needs to “note the disjuncture between the two points of view and explain how he or she was intentionally weaving together the approaches” (ibid.). Understanding qualitative research as an artistic craft (see Tracy 2010, 839), my hope is that the methodological approach presented here contributes to augment the analytic tool box to understand the societal workings of cartographic communication.

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## BIOGRAPHY

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# **APPLICATION OF GIS IN SPATIAL SEGREGATION MEASUREMENT (A CASE STUDY OF PLOVDIV, BULGARIA)**

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## **Abstract**

*In Bulgaria, spatial segregation is mostly related to the Roma quarters, which occupy a significant part of the urban space and thus represent a functional barrier to urban development. The paper presents the results of measuring spatial segregation in its five dimensions proposed by Massey and Denton's conceptual scheme: evenness, exposure, concentration, centralization and clustering. Specific indicators providing information on the above-mentioned dimensions of the Roma segregation in the urban area of Plovdiv have been calculated, based on official national statistical data, satellite and orthophoto images, and GIS. The proposed methodology can be used for other cities as well, making comparison and spatial analysis possible.*

**Keywords:** *spatial segregation, Roma ethnic group, Plovdiv*

## INTRODUCTION

In geographical research, the location of objects / subjects in space is a major determinant in the formation of interaction models. It is difficult to find a clear and commonly accepted definition of *spatial segregation* in scientific literature, as there are different ways of perceiving the problem. The definitions of spatial segregation in recent studies are numerous, and only a few examples are listed below:

- According to Johnston (1983), a low degree of spatial segregation is determined by the even distribution of a certain population group among the rest of the population in a given territory. The greater the deviation from this evenness, the greater the degree of segregation.
- The definition of spatial segregation in the dictionary of human geography is very brief and the term is simply defined as the division of a certain community into subgroups in the area where that community lives (Johnston et al., 1986).
- According to Bourdieu (1989), spatial segregation is the end result of a process where members of the population feel close to each other and are in close spatial proximity.
- Spatial segregation is the spatial division of different population groups within a given geographical area (Saltman, 1991).
- Spatial segregation is a spatial expression of social inequality (Fassmann, 2002).

It can be summarized that spatial segregation is a multidimensional spatial phenomenon concerning the spatial concentration of a particular group of people by social status, ethnicity and /or race. It is a result of both voluntary decisions (internal factors), and direct or indirect coercion, discrimination, economic constraints, social exclusion, etc. (external factors), or a combination of the two groups of factors. In Bulgaria, spatial segregation is mostly related to the Roma quarters, covering a significant part of the urban space and thus - representing a functional barrier to urban development. In recent years, there has been an expansion of the existing Roma quarters in Bulgaria and emergence of new ones.

One of the main reasons for the growing interest in spatial segregation (mainly related to immigrant communities in Western European cities and the Roma ethnic community in Eastern European cities) in recent decades has been the negative effects which the population living in segregated neighborhoods suffers from. As early as 1925, Park and Burgess summarized that "physical distance generates social distance." Later, in 1959, Duncan and Lieberson demonstrated the inverse correlation between spatial segregation and the integration of ethnic groups based on their spatial location in urban areas. Many scholars (Peach 1975; Massey and Denton, 1988, etc.) argue that models of spatial segregation are indicative of either assimilation or integration processes; Haussermann (2005) defines segregation as the "projection of social structure onto space", while according to Francini (2013), the formation of "ethnic enclaves" in cities can threaten the social, cultural and spatial integrity of the city. The prevailing view in most contemporary discussions on the topic is that spatial segregation exacerbates existing social inequalities and leads to many other negative consequences related to limited participation of segregated residents in the social life of the city, low quality of education, low level of integration into the labor market, deteriorating health indicators, etc.

Massey and Denton suggest a conceptual scheme characterizing spatial segregation, which includes five dimensions: *evenness, exposure, concentration, centralization* and *clustering*. The multidimensional nature of spatial segregation requires the application of interdisciplinary methods. Research over the last few decades has begun to develop indices and mathematical models that aim to measure these five dimensions in the most objective way possible. In this study, specific indicators providing information on the above-mentioned dimensions of the Roma population segregation in the urban area of Plovdiv have been calculated using GIS.

## RESEARCH METHODOLOGY

The multifaceted nature of spatial segregation requires the application of interdisciplinary methods and the use of various indicators for its analysis. The indicators used can be grouped into two categories: sociological and spatial or geographical. Geographical research focuses on the spatial aspects of segregation. Sociologists focus their efforts on developing indices that describe social relationships and the reasons why individuals occupy a particular social space. In cases where the research is focused on the analysis of the spatial aspects of segregation, spatial indicators are developed, while in cases where the research is focused on the analysis of social relationships, non-spatial indicators are developed. Non-spatial indicators consider the social environment as a constant, a predetermined organizational or spatial unit - for example - a school, a neighborhood, a census unit, a constituency, etc. The literature on the topic describes two main problems (weaknesses) that exist in the application of non-spatial indicators: the first one is related to the so-called "chessboard problem" (Morrill, 1991; White, 1983), while the second one is related to the modifiable

areal unit problem (MAUP) (Wong, 1997). The chessboard problem is an abstract concept related to segregation. Non-spatial indicators neglect the spatial proximity of individuals and predefine the scope of social spaces. These indicators focus only on the components that are within each predetermined territorial unit. In 1983, White explained the chessboard problem as follows: each square in the chessboard represents a predetermined territory such as a neighborhood, a census unit, a constituency, etc., each of which has its own internal structure (white and black squares). The author gives the following variants of the distribution of the squares: for example, in one case the white squares would be located in one half of the board, while in the other half - all the black squares would be. In another case, the black and white squares are distributed as a checkerboard. These two described cases have a radically different internal structure, and these situations are expected to be defined as contrasting with each other. The non-spatial indicators do not differentiate the internal structure of the spatial models and the two described cases define them as identical. As White notes, a city in which all African-Americans are concentrated in a single ghetto will have the same spatial segregation values as a city where "black neighborhoods" occupy the same area but are scattered throughout the urban space. The second problem with non-spatial indicators, as already mentioned, is related to the fact that these indicators use predefined territorial units. Data are collected and aggregated within these predefined units, and the boundaries are not changed in the course of data collection so as to ensure that territorial units accurately reflect the social environment. For example, two individuals can live relatively close to one-another in the urban space, but fall into different spatial units. At the same time, two individuals living remotely in the urban space may fall into the same spatial unit (Wong, 1997; Reardon, O'Sullivan, 2004). Therefore, the boundaries between the separate units must be precisely delineated.

Cities cannot be studied without considering the processes that take place between their different parts. In 1988, Massey and Denton, based on the work of Duncan and Duncan (1955), created one of the first conceptual schemes characterizing spatial segregation, which assesses the place occupied by the ghettoized structures in urban space (Fig.1). This scheme includes five dimensions of spatial segregation, namely:

- evenness – characterizing the degree of uniformity of the ethnic group in space;
- exposure - the possibility of potential contact or interaction between members of minority groups with the majority within urban spatial units (usually the same neighborhood);
- concentration - the degree of compactness of the studied ethnic group;
- centralization - the degree of remoteness of the ethnic group from the city center;
- clustering - the extent to which the members of a group are located close to each other.

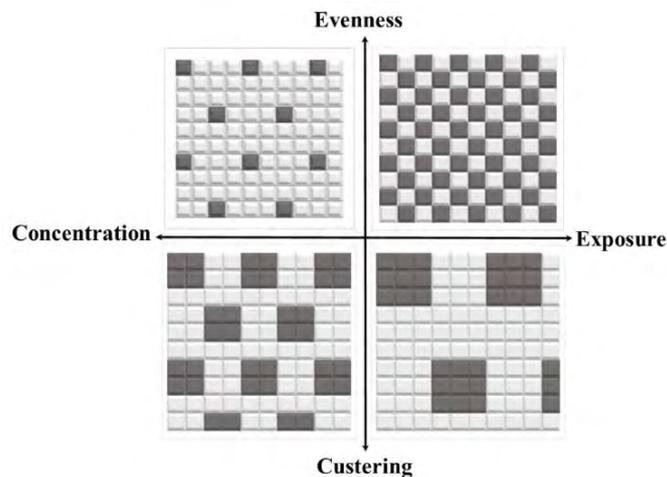


Figure 1. Dimensions of spatial segregation (Source: Reardon & O'Sullivan, 2004)

In general, apart from the lack of precise definitions of the basic concepts in literature, there is also a lack of clearly defined mathematical expressions that best characterize spatial segregation.

Poulsen, Johnston, and Forrest (2002) require that indicators measuring spatial segregation reflect three main characteristics, namely:

- 1) degree of concentration, i.e. the areas in which a certain ethnic group predominates;
- 2) degree of assimilation, i.e. sharing living space with the majority;
- 3) encapsulation or residential isolation of a certain ethnic group from the majority and / or other ethnic groups.

The indicators used in measuring the levels of spatial segregation must meet the following requirements:

- 1) reflect the theoretical statements related to spatial segregation;

- 2) make comparisons possible, both within the city and between different groups of the population;
- 3) have a quantitative expression, which provides the opportunity for the studied processes to be evaluated faster and easier, eliminating the need to collect and process a large array of data.

Another approach to estimating the various dimensions of spatial segregation was introduced by James and Taeuber (1985) who try to compare different methods based on one set of criteria. The criteria introduced by the two authors include: Organizational Equivalence and Size Invariance, Transfers, Composition Invariance, and the Lorenz Criterion. In 2004, Reardon and O'Sullivan expanded the criteria by including also:

1. Scale interpretability: If the group proportions are the same in the local environment of each individual, then the spatial segregation index should take the value zero, whereas a segregation index should reach its maximum value (typically normalised at unity), if the local environment of each individual is mono-racial. This criterion is motivated by the desire to make universal comparisons of index magnitudes across time and space. However, if the chosen index is not margin-free (see below), then simple index comparisons can be misleading.
2. Arbitrary boundary independence: A spatial segregation measure should be independent of the definitions of areal units. This demanding criterion requires that all individuals be precisely located in space and there is a unique and exhaustive set of spatial proximities for all pairs of locations. The MAUP would be overcome, but the scale at which segregation is measured would remain unresolved.
3. Location equivalence: Points  $p, q, \dots$  within a tract can be aggregated if their population compositions are the same within their local environments, and they satisfy  $c(p, q) = c(q, p)$  and  $c(p, s) = c(s, p)$  for all points  $s$  lying outside the tract. These conditions are demanding and are unlikely to be satisfied. Location Equivalence is the spatial analogue of Organisation Equivalence, which enables the aggregation of units, such as occupations and schools, which have the same gender or race composition (Reardon and O'Sullivan, 2004: 132-133).
4. Population density invariance: If the population density of each group  $m$  at each point  $p$  is multiplied by a constant factor, then segregation is unchanged.
5. Composition invariance: If the number of individuals in a particular group increases uniformly across all locations within the region, and the numbers and spatial distribution of all other groups remain unchanged, then the measure of segregation is unchanged.
6. Transfers: The principle is based on the Pigou-Dalton principle which appears in the income inequality literature (e.g. Shorrocks and Wan, 2005). A group  $m$  individual is transferred from point  $p$  to  $q$ , without replacement. If the proportion of group  $m$  in the local environment of all points closer to  $p$  than  $q$  is greater than the proportions of group  $m$  in points closer to point  $q$ , then segregation is reduced (Reardon and O'Sullivan, 2004: 134-135). This criterion is problematic. First the point densities are upset by the one-way transfer. Second points close to both  $p$  and  $q$  may all be dominated by group  $m$ , (relative to its overall population share), so that the transfer reduces the group  $m$  dominance of points close to  $p$  and increases dominance for points close to  $q$ . As a consequence the criterion requires that the index be non-linear. Finally none of the indexes analysed by the authors satisfy the criterion (p.151), so it is ignored.
7. Exchanges: Reardon and O'Sullivan (2004: 135) identify two forms of exchange in which a group  $m$  individual at  $p$  is replaced by a group  $n$  individual from  $q$ . In the first case points close to  $p$  have a greater proportion of group  $m$  and points near point  $q$  have a greater proportion of group  $n$ . Compliance with this condition implies a non-linear index. The second version involves the same exchange but the proportions of group  $m$  at points near to and including point  $p$  are greater than the corresponding proportions of group  $n$  at these points, and conversely for point  $n$ . The Information Theory and Relative Diversity Indexes only satisfy both exchange criteria, if spatial symmetry is assumed, which can be satisfied by two forms of geography, both of which are highly restrictive (Reardon and O'Sullivan, 2004: 156-157). A weak version of both types of Exchange is satisfied by the Index of Dissimilarity, but again spatial symmetry must be assumed. Consequently this criterion is also ignored.
8. Additive Spatial Decomposability This criterion requires that the grouping of points (areal units) into fewer, larger areas enables total spatial segregation to be represented by the sum of within area and between area components. Reardon and O'Sullivan (2004: 147-149) acknowledge that an interaction term would need to be included in the decomposition to reflect the impact on the within area (say  $k$ ) measure arising from points,  $q$  outside  $k$  via the proximity function,  $c(p, q)$  where  $k \in p$ . If significant in size, the interaction term clouds the interpretation of the other two components of the decomposition. Also, the within group index measures use the within group population shares as the benchmark, rather than the regional population shares, so that their interpretation is not straightforward (Brown and Chung, 2006).
9. Additive Grouping Decomposability If  $M$  groups are clustered in  $N (<M)$  supergroups, then a segregation measure should be decomposable into a sum of independent within- and between-supergroup components. Again local benchmarks are being employed in the within group component. This condition is only satisfied by the Information Theory Index.

Scientists seek to measure one, several, or all dimensions of spatial segregation identified by Massey and Denton (1988). It is the purpose of the study which determines the type and number of indices that will be used. According to Massey and Denton, it is pointless to categorize indicators as "most correct" or "best", as each of them measures

different aspects of spatial segregation. In cases where the study aims to analyze the non-spatial characteristics of segregation, the difference index and the interaction index are used. The other three dimensions of segregation and the respective indices are appropriate when the purpose of the study is to establish the exact location of the studied group in space. In cases where it is important to know the location of the group relative to the city center, the centralization index will be used; in cases where the emphasis is on the area occupied by the group in the urban space, the index of concentration or isolation will be used, etc. The authors believe that each of these characteristics has different social consequences, which taken together, represent the complex nature of spatial segregation. According to Massey and Denton, evenness and exposure are non-spatial dimensions, as they are determined by the pre-defined boundaries of the studied area, while concentration, grouping and centralization are spatial dimensions, as they require information about the location of the studied group and the size of the territory it inhabits. The best in-depth analysis of spatial segregation is achieved when all five dimensions are taken into account simultaneously. Such a multidimensional approach gives the most complete picture of segregation, which cannot be achieved with the use of a single index only. It is possible that a group has a high degree of segregation in only one or more of these dimensions. Thus, Massey and Denton (1993) found that blacks in some American cities are highly segregated in all five dimensions simultaneously. The spatial model in which all five dimensions of spatial segregation show high values, was defined by Massey and Denton (1993) as *hypersegregation*.

In the present study, based on literature review, the indicators have been selected so as to meet as much as possible the above requirements and to characterize the five dimensions of spatial segregation with the use of GIS. As a source data, the "Population Grid" was used, which was created by the National Statistical Institute of the Republic of Bulgaria, and bears the following characteristics:

- resolution: 1 km<sup>2</sup>;
- coordinate system: ETRS89\_LAEA (Lambert Azimuthal Equal-Area);
- format: CSV, Esri Shapefile (\*.shp);
- statistical information: distribution of the population according to Census 2011 by number, sex and age groups in a network of 1 km<sup>2</sup>-cell size;
- number of population distributed in the grid, which falls within the city of Plovdiv: 338 153;
- reference date of the statistical information: 1 February 2011;
- distribution method of the population of Plovdiv: aggregation (77.4% of the population); disaggregation (42.6% of the population).

Data from the National Statistical Institute and the CRAS (Civil Registration and Administrative Service) Office of Plovdiv Municipality, as well as satellite and orthophoto images, have been used in outlining the boundaries of the Roma neighborhoods in Plovdiv. The proposed methodology can be used for other cities as well, so as to enable various comparisons and spatial analyzes.

## **RESULTS**

### **General characteristics of the Roma in Bulgaria and the city of Plovdiv**

The actual (or the so-called expert assessment) number of the Roma in Bulgaria is about 750 thousand, which is about 11% of the country's total population. Plovdiv is the second most populous city in the country, with a population as of 1<sup>st</sup> Feb. 2011 of 338 153 people. According to the official data, the number of Roma in Plovdiv is about 6 000, while unofficial data suggest their number is actually around 48 000 (as of 2013).

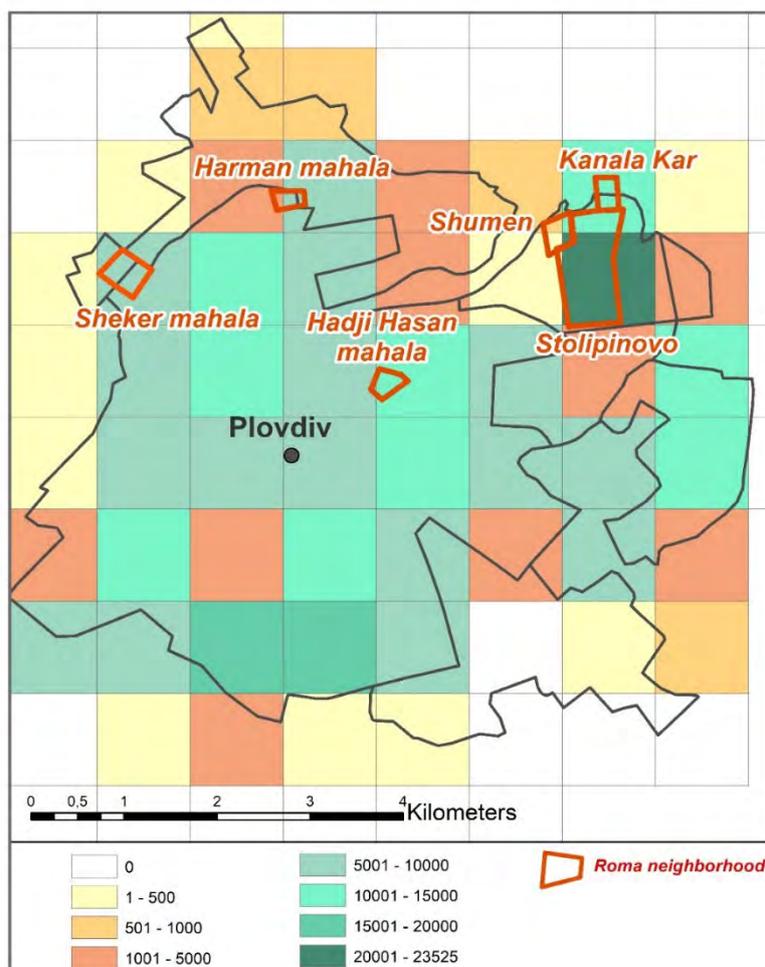


Figure 2. Location of the four Roma quarters of Plovdiv (Source: Authors)

Four Roma quarters exist within the city of Plovdiv, covering a total area of 1380 ha., or 1.7% of the city's urban space:

1) Stolipinovo (formally "Izrev") – situated in the Eastern Administrative Region of the city, over an area of 54 ha, formed around 1910-1915. According to unofficial data, some 45-50 000 people live in that neighborhood. The quarter emerged after the Roma residents were forced to leave the central areas of the city and were driven to the outskirts, to more disadvantaged areas, in obedience of a local authorities' resolution. Initially, those areas were beyond the administrative limits of the city, but due to its territorial expansion, the neighborhood was gradually "swallowed" by the city.

2) "Haji Hasan Mahala" – located within the Central Administrative Region of Plovdiv. Being a nicer residential area, the Roma from the other Roma neighborhoods strive to obtain property in this specific quarter due to the higher social status of its residents and its central location. Haji Hasan Mahala covers an area of about 9 ha and is inhabited by some 3000 to 4000 residents.

3) "Sheker Mahala" or "Todor Kableshkov" – this is the second largest Roma quarter in Plovdiv (area: 10 ha, population: 5000-6000 residents) and is situated in the Northern Administrative Region of the city. After the great flooding of Harman Mahala quarter in 1957, people were relocated in to what is now Sheker Mahala quarter, for which purpose the government built massive, single-storey houses. Later, through illegal construction mostly, the quarter expanded to the northwest. Over the last years, many two- and three-storey houses were built in the area, while another fifty, maisonette-like houses were constructed (within a EU project) for those in extreme need.

4) "Harman Mahala quarter" (area: 5 ha, formally known as "Hadzhi Dimitar") is also located in the Northern Administrative Region of the city, right next to the northern industrial zone of Plovdiv – until the beginning of the twentieth century – beyond the urbanized part of the city, which facilitated the adaptation of most of the migrants arriving from villages around Plovdiv. Asenov (2018) states that "although we have no reliable information about this, we can assume that at the end of the nineteenth and in the early twentieth century, there is a "Roma" neighborhood in

the Harmanite locality outside the city. Asenov justifies his assumption with conversations he had in the early 1990s with elderly inhabitants of the quarter, when those residents were already 75-80 years old: when asked about their place of birth, those people declared Harman Mahala as their birthplace. This suggests that by 1910-1915, the quarter had already existed. The urban space of Harman Mahala is clearly outlined in the urban fabric of the city. The quarter is located between "Severen" Blvd., "Nikola Belovezhov" Str., "Velyu voyvoda" Str. and "Belozem" Str., right next to the "Kaufland" hypermarket. The ghettoized structure is not effectively integrated into the surrounding urban space. Its existence repels investors from that part of the city and makes the area unattractive due to the bad reputation Roma neighborhoods generally have. The quarter is inhabited by 1800 residents (data obtained through the field survey) and is the smallest Roma quarter in Plovdiv in terms of both area and population.

Since the beginning of the so-called transitional period in Bulgaria, as a result of the intra-migratory movements and the concentration of Roma population in urban settlements, the micro-quarters of Shumen and Kanali Kar emerged in the immediate vicinity of Stolipinovo quarter, becoming part of that ethnic megastructure, considered to be the largest Roma neighborhood in Europe (Figure 2).

### Evenness

The evenness of a given population group is measured relative to the location of other groups within the same space. A minority group is segregated if it is unevenly distributed in space, while spatial segregation is the highest in cases where minorities and majorities do not share common territories. The first attempt to measure spatial segregation was made by Duncan and Duncan (1955). The *dissimilarity index* was introduced, after which various modifications were developed. The dissimilarity index is one of the most common measures of spatial segregation. Conceptually, the index measures the share of a group that must change its residence in order to achieve an even distribution in the urban space. The dissimilarity index belongs to the non-spatial dimensions of segregation. For this reason, the relocation of members of a group from areas where they have a high relative share (above the city average) to areas where they are not sufficiently represented (below the city average), but within the same spatial unit, does not affect the value of the index. This is the main drawback of the index. On a positive note, Massey and Denton mention the fact that the index had been used for more than 30 years, which makes it possible to detect trends, it is easy to calculate and to use:

$$D = \frac{1}{2} \sum_i \left| \frac{w_i}{W} - \frac{b_i}{B} \right|$$

where:  $w_i$  and  $b_i$  is the number of white and black population respectively, counted in territorial unit  $i$ , while  $W$  and  $B$  is the number of white and black population in the whole study area respectively. This index can be applied not only when studying the racial affiliation of the inhabitants, but also if other features are taken into account - ethnic, religious, economic, social, etc.

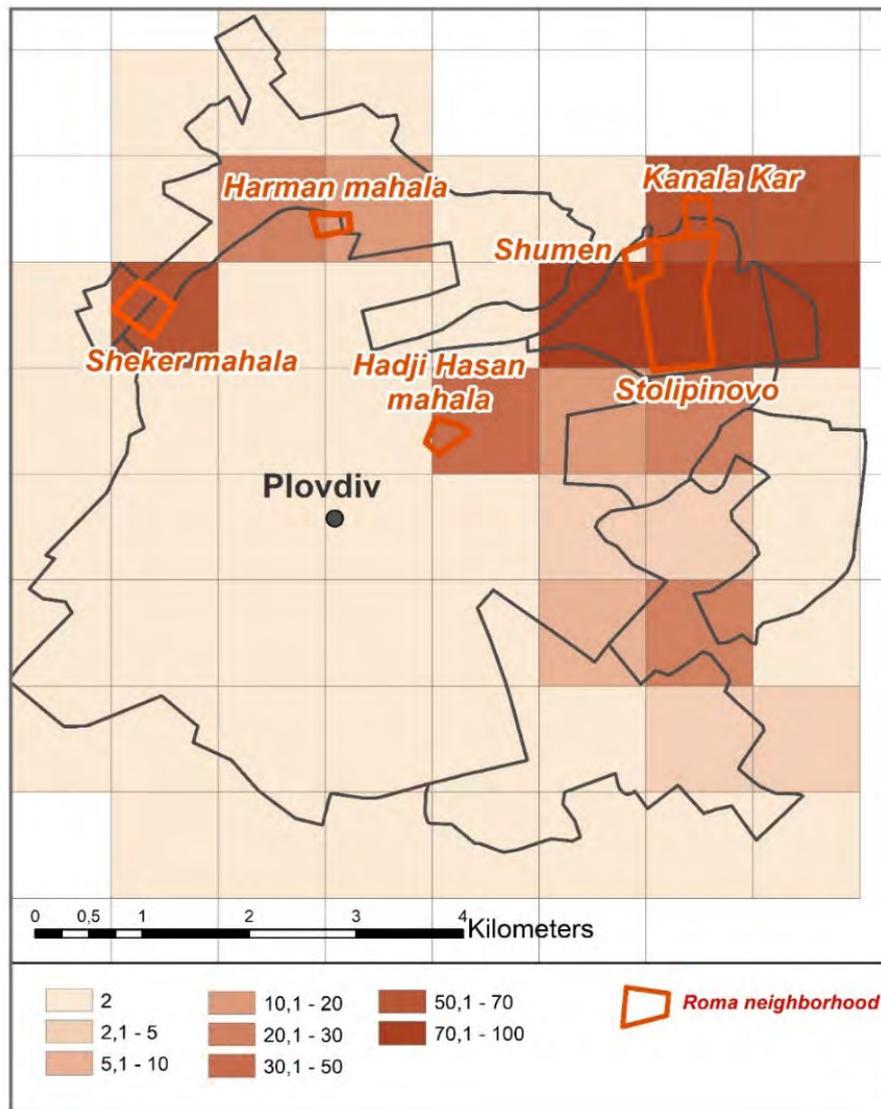


Figure. 3 Share of Roma population by grid cell (Source: Authors)

This index can be interpreted as a share of the population in a given area, which would have to change its place of residence in order to achieve an even distribution across that same area. The numerator in formula (4) represents the number of displacements that would have to be performed in order to obtain an even distribution between the individual spatial units, i.e. each spatial unit be inhabited by an equal number of members of a given minority (Morrill, 1991, 1995; Wong, 2003). The change of residence will be required in the territorial units where the minority group has a higher share (White, 1986). The values of the index vary from 0 to 1, as zero indicates no segregation and one - complete segregation. According to the calculations, the city of Plovdiv exhibits  $D = 0.86$  – an extremely high value, indicating that for every 100 people, 86 would have to change their place of residence within the city in order for the Roma group to be evenly distributed in the urban space. The main drawback pointed out above is that the index only measures the degree of evenness between two groups and is calculated for pre-defined territorial units. As noted by Morrill (1991), "this is not a measure of segregation in a geographical sense" because the index belongs to non-spatial indicators and does not reflect the spatial distribution of individual population groups (Wong, 2003). Therefore, one of the main shortcomings of the index is related to the chessboard problem: for example, if each studied territorial unit is dominated by one ethnic group, regardless of its internal distribution in space,  $D = 1.0$ , which indicates complete segregation. Another problem with using the dissimilarity index is related to the scale effect and the MAUP. The index under consideration is strongly influenced by the size of the territorial unit, i.e. if the index is calculated for a large territorial unit, for example – a country, the level of segregation turns out low, whereas if calculations are only made for a part of the country's territory, the values of the dissimilarity index can reach 1.0. An easier to understand example can also be given: in case the index is calculated for the whole world, then  $D = 0$ . Alternatively,  $D = 1.0$ , if each individual is considered as an independent observation or each territorial unit is dominated by only one group, i.e. given that the group itself is internally homogeneous. Small territorial units are always more homogeneous than large ones.  $D$  also

does not meet other criteria for an acceptable index, such as "transfer and exchange" (White, 1983). The index is only influenced by the cases in which there is a transfer of members of the studied group from territorial units with very high concentration to units with low concentration (White, 1986).

In 1991, Morrill introduced a modified indicator for the dissimilarity index (D), called the neighbor-adjusted index (Dadj):

$$D(\text{adj}) = D - \frac{\sum_i \sum_j |c_{ij}| \times (z_i - z_j)}{\sum_i \sum_j c_{ij}}$$

where: D (adj) is the dissimilarity index based on neighborhood,  $z_i$  and  $z_j$  are the shares of the minority or the majority group between the territorial units  $i$  and  $j$ ;  $c_{ij}$  - the value of the cell in row  $i$  in column  $j$ ;  $c_{ij} = 0$  in cases where  $i$  and  $j$  have no neighbors, and  $c_{ij} = 1.0$  in cases where  $i$  and  $j$  have neighbors (Wong, 2003).

The author emphasizes that segregation is a function of the intensity of interaction between different groups of the population. For this reason, the indices that reflect the degree of spatial segregation should not only consider the internal homogeneity of the studied area, but also the external interactions. The modification of the index is required by the conclusions drawn from the results obtained from the dissimilarity index. Morrill (1991) explains that a high value of  $D$  does not necessarily mean that minority groups are spatially segregated and not interacting with the majority, nor does it mean there is no interaction whatsoever between two adjacent territorial units. For these reasons, Morrill includes a very important component in measuring segregation, namely - the common, shared boundary between territorial units as a line of contact between two groups, as an important element of spatial interaction. The application of this indicator takes into account the different population groups that are located in the immediate vicinity. In cases where the groups have a common boundary, the values of the index will show a low level of segregation and vice versa. Table 1 shows the neighbor-adjusted index (Dadj) calculated for the four Roma neighborhoods in Plovdiv.

Table 1. Neighborhood-adjusted index (Dadj) calculated for the four Roma neighborhoods in Plovdiv (Source: Authors)

Harman mahala				Stolipinovo, Shumen, Kanala Kar											
Cell 5		Cell 6		Cell 9		Cell 10		Cell 16		Cell 17		Cell 18		Cell 25	
Cell	Dadj	Cell	Dadj	Cell	Dadj	Cell	Dadj	Cell	Dadj	Cell	Dadj	Cell	Dadj	Cell	Dadj
1	0.08	2	0.05	8	0.17	9	0.8	7	-0.12	8	-0.12	9	0.84	16	0.14
2	0.08	3	0.05	10	0.8	17	0.5	8	-0.12	9	0.56	10	0.78	17	0.14
3	0.08	5	0.08	16	0.56	18	0.78	9	0.56	10	0.50	17	0.58	18	0.42
4	0.08	7	0.05	17	0.56			15	-0.12	16	0.86	25	0.42	24	0.78
6	0.05	13	0.05	18	0.84			17	0.86	18	0.58	26	0.15	26	0.59
12	0.55	14	0.05					23	0.20	24	0.061			29	0.62
13	0.08	15	0.05					24	0.06	25	0.14			30	0.61
14	0.08							25	0.14	26	-0.13			31	0.59

Hadji Hasan mahala		Sheker mahala	
Cell 23		Cell 12	
Cell	Dadj	Cell	Dadj
14	0.53	4	0,55

15	0.53	5	0.39
16	0.20	11	0,55
22	0.53	13	0,55
24	0.72	19	0,55
27	0.53	20	0,55
28	0.53	21	0,55
29	0.56		

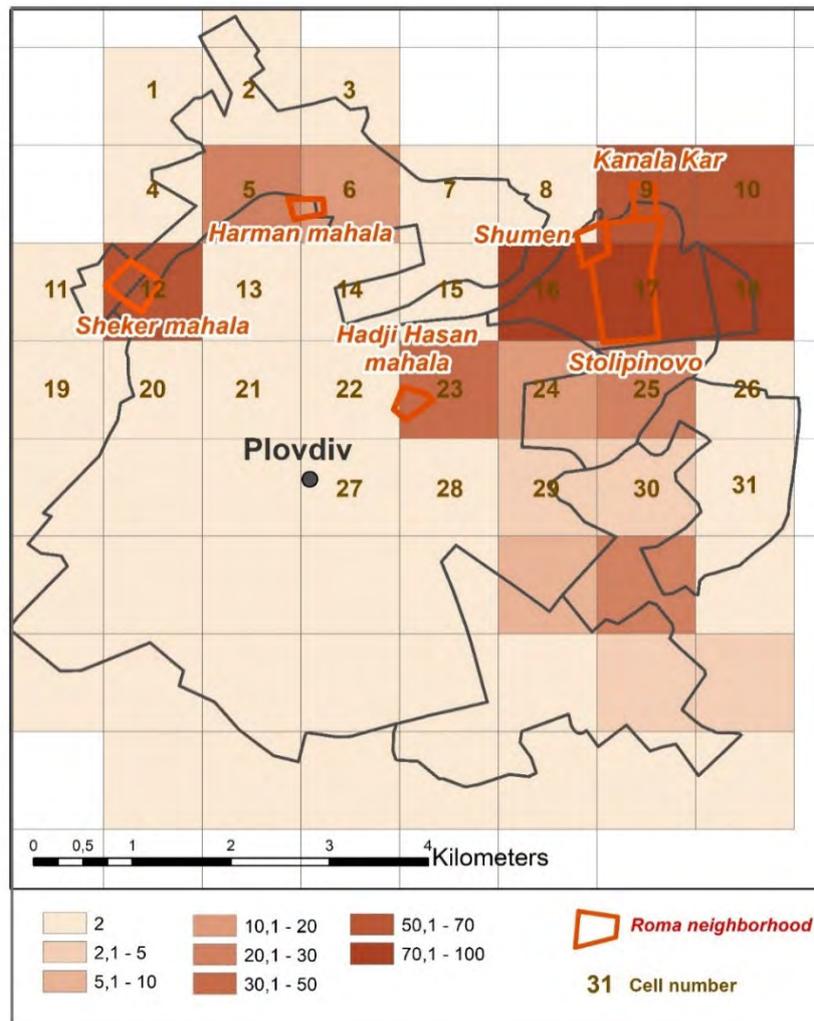


Figure 4. Numaration of grid cells used in the calculation of the Neighborhood-adjusted index (Dadj) (Source: Authors)

## Exposure

Residential exposure refers to the degree of potential contact, or the possibility of interaction, between minority and majority group members within geographic areas of a city. Indices of exposure measure the extent to which minority and majority members physically confront one another by virtue of sharing a common residential area (Massey, Denton, 1988). The two authors point out that although indices of exposure and evenness tend to be correlated empirically, they are conceptually distinct because the former depend on the relatively size of the groups being compared, while the latter do not.

Members of minority groups may be evenly distributed among the residential areas of a given city, and at the same time have a low level of exposure to the majority, if the minorities represent a relatively large proportion of the city's population. Conversely, if minorities constitute a small proportion of the population, their levels of exposure are high.

Exposure is mainly characterized by two indices: the index of interaction (the degree of interaction of the members of the minority group with the members of the majority) and the index of isolation (the degree of interaction of the minority members with each other, but not with the majority). Both indices can be interpreted as a way of measuring the probability of a minority member to share a common territory with members of the majority – when the interaction index is used, or with another minority member – when the isolation index is used (Massey and Denton, 1988).

In the early 1980s, Lieberman (1981) introduced two variants of the exposure index - the interaction index  ${}_xP_y^*$  and the isolation index  ${}_xP_x^*$ :

$${}_xP_y^* = \sum_{i=1}^n [x_i/X] [y_i/t_i]$$

where  $x_i$ ,  $y_i$ , and  $t_i$  are the numbers of X members, Y members, and the total population of unit i, respectively, and X represents the number of X members city-wide. The converse of the interaction index is the isolation index, both varying between 0 and 1:

$${}_xP_x^* = \sum_{i=1}^n [x_i/X] [x_i/t_i]$$

The isolation index is closely related to the exposure index. These two indices are very similar in nature and try to measure the degree of interaction of a member of a given group with other members of the same group, as well as with members of other groups. Therefore, the index of isolation  ${}_xP_x^*$  indicates the level of interaction between members of one group (Bell, 1954), or the probability of intragroup contact, and vice versa - the index of interaction shows the probability of interaction with a member of another ethnic group. The isolation index for the Roma population in the city of Plovdiv reflects a high degree of isolation or intragroup interaction ( ${}_xP_x^* = 0.73$ ) and a low degree of intergroup interaction -  ${}_xP_y^* = 0.27$ .

### Concentration

Concentration is determined by the relative share of physical space occupied by a given group in the urban environment and represents a relative dimension of segregation. In most cases, minorities are concentrated in a small number of neighborhoods, which together make up a small proportion of the urban space. According to Massey, Denton, (1988) "groups that occupy a small share of the total area in a city are said to be residentially concentrated. For example, suppose two cities have the same minority proportion and an equivalent degree of residential evenness, but in one city minority areas are few in number and small in area, while in the former city to be more "segregated" than the latter". In the present study, the so-called "delta" (DEL) measure has been used, proposed originally by Hoover (1941) and later adapted by Duncan, Cuzzort, and Duncan (1961):

$$DEL = 1/2 \sum_{i=1}^n |[x_i/X - a_i/A]|$$

where  $x_i$  and X are defined as before,  $a_i$  equals the land area of unit i, while A is the total land area of the city. DEL is a specific application of the more general index of dissimilarity. It computes the proportion of X-members residing in areal units with above average density of X-members. It is interpreted as the share of minority members that would have to shift units to achieve a uniform density of minority members over all units. In the case of Plovdiv DEL was calculated to be 0.48, indicating that almost half of the Roma population would have to shift units to achieve a uniform density of minority members over all units.

### Centralization

The fourth dimension of segregation is related to concentration, but is conceptually distinct. Centralization is the degree to which a group is spatially located near the center of a given urban area (Massey and Denton, 1988). Theoretically, concentration and centralization are similar, but differ in their interpretation. Centralization is associated with groups that settle near city centers.

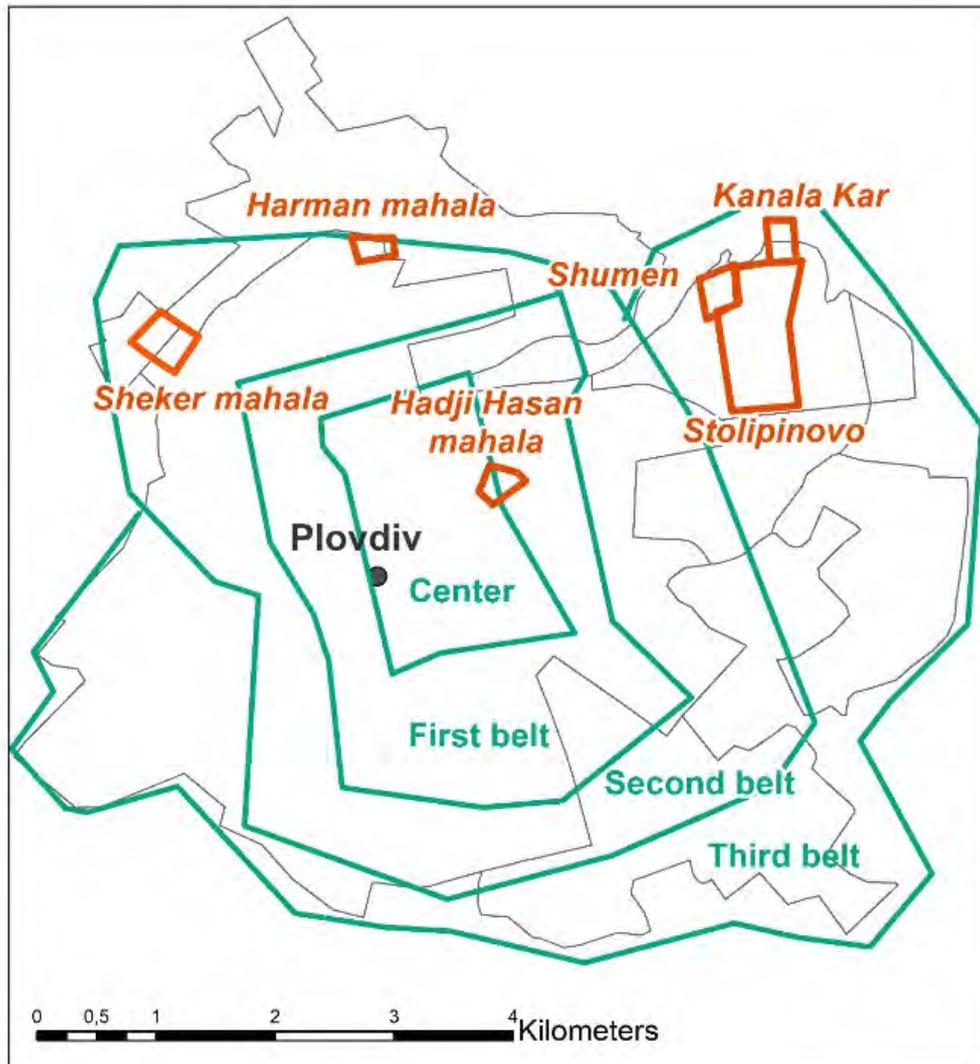


Figure 5. Urban belts of the city of Plovdiv according to the period of construction (Source: Authors)

The city of Plovdiv is featured by its circular urban structure. Four segments are clearly distinct – an urban core, or the "traditional" urban part, and three belts around it, the formation of which is closely related to the different construction periods. The first belt around the "traditional" urban area emerged between the two World Wars but underwent further construction interventions. The second belt was built mainly in the 1950s, while the third belt was formed by the residential apartment complexes, the construction of which began in the early 1970s. Hadji Hasan Mahala is located on the border between the center and the first belt, Harman Mahala and Sheker Mahala fall into the second belt, while Stolipinovo with the two newly emerged neighborhoods around it - Shumen and Kanala Kar - in the third belt (Ilieva et al., 2019).

The centralization index indicates the ratio of X members who would have to change their area of residence in order to achieve an even distribution around the central part of the city.

The easiest way to measure centralization is to take the number of group members who live within the city limits and relate it to their total number throughout the urban area. The simplest group that live within the bounds of the central city, expressed as a proportion of the total number in the entire metropolitan area:

$$PCC = X_{cc} / X$$

where:  $X_{cc}$  is the number of X members living within the boundaries of the central city.

If we look at Plovdiv's GUSs, it is clear that they are located along the edges of the urban fabric of the city (except for Haji Hasan Mahala). The sheer distance to the city center marginalizes the GUSs' residents and creates real problems in terms of access to public services. The distance to the city center hinders the mobility of the GUSs' residents,

considering that they can hardly afford (financially) the regular use of public transport which in most cases is the only way for them to access the city center (Ilieva et al., 2019). In the case of Plovdiv PCC=0.083, which means that only 8.3% of the Roma population reside in the central urban area. Later, social scientists developed other measures of centralization that make fuller use of spatial data. For example, Duncan and Duncan (1955) proposed a relative centralization index defined by the following formula:

$$RCE = (\sum_{i=1}^n X_{i-1} Y_i) - (\sum_{i=1}^n X_i Y_{i-1})$$

where:  $n$  areal units are ordered by increasing distance from the central business district, and  $X_i$  and  $Y_i$  are the respective cumulative proportions of X's and Y's population in tract  $i$ .

This index varies between -1.0 and +1.0, with positive values indicating that X members are located closer to the city center than are members of group Y, and negative values indicating that group X members are distributed farther from the city center. When the index is 0, the two groups have the same spatial distribution around the central district (Massey, Denton, 1988). RCE for the Roma population of Plovdiv is estimated at -0.43, which means that 43% of Roma must change their area of residence to match the degree of centralization of the majority - the Bulgarian population - or in other words RCE measures the extend of X's (the Roma population) centralization relative to group Y's (the Bulgarian population).

Massey and Denton (1988) suggest an analogous index – the absolute centralization index (ACE), which measures a group's spatial distribution compared to the distribution of land area around the city center:

$$ACE = (\sum_{i=1}^n X_{i-1} A_i) - (\sum_{i=1}^n X_i A_{i-1})$$

where: the areal units are ordered as before and  $A_i$  refers to the cumulative proportion of land area through unit  $i$ .

This index also varies between -1.0 and +1.0. Positive values likewise indicate a tendency for group X members to reside close to the city center, while negative values indicate a tendency to live in outlying areas. A score of 0 means that a group has an even distribution of population around the central business district. The absolute centralization index (ACE) for the Roma in Plovdiv is calculated to have negative values of -0.19, in contrast to the Bulgarian population, where the index has a positive value of 0.24. The index therefore gives the proportion of X members required to change residence to achieve an even distribution around the central business district.

## Clustering

High level of clustering occurs in cases where the areas inhabited by the same ethnic group are located close to each other, while the low level of clustering implies their dispersed arrangement in the urban fabric, resembling a chessboard. Clustering is closely related to the chessboard problem. Several indices are used to characterize clustering, such as the spatial proximity index (Clustering index) and the distance-based index of dissimilarity. The index is calculated based on the average distance between the members of the same group and the average distance between the members of different groups, after which their weighted average value is calculated. The spatial proximity index equals 1.0 when there is no differentiated clustering between X and Y, and is  $> 1.0$  when the X-members live closer to each other than to the Y-members. Based on the work of Dacey (1968) and Geary (1954), the following measure of residential clustering can be derived:

$$ACL = \frac{\left\{ \left[ \sum_{i=1}^n (x_i/X) \sum_{j=1}^n (c_{ij}x_j) \right] - \left[ X/n^2 \sum_{i=1}^n \sum_{j=1}^n c_{ij} \right] \right\}}{\left\{ \left[ \sum_{i=1}^n (x_i/X) \sum_{j=1}^n c_{ij}t_j \right] - \left[ X/n^2 \sum_{i=1}^n \sum_{j=1}^n c_{ij} \right] \right\}}$$

where:  $C_{ij}$  refers to an element of "contiguity matrix" that equals 1.0 when  $i$  and  $j$  are contiguous, and 0 otherwise.

Since it is easy to obtain centroid coordinates for areal units in urban areas,  $C_{ij}$  may be taken to represent a distance function between areas. Thus, according to the formula the ACL in the case of Plovdiv was calculated to be 0.66.

## CONCLUSION

Measuring of spatial segregation using computable values of various indicators makes comparison possible, which is of great theoretical and practical value. The indicators used in this study and their values reflect a high multidimensional form of spatial segregation of the Roma population in the city of Plovdiv, which can be characterized as hypersegregation. That being said, not all indicators exhibit extremely high values (i.e. close to 1.0 in cases the given indicator obtains values between 0 and 1.0), however, the cumulative segregation level of the studied ethnic minority can be verbally defined as very high. It is suggested hereby that qualitative evaluations be given to quantitative measurements – e.g. all values between 0.8 and 1.0 can be labeled as “high”, between 0.6 and 0.8 – “significant”, from 0.4 to 0.6 – “medium”, and so forth.

In the case of Plovdiv Roma neighborhoods, it can be said that they all exhibit similar level of spatial segregation, although the situation with one of the quarters is to a certain extent different compared to the other three, mostly because of better levels of the centralization index.

The study demonstrates the ongoing, and even deepening over the last three decades, distancing between the Roma and the ethnic majority of Bulgarians, through the application of a specific quantitative approach to studying spatial segregation. Closing this gap requires not only scientific research, but a combined effort of all actors in the process – the Roma community, the Bulgarian ethnic majority and the authorities at all levels, so as the general population of the city benefits from the solution of the existing problem, may it be only partial if not complete.

## ACKNOWLEDGEMENTS

The study has been conducted within the “Spatial segregation and its impact on the social integration of the Roma population in „Harman Mahala, Plovdiv” project, funded by the National Scientific Research Fund of the Republic of Bulgaria, Grant No ДН15/7.

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# SPATIAL MODELING OF THE MORPHOHYDROGRAPHIC PECULIARITIES IN THE CATCHMENTS OF LOM AND OGOSTA RIVERS

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## **Abstract**

*The spatial modeling of the nature system is common scientific instrument for presentation and interpretation of the basic ecological state and problems of the systems. The present research is related with the modeling of morphological and hydrological peculiarities in the river wetland systems. It observed two main river systems in the geographical space of Northwestern Bulgaria – the catchments of Lom and Ogosta rivers. The interaction between the relief structures and dynamic of the waters is general agent for degradation and evolution of the nature system. The determination of these relations is key element in the process of decision making and management of the territories and regions.*

**Keywords:** *spatial modeling, river, catchments*

## **INTRODUCTION**

The interaction between the relief structures and the dynamic of waters is general problem and agent for the degradation, transformations and evolution in the nature system. The determination of these relations is key element in the process of decision making and management of the territories.

The spatial modeling of the nature system is common scientific instrument for presentation and interpretation of the basic ecological state and problems of the systems. The main goal of present research is related with the modeling of morphological and hydrological peculiarities in the river wetland systems. It observed two of the basic river systems in Northwestern Bulgaria – the catchments of Ogosta and Lom rivers.

## **MODELS AND MODELING**

Robinson et al. (1984) outline the basic concepts in creating spatial models:

1. Geometric focus - is characterized by collecting and manipulating data in order to increase the accuracy (truthfulness) of spatial models.
2. Technical focus - includes determining the dimensions, features of the models, the production and reproduction of spatial models.

3. Presentative focus - the basis of this focus are the features of the models that are a product of spatial data, the applied technology, the visualization conditions and the level of graphic art. The second group of features is the content of the map, the features of the symbols, the planning of the spatial model and the generalization.

4. Art focus - aimed at perfecting the spatial model. It is formed as a result of the colors, features, orientation, graphics, selection, balance, spatial features, the accepted hierarchy and the individual ideas and decisions of the compiler of the spatial model.

5. Communication center - aims to increase the opportunities for interaction between author and user of a spatial model. It consists of two aspects - creating a spatial model and using the spatial model.

- The creation of a spatial model includes the collection, classification, selection, generalization and symbolization of data.

- The use of the spatial model covers the whole range of possibilities for application for its realization. It is expressed in reading, analysis and interpretation of the model.

The spatial model must summarize and represent the real world in certain shapes and sizes. Indeed, for some modeling theorists, the real world is nothing more than a universe of potentially acquired data. Spatially, different systems can be modeled from local to regional and global. They include different areas of human knowledge - natural and humanitarian, theoretical and practical, virtual and real. The most valuable is the ability to combine two or more of these areas (Ziegler et al. 2000).

According to Haggett, Chorley (1967) models in geography are most often based on analogies. Analogies regarding: natural phenomena; social and economic phenomena; alphanumeric images and mathematical formulas. The same authors determine three main groups of models - models analogies with natural systems, models - specialized systems and models - general systems.

Smyth (1998) considers spatial (cartographic) models as abstractions of reality. The latter contain only those features of reality that are important for the interpreted object. The model as an abstraction presents aspects of the real world that can be manipulated and analyzed in the past, define the present and offer opportunities for prediction.

The model is also considered as part of the bilateral model-theory relationship. The model itself is applicable in testing the evidence of a theory. In order to use it correctly, it must determine which of the functions is paramount and how to arrange the data so that the specific function is performed. In this sense, an important function of the model is the interpretation of the theory, but so as not to be identified with it, but to direct the meaning of the model to the logic of the theory itself.

In this regard, Harvey (1996) divides the models into a priori (straight  $A = B$ ) and a posteriori ( $A / B$ ). A priori models are based on constructing a theory. Particularly important here is the problem of interpreting the calculations. These models from a cognitive point of view precede the theory. A posteriori are obtained through the use of formalized theories. The beginning is related to empirical observations. These models simplify the theory test procedure. The obtained results can be transferred to the theory. If a test proves a successful modeling result, it determines a successful theory. In geography, mostly a priori models are applied. In case there is no good model, wrong (inaccurate) predictions often follow.

The use of models requires:

1. Accurate determination of the presumed function of the models.
2. In the course of the implementation the research work must be planned - the function of the data of the model must not be subject to change without observing the necessary preconditions.
3. The model can be used for conclusions in theory.
4. The shortcomings of the model can be coordinated according to the theory.
5. Theories obtained in modeling cannot be disseminated if:
  - (a) It has not been established that the model applies precisely to this theory.
  - b) The area of changes of the model and the nature of its relations with the theory are not precisely and completely defined.

6. For predictive models, the empirical relationship between the individual components and the possibility of full verification must be carefully considered.
7. The functions of the models and the type of model must be taken into account.

In the most general sense, models are through observation and explanation (causal models), time models, functional models and systems. A number of authors consider the triad: space-place-environment as the basic structure of any geographical study. Special emphasis here is placed on the relation: space-time, and hence on the creation of space-time (dynamic) models. It determines the process of creation, development and degradation of objects in space and time, the relationship between space, time and place is determined by the processes that develop the individual stages of the processes in a given place for a given period of time. This manifestation also outlines the framework of space, which Harvey (1969, 1996) defines as the environment. Berlyant (1986) connects this thesis with space-time forecasts as a synthetic type of forecasting, allowing the prediction of the development and evolution of phenomena and their representation through forecast maps.

The present research is based on the modeling of morphological and hydrological peculiarities of the catchments of rivers Lom and Ogosta. It is realized with using of Head-up digitizing technology in the process of modeling of two main layers – relief (hypsometric structures) and hydrology (river systems). The villages are added as additional layer using for better orientation in modeling geographic space.

### **Spatial modeling of morphohydrographic peculiarities of Lom river**

The Lom River (Fig. 1) springs from the Balkan Mountains in the territory of the village of Gorni Lom. The main river system is formed by many smaller tributaries, starting with the springs of the river Barza (at 2100 m above sea level) at the foot of Mount Midzhur (2168 m) in Chiprovtska mountain, Western Stara Planina. In this part these rivers have a mountainous character with very steep slopes of the riverbed and high flow velocities. To the village of Gorni Lom the river flows at a great slope. The afforestation in this area is weak. Only known parts of the catchments area are afforested, mainly with deciduous forests. The longitudinal slope of the river to the village of Gorni Lom is large - an average of 10 %, and the transverse profile of the valley is characterized by deep incisions and steep slopes.

From the village of Gorni Lom to the village of Dolni Lom the river retains almost the same character. In the northern direction it enters almost flat terrain (Dolnolomsko and Sredogrivski fields), where the slope of the river is small and has the character of a flat river. The river valley is surrounded by low hills. The river banks are low and the bottom is covered with sand. Thus, the river continues to the Falkovets village, where it receives its main left tributary Stakevska river, with its right tributary Chuprenska river. In this section the transverse profile of the valley becomes trough-shaped. From the Falkovets village the river enters field terrain, where the valley and the riverbed widen, reaching 100-200 m near the village of Drenovets. From the village of Ruzhintsi to the northeast, its valley has asymmetrical banks with well-developed terraces to the left of the river bed and steep right slopes. The banks of the river in this section are very low and in heavy rains or intense snowmelt its waters go out of the riverbed and cause floods. The bottom of the river is mostly covered with gravel. In small quantities of water, they flow in different directions. Sometimes after a flood the current of the river is in the middle of the riverbed. The catchments area of the river is deforested and occupied by arable land. This character is preserved by the river until its confluence with the Danube River at the 742 km, in the area of the town of Lom, at 28 m above sea level. The estuary is known as "Limana". Characteristic of the river in its lower reaches is the subsidence of its waters, which occurs due to the higher levels of the Danube river.

The area of the catchments area of the river Lom is 1240 km<sup>2</sup>. To the northwest, its catchments area borders the catchments areas of the Archar and Skomlya rivers, and to the southeast - the catchments areas of the rivers Tsibritsa and Ogosta. To the southwest along the ridges of Svetinikolska and Chiprovtska mountains crosses the border with the catchments areas of the rivers Timok and Nishava.

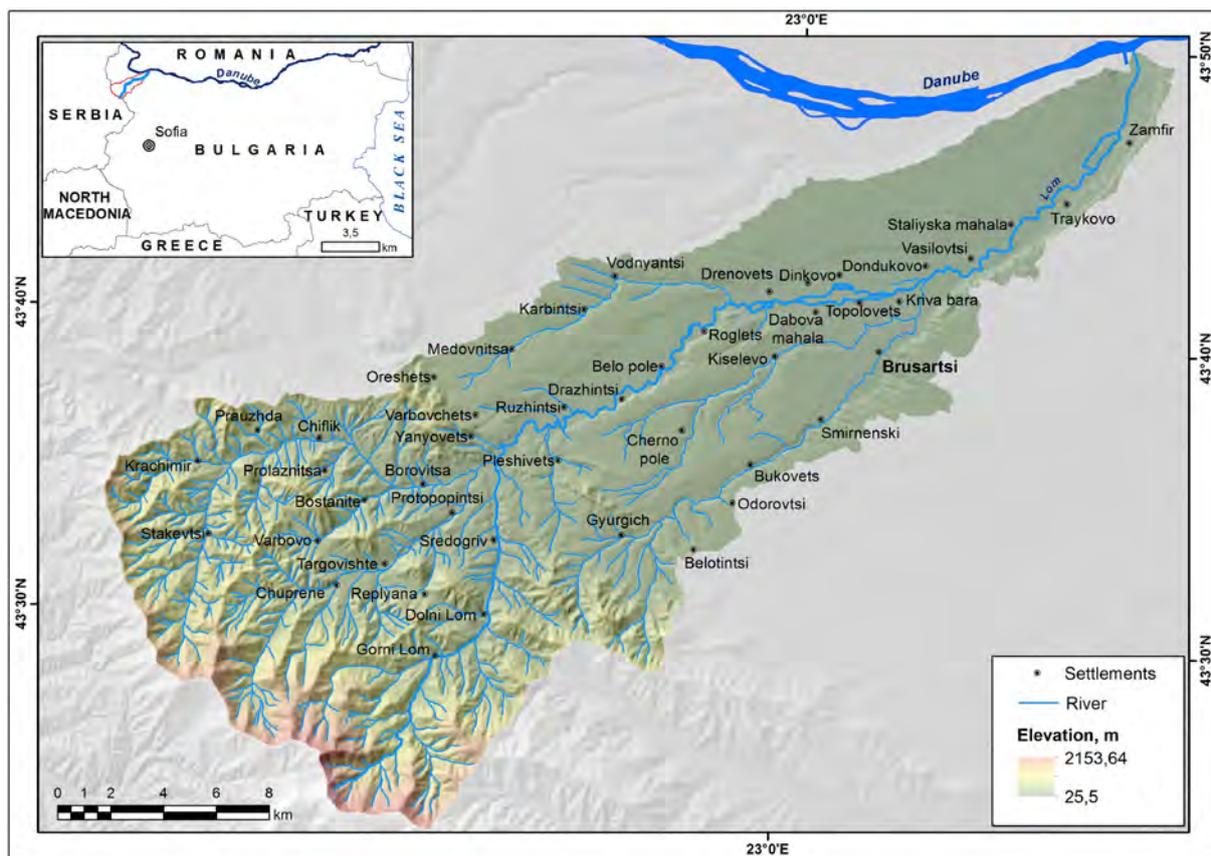


Fig. 1 Spatial model of the morphohydrographic peculiarities in the catchments of Lom river.

### Hydrographic features

The average long-term outflow at the village of Drenovets is 4,7 m<sup>3</sup>/s, and at the mouth 6,4 m<sup>3</sup>/s with a maximum of 11 m<sup>3</sup>/s and a minimum of 2,19 m<sup>3</sup>/s. Average slope 18.3%, forestation 35%, annual runoff 202,106 m<sup>3</sup> (Hristova, 2012).

The average annual runoff at station in village of Traykovo is 7,39 m<sup>3</sup>/s. The maximum is in the spring (March-May), which is due to the melting of the snow cover and spring rains, and the minimum - July-October. The data for the internal annual distribution of the river outflow are for the period 1950/1951 – 2000/2001.

### Spatial modeling of morphohydrographic peculiarities of Ogosta river

The Chiprovtska river with springs below the Vrazha Glava peak (1935 m) in the Chiprovtska mountain, at about 1760 m above sea level, is considered to be the beginning of the Ogosta river (Fig. 2). To the village of Belimel it flows in a northeasterly direction in a narrow valley, afforested mainly with deciduous forests.

After the mouth of its left tributary, the Prevalaska river (Prevalaska Ogosta) turns southeast and forms a wide trough-like valley, occupied mainly by arable land. In this section on its right, the river Dalgodelska Ogosta flows into it. After its mouth, Ogosta enters the second largest dam in Bulgaria - "Ogosta". Here on the right (in the dam) its tributaries Barata, Zlatitsa and Barzia flow. After flowing out of the Ogosta dam, it turns northeast, passes through the town of Montana, receives the waters of the Shugavitsa river on the right, and near the town of Boychinovtsi - the waters of its right tributary, the Botunya river. Then the river enters the Danube plain, retaining its northeasterly direction and flows into a wide asymmetric valley - with steeper right banks. In this section there is only one larger tributary flows into it - Ribine river, right tributary.

After the village of Harlets, through the Kozloduy lowland, the Ogosta river flows into a general riverbed corrected with water protection dikes together with its largest tributary, the Skat river. It flows to the right into the Danube river at the 685-th km at 27 m above sea level. The area of the catchments area of Ogosta river is 3157.1 km<sup>2</sup>, and its borders are the following: - to the northwest and north - with the catchments areas of the rivers Lom and Tsibritsa; to the east,

southeast and south - with the catchments area of the river Iskar; to the southwest - with the catchments area of the river Nishava.

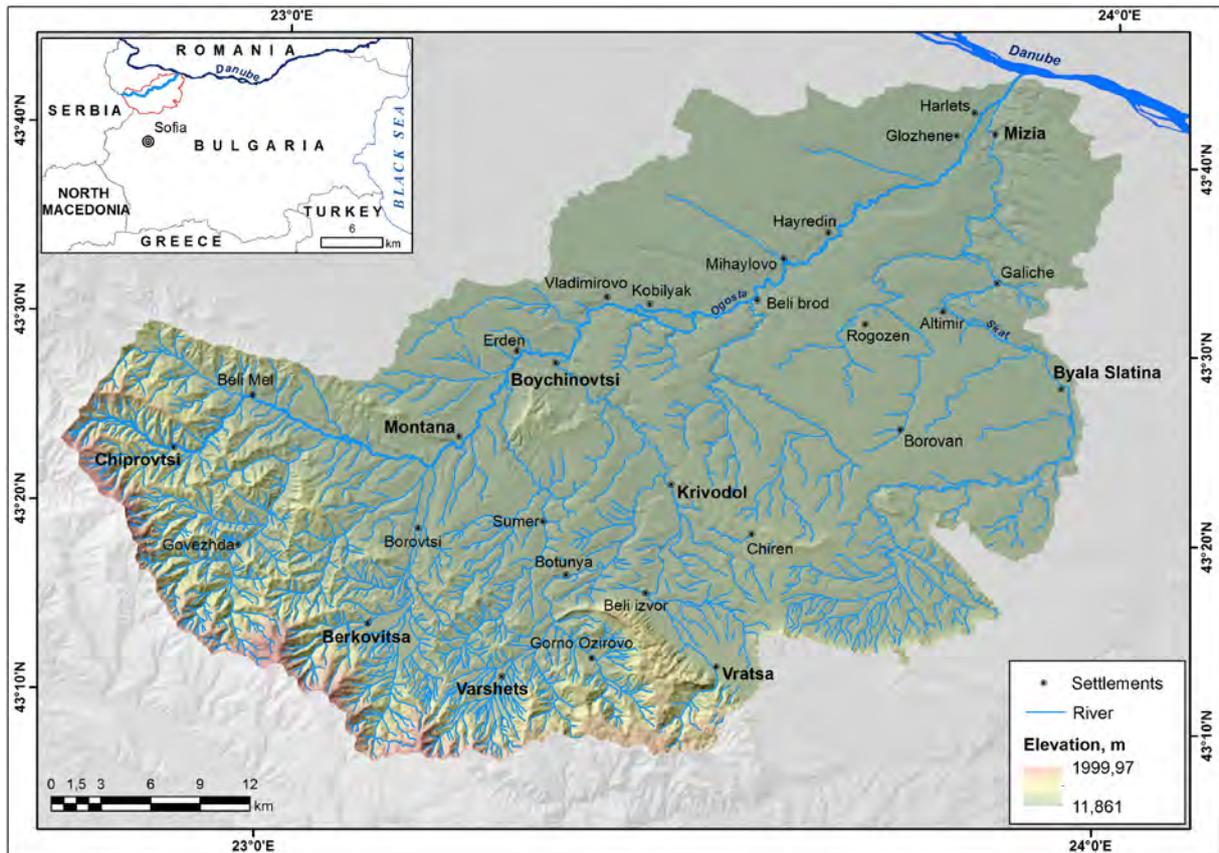


Fig. 2 Spatial model of the morphohydrographic peculiarities in the catchments of Ogosta river.

### Hydrological features

The average annual outflow of the river near the town of Chiprovtsi is 0,81 m<sup>3</sup>/s, and at the station in Mizyia town – 25,40 m<sup>3</sup>/s (Hristova, 2012). The maximum is in the spring (April-May), which is due to the melting of the snow cover and spring rains, and the minimum in October. The data for the internal annual distribution of the river outflow are for the period 1950/1951 – 2000/2001.

### CONCLUSIONS

The general results of research presented two basic spatial models of the catchments of Lom and Ogosta rivers. The spatial models clear showed the picture of main morphohydrographic peculiarities in these river systems. The morphographic elements are modeled on the first level as basic layer. The hydrological elements are added on the second level following the structure of the morphology in the two regions.

The results of the investigation can be use in the process of management of the two of big river catchments in Northern Bulgaria and Danube catchments. It also can apply in the regional plans for development of the regions on the municipality, regional and transregional level. The other aspects for applying of this research are processes and decision of the problems related with sustainable use of recourses and nature protection in the regions.

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## **ACKNOWLEDGMENT**

The scientific results in the paper are part of the work in the project “Relation of the spatial distribution of heavy metals in the soils with the morphology of contaminated river floodplains” (contract KII-06-H24/2) funded by Fund Scientific Researches, Bulgaria and realized in National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences.

# INSPECTION AND ERROR REMEDIATION OF BATHYMETRIC RELATIONSHIPS OF ADJOINING GEO-OBJECTS IN ELECTRONIC NAVIGATIONAL CHARTS

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## Abstract

*Depth areas are utilized by the Electronic Chart Display and Information Systems (ECDIS) along with the vessel's characteristics (e.g., draft, squat) and other situational information (e.g., tides) for separating safe areas from those unsafe to navigate. Any error in their compilation is carried over to the analysis performed in the ECDIS. As a result, waters may be portrayed deeper, thus posing a risk to the vessel navigating them, or may appear shallower, thus triggering useless ECDIS alarms which contribute to the situation known as "mariner's deafness". With the exception of crisp boundaries where abrupt changes are expected, the transition between depth areas should be smooth and continuous. In this paper we present a research toward a mechanism for identifying discontinuities and an error remediation approach that proposes changes to the encoded depth range and the geometry of depth areas with identified discontinuities, for the cartographer's attention.*

**Keywords:** ENC validation checks, Automated nautical cartography, Digital terrain modelling, Topographic surface, Nautical surface, Depth areas, Safety of navigation

## INTRODUCTION

The electronic navigational chart (ENC) contains essential information about the marine and coastal environment for the safe navigation of vessels. ENCs are loaded on shipborne Electronic Chart Display and Information Systems (ECDIS) that, besides displaying the information included in the ENCs, integrate navigation-related systems and sensors aboard ships, such as GPS, AIS, and RADAR/ARPA. ECDIS address limitations and dependencies of the traditional paper chart, such as the need to manually apply corrections and continuously plotting fixes (i.e., vessel's position), allowing the mariners to easily and accurately perform simple or composite tasks such as plotting the vessel's course or activating alarm functions when the vessel is in proximity to hazards (e.g., shallow waters) or impending dangers (e.g., collision course with vessel sailing alongside) (Kastrisios and Pilikou, 2017). With ECDIS, mariners have a complete picture of the instantaneous situation of the vessel and charted dangers in the area (Alexander, 2003).

The electronic chart is a database that consists of a set of point, linear, and polygonal features encoded using the chain-node topology (IHO, 2000). The spatial objects in the ENC are divided into two groups, namely Group 1 (known as the "skin of the earth") and Group 2 features. Group 1 features are the area-type geo-objects: DEPARE (depth area), LNDARE (land area), DRGARE (dredged area), UNSARE (unsurveyed area), FLODOC (floating dock), HULKES (hulk), and PONTON (pontoon). For Group 1 features, each area covered by a meta-object M\_COVR (coverage) with CATCOV = 1 (i.e., that continuous coverage of spatial objects is available within this area) must be totally covered by a set of the above geo-objects that must not overlap so that the required topology is not violated.

To ensure that the topological structure of ENC is valid, the IHO has developed a number of checks defined in Publication S-58 ENC Validation Checks (IHO, 2018). Software that performs S-58 validation (e.g., SevenCs Analyzer, ESRI ArcGIS for Maritime, Teledyne CARIS S-57 Composer, C-MAP dKart Inspector) provide reports for errors among the Group 1 and 2 objects of the ENC in question as well as errors with objects in the adjoining ENCs. The classification of errors is in three categories according to the risk they pose for the safety of navigation (i.e., *warnings*, *errors*, and *critical errors*). In detail, a *warning* is “an error which may be duplication or an inconsistency which will not noticeably degrade the usability of an ENC in ECDIS”, an *error* “may degrade the quality of the ENC through appearance or usability but which will not pose a significant danger when used to support navigation”, whereas a *critical error* “would make an ENC unusable in ECDIS through not loading; or causing an ECDIS to crash; or presenting data which is unsafe for navigation” (IHO, 2018).

As the NOAA Nautical Chart Manual points out, “the most important concept about the formation of depth areas is that the overall succession of depth areas and their defined range values must be continuous. There can be no gaps, overlaps, or discontinuity in the range values of connecting depth areas” (NOAA, 2018). Thus, with the exception of crisp boundaries where abrupt changes are expected (e.g., between piers and depth areas), the transition between depth areas should be smooth and continuous, i.e., the maximum encoded depth of one depth area should be equal to the minimum depth of the adjoining depth area.

S-58 provides many checks that deal with the vertical component of the ENC, however, with the current set of validation checks, the depth continuity of depth areas is not guaranteed and discontinuities of the sea bottom may exist (Kastrisios et al., 2020). For instance, check number 1771 requires that the depth value of a depth contour (i.e., attribute VALDCO) must be equal to the least of the two maximum depth values of the coincident depth areas (i.e., attribute DRVAL2). For a 10m depth contour and two coincident depth areas encoded with depth ranges 5m-10m and 20m-30m will pass the validation check (as the minimum of the two DRVAL2 is also 10m), but the continuous transition in depth ranges of the areas is not achieved.

In the following sections we discuss the situations where depth discontinuities occur in an ENC, their effect on the analysis performed in ECDIS, and research on a mechanism for the identification and remediation of depth discontinuities in chart compilation.

## DEPTH AREAS DISCONTINUITIES

Humans have the ability to infer the depth range of areas by looking at the charted linear features. For instance, in the paper chart of Manele Bay, Hawaii (Figure 1a), between the depth curves of 5ftm and 10ftm the depth range is 5-10ftm. Likewise, one can interpret that the depth in the marked area between the shoreline and the 3ftm depth curve is 0-3ftm. In ENCs the depth range is encoded with the depth areas (DEPAREs) which serve as the principal feature object for the determination of water safe and unsafe to navigate. Any error in the encoding of depth ranges is carried over to the analysis performed in ECDIS and may be negligible or significant depending on the specific geographic configuration. To illustrate this, figure 1b shows the bathymetry encoded in the ENC for Manele Bay, Hawaii, where for visualization purposes the 2-3ftm depth area is colored red, 3-5ftm brown, and 5-10ftm green. For a vessel with a draft of, e.g., 1.8m (i.e., 1ftm), the ECDIS would classify the plotted route (shown in dark blue in Figure 1b) as safe due to the underlying depth areas and soundings that are deeper than the set value. In the ENC, the area near the shorelines (the marked area in Figure 1a), is represented with depth range 2-3ftm instead of 0-3ftm. Although the ideal would be the encoding of two separate depth areas (one with 0-3ftm depth range adjoining the shorelines and one with 2-3ftm for the remaining area), the current situation has no imminent effect to the plotted route and the analysis performed in the ECDIS. However, if the entire 2-3ftm depth area was encoded as 0-3ftm (since it adjoins the shorelines), for all vessels trying to approach the berth, ECDIS would set off alarms for crossing non-navigable waters.

The scenarios discussed with the support of Figure 1 are common depth discontinuities in ENCs, examples of which are presented in the next section of this work. Although the mariner is able to disregard this and similar alarms in ECDIS, they contribute to what is known as “mariner’s deafness”, i.e., the situation where the mariner is called to investigate a considerable number of ECDIS alarms which entails the risk that important alarms do not receive the proper attention, thus increasing the risk of a maritime accident. In addition, depth discontinuities complicate automation of individual generalization tasks in chart compilation, e.g., the validation of the shoal-biased pattern of sounding selection (see e.g., Masetti et al., 2018; Kastrisios et al., 2019).

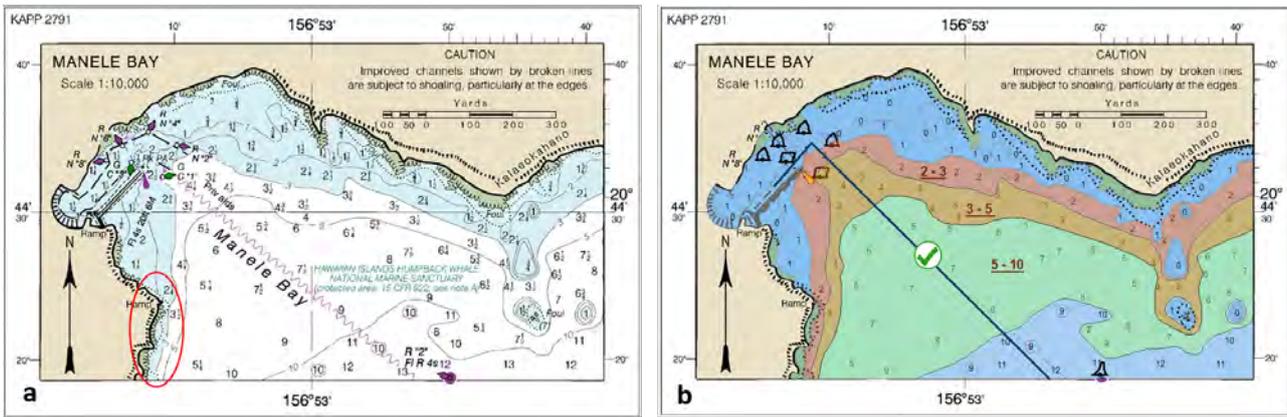


Figure 1: Bathymetry on paper (a) and electronic chart (b) of Manele Bay, Hawaii.

Figure 2a illustrates the ideal situation where the continuous seabed is represented with a continuous transition between depth ranges in the ENC. Contrary to Figure 2a, Figures 2b and 2c illustrate a discontinuous representation of the seabottom on the chart. In Figure 2b, the depth area adjoining the land area is encoded with least depth other than zero, depicting the water depth to be deeper than in reality. Figure 2c illustrates the opposite situation, where the water depth on the chart appears shallower than the reality. A different situation of discontinuities occurs when depth areas or depth curves have been encoded in incorrect units, e.g., fathoms instead of meters. Based on the encoded values, the depth areas may appear deeper or shallower.

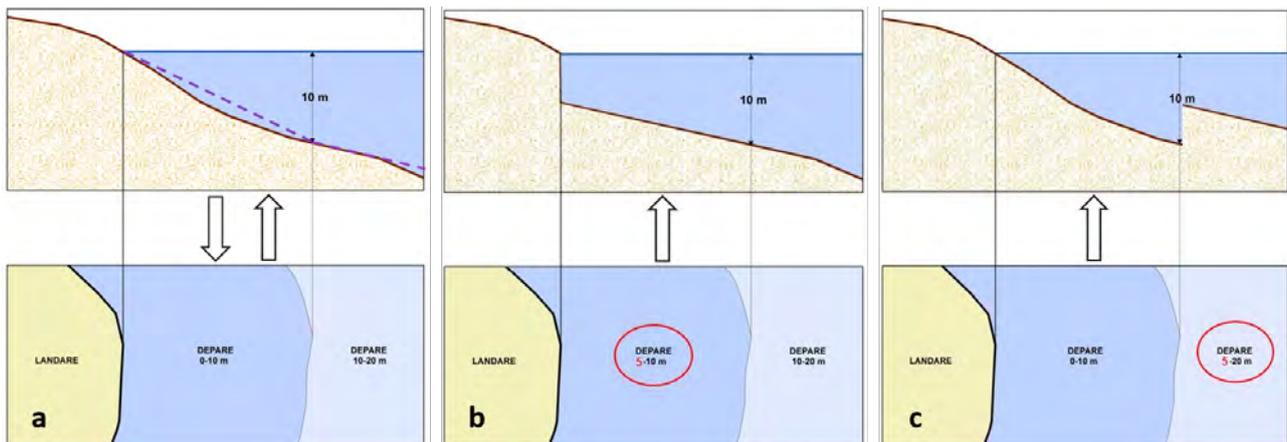


Figure 2: Depth ranges of encoded depth areas and seabottom representation in ENCs: (a) continuous/ideal, (b) discontinuous/waters appear deeper than reality, (c) discontinuous/waters appear shallower than reality.

Here we have developed a mechanism that identifies the coincident geometries where discontinuities occur. For that, we compare the depth values of adjoining depth areas and shorelines, depth curves, and other geo-objects (e.g., dredged areas). With the exception of the geographical situations where vertical discontinuities are expected (e.g., in the crisp boundaries of shoreline constructions or dredged areas and the adjoining depth areas), the algorithm captures the discontinuities of the sea-bottom surface that should not, in principle, occur (e.g., the fuzzy boundaries of two depth areas or a depth area and the shoreline).

The research effort focuses on solutions for the identified discontinuities, and providing them as suggestions to the cartographer. The initial approach is iterative and begins with finding corrections for the attribute values. That includes, in the first iteration, the depth areas encoded in incorrect units and, in the second iteration, the depth areas that adjoining land areas. For the former, the algorithm compares the depth value to hard-coded dictionaries of the succession of depth curves in U.S. charts in meters, fathoms, and feet, and converts the value in the wrong units to the proper value in the units of the chart under validation. For the latter, the algorithm substitutes the minimum depth value (DRVAL1) of the depth area to zero and if this value change solves or improves the current situation, the change is accepted.

Once the attribute corrections steps are complete, the algorithm determines the final list of the shared edges with errors. Following the idea of medial line delineation described by others (see e.g., Gold, 2000; Cosquer and Hangouët, 2003;

Lygeros, 2012; Kastrisios and Tsoulos, 2017; Kastrisios and Tsoulos, 2018), the algorithm then determines the areas of dominance for each edge with errors which are returned as suggestions for implementation by cartographers. The cartographer is responsible for reviewing the individual polygons, splitting the depth areas, and assigning the new depth ranges based on these recommendations. The complete elimination of discontinuities may potentially be incompatible with legibility constraints and cartographic design principles. Therefore, this work currently focuses on a mixed machine/human process, but future work will investigate the feasibility of a fully automated solution.

## TEST CASE

This section presents the results of the error identification and remediation process for US5AK4DM, a large scale ENC for the northern part of Tlevak Strait and Uloa Channel, west side of Prince of Wales Island, AK. For this particular ENC, the algorithm identified a total of 53 depth areas and 553 coincident geometries (edges) with errors. As Figure 3 shows, the output table of the error identification process includes the identifier of the adjoining features, i.e., the long names of the depth contour (DEPCNT\_LNAM), shoreline (COALNE\_LNAM), or depth area (DEPARE\_LNAM) that share a depth discontinuity. It also includes the encoded depth values that are identified as discontinuities (i.e., VALDCO, DEPARE\_DRVAL1, DEPARE\_DRAVAL2).

OID*	Shape*	DEPCNT_LNAM	VALDCO	COALNE_LNAM	DEPARE_LNAM	DEPARE_DRVAL1	DEPARE_DRAVAL2	TYPE	Shape_Length	Length_M
65	Polyline	US099515257512345	0 0		US075746485412345	5.4	9.1	DEPCNT	0.002505	278.897047
66	Polyline	US070038545812345	0 0		US075746485412345	5.4	9.1	DEPCNT	0.018949	2109.441929
67	Polyline	US088840287012345	0 0		US075746485412345	5.4	9.1	DEPCNT	0.00321	357.313823
68	Polyline	US046034698812345	0 0		US091717752710017	9.1	18.2	DEPCNT	0.002247	250.131073
69	Polyline	US011623061512345	0 0		US091717752710017	9.1	18.2	DEPCNT	0.005774	642.800699
70	Polyline	US002275769712345	0 0		US091717752710017	9.1	18.2	DEPCNT	0.000917	102.065352
71	Polyline	US096102986012345	0 0		US091717752710017	9.1	18.2	DEPCNT	0.00214	238.241698
72	Polyline	US074367197312345	0 0		US091717752710017	9.1	18.2	DEPCNT	0.000775	86.253777
73	Polyline	US089417345712345	0 0		US091717752710017	9.1	18.2	DEPCNT	0.001386	154.265792
74	Polyline	US099272617312345	5.4 0		US091717752710017	9.1	18.2	DEPCNT	0.017995	2003.155879
75	Polyline	US011677662712345	0 0		US091717752710017	9.1	18.2	DEPCNT	0.001166	129.765263
76	Polyline	US067706742512345	0 0		US091717752710017	9.1	18.2	DEPCNT	0.001292	143.813924
77	Polyline	US033099764410017	0 0		US091717752710017	9.1	18.2	DEPCNT	0.001052	117.139623
78	Polyline	US055022088912345	0 0		US091717752710017	9.1	18.2	DEPCNT	0.002366	263.414483
79	Polyline	US035034879012345	0 0		US091717752710017	9.1	18.2	DEPCNT	0.004452	495.638253
80	Polyline	US030149364012345	5.4 0		US091717752710017	9.1	18.2	DEPCNT	0.003671	408.6177
81	Polyline	US072524941012345	5.4 0		US091717752710017	9.1	18.2	DEPCNT	0.005622	625.832401
82	Polyline	US099620475712345	5.4 0		US091717752710017	9.1	18.2	DEPCNT	0.003099	344.949075
83	Polyline	US092102858312345	0 0		US082178747112345	9.1	18.2	DEPCNT	0.000119	13.194436
84	Polyline	US030378490512345	0 0		US082178747112345	9.1	18.2	DEPCNT	0.001589	176.917826
85	Polyline	US082314336112345	5.4 0		US082178747112345	9.1	18.2	DEPCNT	0.0017	189.188485
86	Polyline	US083993303712345	0 0		US082178747112345	9.1	18.2	DEPCNT	0.003907	434.944299
87	Polyline	US022479393112345	0 0		US073917884610017	9.1	18.2	DEPCNT	0.001557	173.349217
88	Polyline	US086060005112345	5.4 0		US098888468512345	9.1	18.2	DEPCNT	0.005603	623.703049
89	Polyline	US010517324712345	0 0		US066799155310017	18.2	548.6	DEPCNT	0.003284	365.584103
90	Polyline	US084360025312345	0 0		US066799155310017	18.2	548.6	DEPCNT	0.005425	603.910638
91	Polyline	US013233047712345	0 0		US066799155310017	18.2	548.6	DEPCNT	0.000807	89.790845

Figure 3: The output table for US5AK4DM for which the application identified 53 depth areas and 553 coincident edges with errors in depth continuity.

The following three figures show examples of the identified discontinuities. Figure 4 illustrates a depth area which has been encoded with depth range 9.1–18.2m (shaded area). However, it is apparent that the populated depth range is incorrect for many parts of the specific depth area (e.g., where the outline of the depth area touches that of land features). Discontinuities such as the discussed may pose a threat to navigation as the water depth appears deeper than reality. For instance, for a vessel with a safety contour set to 9.1m, ECDIS will treat the water within the entire extent of the shaded depth area as navigable and will not trigger any alarms, although the water depth is apparently less than 9.1m in many parts of the depth area.

In a different situation of depth discontinuity, and opposite to that illustrated in Figure 4, Figure 5 shows a depth area that appears shoaler than the reality. The shaded depth area is populated with minimum depth value of 18.2m (depth range 18.2m – 91.4m) and adjoins a depth area with depth range 18.2m – 36.5m. The coincident depth curve has populated depth value of 36.5m, thus the depth area in question should be split and, where appropriate, be assigned a depth range of 36.5m – 91.4m. Cases like this may make navigable waters appear as non-navigable in ECDIS and trigger useless ECDIS alarms, contributing to “mariner’s deafness”.

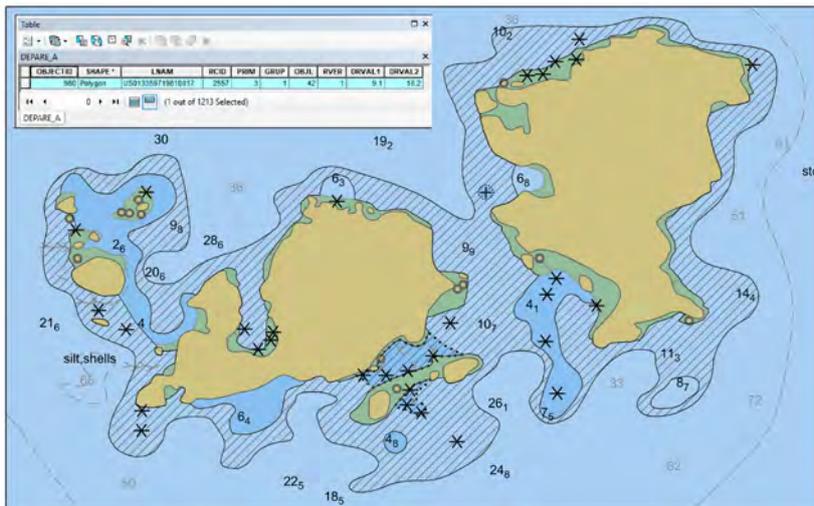


Figure 4: Depth area (depth range 9.1m – 18.2m) inconsistent with the adjacent land and depth areas.

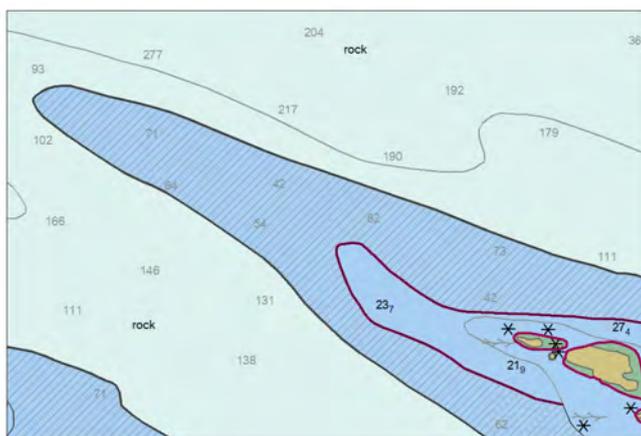


Figure 5: Depth area encoded shoaler than the actual depth in the area (i.e., 18.2m – 91.4m instead of 36.5 -91.4m).

Figure 6 illustrates an example of a depth area that has been encoded in units different than the adjoining depth areas; here, fathoms instead of meters. The shaded area has populated depth of “3” (apparently in fathoms) contrary to the proper 5.4 (in meters) whereas the adjoining depth areas have been properly encoded in meters. Cases of vertical discontinuity like the discussed may be encountered in ENCs produced by hydrographic offices that use more than one systems of units in their folio of charts (NOAA’s Office of Coast Survey is one of those).

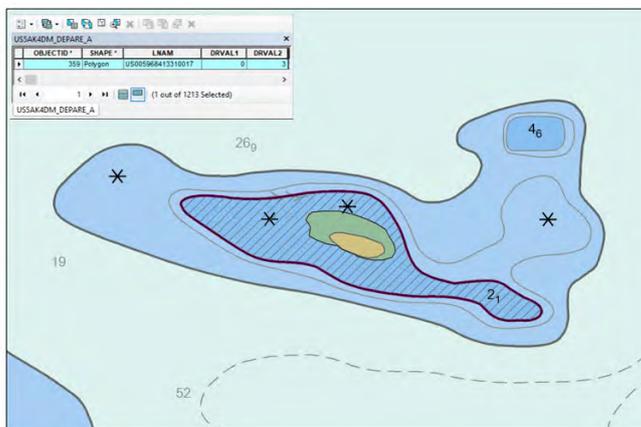


Figure 6: Depth area encoded in different units than the adjoining depth area and depth curve (i.e., fathoms vs meters).

After applying the attribute fixes of the error remediation, the number of common geometries with errors are reduced to 365 (i.e., a reduction of 33%). Figure 7 shows that the populated DRVAL2 depth value of 3 fathoms discussed previously has been corrected to 5.4 meters.

OBJECTID *	SHAPE *	LNAM	DRVAL1	DRVAL2
359	Polygon	US005968413310017	0	3

OBJECTID *	SHAPE *	LNAM	DRVAL1	DRVAL2
359	Polygon	US005968413310017	0	5.4

Figure 7: The attributes table of the depth area in Figure 6 before and after the attribute fixes.

Subsequently, the tool iterates between the edges with identified errors suggesting fixes and altering the geometry of the depth areas. That includes splitting the respective areas and assigning the proper depth range to each new depth area. Figure 8 illustrates the dominating polygons that may be used as the guide for the splitting of the shaded area of Figure 4. Figure 9 shows the attribute table of these polygons, along with the current and recommended depth ranges.

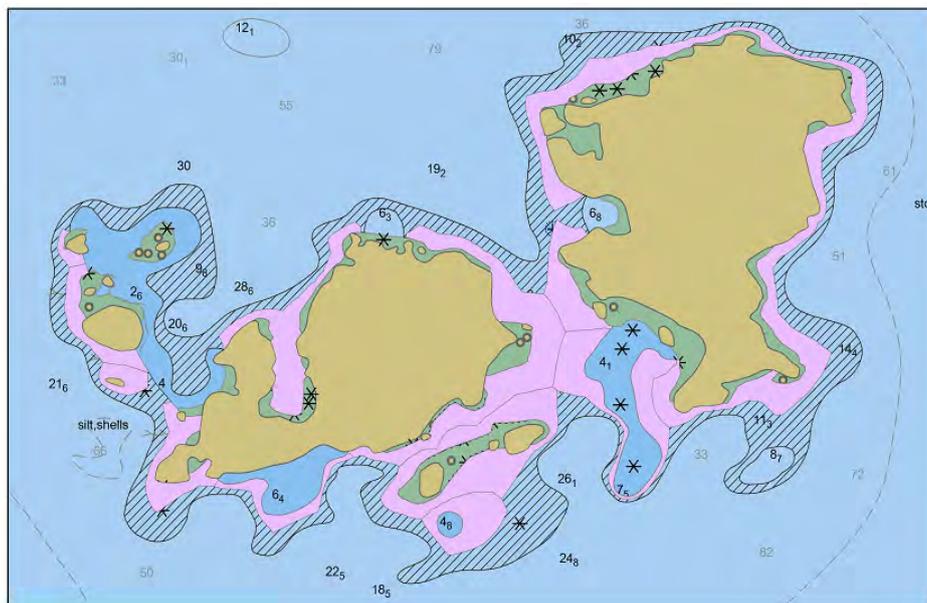


Figure 8: The recommended geometry changes to the depth area of Figure 4.

Lastly, Figure 9a shows an example of the dominating polygons of the edges with error (in yellow) and how they were utilized for splitting the depth area with errors into smaller areas (green and red shaded areas in Figure 9b). The automation of this process is under development.

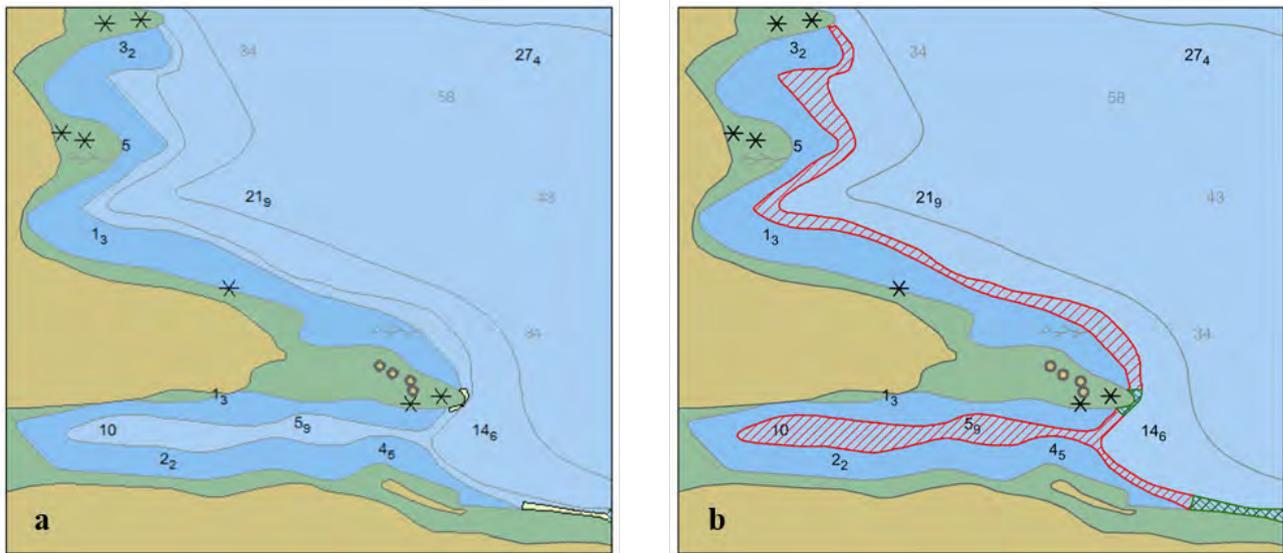


Figure 9: Recommended geometry changes are in yellow (a) and their incorporation as four new depth areas by the cartographer (b).

## CONCLUSION

This paper presents the problem of depth discontinuities in ENCs and how they affect the ECDIS analysis in determining safe and unsafe navigation areas. It also presents the research work for the development of an algorithm to identify such discontinuities, and an iterative approach for error remediation. The approach begins with errors that may be fixed by making attribute changes, then proposes changes to the geometry of depth areas. The process is currently a mixed machine/human process, but a fully automated solution, pursuant to the limitations set by the cartographic constraints, is under investigation.

## ACKNOWLEDGEMENTS

The work of Christos Kastrisios and Brian Calder is supported by the National Oceanic and Atmospheric Administration grant NA15NOS4000200.

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## BIOGRAPHIES

Christos Kastrisios graduated from the Hellenic Naval Academy (HNA) in 2001 with a B.Sc. in Naval Science. After his graduation he served aboard frigate HS Aegean and submarines HS Protefs and HS Poseidon, mostly as the navigator and sonar officer, and participated in several deployments at sea. In 2008 he was appointed to the Hellenic Navy Hydrographic Service where he served in various positions and represented his country at international committees and working groups. He holds a Pg.Dip. from the Hellenic Naval War College, a M.P.S. in GIS from the University of Maryland at College Park, and a Ph.D. in Cartography from the National Technical University of Athens (NTUA) for his work on the scientific aspects of maritime delimitation. He has worked as a part-time lecturer in GIS and Cartography at the HNA and NTUA. His research work at the Center focuses on data generalization, visualization, and topology on nautical charts.

Brian Calder graduated with a M.Eng (Merit) and Ph.D in Electrical and Electronic Engineering in 1994 and 1997 respectively, from Heriot-Watt University, Scotland. His doctoral research was in Bayesian statistical methods applied to processing of sidescan sonar and other data sources. He joined the Center for Coastal and Ocean Mapping & NOAA-UNH Joint Hydrographic Center at the University of New Hampshire as a founding member in 2000, where his research has focused mainly on understanding, utilizing and portraying the uncertainty inherent in bathymetric (and other) data, and in efficient semi-automatic processing of high density multibeam echosounder data, and associated technologies. He is a Research Professor, Associate Director of CCOM, the Chair of the Open Navigation Surface Working Group, and a past Associate Editor of IEEE Journal of Oceanic Engineering.

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# CREATING CARTOGRAPHICAL SIGNS WITH DOUBLE ARTICULATION

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## **Abstract**

*The term articulation in cartography denotes the division of signs into their constituent parts. From the point of view of articulation, the signs are separated into three groups: **signs without articulation** (cannot be divided into simpler parts); **signs with a single articulation** (the components, of which they are composed, do not have their own meaning) and **signs with a double articulation** (they consist of two or more elements that have their own meaning).*

*The meaning of double articulation signs is not described in the legend, but their constituent parts are characterized. On the map field, these components are combined in different ways. This gives the general meaning of double articulation signs, which carries more information than the sum of the meanings of their components.*

*The usage of double articulation allows a large number of characters to be constructed with few structural elements. This results in language economy and makes signs easier to understand: it is necessary for the map reader to memorize a small number of signs in order to understand the meaning of a large number of signs on the map. Therefore, double-articulation signs are easier to recognize and more meaningfully assigned. They allow to encode more information in them without requiring the creation of many new signs in the legend.*

*This article discusses the basic rules for constructing double articulation signs. Two types of components are defined: **base units** (showing the location of the object and its basic meaning) and **additional units** (explaining the type of the object or its quality features). The basic requirements for these elements and the ways of combining them in one sign are shown. Examples of successful and unsuccessful application in existing maps are given.*

**Keywords:** sign system, articulation of the signs, sign system with double articulation, meaning of signs, semiotic economy

## **1. ARTICULATION**

### **1.1 What is articulation?**

The term articulation is used in different sciences, having different meanings:

- In phonetics: the formation of clear and distinct sounds in speech.
- In music: clarity in the production of successive notes.
- In medicine: something that consists of two or more parts, where the parts are joined and able to move in relation to each other;
- In anatomy: a joint (an area where two bones are attached for the purpose of motion of body parts);
- In dentistry: the contact of the teeth in the upper jaw and the teeth in the lower jaw;

In all of these cases, articulation denotes the ratio or interaction of two or more parts.

## 1.2 Articulation in semiotic

In semiotics, articulation is called *the division of signs into their signifying components*. One of the fathers of modern semiotics, Ferdinand de Saussure, points out that signs can contain other signs. Then they become ‘*complex signs*’, such as the word ‘*twenty-nine*’, which contains the ‘*simple signs*’ *twenty* and *nine*. (Chandler, 2004)

The purpose of articulation is to decompose a sign into basic (elementary) structural units so that each of them can be examined. In this way, more appropriate sign systems can be created to describe the depicted objects or to express the meaning of the signs.

The general theory of articulation, as described by Daniel Chandler, allows these levels to be: *low level (first articulation)* and *high level (second articulation)*. Signs with low level articulation can be divided into smaller elements that do not have their own meaning, i.e. they are not signs. Chandler (2007) called them ‘*non-signifying sign elements*’. Signs with high-level articulation are composed of elements that have independent meaning, i.e. from other signs. Such are all cartographic signs, as they are composed of one or more graphic signs, each of which is assigned a certain meaning in the legend.

It should be born in mind that in semiotics articulation is the division of signs according to their meaning (mostly semantic) and not physical components. Semiotics do not study the structural side of articulation because all words consist of sequentially arranged sounds (when pronounced) or letters (when written).

## 2. ARTICULATION OF THE SIGNS

In classical semiotics, three levels of sign articulation are considered:

- Signs without articulation;
- Signs with single articulation;
- Signs with double articulation.

The term ‘double articulation’ was first used by the French linguist André Martinet (Martinet, 1961).

### 2.1 Signs without articulation



Fig. 1

Signs without articulation are extremely simple and cannot be broken down into simpler units. For example, the red circle used in Fig. 1 is a simple geometric figure, which does not contain other structural elements. That is why it is a sign without articulation. Such characters are perceived quickly, but do not allow additional information to be encoded in them.

### 2.2 Signs with single articulation



Fig. 2

Signs with single articulation have more than one lower level component. But each of these elements does not have its own meaning. For example, the Morse code is composed of dots and dashes (Fig. 2), which are combined in different ways to obtain characters for letters, numbers and punctuation. The only function of any point or dash is to distinguish one character from another. Outside the sign, they have no independent function.

### 2.3 Signs with double articulation



Fig. 3

Signs with double articulation contain signs that have their own meaning. Fig. 3 shows an example of the use of signs with double articulation in traffic sign system: the shape of the sign indicates its function (triangular signs are warning and round signs are prohibitive); and the figure in the center carries the meaning of the warning / prohibition. Signs with double articulation consist of smaller semantic elements.

## 2.4 Language economy

Sign systems with double articulation offer greater '*language economy*' or '*semiotic economy*'. They allow to build a huge number of significant second-level elements by using a relatively small number of low-level elements. Semiotics view this property as inherent only in mankind. Animals do not use double articulation in their behavior and language of communication. According to Chandler (2007), Hockett views it as a '*key constructive property*' of language, and Louis Hjelmslev views it as a '*defining characteristics*' of the languages used by man (Hjelmslev, 1961).

To explain semiotic economy, Hervey (1982) uses the terms '*figurae*' and '*signa*'. The first term indicates the number of notations, and the second - the number of their semantic combinations. Hervey gives an example with the designations of the taps in the bathroom, which have three designations ('*figurae*'): **H**, **W** and **C**. From them are obtained three meanings '*signa*': **H** - hot water, **W** - warm water and **C** - cold water. In this example, the ratio '*figurae*' / '*signa*' is **1:1**, i.e. we do not have an economy of linguistic means. On the other, MacEachren gives another example: On a map, with different geometric shapes, seven different manufacturers are marked. The type of their production is shown in three different colors of the figures. In this case are used **10 designations** - 7 shapes and 3 colors, from which **21 different combinations** can be obtained. Therefore, the ratio '*figurae*' / '*signa*' is **1: 2.1**, i.e. we have twice as many meanings as there are signs. This, according to MacEachren (1995, p. 240), means, ,,... *that we have a system with huge semiotic economy.*"

We have a system with double articulation when one of the sign is basic and can be used independently, i.e. it indicates an object of a higher step in the classification scheme. In the example from Fig. 3 this is the shape of the road sign. Other signs that make up the sign with double articulation do not have the ability to be used on their own. In MacEachren's example above, shapes can be used without being colored in different colors, but colors cannot be used if there are no shapes. They only make sense when combined with a base sign.

## 3. GENERAL THEORY OF CARTOGRAPHIC ARTICULATION

### 3.1 Level of articulation in Cartography

Initially, in cartography, the term '*articulation*' was used to denote an emphasis on certain aspects of what was depicted on the map (see Halford J. Mackinder). With the entry of semiotics into cartographic science, it began to be used to divide signs into semantic units.

The signs studied by linguistics are always arranged in a linear sequence (the sentences lose their meaning if the places of the words in them are mixed up). In contrast, the cartographic signs can be combined in various ways in the field of the map: they create connections of proximity, neighbourhood, intersection, etc. The environment of the signs also creates additional meaning. The same graphic symbol placed in a different place on the map indicates different objects. Signs have richer possibilities of expression using Bertin's six visual variables, so there are many more ways to articulate cartographic signs.

According to Charles Peirce each sign on the map has two sides: sign vehicle and meaning. Each of these sides can create three levels of articulation.

The meaning of cartographical signs has three components:

- **Sense** – what kind of object represent the sign;
- **Value** – the ratio between the sign and other signs on the map (such as size, brightness, frequency of use), which adds worth to the objects being displayed.
- **Feature** – characteristics of depicted object, shown on the map.

Each of the three components of the meaning of the sign can be without articulation, with single or double articulation.

As sign vehicle, symbols have the following structure:

Entity		Meaning
o...	Graphic primitive	No meaning in legend
o*	Graphic sign	In legend: Brush
	Cartographic sign	On the map: Single brush
	Super sign	5 m north of the path

Fig. 4 Graphic entity and its meaning

- **Graphic primitives:** the smallest constructive elements of the signs, to which no specific meaning is assigned by the legend. They can have their own meaning thanks to their visual variables (according to Bertin: size, shape, color, value, orientation, texture). For instance, on an ornithological map the color of the sign can show the type of bird habitat (swamp, field, forest, mountain), the form of the primitive - the way of nesting, and the texture - the eating habits of birds.

- **Graphic signs,** which consist of one or more graphic primitives. They denote general mental concepts, such as city, road, and factory, due to what is stated in the legend or due to their traditional usage. Fig. 4 shows how four graphic primitives form a graphic sign, which receives from the legend the ability to mark bushes on the map.

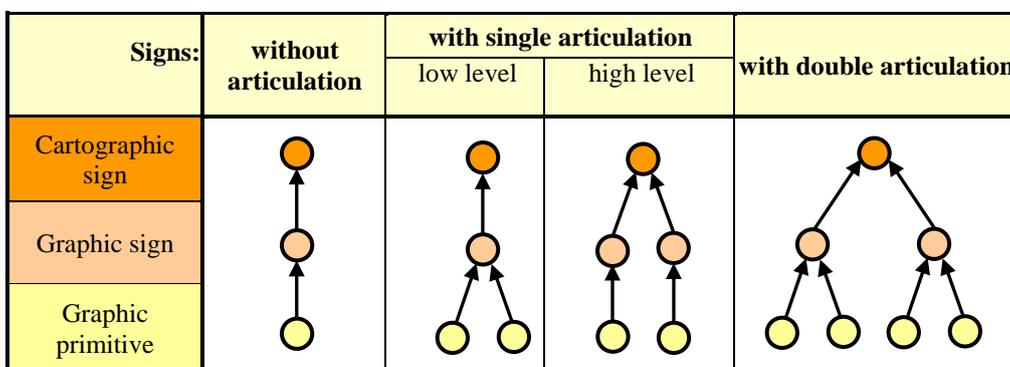


Fig. 5 Articulation in depth of cartographic sign

- **Cartographic signs,** which consist of one or more graphic signs. Through them in the field of the map are depicted specific objects of reality. By placing the cartographic signs on the map, they inherit the qualities of the map field (scale, projection, coordinate system, etc.) and get two new specific characteristics: location (which allows them to represent specific objects) and surroundings (ambient signs). Due to these new features they acquire a new set of meanings that are missing in their constituent graphic signs.

- **Super-signs,** which are obtained by mentally combining cartographic signs in the process of working with the map. Due to this combination of signs on the map, data that is not directly set by the cartographer can be extracted. The highest level of organization of the signs will not be considered as a source of articulation of the signs because it is created in the reader's mind. In addition, super-signs may contain a huge number of combinations of signs.

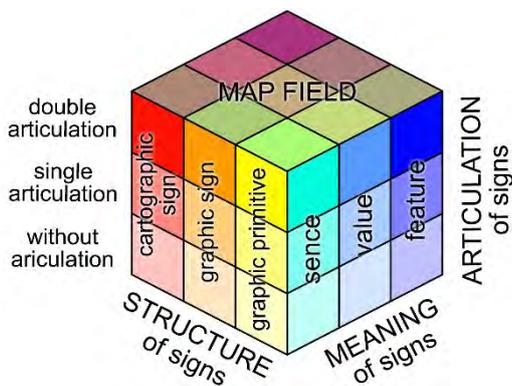


Fig. 6

The ways of combining the graphic primitives into graphic signs and the graphic signs into cartographic signs are shown in Fig. 5

The three types of sign meanings (sense, value and feature) can be obtained at any of the four levels of the sign structure. Graphical primitives, thanks to their visual variables, can indicate belonging to a certain type of objects (rivers are formed in blue) and value (larger primitives have a greater value than smaller ones) and show properties of objects (by orientation or by pattern). The legend can describe all three types of meanings, so graphic signs can give cartographical signs sense, value and feature. This feature allows them to make much more and more complex semantic combinations than those used in linguistics.

Therefore, the structure of cartographic articulation is significantly more complex. Instead of the three levels of articulation as it is in linguistics, in cartography can be obtained 27 levels of articulation (see Fig. 6).

### 3.2 Construction of signs with double articulation

Signs with double articulation have two types of meaningful elements:

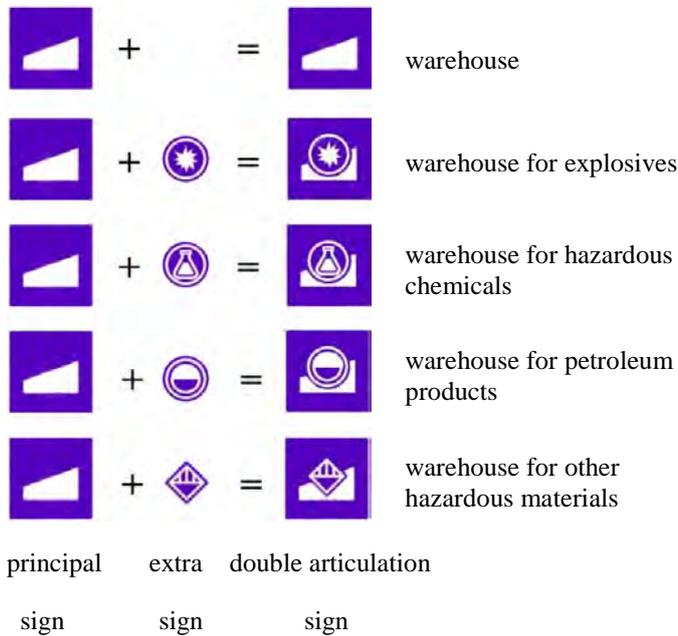


Fig. 7 Creating a double articulation sign



Fig. 8 An extra sign add meaning to two principal signs (Marinova, 2018b)

tion, compared to the sign with double articulation, in order to be able to understand base meaning of the sign with double articulation, without understanding the meaning of the extra signs;

- to allow seamless addition of extra signs (without losing some of their content).

The greatest economy of the language is obtained when the extra signs can be combined with several principal signs. Fig. 8 shows how an extra sign gives meaning to different principal signs by adding them to the warehouse and factory signs. Thus, the reader has to memorize fewer notations and the probability of errors in assigning the meaning decreases.

- a **principal sign** that has two main functions: to show the basic meaning of the sign and to indicate the location (insertion point) of the symbol.

- **one or more extra signs** that allow a more precise classification of the objects or show specific characteristics of their objects.

In addition, double-articulated signs may have one or more not signifying sign elements that give aesthetic value or graphic weight to them. They do not change the meaning, but make the symbols easier to notice or more attractive to the reader.

The principal sign shows the general meaning of the whole signs group. On Fig. 7 the principal sign shows general meaning (warehouse). The extra signs give a complementary classification of the objects depicted through them. In this way, even if the map reader does not understand the meaning of each of them, he will be able to understand the general meaning of the sign, in this case: warehouse.

The components of the sign with double articulation must be constructed in such a way that there is no doubt as to which the principal is and which the extra signs are. This is usually achieved by making the principal sign considerably larger. When the meaning of the extra signs is very important, they are shown with brighter colors to make them easier to notice, as done on Fig. 9.

In order to be able to perform their functions, the principal signs must meet the following conditions:

- to have a well-defined insertion point, because they determine the location of the depicted object;
- to depict an object of a higher level of classification,

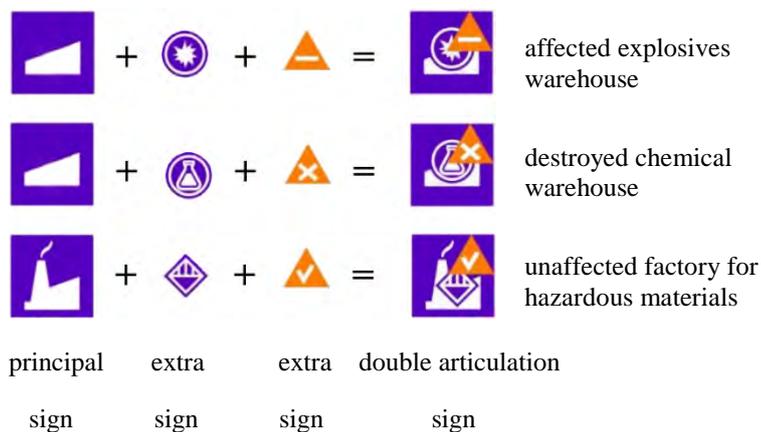


Fig. 9 Two extra signs in a sign with double articulation  
 (Marinova, 2018a)

### 3.3 Sign systems with three-level articulation

The sign with double articulation can consist more than one extra sign. By adding more extra sign to the principal sign, an additional meaning can be given to a sign with double articulation. This allows to show more characteristics of the objects depicted on the map or to create an additional classification. Fig. 9 shows an excerpt from a sign system in which extra signs on the one hand clarify the type of materials produced or stored and also its state in case of disaster.

### 3.4 Sign systems with multi-level articulation

A cartographic example of multilayer articulation is shown in Fig. 10. The signs are from the manual for creating special military maps of the US Army<sup>1</sup>. The total number of signs is over 1000. They cannot be remembered even by the most intelligent reader. With the introduction of several levels of articulation, it is now necessary to memorize four principal signs (Friend, Hostile, Neutral, and Unknown) plus a number of complementary symbols. Since four additional levels of articulation have been introduced, the number of different characters is reduced to 50-60, which can be memorized relatively easily. For example, the sign of the bottom row in all combinations means a place for repair and can be added to any sign, indicating some kind of technique. The three-circle sign , introduced on the penultimate line, indicates wheeled transport for all types of equipment in all signs.

	<i>Friend</i>	<i>Hostile</i>	<i>Neutral</i>	<i>Unknown</i>
<i>Principal signs:</i>				
<i>Level of extra signs:</i>				
1. <i>Armoured forces</i>				
2. <i>Armoured amphibious</i>				
3. <i>Armoured wheeled amphibious</i>				
4. <i>Maintenance of armoured wheeled amphibious</i>				

Fig. 10 Example for Sign systems with multi-level articulation

The multi-layered articulation results in a very large economy of language. However, the signs are read very slowly because they look like Chinese hieroglyphs. On the one hand, they become very large in size (so that several extra signs can be placed), and on the other hand, the assignment of the meaning of the signs is slow and requires some effort from the map reader. Therefore, multi-layered articulation is only recommended when creating specialist map when the signs are required to convey a large amount of information.

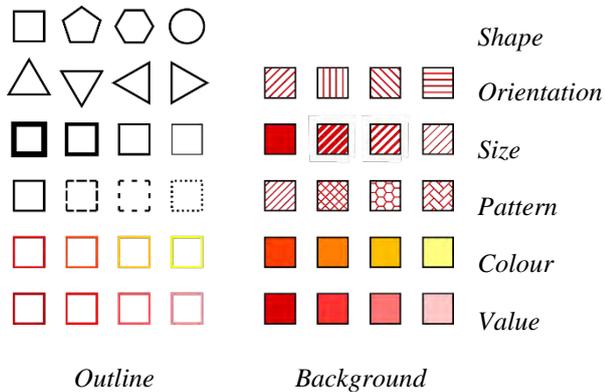
<sup>1</sup> Document COMMON WARFIGHTING SYMBOLOGY (US\_Army, 2008) describes all signs and contains 1090 pages.

## 4. HOW TO CREATE SIGN SYSTEMS WITH DOUBLE ARTICULATION

### 4.1 Principal signs

Principal signs can be of two types:

1. Large signs in which to place extra signs, such as those shown in *Fig. 9* and *Fig. 10*;
- 2 Small signs around which to place extra signs;



*Fig. 11*

#### 4.1.1 Large signs

Such signs do not show the exact location of the depicted object, but they quickly attract attention, due to their size. Other advantages are:

- a) The possibility of placing several extra signs in the area of the sign (see *Fig. 10* and *Fig. 14*), which describe the object which is mapped better;
- b) By using a combination of different visual variables of the principal sign's outline and background, a large number of object characteristics can be represented on the map. *Fig. 11* shows the possibility to present using all six visual variables using different outlines and five visual variables using different backgrounds, which gives a huge number of combinations (not all of them are practically possible).

- **PO** Post Office
  - **PS** Police Station
  - **FS** Fire Station
  - **SES** State Emergency Services
  - **S** School
- Fig. 12*

#### 4.1.2 Small signs

The size of these signs does not allow extra signs to be placed in them, but allows the location of the depicted objects to be indicated exactly. Extra signs must be located around the principal sign. Their size must be larger to attract the attention of the map reader. *Fig. 12* shows how public buildings are depicted on US Topo Maps. Principal sign allows to accurately display the shape and location of buildings, and the extra sign shows the type of building. The distance between the signs must be chosen so that they can be easily grouped visually and there is no doubt to which sign they belong. When using several extra signs, the fulfillment of this requirement is difficult to achieve.

### 4.2 Extra signs

Extra signs have various functions on the map: to give specific meaning to the signs, to present qualitative or quantitative characteristics of the depicted object or to indicate its name. As extra signs can be used:

1. Graphic primitives
2. Graphic sign
3. Inscription

### 4.2.1 Graphic primitives

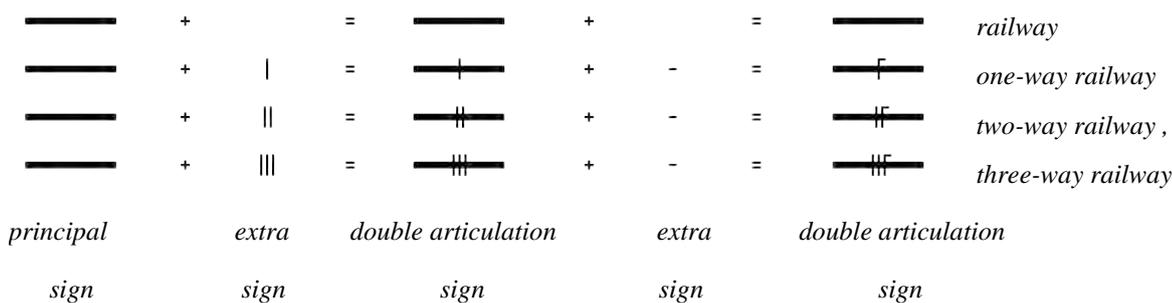


Fig. 13 Creating a linear sign with double articulation through additional signs

Graphic primitives have no meaning on their own outside the sign with double articulation. They only serve to distinguish the signs. Fig. 13 shows an example of the usage of graphic primitives in the sign system of the medium-scale topographic maps in Bulgaria when depicting railways. Principal sign shows the general direction of railways with a line which is 0.8 mm thick. The extra signs indicate the number of lanes (one-way, two-way or three-way). To show the electrified railways, a second extra sign is provided, which is placed across the first. Dashes are used, as extra sign, which only makes sense when placed along the principal sign.

### 4.2.2 Graphic signs

As extra signs can be used symbols that are given a certain meaning in the legend or have their own meaning due to their traditional use. Then the meaning of the sign with double articulation is perceived faster and more securely.

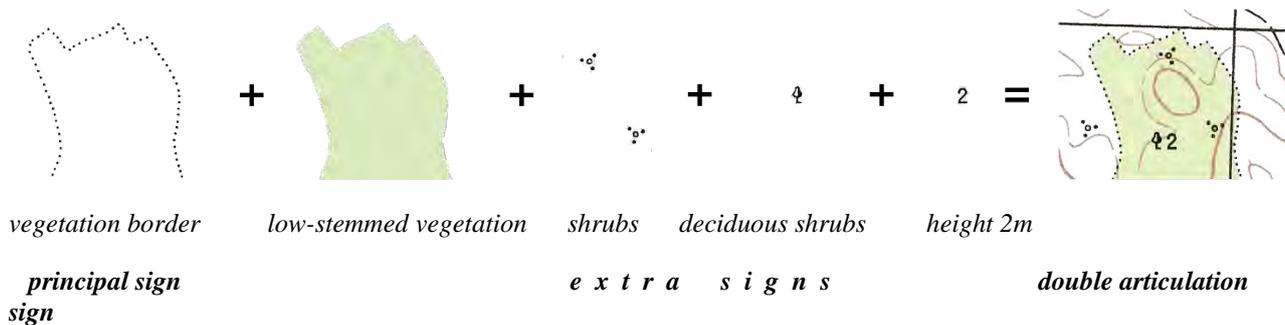
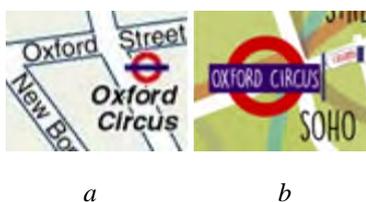


Fig. 14 Creating an area sign with double articulation by several extra signs

Fig. 14 shows an example of the Bulgarian topographic sign system for depicting shrubs. The principal sign shows the boundaries of the area occupied by vegetation. The legend gives the graphic sign the meaning to depict bushes, and to represent deciduous vegetation. The height of the bushes (2 m) is shown by an inscription.

### 4.2.3 Inscriptions

The use of inscriptions as extra signs has several advantages: they are perceived unconditionally; they allow a large number of characters to be formed without having to remember the meaning of each of them; they give the opportunity to write the name of the object and many of its characteristics. The inscriptions take up considerable amount of space on the map, but when placed around small principal signs they can be put in any free space around the sign. The meaning of the inscriptions is appropriately assigned: it is very seldom wrong (usually when abbreviations are used).



a b

Fig.15

Inscriptions can be added in two ways: by placing them next to the sign (Fig.15a) and by combining them within the sign (Fig.15b).

Inscriptions allow giving an exact quantitative characteristic to the object, as it is done in Fig. 14 (bushes are 2 m high). Combining several quantitative characteristics can lead to confusion and misunderstanding of the meaning of each of the inscriptions. In Fig.16 it is shown the description that the bridges of the small-scale topographic maps in Bulgaria have. The map user should know that the location of the caption in the group indicates what feature it explains. In Fig.16 "44" shows the length of the bridge in meters, "6" - its width, and "50" - the load capacity in tons. The inscription "ЖБ" explains the



Fig.16

type of construction - reinforced concrete. All these inscriptions well characterize the bridges, but can be understood only after prior training.

A new meaning of the sign can be added through the inscriptions. *Fig. 17* shows signs in which the meaning of the sign is explained by inscriptions. Such signs are less likely to be mistaken and easier to be remembered, but they are not associative (for example, if you do not know the meaning of abbreviations you cannot understand the meaning of the sign). But once the meaning is understood, it is seldom misunderstood.

	<i>Unknown</i>	<i>Friend</i>	<i>Neutral</i>	<i>Hostile</i>
<i>Military intelligence interrogation</i>				
<i>Joint intelligence center</i>				
<i>Shore patrol</i>				
<i>Military police</i>				

*Fig. 17* (US\_Army, 2008)

## 5. CONCLUSION

The creation of sign systems with double articulation gives great advantages when making maps: it allows to make a more detailed classification scheme; to show additional characteristics of the objects; to focus on their essential aspects. In general, double-articulated characters allow more information to be presented on the map.

Limiting factors must also be taken into account: slower reading and perception of the characters, larger size of the signs, which lead to a greater risk of overlapping and intersecting characters.

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## **BIOGRAPHY**

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# METHODS AUTOMATED CREATION OF TYPICAL GEOGRAPHICAL BASES FOR ATLASES

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## **Abstract**

*An important stage in the design of any Atlas is the creation of typical geographical bases, the number of which in the Atlas can be different and depends on the coverage of the mapped territory, the purpose and subject of the Atlas. Designing the typical geographical bases of the Atlas is a time consuming task due to the interrelated factors. The article offers approaches and methods for automated creation of typical geographical bases with optimal density and graphical load of objects. The study is based on the determination of quantitative indicators of the created basis, taking into account the styles and sizes of symbols, the methods used for mapping general geographic and thematic content. The proposed solutions will allow to quickly create geographical bases for various types of atlases (geographic, complex (integrated) and thematic) and improve their quality.*

**Keywords:** atlas mapping, cartographic databases, geographic base maps for atlas.

## **INTRODUCTION**

An important stage in the design of any Atlas is the creation of typical geographical bases, the content of which is represented by elements of boundaries, hydrography, settlements and routes. The number of typical bases in the Atlas may vary. This depends on the coverage of the territory being mapped, the purpose and subject of the Atlas. Designing the typical geographical bases of the Atlas is a time consuming task due to the interrelated factors. For example, if you create typical geographical bases for the same territory, but at different scales, you should conduct a coordinated selection of objects. When designing thematic and complex atlases, it is necessary to ensure the unity of content and complete internal consistency of all geographic and thematic elements of the map. In this case, the same objects can be both elements of the basis and the thematic content, and in some cases, the conditional signs of the thematic content replace the conventional signs of the geographical basis. In addition, thematic maps differ in how they are mapped.

At present time the concept of automated creation of atlases [1] is developed in Moscow State University of Geodesy and Cartography. It focuses on automatization of most labor-intensive processes of atlas mapping, among which is the automated creation of typical geographical bases for Atlases.

## **SOLUTIONS FOR AUTOMATED CREATION OF TYPICAL GEOGRAPHICAL BASES FOR ATLASES**

To formalize the creation of the geographical basis of the Atlas, the method is proposed (Figure 1).

### **Selecting source data**

In order to automate the process of creating a geographical foundations of Atlas it is proposed to use the cartographic database as a data source. This choice is determined by the initial database composition (hydrography, settlements, communications and borders), development the system of classification and coding of geographical objects, a single fixed digital cartographic information record format, as well as the option to use semantic information about entities from different sources. Thus, to create the basis for the territory of the Russian Federation, it is advisable to use a small-scale cartographic database of 1:2 500 000 scale, formed on the basis of the General geographical map "Russia and neighboring States" of 1:2 500 000 scale and representing a set of layers containing metric and semantic information.

To create thematic or complex regional atlases, in addition to the cartographic database, you must create a thematic database containing quantitative and qualitative indicators of the object or phenomenon being mapped. To create socio-economic maps, the main source data is statistical data. For example, for the territory of the Russian Federation, the source of such data is the Federal State Statistic Service [2]. Databases created by international organizations (for

example, the UN statistical division, UNESCO, Eurostat, etc.) can also be used. In addition, statistics data for the subjects of the Russian Federation and Federal districts can be obtained on the websites of territorial bodies of the Federal state statistics service. In addition to statistical data, you can also use official, open, documented datasets from Federal, regional, and other organizations to create thematic maps.

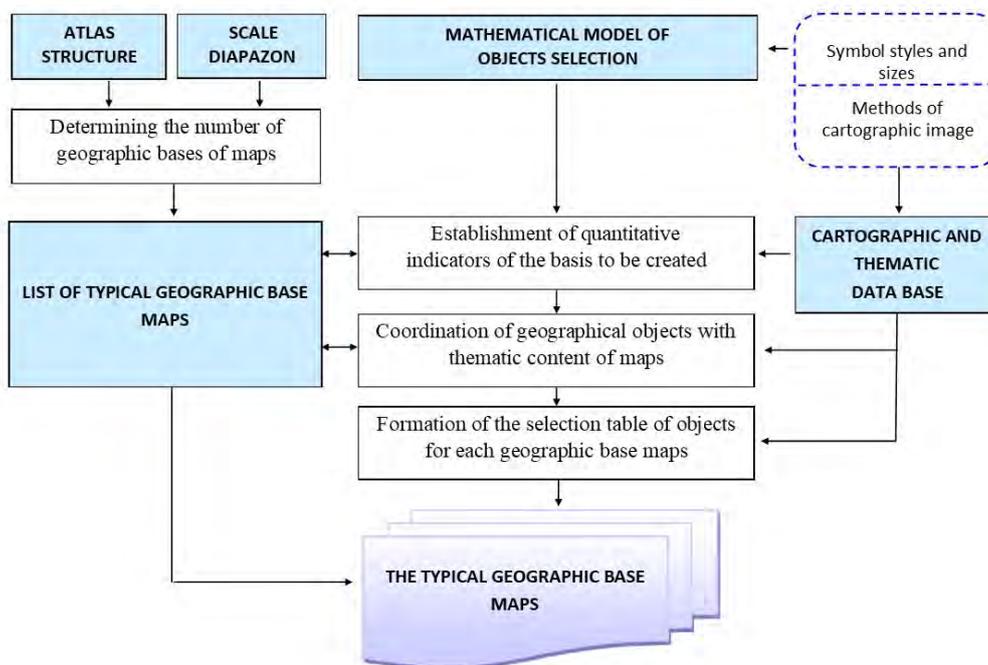


Figure 1. Methods of automated creation of typical geographic bases

When creating a thematic database for Atlas mapping, you need to develop tables that take into account all the indicators on all the created thematic maps. At the same time, depending on the methods used for mapping images, and therefore on the method of placing the mapped phenomenon, you can group indicators into a single table. For example, for objects and phenomena located in administrative divisions, it is proposed to create a single table containing indicators even for different methods of mapping (for example, for choropleth and diagram map). A separate table is created for objects localized in localities. Statistical information is linked to the metric information of layers in the map database by unique codes of administrative divisions and localities (for example, the OCTMO code). Table 1 shows an example of the structure of tables with thematic data.

Table 1. Structure of tables in the thematic database

The name of the layer (methods of cartographic representation)	Field names	A description of the fields
1	2	3
THEME_ADMIN (choropleth, method of quantities and quality background, diagram map)	Code_ISO	Code state by ISO 3166
	OCTMO	Code OCTMO of subject / district
	Them1_map1	Parameter №1 of thematic map 1
	Them2_map1	Parameter №2 of thematic map 1
	....	
	ThemK_map1	Parameter №K of thematic map 1
	....	
	Them1_mapN	Parameter №1 of thematic map N
	Them2_mapN	Parameter №2 of thematic map N
....		
	ThemL_mapN	Parameter №L of thematic map N

THEME_NP (Method of cartographic symbols)	OKTMO	Code OCTMO of human settlement
	Them1_map1	Parameter №1 of thematic map 1
	Them2_map1	Parameter №2 of thematic map 1
	....	
	ThemK_map1	Parameter №K of thematic map 1
	....	
	Them1_mapN	Parameter №1 of thematic map N
	Them2_mapN	Parameter №2 of thematic map N
	....	Parameter №1 of thematic map 1
	ThemL_mapN	Parameter №2 of thematic map 1

### Determining the number and creating a list of geographical bases of the Atlas

Based on the developed structure of the Atlas and the identified groups of scales in which maps will be created, it is necessary to determine the number and form a table list of typical geographical bases to be created, which for each base will indicate the calculated and proposed scale, the mapped territory, the section(s) of the Atlas, the map type (General geographic maps, nature maps, socio-economic maps). For thematic maps, you should also define and specify in the table the elements of the General geographical basis that are shown on the map you are creating, depending on the map topic. The main blocks of information are provided with the description of fields and possible values for some fields (Figure 2). The connection between the list of typical geographical bases and tables of maps and sections should be made by the unique number of the Atlas section.

Information about the base	Information about the adjacent territory
Base ID The computed scale denominator The proposed scale denominator Layout option (1-floating, 2 – on the frame, 3-on the map grid) Name of the region to map Codes of mapped region Area of the mapped territory, km <sup>2</sup> Area of the mapped region, km <sup>2</sup> List of Atlas section numbers Map type (1-General geographic, 2-nature, 3-socio-economic) Elements of the General geographical basis (0 – no elements, 1-river network, 2-localities, 3-road network).	Number of States on the adjacent territory List of ISO 3166 country codes in the contiguous territory Number of administrative divisions of the 1st order on the adjacent territory The list of codes of administrative units List of main categories of human settlements shown on the adjacent territory Area of adjacent foreign territory, mm <sup>2</sup> The area of the adjacent territory (administr. units of the 1st order), mm <sup>2</sup> The total area of the adjacent area, mm <sup>2</sup>
Theoretical quantitative indicators ("selection thresholds»)	Actual quantitative data indicators
Optimal density of human settlements, number of human settlements per 1 dm <sup>2</sup> Coefficient of optimal density of the river network, mm/mm <sup>2</sup> Coefficient of optimal density of the road network, mm/mm <sup>2</sup> Number of human settlements The total length of the rivers, mm Total length of roads, mm The graphics load of the rivers, mm <sup>2</sup> Graphic load of human settlements, mm <sup>2</sup> Graphic load of roads, mm <sup>2</sup> Graphic load coefficient of the river network, mm <sup>2</sup> /mm <sup>2</sup> Graphic load factor of human settlements, mm <sup>2</sup> /mm <sup>2</sup> Road graphic load factor, mm <sup>2</sup> /mm <sup>2</sup>	Number of human settlements in the region being mapped Number of human settlements on the adjacent territory The total length of the rivers, mm Total length of roads, mm The graphics load of the rivers, mm <sup>2</sup> Graphic load of human settlements in the region, mm <sup>2</sup> Graphic load of human settlements on the adjacent territory, mm <sup>2</sup> Graphic load of roads, mm <sup>2</sup> Graphic load coefficient of the river network, mm <sup>2</sup> /mm <sup>2</sup> Graphic load factor of human settlements, mm <sup>2</sup> /mm <sup>2</sup> Road graphic load factor, mm <sup>2</sup> /mm <sup>2</sup>

Figure 2. Information blocks for the list of standard geographical bases

### Determination of quantitative indicators of typical geographical bases

At this stage, you should automatically set the theoretical quantitative indicators of the created base, ensuring optimal density and graphic load of objects, as well as their alignment with the thematic content of maps. Depending on the type of map being created (General geographic, thematic), an algorithm for calculating these indicators has been developed (Figure 3).

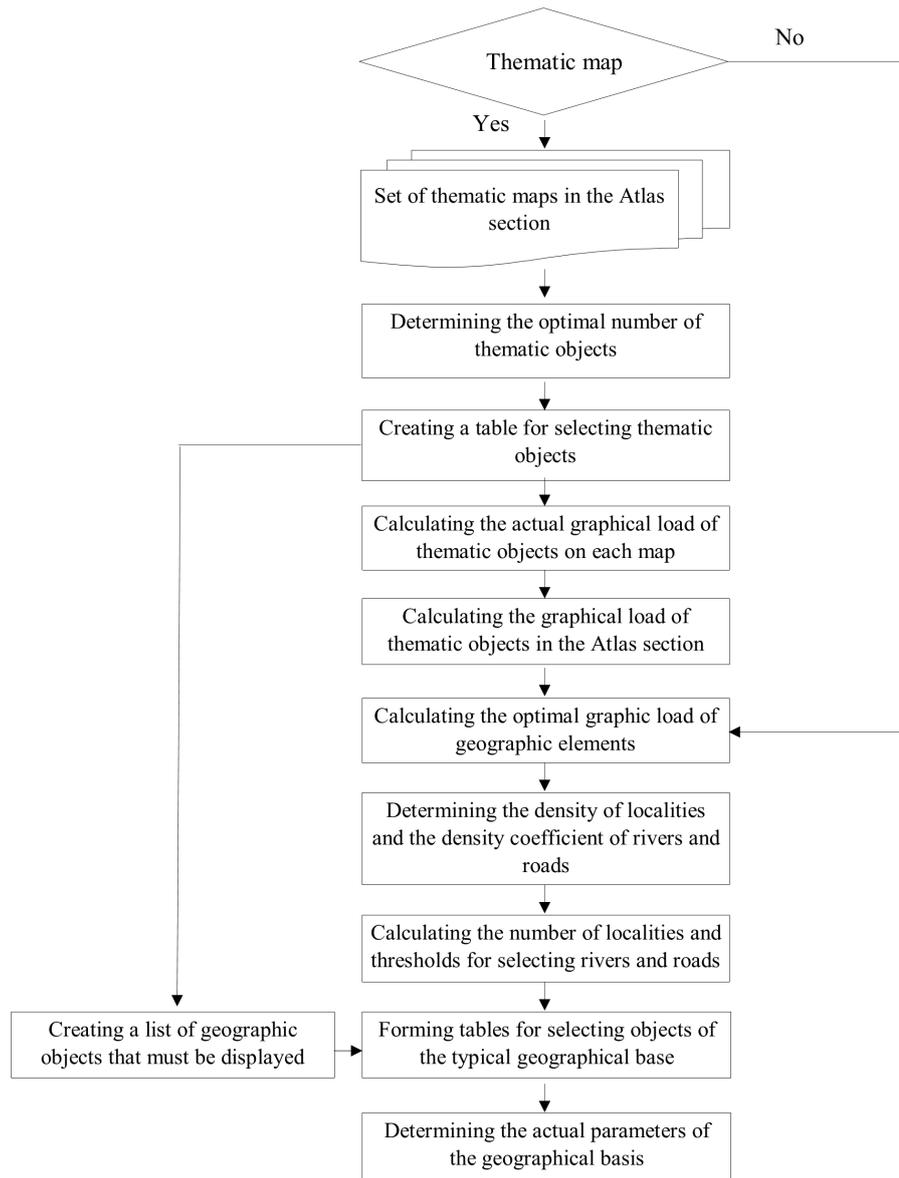


Figure 3. Algorithm for calculating theoretical and actual indicators of the geographical bases

To implement this, it is proposed to use a previously developed mathematical apparatus for solving the quantitative aspect of automated selection of cartographic objects [3], which implies taking into account the relationship between the density of the mapped objects and the map scale. The mathematical apparatus is based on an empirical approach to the study of the density of cartographic objects on published topographic and General geographic maps of the following scale series: 1:200 000, 1:1 000 000, 1:2 500 000 and 1:8,000,000. In this case, it is necessary to take into account the styles and sizes of symbols and methods of cartographic representation of General geographical and thematic content. As a result, the following parameters should be set: the optimal density of geographical items; thresholds for selecting General geographical items - the number of localities, the total length of the river and road network

For Atlas mapping, quantitative indicators should be calculated for all typical bases of Atlas. The results of calculations for elements of the General geographical basis should be entered in the table, and if thematic maps are created, the calculations are adjusted depending on the graphical load of the thematic content [4].

### Formation of the selection table of objects for each geographic base maps

The calculated thresholds for selecting elements of the geographical basis and the established rules for automatic ranking allow you to create object selection tables for each typical geographical basis. The upper part of these tables

(above the selection threshold) contains objects to display on the basis being created (due to the significance of their characteristics), and the lower part contains objects selected for deletion.

Interactive selection is used to determine related objects, as well as to account for objects in other layers that are related to objects in the current layer. It should be noted that if geographical bases of different scales are created for the same territory, the selection table for the basis of a smaller scale should be formed taking into account the selection table for the basis of a larger scale. This ensures a consistent selection of objects based on all scales, which is especially important for geographical and complex regional atlases.

The problem of generalizing elements of General geographical content (borders, coastlines, rivers and roads) can be solved by using existing methods of simplification, smoothing, shifting and exaggerating objects, as well as available tools of geoinformation systems.

## CONCLUSIONS

The proposed solutions will allow you to quickly create geographical bases for different types of atlases and improve their quality. The results of the research can be used not only for creating traditional atlases, but also electronic atlases, including those based on geoport solutions.

## ACKNOWLEDGEMENTS

The study was financially supported by the Ministry of Education and Science of the Russian Federation, grant No. 5.8029.2017/8.9

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# WEB-GIS BASED CAMPUS SPATIAL INFORMATION SYSTEM FOR A UNIVERSITY

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## **Abstract**

*Keeping consistent and standardized records of geospatial data in terms of the attributes of elements of spatial setting such as buildings, green areas, pedestrian and vehicular circulation facilitates the spatial planning activities in university campuses by making it possible for the experts to conduct queries on these attributes and retrieve them. Within this context, the aim of this study is to develop a framework for the Campus Spatial Information System (CSIS) based on web and GIS (Geographic Information Systems). This framework will, on the one hand, allow dynamic interactions between desktop GIS and Database Management Systems (DBMS) for the creation and manipulation of spatial data and relevant attribute data, and on the other hand, integrate DBMS into a web-mapping platform serving maps from different sources to the end users. Muğla Sıtkı Koçman University is designated as the case study area for the implementation of the respective CSIS. Similar kinds of studies have been conducted by employing web mapping technologies for many of the university campuses all around the world. Nevertheless, it is observed the number of studies conducted for the establishment of CSIS by using mainly Free and Open Source Software (FOSS) for GIS is very limited. In this respect, one of the principal objectives of this study is the demonstration of the fact that CSIS can be developed by employing FOSS available for both GIS and web, and in this context another objective is the initiation of implementation of a pilot study for Muğla Sıtkı Koçman University.*

## **INTRODUCTION**

The aim of the study is both to develop a framework for the Campus Spatial Information System (CSIS) based on GIS that can be accessed via internet and easily configurable for those having administrative privileges, and also to initiate the implementation of the respective information system for the selected pilot areas in Muğla Sıtkı Koçman University. Keeping records of the existing settlement information in terms of the attributes of the elements of the spatial setting such as buildings, green areas, pedestrian and vehicular circulation facilitates the spatial planning activities in university campuses by making it possible for the experts to conduct queries on these attributes and retrieve them. In this context, many researches and projects have been developed in both Turkey and other countries (see Dimopoulou, Christodoulou and Polydorides, 1999; Schneider, Khattak and Zegeer, 2001; Jo et al. 2001; Aydınöğlü and Yomralıoğlu, 2002; Tarhan et al., 2006; Sinnakaudan et al., 2007; Hien and Jusuf, 2008; Jacob et al., 2009; Yang, et al., 2009; Huang et al., 2010; Kahraman, Karas and Abdul-Rahman, 2011; Yıldız and Gümüşay, 2011; Çakır et al., 2011; Sarı, Erdi and Kırtıoğlu, 2011; Uşun, 2011; Robles, 2014; Küçükşarı et al., 2014; Qutieshat, 2015; Çeker et al., 2016; Guduru and Keesara, 2016; Elwahab, 2017; Gümüşay, 2017).

In Turkey, similar kinds of projects are also supported by the central government institutions within the framework of “Higher Education Facilities Investment Decision Support System” (Mek-Sis) and “The Inventory Classification System of Higher Education Facilities” (YMESS) (meksis.gov.tr). Keeping the records of the existing building stock and the detailed technical characteristics of this stock provides us with updated and synchronized information required in many fields. In this

context, employment of GIS as a spatial information system facilitates the production and harmonization of information about the physical characteristics of campuses. The classification of the existing physical building stock of the universities according to the different uses such as class rooms, office spaces, depots and so on, and subsequently making it queryable together with the physical properties such as the size, width, and height, provides us with the instantaneous retrieval of the information required by different bodies in the University and the identification of the most appropriate options for a particular use. For example, the information in relation to the structure and infrastructure (SI) topic required in the preparation of the action plans for the Green Campus project supported by GEKA (Güney Ege Kalkınma Ajansı – Southern Aegean Development Agency) and implemented by Muğla Sıtkı Koçman University can easily be compiled by using CSIS.

Free and Open Source Software (FOSS) for desktop GIS and FOSS for network-based GIS are actively used for the development of a systematic framework for the presentation and collection of spatial data in many projects and studies. Whereas, it is observed that in the case of CSIS, mainly Proprietary Software (PS) for GIS are used in the majority of studies concerned (see Dimopoulou, Christodoulou and Polydorides, 1999; Park, Kim and Jo, 2001; Aydınoglu and Yomralioğlu, 2002; Tarhan et al., 2006; Sinnakaudan et al., 2007; Huang et al., 2010; Kahraman, Karas, and Abdul-Rahman, 2011; Yıldız and Gümüşay, 2011; Çakır et al., 2011; Uşun, 2011; Küçükşarı et al., 2014; Qutieshat, 2015; Çeker et al., 2016; Gümüşay, 2017). There are only a few studies using mainly FOSS for GIS in the establishment of CSIS (see, for example, Robles, 2014; Guduru and Keesara, 2016). Unfortunately, the main contribution made in these studies in terms of FOSS for GIS are not properly elaborated. In this respect, one of the most distinctive contribution of this research is the fact that it is completely based on FOSS for GIS.

Within the introductory framework drawn above, one of the principal objectives of the study is the demonstration of the fact that CSIS can be developed by employing FOSS for GIS and web, and in this framework another objective is the initiation of implementation of a pilot study for Muğla Sıtkı Koçman University. Employment of FOSS in this project will scientifically, on the one hand, facilitate the overview of the existing knowledge stock in a critical perspective, and on the other hand, reveal the knowledge that can enrich the formulation of similar kinds of studies. Via the illustrative implementation of CSIS in Muğla Sıtkı Koçman University, it is expected that particularly local private and public institutions inspired by the project will be motivated to initiate similar kinds of processes owing to the demonstration of the fact that spatial information systems and web mapping needed by these institutions can be realized with out any cost for software. In this respect, on the one hand, public institutions can economize in their spending in relation to these systems, and on the other hand, over time the use of FOSS for GIS leads to both an increase in the quality of the workforce, and also the emergence of a social milieu in which experts effectively share their knowledge and experience.

In the subsequent sections, first, previous studies conducted for the establishment of CSIS are briefly reviewed together with the suggested use profile of the CSIS formulated in this study. In the 3<sup>rd</sup> section, software system structure of CSIS framework are elaborated by drawing on the components of the CSIS and alternative FOSS for each component of the system. This is followed by a brief presentation of the stages of the implementation of CSIS in the 4<sup>th</sup> section. Final section draws on some concluding remarks.

## **PREVIOUS STUDIES ON CSIS AND DESIGNATED USER PROFILE**

One of the first studies for the establishment of CSIS is conducted by Dimopoulou, Christodoulou and Polydorides (1999) within the framework of the planning activities for Patras University in Greece, but without any consideration for web mapping. The first two studies aiming at the development of a web-GIS-based CSIS were conducted by Jo et al. (2001) for Kyungil University in Korea, and then, by Aydınoglu and Yomralioğlu (2002) for Karadeniz Technical University in Turkey. In the subsequent years, it is observed that, similar kinds of studies are conducted for other university campuses all around the world such as for İzmir Institute of Technology by Tarhan et al. (2006) in Turkey, MARA Technology University by Sinnakaudan et al. (2007) in Malaysia, National University of Singapore by Hien and Jusuf (2008), National University of Ireland Maynooth (NUIM) campus by Jacob et al. (2009), Xinjiang University by Yang et al. (2009) and Wuhan University of Technology by Huang et al. (2010) in China, Karabük University by Kahraman, Karas and Abdul-Rahman (2011), Yıldız Technical University by Yıldız and Gümüşay (2011), Çakır et al. (2011) and Gümüşay (2017), Selçuk University by Sarı, Erdi and Kırtıoğlu (2011), Dokuz Eylül University by Uşun (2011), Marmara University by Çeker et al. (2016) again in Turkey, University of San Agustin by Robles (2014) in Philippines, University of Jordan by Qutieshat (2015), and National Institute of Technology Warangal by Guduru and Keesara (2016) in India.

Parallel to Jo et al. (2001) and Aydınoglu and Yomralioğlu (2002); Jacob et al. (2009), Yang et al. (2009), Kahraman, Karas and Abdul-Rahman (2011), Yıldız and Gümüşay (2011), Sarı, Erdi and Kırtıoğlu (2011), Uşun (2011), Guduru and Keesara (2016), and Gümüşay (2017) develop a concern for the establishment of CSIS on the base of web. Among these studies Kahraman, Karas and Abdul-Rahman (2011), Yıldız and Gümüşay (2011), and Uşun (2011) exclusively focus on 3D modelling of the university campuses or individual buildings in the campus with little attention paid to the provision of spatial data via web. It is observed that majority of the studies aiming at the establishment of CSIS are

based on the employment of closed source software systems. Among the studies reviewed in this paper, only Robles (2014) and Guduru & Keesara (2016) mainly use FOSS for GIS. However, neither in these studies nor in other studies, user profiles and their authorizations in the system are not elaborated in a detailed framework. The elaboration of the alternatives in FOSS for GIS in relation to the implementation of CSIS is also missing. In this context, in this study not only FOSS for GIS and web alternatives are reviewed by focusing on the alternatives for each component of CSIS, but also user profiles of the system are also elaborated in a detailed context.

In this respect, it is important to remark that the users of CSIS are structured at four different levels. In the first level, there are users with some administrative privileges such as creating new layers in the database and modifying the spatial data in the existing layers. At this level, selected technical staff of Computing and Information Services Office and Construction and Technical Works Office will have privileges to create spatial data and, if necessary, modify it. Selected staff of Administrative and Financial Affairs Office and Strategy Development Office will also have privileges to modify the attribute table of the spatial data in the database. The users at this level will be created by system administrator at Computing and Information Services Office, and they will be privileged to create new users at different academic and administrative units of the university to create and modify data within their field of operation. At the second level, there will be user with certain administrative responsibilities requiring preparations of reports requested by either the central authorities or the University administration in relation to the allocation of physical space at the university according to different functions and units. These users will have access to the databases concerned for the preparation of these reports by conducting queries. They will also be able to use these databases for the spatial planning activities in their own units.

The third level covers all the staff of the university and students. Provided that these users have IP addresses defined by the Computing and Information Services Office, they will be able to navigate over the maps of campuses of the university including the layout plans of the buildings in order to find a specific office, laboratory and etc. Within the framework of the initial study, for only one or two buildings in the main campus of the university, spatial layouts of the buildings concerned will be processed in order to construct building information system for navigation and other purposes. The last level of users is composed of all users of the internet. These users will be able to navigate over the maps of the campuses of the university in order to find a specific building or unit. At first phase, firstly, the main campus of the university will be processed in order to construct campus information system for navigation and other purposes.

## **SOFTWARE SYSTEM STRUCTURE OF CSIS FRAMEWORK**

Software system structure of CSIS developed in this study can be seen in Figure 1. In line with this structure, firstly, FOSS for desktop GIS programs appropriate for creating and editing the spatial data compiled from different departments of the University, and FOSS for spatial Database Management Systems (DBMS) programs suitable for the storage and retrieval of the spatial data processed by using desktop GIS programs are reviewed in order to design the optimum system that can be used for the creation, maintenance and delivery of the spatial data.

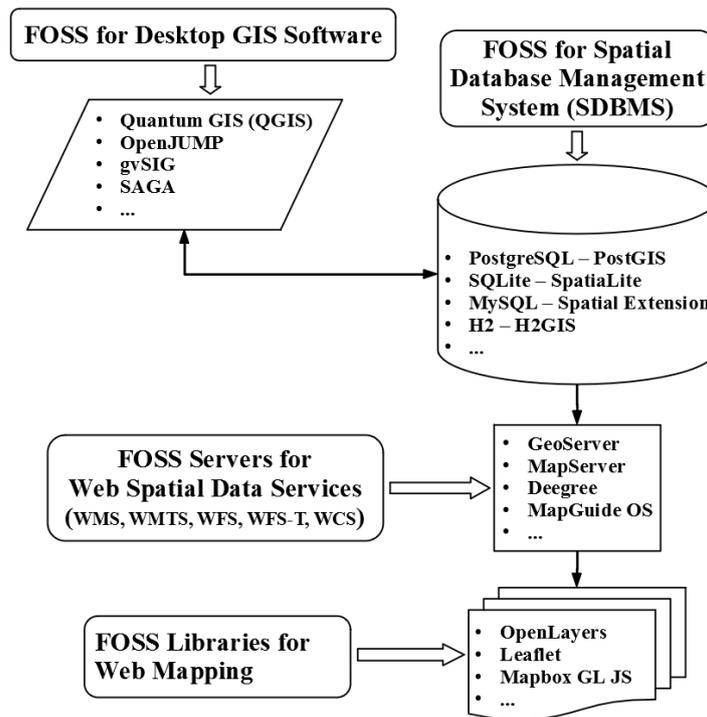


Figure 1. Software system structure of CSIS.

A desktop GIS allows the user to create, manipulate, analyze and visualize geographical data. In this respect, it is important to notice that there are many FOSS alternatives for desktop GIS programs (Table 1) supporting operations on both vector and raster data. Some reviews of FOSS for desktop GIS (FOSS4DGIS) programs are available in Steiniger and Bocher (2009), and Beyhan et al. (2010). As remarked by Steiniger and Bocher (2009), each of these software projects concentrates their efforts on a specialized set of functionality. However, thanks to flexible and modular FOSS architecture, any FOSS4DGIS may easily draw on the functions available in other FOSS4DGIS. For example, all SAGA functions can be accessed in QGIS via its Toolbox. In a similar fashion Whitebox and Orfeo ToolBox (OTB) functions can also be accessed from within QGIS. Furthermore, SEXTANTE, an extensive extension developed on the base of SAGA (Olaya, 2008), is available in many FOSS4DGIS including OpenJUMP and gvSIG.

Table 1. Comparison of FOSS for Desktop GIS Programs.

Properties	FOSS for Desktop GIS Programs							
	Quantum GIS	SAGA	gvSIG	OpenJUMP	OrbisGIS	TerraView	Map Window	uDig
Data Type Supported	vector, raster	vector, raster	vector, raster	vector, raster	vector, raster	vector, raster	vector, raster	vector, raster
Supported Database Connection	PostGIS, MySQL, SpatiaLite	PostGIS, ODBC	PostGIS, H2Spatial, SpatiaLite, JDBC	PostGIS, MariaDB, MySQL, SpatiaLite	PostGIS, H2GIS	PostGIS	PostGIS, MySQL, SpatiaLite	PostGIS, MySQL, SpatiaLite, H2
Styling Format Support	SLD, qml	qml import	SLD, gvsleg	SLD, Style.xml	SE	SLD	mwlayer	SLD

Source: qgis.org, saga-gis.org, gvsig.com, openjump.org, orbisgis.org, dpi.inpe.br/terralib5, mapwindow.org, udig.refractions.net

It is noticeable that QGIS, gvSIG, OpenJUMP and Terraview can directly write to PostGIS vector database. In SAGA, PostGIS vector database can be replaced with the edited vector file, which actually results in the same result with the ability to write to PostGIS vector database. Overall, this is one of the desired characteristics of the FOSS4DGIS program that will be used in the CSIS as the desktop GIS component of the system. It is also important to remark that except for QGIS, gvSIG and OpenJUMP, all the other FOSS for desktop GIS create problems when either space or Turkish characters are used in the names of tables. In Terraview space character is not allowed to be used in the table

name. In SAGA and OrbisGIS, Turkish characters such as “ı” creates problems when they are used in table names. Thus, for practical considerations, the viable options for this study are QGIS, gvSIG and OpenJUMP.

Another desirable characteristic of FOSS4DGIS is the ability to export the style created for a particular layer to a standard styling formats such as SLD (Styled Layer Descriptor). This is an important issue in the delivery of maps created for web publishing. In this respect, the existence of SLD option in both Desktop GIS and server side deserves attention and it is very important for the maintenance of the system. Handling styles on server side is not an easy task due to the restrictions of the environment. However, desktop GIS programs have better options for design of the appearance of the layers. In this respect, it is observed that except for SAGA and MapWindow, all FOSS4DGIS programs have options for the exportation of the layer style in SLD format. This actually provides an integration of Desktop GIS with server side in terms of also cartographic design of the layers or maps concerned.

In a similar fashion there are many FOSS alternatives for Database Management System (DBMS) (Table 2) acting as a backend in the system. A SDBMS can be described as a DBMS offering spatial data types in its data model and allowing spatial-topological queries (contain, within etc.) and analysis operations (Steiniger & Hunter, 2013). Since the data used in the CSIS is structured and further it is relational in character, SQL (Structured Query Language) based DBMS are more suitable. SQL based FOSS alternatives for DBMS cover PostgreSQL, SQLite, MySQL, MariaDB and H2. Thanks to the spatial extensions in these DBMS, spatial data can easily be stored in and retrieved from them (such as PostGIS extension in PostgreSQL, SpatiaLite in SQLite and H2GIS in H2). A SDBMS may also support spatial indexing (such as R-Tree). Among the relational SDBMS, it is observed that only PostGIS are supported in all of the FOSS4DGIS programs reviewed in this study (Table 1). This creates a flexibility in terms of the options that can be used by the users of the systems responsible for the creation and manipulation of the spatial data stored in the database. MySQL Spatial comes after PostGIS in terms of availability as an option for connection to a SDBMS. It is followed by H2GIS. It is remarkable that each SDBMS has at least one GUI tool for the administration of the database concerned. This issue is also important in the maintenance and administration of the system in terms of creation of new users, adjustment of privileges and other tasks.

It is important to note that SQLite is actually an ‘embedded’ database meaning that it’s serverless. Thus, as an extension of SQLite, SpatiaLite is actually a file-based single user SDBMS (Garnett & Kanaroglou, 2016). SQLite reads and writes directly to an ordinary disk file whose accessibility permission is only conditioned by the underlying operating system. This characteristic of SQLite makes SpatiaLite a poor choice for the applications requiring multiple users having special access permissions that may be required in a comprehensive CSIS. Except for this, it is noticeable that SpatiaLite is quite rich in terms of topological functions like PostGIS and H2GIS. MySQL and MariaDB, a fork of MySQL with new options and extension, also offer a wide range of topological functions.

*Table 2. Comparison of FOSS for Spatial Data Base Management Systems.*

Properties	FOSS for Spatial Data Base Management Systems (SDBMSs)				
	PostgreSQL-PostGIS	H2-H2GIS	SQLite-SpatiaLite	MySQL-Spatial	MariaDB
Data Type Supported	vector, raster	vector, raster	vector, raster	vector, raster	vector, raster
Indexing Support	R-tree-over-GiST	R-tree	R-tree	R-tree, B-tree	R-tree
GUI Tools	pgAdmin	H2 Console	DB Browser, SQLite Admin	MySQL Workbench	Database Workbench
Topological Functions	All, Covers, Equals, Relate	All, Covers, Equals, Relate	All, Covers, Equals, Relate	All, Covers	All, Relate

Source: postgis.net, h2gis.org, gaia-gis.it/spatialite, mysql.com, mariadb.com/kb.

Notes: For Topological Functions, All includes Intersects, Contains, Crosses, Equals, Within, Disjoint, Overlaps, and Touches.

After selection of SDBMS, the second concern should be devoted to the specification of free and open source web mapping server software (FOSWMSS) acting as a middleware tier and capable of delivering spatial data via certain standards and within a user friendly environment (Table 3). In the delivery of spatial data to the users there are various standards based interfaces, such as WMS, WMTS, WFS, WFS-T, and WCS (ogc.org/standards). A WMS (Web Map Service) is a standard protocol developed by the Open Geospatial Consortium (OGC) for serving georeferenced map images over the Internet. It delivers images of requested sections of geographic data as raster data ‘even when data is of a vector nature’. WMTS stands for Web Map Tile Service. Although a WMS delivers one image per request, a WMTS delivers tiles.

Table 3. Comparison of Free and Open Source Web Mapping Server Software Programs.

Properties	Free and Open Source Web Mapping Server Software Programs			
	GeoServer	MapServer	Deegree	MapGuide OS
Tool for Administration-Configuration-Styling	Web tool for all functions	Studio Fusion	Web tool for configuration	MapGuide Maestro Fusion
Styling Format Support	SLD QGIS QML	styles are part of mapfile, SLD	SLD	XML
Supported Databases	PostGIS, MySQL, MongoDB, Neo4j, H2	PostGIS, SpatiaLite, MySQL, CouchDB	PostGIS	MySQL, PostGIS, SpatiaLite
Web Mapping Libraries	OpenLayers, Leaflet	OpenLayers, Leaflet	OpenLayers	OpenLayers
Supported Web Services	WMS, WMTS, WFS, WFS-T, WCS, WMC	WMS, WFS, WCS, WMC	WMS, WMTS, WFS, WCS, WPS, CSW	WMS, WFS
Extensibility	Java	Python, Perl, Ruby, Java, PHP	Java	PHP, .NET, Java, and JavaScript
Language	Java	C	Java	PHP, Javascript
Web Servers	Apache Tomcat, Jetty	Apache, IIS	Apache Tomcat, Jetty	Apache, IIS
Map Tile Server	GeoWebCache	MapCache	deegree WMTS	MapGuide tile server

Source: [osgeo.org/projects/](http://osgeo.org/projects/), [geoserver.org](http://geoserver.org), [mapserver.org](http://mapserver.org), [ms4w.com](http://ms4w.com), [deegree.org](http://deegree.org), [mapguide.osgeo.org](http://mapguide.osgeo.org), Steiniger & Hunter (2013).

The WFS (Web Feature Service) is created by OGC as a standard for direct fine-grained access to vector format geographic information on the Internet at the feature and feature property level for querying and retrieval of features. Complementary to WFS, a WFS-T (transactional Web Feature Service) allows creation, deletion, and updating of features. The Web Coverage Service (WCS) allows for the configuration of metadata information common to WCS, WFS and WMS requests. Although the WCS is similar to a WFS as it enables access to geographic features, instead of discrete geospatial features it can return either whole coverages, a set of features, or a grid coverage. In fact, as Steiniger & Hunter (2013) remark, a web map server is a specialization of a standard web server for provision of these services. Many FOSWMSS such as GeoServer, MapServer, and Deegree have majority of these services in their software architecture.

Another desired characteristics of a FOSWMSS is its ability to allow easy configuration and administration of the content. In this regard, GeoServer that is built on Java technology and run in an integrated Jetty or Apache Tomcat web server environment is the most acknowledged FOSS having a web tool making the configuration and administration of the system easy. Some FOSWMSS such as deegree and MapGuide OS (Open Source) have also similar tools. As a FOSS for web mapping, deegree have various components for spatial data management, visualization, discovery and security ([deegree.org](http://deegree.org)). MapGuide OS written in PHP and Javascript makes use of OpenLayers and includes an XML database for managing content. Management of spatial data for MapGuide OS is realized via MapGuide Maestro, an open source GUI tool and client for management of data, layers, maps and layouts (MapGuide OS, 2020). Another FOSS tool used in MapGuide OS to build mapping applications is Fusion built mainly in JavaScript. Fusion can also be used in MapServer.

In MapServer that runs as a Common Gateway Interface (CGI) application within the Apache web server environment, the Mapfile is the core of server. It is a text file (.map) configuring MapServer application by informing the program about the locations of data and output images. It also defines the area of maps and how maps are to be drawn (i.e. projections and symbology) ([mapserver.org](http://mapserver.org)). Studio allowing to manage MapServer mapfiles by using an easy-to-use web interface is an administration tool for MapServer ([camptocamp.github.io/Studio](http://camptocamp.github.io/Studio)). It provides graphical tools for editing styles and symbols with an ability to handle different datastores. For MapServer, map file generation can also be aided by QGIS via employment of some plugins such as GeoCat Bridge that can be used to configure layers in MapServer and to convert from QGIS Desktop to mapfiles ([geocat.net/docs/bridge/qgis/v4.0](http://geocat.net/docs/bridge/qgis/v4.0)). GeoCat Bridge can also be used for similar purposes for GeoServer, but it is not comparable to GeoServer's web admin tool.

Overall, compared with the other FOSWMSS and web mapping software, GeoServer seems to have one of the most developed tool easy to use for the administration, configuration and styling of the content and components of web mapping server. It is also simple to install the system. There is a platform independent binary that can be used to install all the components of the system. In terms of installation of FOSWMSS, it is important to remark that there are

different options for some FOSWMSS. For example, binaries for MapServer can be installed by using various options for different operating systems. One option is to use MapServer for Windows (MS4W) package that installs not only Apache, PHP, MapServer CGI, and MapScript, but also provides the options for the installation of additional applications such as GeoMoose, Mapbender, MapServer CGI Viewer, OpenLayers, pycsw and ZOO-Project WPS Server (ms4w.com).

Among these applications, GeoMoose and Mapbender that can be used together with MapServer are web mapping frameworks for viewing, editing, and querying geospatial data (geomoose.org, doc.mapbender3.org/en). pycsw is an Open Source OGC CSW (Catalogue Services for the Web) server implementation written in Python (pycsw.org). In web mapping, GeoNetwork opensource is another FOSS cataloging application written in Java for geospatial resources (geonetwork-opensource.org). For a similar function, deegree offers its own CSW server. CSW servers make geo-referenced databases and related metadata from various sources accessible by using the capacities of the internet in order to enhance the spatial information exchange and sharing between organizations and their audience. pycsw and GeoNetwork are used as CSW servers in a number of Spatial Data Infrastructure (SDI) suits such as geOrchestra, GeoNode and MapFish. GeoServer itself is also packaged with GeoNetwork in order to provide default base layers for the GeoNetwork map viewer. Actually, MS4W can also be considered as a SDI suit as it can be used to establish SDIs. Although it is no longer maintained, based on FOSS, OpenGeo Suite in conjunction with GeoNetwork also allows building a SDI (Astsatryan et al., 2012).

Overall, the modularity of FOSS provides FOSWMSS with more flexibility and extensibility. For example, GeoWebCache, a map tile server used for accelerating and optimizing map image delivery, is available as a built-in extension to GeoServer. For a similar function, deegree has its own WMTS as an implementation of the OGC Web Map Tile Service specification. Another library used by many FOSS projects is GeoTools, an open source Java GIS toolkit (geotools.org). Among FOSWMSS and web mapping software, GeoServer and GeoMajas are built on GeoTools. uDig, as a FOSS4DGIS, is also built on top of GeoTools. In GeoTools that supports not only numerous raster and vector formats and data access, but also database connections to many SDBMS including H2GIS, MySQL, PostGIS, Spatialite, and XML bindings such as wcs, wfs, wms, gml, kml, and sld; once a DataStore implementation is written, it becomes available for the projects built on top of it (geotools.org).

Spatial data stored in a SDBMS has no inherent visual component. Once it is served by a FOSWMSS, it needs to be styled by specifying color, thickness, and other visual attributes that can be used to render data on a map. In this respect, as discussed above, preparation of the styles on FOSWMSS side is not an easy task due to the restrictions of the FOSWMSS environment. Thus, the ability of FOSWMSS to import and export styles of the layers is an important characteristic. For example, once a style is created for a layer in a FOSS4DGIS, it can be exported to SLD format that can be applied to the layer concerned in FOSWMSS having the ability to import styles in SLD format that preserves the visual reliability of the spatial data. A SLD is an XML (eXtensible Markup Language) schema specified by OGC for description of the appearance of map layers (en.wikipedia.org/wiki/Styled\_Layer\_Descriptor). It instructs a WMS how to render a specific layer that can be either vector or raster data. The styling rules used in this process needs a styling language that can be understood by the client and server. While the OGC Symbology Encoding (SE) Standard (opengeospatial.org/standards/symbol) provides this language, the SLD profile of WMS enables application of SE to WMS layers using extensions of WMS operations (ogc.org/standards/sld).

In this respect, the last concern in the publication of maps in a CSIS via FOSWMSS is related to the specification of FOSS library as a frontend for browsing and generation of maps from the served spatial data. In this regard, there are again various options for Free and Open Source Web Mapping Libraries and APIs (FOSWMLAPI) such as OpenLayers, GeoExt, Leaflet and Mapbox (Table 4). An overview of some of these options can also be found in Farkas (2017) and Macleod and Hewitt (2018). In some of the webmapping FOSS such as GeoServer, some of these libraries are available within the respective FOSS architecture and developer may easily use them for the generation of maps that will be published. In this context, OpenLayers is integrated in GeoServer. Map Markup Language (MapML) module can also be used in GeoServer by installing MapML extension in order to have an option for a Leaflet-based map viewer. As it can be followed from Table 3, both OpenLayers and Leaflet are agnostic of server-side technologies thanks to the provision of the data by FOSWMSS in a standard way (WMS or WFS) that can be understood by many FOSWMLAPIs.

Table 4. Comparison of Free and Open Source Web Mapping Libraries and APIs.

Properties	Free and Open Source Web Mapping Libraries and APIs			
	OpenLayers	GeoExt	Leaflet	Mapbox GL JS
Language	JavaScript	JavaScript	JavaScript	JavaScript
Supported data source	WMS, WFS, WFS-T	WMS, WFS, WFS-T	WMS, WFS, WFS-T	WMS

from FOSWMS				
Projections	Yes	Yes	Yes	-
Support to load tiles	Image / Vector	Image / Vector	Image / Vector	Image / Vector
Query/Filter	Yes	Yes	Yes	Yes

Source: [osgeo.org/projects/](https://osgeo.org/projects/), [openlayers.org](https://openlayers.org), [geoext.org](https://geoext.org), [leafletjs.com](https://leafletjs.com), [github.com/Leaflet](https://github.com/Leaflet), [github.com/mapbox/mapbox-gl-js](https://github.com/mapbox/mapbox-gl-js), [vincentbroute.fr/mapael/](https://vincentbroute.fr/mapael/), [polymaps.org](https://polymaps.org), [github.com/simplegeo/polymaps](https://github.com/simplegeo/polymaps), [d3js.org](https://d3js.org).

OpenLayers implements standard methods for geographic data access, such as OGC’s WMS and WFS protocols, KML, GML and many other formats ([openlayers.org](https://openlayers.org)). It is an all-encompassing mapping library containing all the required features in the core library simplifying the addition of dynamic maps to web pages. The marriage between ExtJS and OpenLayers results in GeoExt that enables building desktop-like GIS applications through the web ([geoext.org](https://geoext.org)). Compared with the others, Leaflet library is very small. Nevertheless, it can be extended by using plugins ([leafletjs.com](https://leafletjs.com)). As Leaflet’s basic library is very small, it is a great option for mobile applications. Since the creator of Leaflet library, Vladimir Agafonkin, was also involved in the development of Mapbox GL, one can observe some similarities between two libraries. Mapbox GL JS library employs WebGL for rendering interactive maps from vector tiles and Mapbox styles ([docs.mapbox.com/mapbox-gl-js/overview](https://docs.mapbox.com/mapbox-gl-js/overview)). Although the core functionality of Leaflet doesn’t support vector tiles, external plugins can be used for vector tiles (such as Mapbox GL Leaflet). Except for Mapbox GL JS that uses the Web Mercator coordinate system, all mapping libraries reviewed support custom projections that can be adjusted with Proj4 library which can do any transformation from one coordinate system to another.

## STAGES OF THE IMPLEMENTATION OF CSIS FRAMEWORK

The first stage is actually the formulation of the software system structure of CSIS as elaborated in the preceding section by reviewing alternative FOSS for each component of the CSIS. In the second stage, the spatial plan of the main campus of the university will be created in GIS. After creation of the spatial plan, it will be ready for querying and navigational purposes. Accordingly, the users will be able to navigate over the buildings in the map of campus for finding a specific academic unit or department of the university such as an institute, faculty or highschool.

In fact, the existing spatial plans of the campuses of the University are partially digitized and available in CAD (Computer Assisted Drawing) format at the Construction and Technical Works Office. Nevertheless, they are not converted into common GIS file formats to be used in CSIS. Thus, first, these spatial plans have been converted to GIS file formats. Since some of the new buildings are not drawn in these plans (for example, the building of Faculty of Fisheries is missing in the spatial plan), layout plans of these buildings missing in the spatial plan will be georeferenced by using the functions and tools available in FOSS4DGIS programs (such as warping tool in OpenJUMP and SAGA). As usual in this process, two map are required; (1) a source map that will be georeferenced and a target map that will be used as a reference.

Source maps in vector format were obtained from the Construction and Technical Works Office. Satellite photographs of the campuses again obtained from the Construction and Technical Works Office were already georeferenced and they are ready to be used both as target maps and also as the basemaps in the delivery of maps in the CSIS for different purposes. Other missing spatial entities (such as pedestrian routes and connections, bicycle route etc.) in the existing spatial plans are being drawn by the team members by using again these target maps in QGIS and OpenJUMP. Another problem in the vector data obtained from the Construction and Technical Works Office is the existence of multiple but slightly different drawings for the same geographic features. Thankfully, this problems can easily be solved by using the topological functions available in the selected FOSS4DGIS.

After completing creation of spatial plans compatible with GIS, resulting vector files will be exported to SDBMS by using QGIS. As discussed in the previous section, in QGIS, Data Source Manager can handle connection to many FOSS for SDBMS such as PostGIS, SpatiaLite, and MYSQL. Owing to its advantages elaborated in the previous section, PostGIS in PostgreSQL has been designated as SDBMS in the CSIS. Once a connection is established to the database by providing the required parameters, shp files edited in QGIS can be exported to SDBMS via Data Manager. It is planned that other FOSS4DGIS such as OpenJUMP and gvSIG can also be actively used in the maintenance of the SDBMS by the staff of the Construction and Technical Works Office thanks to the capability of the FOSS4DGIS concerned to directly write the changes made in the features to PostGIS vector database and their ability to handle table names in Turkish.

In the third stage, the layout plans of the building designated as the pilot project will be converted to GIS file format and georeferenced by using the already georeferenced spatial plan of the campus. In the first phase of this stage, the physical characteristics of the spatial entities (rooms etc.) in the building will be queryable (such as the area occupied by a room,

its volume etc.). In the second phase of this stage, the functions of these rooms (office, depot, class etc.) will be defined in the building information systems for querying and navigational purposes. At the end of this stage, those users of the system having the required privileges will be able to compile statistical information from CSIS in relation to spatial and functional characteristics of the units in their schools or buildings by using the web mapping platform or FOSS4DGIS programs selected in the system.

Last stage of the framework is designated as the stage of informing experts about the installation and use of CSIS. In this respect, for example, experts at the Computing and Information Services Office will be informed about the installation and components of CSIS, and experts at the Construction and Technical Works Office will be informed about the use of the system for creation and maintenance of spatial data, and also about the process of compilation of statistics in relation to the physical characteristics of the spatial units. Experts at the Administrative and Financial Affairs Office and Strategy Development Office will also be informed about the queries and analysis (such as listing classes having projectors, spatial allocation of computers in the university according to academic units etc.) that can be done by them if all the data required for such queries are entered by them into CSIS.

## CONCLUDING REMARKS

As evident from this study, thanks to their modularity, openness, and extensibility, FOSS for GIS solutions may remarkably contribute to the establishment of CSIS. Since their development objectives are different, none of the FOSWMSS is actually better or worse. However, compared with the other FOSWMSS and web mapping software, GeoServer seems to have some advantages for the CSIS framework formulated in this study. This mainly stems from the profile of the users who will maintain the system in the University. Organizational dimension of GIS in terms of the staff involved in the system is very important. The technical staff who will maintain the system at the Computing and Information Services Office and the Construction and Technical Works Office don't have an expertise in particular in GIS and in general in web mapping. That's why it is important for us to have an easy to use FOSWMSS component in the CSIS for the administration, configuration and styling of the content and components of web mapping server.

The fact that GeoServer deals better with WFS and straightforwardly supports WFS-T is also an important factor for its operationalization in CSIS together with its easy extensibility made possible with additional functionality added via extensions. Indeed, while it seems that FOSS4DGIS is the feasible solution for creating and modifying spatial database that will be used in the system, the attribute data for the spatial entities can be populated by using WFS-T service via internet by those staff responsible for the management of the space in each academic unit. Accordingly, only limited number of experts at the the Construction and Technical Works Office can be trained for the use of the selected FOSS4DGIS in connection with creating spatial data, exporting it to PostGIS and editing it from within the FOSS4DGIS concerned by connecting to PostGIS. Other staff can edit tabular data directly via internet by using WFS-T protocol.

The fact that in the publication of the maps there are multiple options in GeoServer in terms of FOSWMLAPIs available either as a built-in module or via an extension is another attracting factor for the FOSWMSS concerned. In this respect, future studies can address the integration of routing functionality into the CSIS framework formulated in this study. Although as an extension adding routing and other network analysis functionality to PostGIS/PostgreSQL databases pgRouting can be used for this purpose, further research is necessary for the provision of the respective function in the CSIS in terms of different modes of transportations (for example, car driving, cycling, and walking).

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# COMPARATIVE STUDY OF FIELD MEASUREMENT TO DETECT LIGHT POLLUTION AND LUMINOUS FLUX IN URBAN AREA WITH CROWDSOURCING

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## Abstract

*Light pollution in an urban environment is gaining interest due to its relevance for causing health problems, threatening wildlife. In this study, the authors measured light pollution in urban environments in a typical small study area (the city of Székesfehérvár, Hungary). The goal of the study was to analyse how well crowdsourcing could be used to detect urban light pollution. One type of measurements was carried out with the Sky Quality Meter which can be directly used to measure night sky quality. Parallel we used mobile phone equipped with an ambient light sensor with a freely downloadable software Lux Light Meter which is measuring lux. The results were processed and analysed in ArcGIS. During the test, we used approximately 70 measurement points in each study areas. We found that although parks are not affected by light pollution as much as blockhouse area, they are not suitable to investigate night sky properly.*

**Keywords:** light pollution, GIS, project-based learning

## INTRODUCTION

The process that started when the incandescent light bulb was invented is now in an advanced state. This process is light pollution, which has led to the threatening of wildlife, human health, and a kind of nightlife that is part of our cultural heritage. Also, we should be aware of the fact that it is a great waste of energy, with many negative effects on our lives.

We can distinguish three types of light pollutions. (1) Ecological light pollution (Longcore & Rich, 2004) is an effect on the biology and ecology of species in the wild. It means that the effects of artificial lights can have a positive but mainly negative impact on species, in some cases even it can be lethal. (Horváth, et al, 2009). (2) Astronomical light pollution (Cinzano et al, 2001) is the phenomena when the natural night sky cannot be observable because of artificial light. To reserve natural night sky some night-sky protected areas were established (Kolláth, 2010). (3) Impact on human health, specifically harming effects on the human body are the consequence of counterfeit light that negatively affects melatonin delivered by the pineal organ. Light pollution can be associated with many health problems such as breast cancer (Kloog et al, 2010).

In Hungary the 211/2012 [VII. 30.] Government Decree on National Settlement and Building Requirements defined first this phenomenon. According to the decree, light pollution is a disturbing light that is above the horizon or not only points to the area what should be illuminated and or not for the appropriate period, thereby causing glare, an artificial glare of the sky or damaging physiological and environmental effects, including negative effects on the wildlife.

In the decree, the trespassing by light pollution is also mentioned. Trespassing is the light that falls on the buildings and surrounding the illumination area, causing dazzling or other discomforts. Lights on the windows, which disturb the night rest, require special attention.

To eliminate light pollution, additional nature-friendly lighting solutions can be used, such as fully shielded lamps towards the sky and neighbouring buildings, flexible illumination towards the level of traffic (Bruehlmann, 2014).

There are light pollution maps available (Bruehlmann, 2014), based on satellite images or in case of Falchi et al, 2016, their world atlas of artificial sky luminance, computed with their light pollution propagation software using new high-resolution satellite data and approximately 350,000 sky brightness measurements. In this paper, we also use their atlas as a reference data to compare to our measurements.

The above-mentioned solution does not give detailed information about light pollution within certain cities, therefore we used our project-based teaching method to gain more information about the value of light pollution within the city of Székesfehérvár. The goal of our case studies was to (1) detect whether it is possible to measure light pollution within a city and (2) to compare possible methods for measurement techniques in a potential crowdsourcing campaign. In the measurement, our focus was mainly to detect light pollution which can be disturbing for locals.

## PROJECT-BASED LEARNING APPROACH

We were involving students in a different type of project-based learning methods, in this way we have certain research topics to investigate with the students as a model for crowdsourcing like fear of crime, noise and light pollution. (Pődör et al, 2019). Distinctive learning techniques have been portrayed by researchers. The most popular is crafted by Dewey, Piaget and Vygotsky on joint effort and collaboration between rises to (Wood 1994; Pound 2005). Different hypotheses incorporate behaviourism, learning styles, multiple intelligences, constructivism, constructionism right brain/left brain thinking (Cuthell 2005). Training for a long time bolstered the learning procedure called behaviourism in the educational plan of surveyors at our college. Behaviourism is a learning procedure which is based on redundancy and affirmation. The instructor transmits the learning material, the students retain repeats and compose it. Behaviourism was the main learning strategy for the vast majority of the previous century. The other conventional strategy is cognitivism, which implies that during the learning procedure we make a model about the outside world and we make it interior. Teachers should present an appropriate model with their metacommunication (Kulcsár 2008).

Throughout the past years our university made efforts to introduce new types of learning methods in education. New sorts of learning techniques, similar to Bruner's constructivist (Bruner, 1966) hypothesis, made it important that the conventional instructive strategies should have been totally transformed. His hypothesis certifies that learning is an active procedure and that students build new thoughts through their knowledge. In this procedure, students can choose data, information, form hypothesis and make decisions. Then again, teachers have an alternative job. Teachers need to change exercise resources into a structure that the students can comprehend and encourage them to gain experiences on their own. Utilizing Bruner's technique the teacher should plan the educational program such a way that it expands on what students have known and gains ground and advancement with the students' dynamic work in new fields (Smith 2002). As such, we made endeavours to change a part of our GIS course. The idea is that the teacher is not to teach the students; instead of this, the teacher becomes a mediator of studying. Students construct understanding and draw their conclusion through creative experimentation

In this manner, we designed a project-based learning style.

This kind of subject can aid those learning principles where the students are in the centre.

Some characteristics of the classes are:

- Active learning against passive.
- The autonomy of the students.
- Assuring extracurricular learning.
- The connection among students are equal, the teacher acts rather like a mentor. (Pődör, 2011)

This GIS subject can model the workflow from data acquisition, database design, analyses to data publication. Each year the teacher generates a project which is suitable to present the students the whole process. In each project the students had to go through several steps consistently:

- Geodatabase design,
- Data acquisition,
- Processing of the collected data,
- Control of the accuracy of the data,

- Analysis of the data,
- Querying of the data,
- Publication of the data. (Pődör, 2011)

## METHODS

As project-based learning (PBL) method and a possible model for crowdsourcing, we have been performing light pollution measurements since 2015. In this study we introduce a high density measurement with SQM-L equipment (since 2017), and a comparative study with SQM-L and a mobile device (since 2018). In both cases we processed measurement data with ArcGIS software using Inverse Distance Weighting (IDW) interpolation method.

### Preliminary measurements in Székesfehérvár

In 2017 we accomplished a noise measurement campaign to demonstrate that it is possible to discover differences within street segments in light pollution. According to *lightpollutionmap.info*, in Székesfehérvár on a Bortle scale, the outskirts of the city can be categorized as class 5, the inner part of the city as class 6 in 2015 which equals to a suburban sky on the scale (see Table 1.). Bortle scale, used by astronomers, is a nine-level scale where scale 1 means excellent night sky in contrast 9 means inner city sky (Bortle, 2001). According to the recent scale of the map, we could not get more detailed information.

Table 1. Zenith sky brightness info about Székesfehérvár from *lightpollutionmap.info*

Coordinates	47.17610, 18.43431	47.19365, 18.41097	47.19443, 18.40916
Sky Quality Meter (SQM)	20.04 mag./arc sec <sup>2</sup>	19.31 mag./arc sec <sup>2</sup>	19.31 mag./arc sec <sup>2</sup>
Brightness	1.04 mcd/m <sup>2</sup>	2.05 mcd/m <sup>2</sup>	2.05 mcd/m <sup>2</sup>
Artificial brightness	872 $\mu$ cd/m <sup>2</sup>	1880 $\mu$ cd/m <sup>2</sup>	1880 $\mu$ cd/m <sup>2</sup>
Ratio	5.10	11.0	11.0
Bortle	class 5	class 6	class 6
Elevation	108 meters	106 meters	113 meters

The last column is the main street in Székesfehérvár, Fő street. As a preliminary study, we wanted to investigate the inner part of Székesfehérvár (e.g. Fő street) to see how global estimation and local measurement can coincide.

Following the PBL method, first we selected the measurements points. As part of the selection process, we created maps with pre-marked and numbered points. The points were selected in a way that they should have been at equal distances from each other in order to get homogeneous result.

The number of points was determined by the cross-section and length of the streets. As indicated in Figure 1, we categorized streets into three groups, where we defined different sample density. In narrow streets, we have less, on the widest streets and squares, we have several parallel measurements.

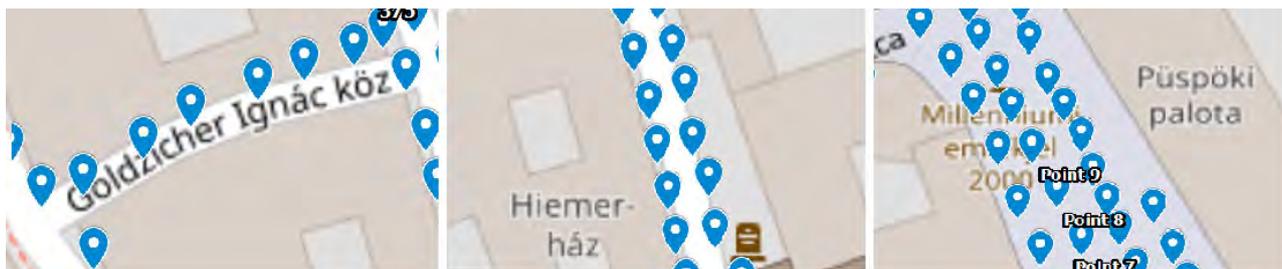


Figure 1. Arrangement of the measurement points in the different street categories

As part of the planning process, we have chosen 23:00 as the starting time, as the external light and the number of passers-by is already uniform at this time, and 03:00 as the end time, as it will start brightening and pedestrians and passers-by will appear, and it may influence the results.

Along the pre-planned route, measurements were taken. Some details about the measurements:

- Date of measurements: 01/11/2017–14/11/2017
- Measuring period: 23:00–03:00
- Number of points measured: 712

### A comparative study in Székesfehérvár

We thought that it is important to use the mobile phone measurement option because in this case, it is enough to install only one software, and it is not necessary to buy a special device, and thus more people can be involved in the voluntary measurements. In this study, we chose two sample areas inside the city. Both of them comprises from a local park with a lake where presumably light pollution is less to a blockhouse area where light pollution is probably higher.

Table 2. Some details about the comparative measurement

Study area	Study area A	Study area B
Date of measurements	20/11/2018	08/11/2018.
Measuring periode	22.00-24.00	22.00-24.00
Number of points measured	70	63
Environment	The temperature ranged from (+2) to (+5) ° C. The sky was cloudy all night	The temperature ranged from (+2) to (+5) ° C. The sky was moonless.

In both cases, we measured the area around the lake in such a way that the points fill the measurement area at a relatively equal distance from each other, like a lattice structure. In this way, homogeneity between points was maintained. In both cases, we measured parallel with the SQM-L and the mobile device.

### Equipment and software

A high sensitivity photometer was selected for the measurement. The Sky Quality Meter was designed by Unihedron, the exact type what we used was SQM-L. It measures the brightness of the night sky in magnitudes per square arc second (Unihedron).

This instrument is utilized generally for light pollution checking. SQM-L is handheld equipment; it gathers the light from a moderately large angle. SQM-L is temperature-adjusted and gives the luminance with the accuracy of 0.1 mag/arc sec<sup>2</sup>, which is comparable to 10 per cent in a direct luminance (cd/m<sup>2</sup>) units (Cinzano, 2005)

The instrument is simple to operate, holding down the single button on it and it will print the value, which is the brightness value at that point. At each point, we recorded the measurement value and moved on to the next point.

In the comparative study, we wanted to include the possibility of mobile measurements, therefore we chose one software. In this case, the software is using the camera of the mobile phone. The equipment was the Huawei P10 Lite mobile phone and we used Lux Light Meter software on it.

The Lux Light meter phone application is installed on the phone for brightness measurement. This program uses the phone's light sensor to determine the intensity of light in each location. This measurement was done continuously by the application, so when it was necessary, we have just looked at our phone and the result have been printed.

This application can measure light intensity in two units, FC (foot candles) and LUX. We used the latter in our measurements. Illumination is the luminous flux incident per unit area, so its unit is  $\text{lm}/\text{m}^2$ . As this unit also occurs frequently, it has also been given a separate name: lux and its abbreviation is lx. Holding the mobile device at chest height, horizontally towards the light source, the software displays the value immediately.

## RESULTS

The results of the preliminary test measurements clearly showed that with this method it is possible to detect spatial differences in light pollution. On Figure 2, we can see the interpolated results of the measurements. On the map, the blue colour indicates fairly darker areas, meanwhile yellow and red colours display strongly illuminated areas. Photos from StreetView give an explanation behind the darker areas: one site is under construction, the other one is partly planted with trees that provide protection from light pollution.



Figure 2. The results of high-density measurement reveal spatially diverse light pollution. Google StreetView photos.

The opposite case is also well observable on the map, as the street lights used in front of the theatre provide very strong illumination at night, however, there are no private homes in this area, so this is not disturbing for those living nearby in the area.

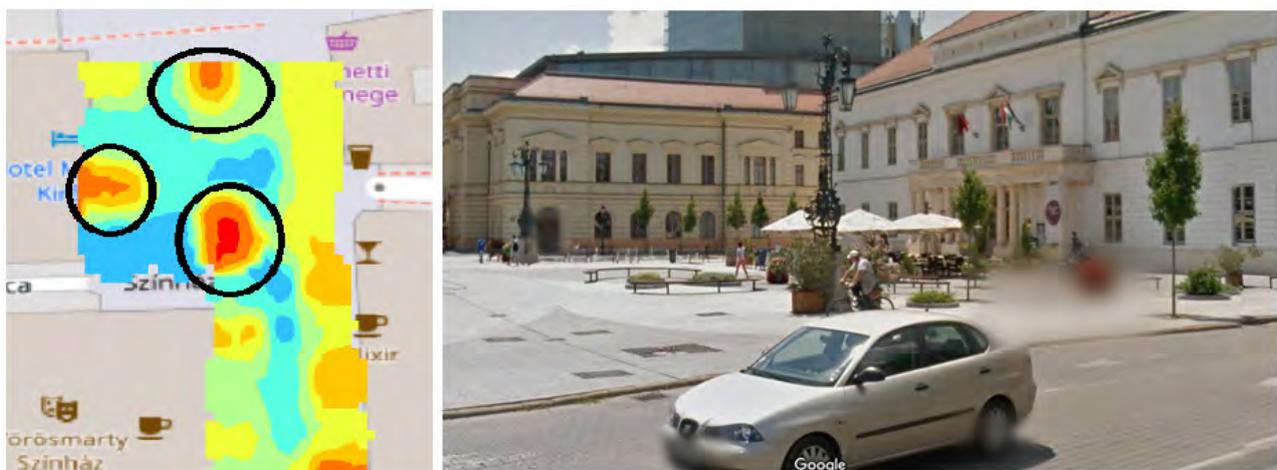


Figure 3. The results of high-density measurement in front of the theatre. Google StreetView photo.

Comparing the results of the *lightpollutionmap.info* (see Table 1) to our map (Figure 3) we can declare that high-density measurement can provide greater distinction within street segments. Also, globally *lightpollutionmap.info* can give a very good estimation which is corrected with on-site measurement usually with SQM. Although if we look at the histogram of the measurement (Figure 4) we can conclude that the majority of the measurements is less than the estimated one. This can be the result of the scale, as in the outskirts of the city there are huge industrial parks which would enhance the level of light pollution to a great extent.

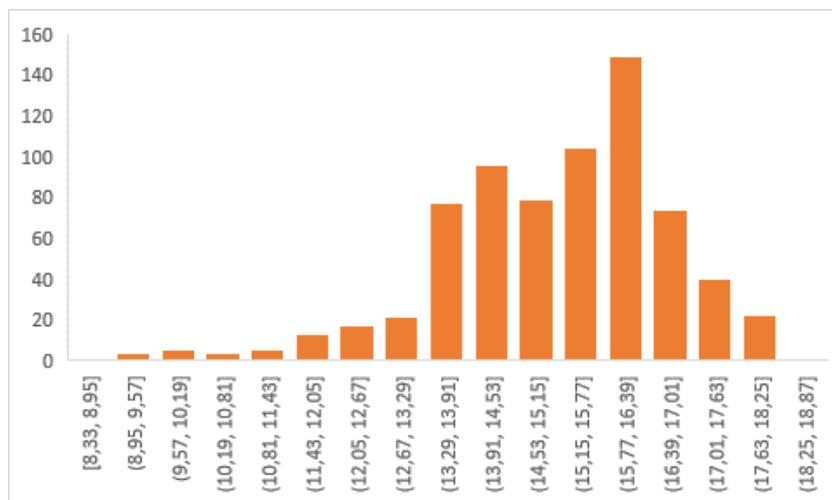


Figure 4. Histogram of the high-density measurement

Generally, it is very difficult to compare the results of the two parallel measurements as the two devices measure different things because they were designed for measuring contrasting things. In the case of Lux meter, we were interested in how much light the lamps are emitting, in the case of SQM-L we are concerned about how dark is the sky, how well stars and planets are observable. Although in this case, visual interpretation can support the idea that both types of equipment can uncover illuminated areas within the neighbourhoods. Similarly, they indicate darker areas as well.

The visual interpretation of the comparative study (Figure 5) shows that although we can notice slight differences between the two type of measurement, both clearly indicates the highly illuminated areas and darker areas. At Case Study A we can notice that the bus station and traffic junctions are well illuminated, but inside the blockhouse area (in the middle of the map) there is not much light, allowing those living there to rest at night. At Case Study B we can experiences brighter lamps along the lake, and similarly, at the edge of the park, we can see brighter lamps.

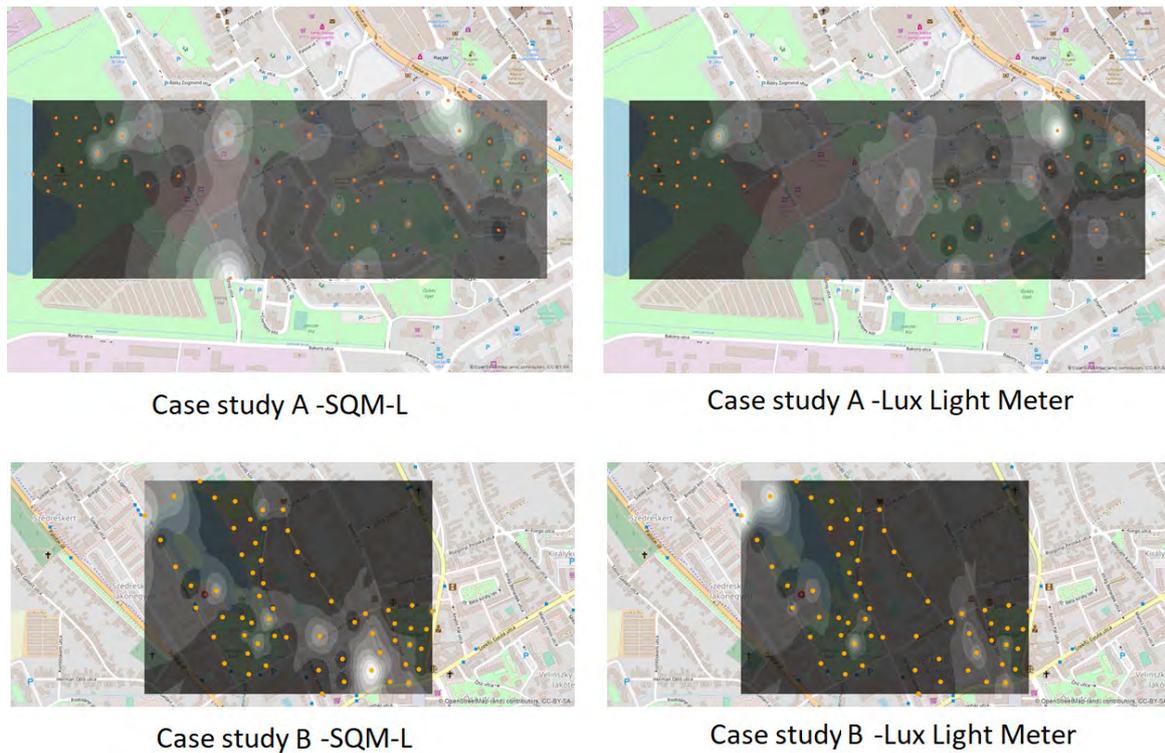


Figure 5. The interpolated results of the parallel measurements at Case Study A and B with the measurement points.  
Map source: OpenStreet Map.

As we measuring different phenomenon, we expected a negative correlation between the parallel measurements. At Case study A Pearson product-moment correlation coefficient was  $r=-0,7207428$ , at Case study B  $r=-0,85113497$ . These results also support that both approaches can be used in a crowdsourcing campaign, however during data processing and interpretation we need to pay attention to what data we are working with.

## CONCLUSION

Light pollution is recently recognized as a serious environmental pollution problem. It has many aspects, one of them is the connection and correlation between light pollution and certain illnesses. As *lightpollutionmap.info* can give a very good overview of light pollution situation all over the world, if we would like to detect light pollution trespassing within the neighbourhood level, it is necessary to execute high-density measurement campaign. In general, very good equipment for this is SQM-L meter, although it is necessary to purchase it. This equipment is also used by many amateur astronomers and also in various crowdsourcing campaign, Another option for detection of over illuminated areas the usage of our mobile devices with appropriate software installed on it. In our study, we used Lux Light Meter, as freely downloadable software. In our study, we compared the results of the devices with parallel measurement and we have found that there is a strong negative correlation between the results. As one equipment is detecting darkness, the other is brightness, so these results support that both approaches can help us to create a detailed map of the light pollution situation in our neighbouring areas.

For visualization of the results we used IDW interpolation method. We had to be careful to use reverse colour-coding of the results. With this simple mapping method we could create maps which were suitable for visual interpretation and comparison. Not only the negative correlation of the measurement result of the different methods, but the visual interpretation of the maps confirmed that both equipment and method can reveal overlit areas.

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# HOW TO MANAGE NECESSARY AND BORING EVIL OF PYTHON APPLICATIONS SETTINGS FILES

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## **Abstract**

*Python programming language is widely used in GIS, machine learning, and data analysis applications. The richness of powerful libraries, together with the speed of coding and rapid learning curve, makes Python language a valuable tool for various tasks connected with spatial data analysis and data analysis in general.*

*On the other hand, Python language gives coder, in comparison with, e.g., Java language, a high level of freedom, which can lead to poorly arranged and hardly manageable spaghetti application code.*

*Fortunately, such problems can be overcome with the careful organization of the application code and settings (or configurations). Owing to this fact, one of the very first steps in the organization of application code must be a design of the hierarchy and structure of application settings files and their processing mechanism.*

*In this contribution, we would like to show one of the possible approaches to application settings files organization and processing. Our approach is based on the careful analysis of the application setting needs, its separation to the hierarchical structure of files, file processing, and final creation of the tree of the dynamically build classes and its attributes containing easily accessible application task settings.*

**Keywords:** Python, settings, configurations, processing

## **INTRODUCTION**

Sooner or later, each programmer or coder will face the problems connected with the organization and processing of application settings. Unfortunately, wrong decisions in this area can make further work a nightmare, substantially slow down the progress of work, make application error-prone. They can cost additional demanding efforts to correct it. It also negatively influences the feature development of the application.

It is very tempting to neglect issues concerning the settings because it is “useless work” that provides no immediate results related to the application's main aim. On the other side, if we overcome this temptation, we will soon discover that the time and work invested into the organization and processing of settings will return, and the further development of the application will be much easier.

The approaches described in the further text were used during the development of the application used for the generation of the maps and charts for the Statistical Yearbook of Fire and Rescue Service of the Czech Republic. This Yearbook is published every year in the March issue of the 112 magazine [1, 2] in the Czech language. It contains about 60 maps and charts, which must be carefully prepared from the data collected during the year on various departments of General Directorate and regional directorates of Fire and Rescue Service of the Czech Republic. Besides, some of the maps and charts are selected for the English version of the Yearbook.

The preparation of the Statistical Yearbook of Fire and Rescue Service of the Czech Republic is time and precision demands. It requires careful processing of a large amount of data of various types from various sources. Because of that fact, it was decided to create an application for data processing and map and charts creation. The main aim of the application is to make the whole process as much as possible automatized, standardized, repeatable, and less error-prone.

## ORGANIZATION OF THE SETTINGS FILES

The buildup and maintenance of such an application, as is previously mentioned, is hardly ever possible without external settings files. They enable rapid reaction to the demands concerning the application outputs. Owing to this fact, great attention was paid to its organization, hierarchy, internal structure, and processing. The starting point for the design of structure and procedures for the processing of settings files was a careful analysis of the application processes. During the application design phase, the following application model was proposed:

1. The application will produce in principle two types of graphical outputs, maps, and charts in various formats.
2. Each output (map or chart) will be an application task.

From the application model, follow the hierarchy of the entities mentioned above:

1. Application.
2. Task type (map or chart).
3. Application task.

Owing to these facts, the five types of settings files were proposed:

1. Main application settings file, which contains application-wide settings. It encompasses both settings of application as is and common and default settings of task types and tasks carried out by the application. The main settings file also contains the instruction for processing the settings in it, which will be taken over by the task type settings and task settings.
2. Settings file of map task. It contains the settings common to all map tasks. During the processing, it takes over the settings from the main settings file and overwrites it, if more specific settings are given. This settings file also contains the instruction for processing the settings in it, which will be taken over by the task settings.
3. Settings file of chart task. It contains the settings common to the all chart task. During the processing, it takes over the settings from the main settings file and overwrites it, if more specific settings are given. This settings file also contains the instruction for processing the settings in it, which will be taken over by the task settings.
4. Settings file of the particular task. It uses main application settings and map or chart task settings and overwrites it if settings that are more specific are given in it.
5. The application uses a logging framework for protocolling of its run [3]. The settings of the logging is independent on the other settings of the application. Because of that fact, it was decided to store logging settings into a separate file. Application mechanism is used for its load, and the standard mechanism of the logging library is used for logging initialization with settings in the form of a dictionary [4]. After its load, the settings file is only slightly modified to set the actual path for the log file because all outputs generated by the application, including the log, are stored in the output folder and subfolder.

## FORMAT OF THE SETTINGS FILES

The application settings must be stored in some hierarchical and structured form. Usually, three types of file formats are used for storing such kinds of information, xml [5], json [6], and yaml [7]. Each of these formats has its strengths and weaknesses. The xml file format is for a long time established and used. There are well-established tools for its processing and validation. Some languages, like, e.g., Java, have a mechanism for its automatic conversion into a tree of full-featured objects.

The Python 3.X language was selected for the creation of the application. The main reasons for its selection were the existence of the well-established libraries for productions of the maps and charts, the ArcPy [8], and Matplotlib [9] libraries. In the light of the selection of the Python language, the possible formats of the settings files were compared, and json format was selected. The main reason for its choice was its simple conversion to the Python natural language structure – dictionary [10]. The settings are stored in the JSON file format, which is in principle kind of text file, both human and machine-readable. It can be quickly loaded from a file as a string and further processed into the Python dictionary. On the other hand, the Python dictionary does not provide dot notation for access to lower levels of information and does not give the possibility to define their own methods. Its conversion to the object with a complex structure and modifiable attributes is not simple. Owing to these facts, the simple mechanism for the transformation of the dictionary to the full-featured object is further discussed.

## SETTINGS FILES PROCESSING

The task settings were processed in the form of a tree of user-defined classes and their attributes. This approach enables a better and more logical organization of the application code. The task settings respects hierarchy of settings files and usage of the values specified on the highest levels of hierarchy enables the basic unification of the tasks, especially the unification of the maps and charts look. The values defined on the highest level are taken over if no more specific value is defined.

The instruction for processing the dictionary of task settings into the tree of the classes and its attributes are created by the merging of the instruction contained in main settings and task type settings. They describe the classes and attributes to which the settings of the task will be converted and its place in the hierarchy tree. It is the dictionary with class names as keys. The value in the key-value pair in the dictionary is a list of the dictionaries with instruction for processing particular class attribute. The instructions consist of the following entries:

1. Name of the attribute.
2. The initial value of the attribute, which is used if the value that is more specific is not given.
3. Description of the attribute, which is used in the string representation of the class.
4. Name of the class, if attribute value will be converted into a class of a particular type.
5. Special parameter signaling if a list of text string will be joined into one text string. This parameter is used exclusively during the processing of the SQL queries, which are responsible for downloading and treatment the data from the database. The SQL query has a form of a list of strings in the settings file because this enables its better readability in the settings file. This list of strings must be converted to the string before its sending to the database. When task settings as a dictionary are ready together with its instruction for processing, they are send to the special class – task settings factory, which generates the task settings as tree of classes and its attributes. During the generation the more specific values replaces the less specific predefined values. For each class its variables, constructor and string representation are set.

During the creation of the constructor, the class variables are defined, and its values are set. This process is simple except the situation when the class variable is an instance of another class or list of instances of the other classes. In this case, the procedure for class creation is recursively invoked. It can be invoked one time if the creation of the one class is necessary or many times if there is a necessity to create a list of classes.

The class variables use a slot [11] mechanism for its storage. The special attribute `__slots__` allows you to explicitly state which instance attributes you expect your object instances to have, with the expected results:

1. faster attribute access,
2. space savings in memory.

The string representation of the class is created by iteration through the class variables. Each variable is represented by the string consisting form the variable description and its value. The string representation also respects the hierarchy of the classes in the task settings class tree and gives appropriate ident to the string representing the particular class.

The description of the procedures for the dynamic creation of the class during the application run can be found in the literature [12]. The algorithms described there was taken as a background for task settings processing and was substantially modified and extended.

## CONCLUSIONS

The proposed approach to the settings file processing was successfully tested and deployed for processing of the settings files of the application for maps and charts preparation for the Statistical Yearbook of the Fire and Rescue Service of the Czech Republic.

It provides an easy and straightforward way from the settings files in the json format to the dynamically created classes and its attributes containing application settings. The process of class creation is fully under coder's control and can be easily modified according to the current needs. The settings, which control the creation of the tree of classes, are simple parts of the json files.

The application uses direct access to the class variables containing settings. Still, the addition of the code for generation of the setters and getters methods for accessing the class attributes is simple, if it will be needed in the future.

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# LAND ADMINISTRATION AS A KEY ELEMENT IN SDG'S SUCCESS

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## **Abstract**

*To achieve a successful implementation of SDGs, good land governance as well as a well-functioning land administration system are indispensable. From SDGs' 17 goals and 169 targets many directly and some generally related to land. Some of them are, secure tenure rights to land, ending hunger, peace, justice, sustainable cities etc. For SDGs' success not only a country level adoption is required, but cross-border cooperation, harmonization are needed as well. Hungarian Land Administration as an integrated system (cadastral mapping and land registry are integrated in one institutional framework) is functioning really well, and is able to serve the state for the implementation of a good land policy, land governance. International issues in land administration (in cadaster) are interesting. Different legislations, traditions strongly influence the cooperation in this field. For better, and flexible communication, data exchange, information sharing among land administrations, standards are required.*

**Keywords:** Sustainable Development Goals, Digital Cadastre, Land Administration Domain Model

## **INTRODUCTION**

Land Administration is a process. Land Administration is the process of determination, recording and dissemination of information on the relationship between the land and people (LADM, 2010). Land Administration is not only one process, it is better to speak about a set of processes, which provide reliable, and secure land tenure.

Digital Land Administration is not only a Land Administration with digital format data, and their relationships (e.g. constrains, connections). In Digital Land Administration the above mentioned processes are also digitalized anyway, and IT environment is able to help the operation of the whole Digital Land Administration.

Land Administration and as a part of it, Cadastre is a key element in implementation of Sustainable Development Goals.

Cadastre is a core element of any Land Administration system. In this case an integrated, multipurpose cadastral system is taking into account, where cadastral mapping and the registration of rights, restrictions and responsibilities (in LADM, ISO 19152:2012 Standard, Land Administration Domain Model; term RRR) are realized in an integrated system, called Cadastre. Such an integrated system can be developed independently from the institutional or organizational issues, based on the modern IT technology. (Iván, 2019.)

Land administration services unfortunately are not available for all people around the world. 70% world's population have no access to formal Land Administration services, while only 25% of the 6 billion land parcels worldwide are formally registered and have robust security of tenure. Therefore UN and its organizations (FAO, HABITAT), FIG, Worldbank and others are focusing on the development of Land Administration (Cadastre) in the countries, where these services are not accessible, and trying to provide secure land tenure for people. (McLaren, Enemark, 2017)

Mentioned activities of these organizations are really important, and it is natural, that they are concentrating on the different tools, which will solve this huge problem (like Fit-for-Purpose Land Administration), and after all the success of Sustainable Development Goals.

## LAND ADMINISTRATION AND SUSTAINABLE DEVELOPMENT

Sustainable Development has been a key issue for a long time in Land Administration. The Bathurst Declaration on Land Administration for Sustainable Development dealt with it generally at first time (FIG, 1999). The joint United Nations and International Federation of Surveyors Bathurst Workshop on Land Tenure and Cadastral Infrastructures for Sustainable Development has responded to this challenge. As it was written in this Declaration:

„Almost all societies are currently undergoing rapid change brought about by a diverse range of factors that include growing population pressures on the land, especially in urban areas. The world's population has already reached six billion people. The poor are becoming increasingly concentrated in slums and squatter settlements in our ever-expanding cities. The gender inequities in access to economic and social opportunities are becoming more evident. Within 30 years, two-thirds of the world's population will live in cities. Fresh water availability is now approaching crisis point. At present consumption levels, two-thirds of the world's population will live in water-stressed conditions by the year 2025. The challenge is not only to meet world population needs for food, shelter and quality of life, but also to ensure that future generations can also have their needs met.

Insecure property rights inhibit use and investment in rural and urban land. They hinder good governance and the emergence of engaged civil society. Uncoordinated development, poor planning and management of land and its use, and the increasing vulnerability of populations to disaster and environmental degradation all compound the difficulties of meeting this challenge. Without effective access to property, economies are unable to progress and the goal of sustainable development cannot be realised.

However, the world is changing. Growing awareness of the issues, better understanding of the consequences of actions, and greater capacity to secure and use relevant information are helping to bring about the necessary changes. These issues are forcing the re-engineering of land administration systems to ensure that they support sustainable development and efficient land markets. Land administration frameworks will be forced to respond rapidly to these unprecedented changes.”

Bathurst Workshop defined the following recommendations, as a global commitment to:

1. **Providing** effective legal security of tenure and access to property for all men and women, including indigenous peoples, those living in poverty and other disadvantaged groups;
2. **Promoting** the land administration reforms essential for sustainable development and facilitating full and equal access for men and women to land-related economic opportunities, such as credit and natural resources;
3. **Investing** in the necessary land administration infrastructure and in the dissemination of land information required to achieve these reforms;

4. **Halving** the number of people around the world who do not have effective access to secure property rights in land by the year 2010.

The Workshop in confirming the *UN-FIG Bogor Declaration on Cadastral Reform*, extending the professional debate on desirable land administration and recognising that the community of nations have committed themselves to the various United Nations Global Plans of Action arising out of the UN Summits over the last decade, recommends the following:

5. **Encourage** nations, international organisations, Non-Government Organisations (NGO)s, policy makers, administrators and other interested parties to adopt and promote the *Bathurst Declaration* in support of sustainable development.
6. **Encourage** all those involved in land administration to recognise the relationships and inter-dependence between different aspects of land and property. In particular there is need for functional cooperation and coordination between surveying and mapping, the cadastre, valuation, physical planning, land reform, land consolidation and land registration institutions.
7. **Encourage** the flow of information relating to land and property between different government agencies and between these agencies and the public. Whilst access to data, its collection, custody and updating should be facilitated at a local level, the overall land information infrastructure should be recognised as belonging to a national uniform service to promote sharing within and between nations.
8. **Improve** security of tenure, access to land and to land administration systems through policy, institutional reforms and appropriate tools with special attention paid to gender, indigenous populations, the poor and other disadvantaged groups. In many nations, this will entail particular efforts in areas under customary or informal tenure and in urban areas where population growth is fast and deficiencies are most prevalent.
9. **Recognise** that good land administration can be achieved incrementally using relatively simple, inexpensive, user-driven systems that deliver what is most needed for sustainable development.
10. **Recognise** that the unacceptable rise in the incidents of violent dispute over property rights can be reduced through good land tenure institutions that are founded on quality land information data. Good land information underpins good governance. Where conflict arises, there must be inexpensive land dispute resolution mechanisms in place that are readily accessible to all parties concerned.
11. **Encourage** national and local government bodies to document and manage their own land and property assets.
12. **Recognise** that land markets operate within a range of land tenures of which freehold is but one. It is important to facilitate the efficient operation of land markets through appropriate regulatory frameworks that address environmental and social concerns.
13. In order to increase knowledge of the global situation of land administration and land tenure, the United Nations **undertake** a study of global land administration issues such as the range of tenure issues, gender, urban agglomeration, land disputes, problems and indicators with a view to producing a global atlas and related documentation. Much of the needed data are already available in different UN databases.
14. **Recognising** the difficulties in interpretation of the many land administration related terms, **develop** a readily accessible thesaurus, translated into appropriate languages, to facilitate a better understanding of the terminology used. Further, on the basis of selected criteria, use this to **prepare** examples of best practice in the field of land administration. This can be done using work already completed by FIG and FAO.
15. In view of the crucial importance of human resources in the management of land, **ensure** that there is sustained education and training in land administration. In particular, international agencies should seek to develop multi-disciplinary, multi-national training courses in land administration and make these available at the local level through the use of modern information technology.
16. International and national agencies, NGOs and other interested parties **to arrange** workshops and conduct studies with regard to such matters as the quality of access to land and information, gender issues, customary law and indigenous rights, land tenure systems, interaction between land and water rights, maritime cadastres, and the management of land administration systems.
17. In order to **coordinate** foreign assistance, countries seeking help should play a more active role in the coordination of aid and prepare a country profile analysis, describing the status of land administration and the need for improvements. Based on this the countries should then prepare a master plan to which all land administration, initiatives and projects should adhere.
18. In order to ensure sustainable development of territorial oceans claimed under UNCLOS (United Nations Convention on the Law of the Sea), the United Nations **emphasise** the need for claimant countries to develop

their capability to support effective marine resource administration through the national spatial data infrastructure.

19. **Undertake** analyses and *develop* performance indicators that can monitor the effectiveness of land administration and land tenure systems in relation to sustainable development and poverty alleviation.
20. That the Workshop and FIG strongly **support** the "Global Campaign for Secure Tenure" undertaken within the implementation of the Habitat Agenda, presently launched by the UNCHS (Habitat), and **commit** to promoting activities in terms of this campaign in future FIG programs."

As a continuation of this Declaration the famous book on „Land Administration for Sustainable Development” was published in 2010 (Williamson et. al., 2010). In this book the relationships between Land Administration and Sustainable Development deeply analysed. It defines four components within the broad goals of sustainability:

- Efficiency and promotion of economic development,
- Equality and social justice,
- Environmental preservation and a sustainable pattern of land use,
- Institutional and government capacity to deliver sustainable development.

Figure 1. shows the connections between Land Administration components and Sustainable Development:

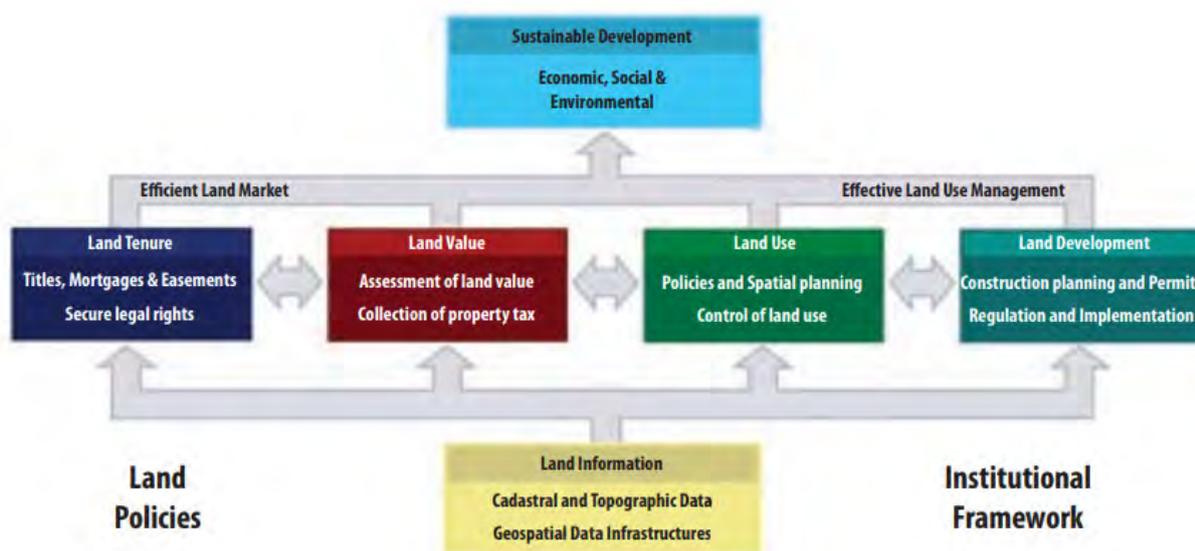


Figure 1.: A Global Land Administration Perspective (Enemark, 2004)

The four land administration functions (land tenure, land value, land use, and land development) are different in their professional focus, and are normally undertaken by a mix of professionals, including surveyors, engineers, lawyers, valuers, land economists, planners, and developers. Furthermore, the actual processes of land valuation and taxation, as well as the actual land-use planning processes, are often not considered part of land administration activities. However, even if land administration is traditionally centered on cadastral activities in relation to land tenure and land information management, modern LAS designed as described in Figure 1. deliver an essential infrastructure and encourage integration of the four functions:

**Land tenure:** the processes and institutions related to securing access to land and inventing commodities in land and their allocation, recording, and security; cadastral mapping and legal surveys to determine parcel boundaries; creation of new properties or alteration of existing properties; the transfer of property or use from one party to another through sale, lease, or credit security; and the management and adjudication of doubts and disputes regarding land rights and parcel boundaries.

**Land value:** the processes and institutions related to assessment of the value of land and properties; the calculation and gathering of revenues through taxation; and the management and adjudication of land valuation and taxation disputes.

**Land use:** the processes and institutions related to control of land use through adoption of planning policies and land-use regulations at the national, regional, and local level; the enforcement of land-use regulations; and the management and adjudication of land-use conflicts.

**Land development:** the processes and institutions related to building new physical infrastructure and utilities; the implementation of construction planning; public acquisition of land; expropriation; change of land use through granting of planning permissions, and building and land-use permits; and the distribution of development costs. (Williamson et. al. 2010).

Sustainable development policy requires the four functions to be integrated. This is achieved in four general ways:

1. In theory, the functions are approached as four parts of a coherent whole, not as independent activities. This means that each function is not an end in itself, but all four together are the means to support sustainable development.
2. The processes used to perform the functions must pursue sustainable development, ideally within a broad framework of monitoring and evaluation of performance against sustainability outcomes.
3. Information and outputs generated by processes need to be mutually shared and made widely accessible.
4. All functions must be built on core cadastral knowledge. (Williamson et. al. 2010).

## TECHNOLOGICAL CHALLENGES

Technological developments strongly influences our world into the direction of openness. Internet, Social media, Meta-platforms are all opening the world for everyone and everywhere. Fast transport, information exchange and others are also increasing this openness among countries, societies and individuals. Everyone can be informed of anything. It is very important, that not only the rich, developed countries' citizens are coming in for this information, data sharing, but the poorer side of the world as well, thanks for the advanced communication technology. All in all technological developments strengthens globalism.

But after the global economic crisis in 2008, new economic and political concepts have arisen, which affect into the opposite direction than globalism. The countries became more-closed, national interests were increased against the global needs. As it was mentioned by Mr. Nick Wilkinson (Interview with Mr. Nick Wilkinson, Former DA-Notice D-Notice Secretary UK, in the newspaper Magyar Nemzet, Budapest, Hungary, on 13th September 2017. Translated from Hungarian by the authors): „*Accelerated globalism kindles nationalist emotions, which are not compatible with the laws of liberal market economy. Political leaders are not able to resolve this contradiction.*”

And the citizens, the people, both in the developed and developing side of the world, are staying under this double pressure. They like to come in for the benefits of the globalism, but are living in a more-closed political, societal environment. But what a citizen needs? Safety and peace, which are not really achievable in such a situation. (Iván, 2018.)

Checking the trends, which influence Land Administration in our days, the following could be found (Figure 2.):

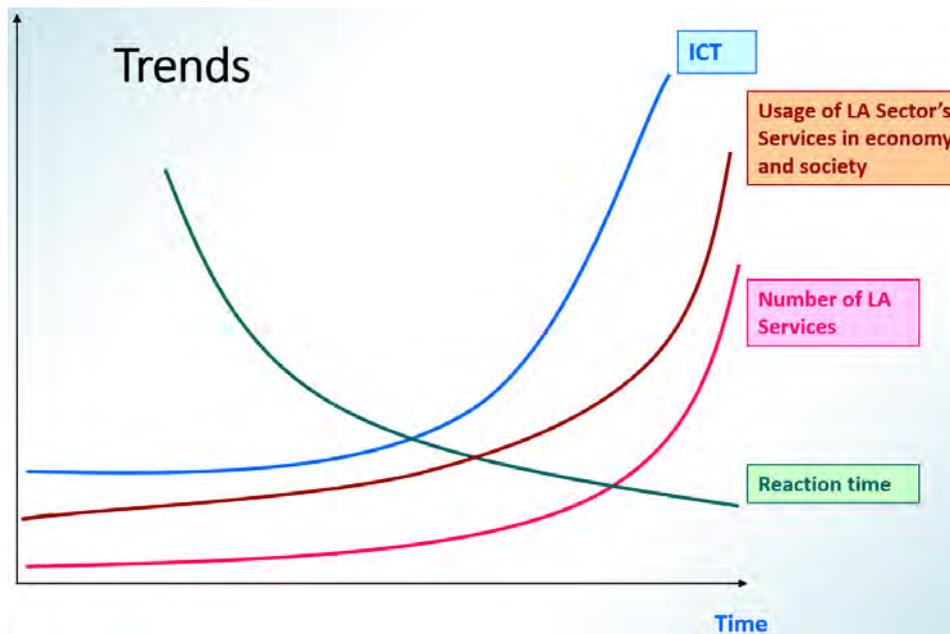


Figure 2.: Trends in Land Administration

The fast development of InfoCommunication Technology (ICT) has the strongest influence in Land Administration processes. Usage of Services in economy and society is increasing together with ICT and the number of Land Administration Services, but the Reaction time of Land Administration is getting less and less. This is one of the main challenge for Land Administration in these days.

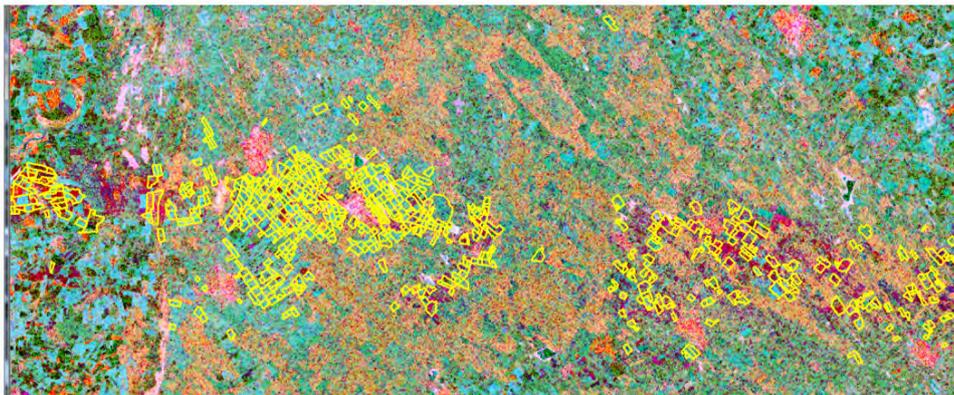
Above only the trends were mentioned, but the continuous developments of different instruments, sensors in the field of positioning (e.g. UAVs, LIDAR, In-door positioning) become more and more important not only for the determination of location, but the monitoring of changes.

In the field of Land Administration, Land Management Remote Sensing methods and technics are generally not discussed on the level, which they should be deserved. As an example, Department of Geodesy, Remote Sensing and Land Offices of the Government Office of the Capital City Budapest, Hungary has really good results in the usage of remote sensing technics on Land Management. Own-developed solution for the mixed use of optical and radar-polymetric are successfully utilized in the monitoring of different agricultural hazards, from the effect of western corn root worm till hailstorm damages (Figure 3. and 4.).

**Ordered and disordered „grating”.  
Different effect on polarized waves.**



*Figure 3.: Western corn root worm damages (Surek et. al. 2012)*



LPIS blocks of claims of damages and damages detected by the analysis of radar satellite images are coincided well  
Analysis were carried out within 10 days after the storm (including satellite image purchasing)

*Figure 4.: Hailstorm damages (Surek et al., 2016)*

New devices introduced new definitions in our profession. Positioning replaced field measurements, smart devices arose crowdsourcing (FIG Commission 7. WG 7.3), new, multispectral sensors increased the importance of change mapping. In some cases algorithms solves positioning problems, usage of augmented reality is a reality, cadastral parcels become an intelligent object on the field etc.

This fast technological development requires new conceptual solutions such as Land Administration Domain Model ISO 19152:2012 Standard (LADM). Introduction of this standard was one of the most important result in Land Administration in the last decade. It is a conceptual model for designing Land Administration systems, an interface for exchanging information among Land Administration Systems. LADM became a common Land Administration “language” all over the world. And it a very a very important issue, that the development of LADM continues.

A real high technological (and legal) challenge is 3D Cadastre. A joint working group of FIG Commission 7. and 3. are working on this issue. 3D Cadastre is not only the extension of traditional cadaster to the third dimension. In 3D Cadastre the most important theme is the handling of 3D rights, restrictions and responsibilities (RRRs).

Building Information Modeling (BIM) is a new, real complex solution for the management of physical and functional characteristics of places, structures etc. Spatial (and sometimes legal) information are indispensable in design, construction, operating and maintenance of buildings. Therefore the importance of surveyors, spatial and land knowledge are increasing in BIM. Based on the spatial knowledge of surveyors, we surveyors have an integrating role in any BIM solution. It is interesting, that in many languages the word "engineer" is derived from engine (motor). But in Hungarian language this word derived from "surveyor" (mérnök), which shows this integrating role of geodesist.

Financial techniques (Fintech) have just arrived in Land Administration, thanks for the wide usage of blockchain technology. Blockchain is a real challenge, since it looks like, is able to revolutionize Land Registry, and Land Administration all over the world. by the use of blockchain technology all transactions will become transparent, irreversible and publishable, which shows its importance. (van Bochove et al., 2016) But an important question arises related to this characteristics, all the politicians like such a Land Administration system?

The above mentioned technological challenges strongly influences the future of Land Administration systems. The operation of systems should be faster, more reliable and highly automated, including document handling, processing and decision making. This is not only a technological challenge, but a defiance in organizational structure of Land Administrations as well, including human resource management. Since Land Administration "is the process of determining, recording and disseminating information about the relationship between people and land" (LADM, 2012), these changes also impact the society, the people. Therefore Land Administration has a great responsibility to prepare citizens for these new situation. (Iván, 2018.)

## **HUNGARIAN ACTIVITIES IN THE IMPLEMENTATION OF SUSTAINABLE DEVELOPMENT GOALS**

UN Agenda 2030 for Sustainable Development were adopted by all UN Member States in 2015. It is a universal call for developing social, environmental and economic sustainability. Efficiency of the Agenda is influenced by global and local level cooperation based on the skills, interests, capabilities and the intentions of the participants. Global actions are executed by governments, industry, education and academic sector, businesses and global NGOs. Local actions are based on the activities of local governments, national NGOs and the people themselves.

Large part of the Sustainable Development Goals and related tasks are referred to spatial information. In the implementation, change monitoring and documentation of the goals and tasks, geodetic reference frames, Earth observation data and geoinformation datasets are playing fundamental roles.

A volunteer Working Group started its work in 2017 for the national awareness raising of the importance of spatial information for Sustainable Development Goals. Executive Board of the Hungarian Society for Surveying, Mapping and Remote Sensing (MFTTT) recognized this work and established a permanent committee for national and international activities in this field, in its No. 16/2018. (XII. 10.) resolution. Because of the international activities the name of the committee derived from an English abbreviation "MFTTT-WG4SDG".

During the execution of UN Agenda 2030 focusing on the measurement, monitoring and documentation of Sustainable Development Goals' indicators needs a special attention by the utilization of statistical, geoinformation and Earth observation data.

It needs special efforts from the participating countries to provide policies, actions, cooperations, knowledge base, human resources, organizational and financial background.

Direct support by EO/GI tools of SDG has not been established yet in Hungary. During the years 2017-2018 MFTTT-WG4SDG made preparation works, by the motivation of public and private sector for cooperation.

Results of these activities should be included Voluntary National Review of Hungary and in the report of national EO4SDG Group as well.

Actions should be taken:

- Continuing the involvement of national geoinformation and Earth observation bodies,
- Strengthening collaboration with UN and SDG bodies on national and international level,
- Starting geoinformation and Earth observation services for SDGs and establishing related jurisdiction,
- Establishment of Hungarian National Spatial Data Infrastructure, including the legal framework, data policy and interoperability.

- Integration of statistical, Earth observation and geoinformation data,
- Establishment connections to Governmental organizations responsible for the achievement of SDGs in Hungary.

In 2019 WG4SDG recommended the following actions for MFTTT:

- Survey on the higher education and trainings in Hungary and SDGs related international experiments
- MFTTT-WG4SDG recognized the main institutions and experts play important roles in education
- MFTTT-WG4SDG digested:
  - starting packs of education materials
  - themes to be educated
  - national education institutions related to SDGs
- Tasks:
  - Starting the initiation of:
    - legal,
    - financial,
    - capacity and
    - organizationalconditions for education in EO/GI for SDGs theme. But at least, organically inspire the potential players, and concerned people.
  - Starting
    - Adoption of education packages,
    - The work with the related education institution experts.
  - Continuing the cooperation with international institutions.
- At CEOS-WGISS-47 Workgroup meeting, NOAA, 29 April – 2 May 2019, Silver Spring, USA, a wide-range of international experts were informed about the Hungarian activities, including
  - Earth observation,
  - Space Industry Cluster
  - Activities of Hungarian experts in Copernicus and SDG monitoring
  - Activities of Hungarian Bodies (Hungarian Space Research Office, MFTTT-WG4SDG, Airbus-DS-GEO-Hungary, GEODATA Ltd., Lechner Ltd., COSIMA Ltd., Governmental Informatics Development Agency
- Operated by the Ministry of Foreign Affairs and Trade, the Hungarian Space Office (HSO) should consider to join CEOS, where MFTTT-WG4SDG could play an important role.
- MFTTT-WG4SDG recommends the extension of Hungarian Earth observation activities with SDG purposes, surveying and geoinformation activities.

## CONCLUSIONS

Land Administration is a key element of the implementation of UN Agenda 2030. The Agenda defines the Sustainable Development Goals, which have many relationships to Land Administration. The modern Land Administration must be based on cadastral knowledge. As a result, these new Land Administration systems must be built to serve the sustainable development objectives of economic development, environmental management, social justice, and good governance.

Fortunately, thanks to the fast development of technologies (including positioning, remote sensing, ICT), building-up these Land Administration systems, supporting SDGs, is not hard, as it seems.

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# ON THE PROBLEMS OF INTEGRATION OF SPATIAL DATA OF CONSTRUCTION PROCEDURES IN THE CONTEXT OF THE E-GOVERNMENT OF THE CZECH REPUBLIC

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## **Abstract**

*An e-government has been under construction under the auspices of the Home Office of the Czech Republic for many years. This system is a complex of application tools, that should make contacts between public and administration authorities easier and more effective. The GeoInfoStrategy has been implemented in this complex since 2014, based on Government Regulation. Its main task was to effectively administrate and spatial data guarantee. Every individual information system works well in vertical relation (state – regions – districts – municipality), but isolated without any horizontal relations currently. There is a system, that will integrate individual components of applications system used by authorities in spatial data management, designed in this article. Components of GeoInfoStrategy are ISKN (Information System of Cadastre of Real Estates), system of basic registers, especially RUIAN (Register of Territory Identification, Addresses and Real Estates) and NIPI (National Infrastructure for Spatial Information) and relations among them are very important. Considering the relation with problematics of BIM (Building Information Modeling) is very perspective. The System of Construction's Register is designed by authors in order to build a tool for digital construction proceedings. Due to unclearly defined inputs, insufficient legal base and inconsistent user's requirements of the process, it is in general very difficult problem. There is also another point of view that has to be considered, primarily the necessity of international standards observing and also respecting of contemporary systems of e-government.*

**Keywords:** eGovernment, spatial data, System of Construction's Register, BIM

## **1. INTRODUCTION**

### **1.1 Definition of the solved problem**

In 2018, Resolution No. 629 of the Government of the Czech Republic on the Digital Czech Republic Program [1] and a proposal for amendments to the Statute of the Government Council for the Information Society were adopted. The "Digital Czech Republic" program is a set of concepts ensuring the preconditions for the long-term prosperity of the Czech Republic in the environment of the ongoing digital revolution. Its content can be defined by the term: "Strategy of coordinated and comprehensive digitization of the Czech Republic 2018+". "Digital Czech Republic" covers three main pillars (partial concepts / strategies), which form one logical unit with a large number of internal links, but at the same time in the structure reflect the targeting of different users as well as differences given by the current legislative definition:

1. The Czech Republic in digital Europe (under the responsibility of the Office of the Government).
2. Information concept of the Czech Republic (under the responsibility of the Ministry of the Interior).
3. The concept of Digital Economy and Society (under the responsibility of the Ministry of Industry and Trade).

Within the strategy ad 2) (Information Concept of the Czech Republic), among other things, objective No. 5 is defined - "Effective and centrally coordinated Information and Communication Technologies (ICT) of Public Administration". The scope of fulfilling this important goal includes in particular the overall management of the implementation of the Information Concept of the Czech Republic (IKČR) and the overall central coordination of the development of eGovernment. One of the sub-objectives is item 5.11 on the title GeoInformation. The aim is to design and implement data policy, ensure interoperability, eliminate duplication and make spatial information owned by the public

administration and in the public interest accessible to friendly public services in the same / similar way as for other reference and authoritative data (e.g. online applications in construction proceedings). It is also necessary to connect central shared spatial information with information in the administration of regional data centers and other systems of local governments, which serve mainly for spatial planning, crisis management and other areas using geoinformation, in the form of Digital Technical Map of the Czech Republic and data sources created BIM - Building Information Modeling. The potential of geoinformation and construction information as open data will be further developed.

### ***1.2 The aim of the paper***

Within eGovernment of the Czech Republic, functional agenda information systems are in the vertical line, i.e. state - region - district - ORP (municipality with extended powers) - municipality, but in the horizontal line (systems at the same level) manual or semi-automated information transfer predominates. The same situation is in the process of construction proceedings, in which 2 categories of documents are assessed:

1. textual (justification of the construction plan, comments of the participants, etc.), and
2. graphic (project documentation of the construction).

In accordance with Act No. 183/2006 Coll., On Spatial Planning and Building Regulations (Building Act), the Ministry for Regional Development (MRD) has launched the project "Digitization of Building Management and Spatial Planning" [2], the aim of which is to build a live digital system, which will facilitate the process for all participants in the construction proceedings, as it will no longer be necessary to bypass the authorities, but everything will be handled from the comfort of home.

The aim of this paper is to propose the concept of automated support for digital construction management in the field of assessment of graphic project documentation. From the point of view of the whole concept of digital construction management, it is only a specific partial part, which is, however, the most time-consuming and content-intensive of all related processes..

## **2 CURRENT STATE OF THE PROBLEM**

In order to be able to design the optimal automation of processes within the goal defined in the previous chapter, it was necessary to obtain information about the current state of construction practice in the field of construction management. This information was obtained through interviews with actors from public institutions and experts in the field. The consultations took place at the territorial workplace at the level of the ORP (municipality with extended powers), specifically at the Kuřim Building Authority (Czech Republic). Further consultations concerning construction proceedings from the point of view of public contracting authorities took place in the companies Railway Infrastructure Administration (SŽDC) Brno and Railway Transport Automation (AŽD) Prague. These institutions were selected because they have a rich investment activity in the construction industry both in the Czech Republic and abroad. The aim of the survey was to find out the state of the partial processes related to building permits, to identify critical points and to design suitable automated processing for these procedures..

The investigation revealed that the building authorities III. categories (territorial workplaces at the ORP level) mostly use proprietary software purposefully created by IT companies, e.g. VITA software, s.r.o. The applications have a functional repertoire in accordance with the Building Act and related regulations. Furthermore, they enable partial compatibility with agenda information systems of state administration and self-government through standard or interchangeable formats. The disadvantage of these applications is that they are mostly database or registration, while many analytical functions are not available. Another disadvantage is that these software products were designed relatively in isolation and their analysis took place at the local level, which means that in many cases they are not connected to related structures of eGovernment, GeoInfoStrategy - National Infrastructures for Spatial Information (NIPI), BIM and others. In addition, the SW design is based on a local ontological model and European standards and metainformation are not fully respected as proposed, for example, in [5].

The final decision based on the assessment of textual or graphical documents is thus up to the user - the official. Another problem of the current construction procedure is the communication between the individual participants. This takes place either electronically via data boxes or classically by official letters delivered by the Czech Post. The disadvantage is that the comments of the last participant must be awaited throughout the proceedings, and in the case of communication by letters, the entire construction process is disproportionately prolonged. The situation is even more complicated in the area of assessing graphic materials, i.e. project documentation of a construction. If the documentation is in the form of paper drawings, it is assessed visually, if it is in electronic form (PDF, DWG, etc.), it is viewed by an official on a computer screen. The problem is that with extensive documentation, the entire content does

not fit on the screen in a readable form and it is necessary to view the drawing in sections. In this case, it often happens that the user loses the context of the overall image, which can lead to overlooking critical parts of the drawing. It follows that in the case of extensive electronic documentation, its visual viewing is no longer effective and it is therefore necessary to automate the entire process. This is the issue that our article deals with.

### 3 MATERIALS AND METHODS

A mixed strategy was chosen for the design of part of the digital construction management, partly from the “top-down” method - in order to respect the integration into superior structures and partly from the bottom-up, which is to ensure the functionality of the proposed application and adapt to end users and their current customs as much as possible. The top-down design was based on the concept of digital building management, which is shown in Fig. 1. In practice, this is the design of the bold block marked in Fig. 1 as “New SW of building authorities”.

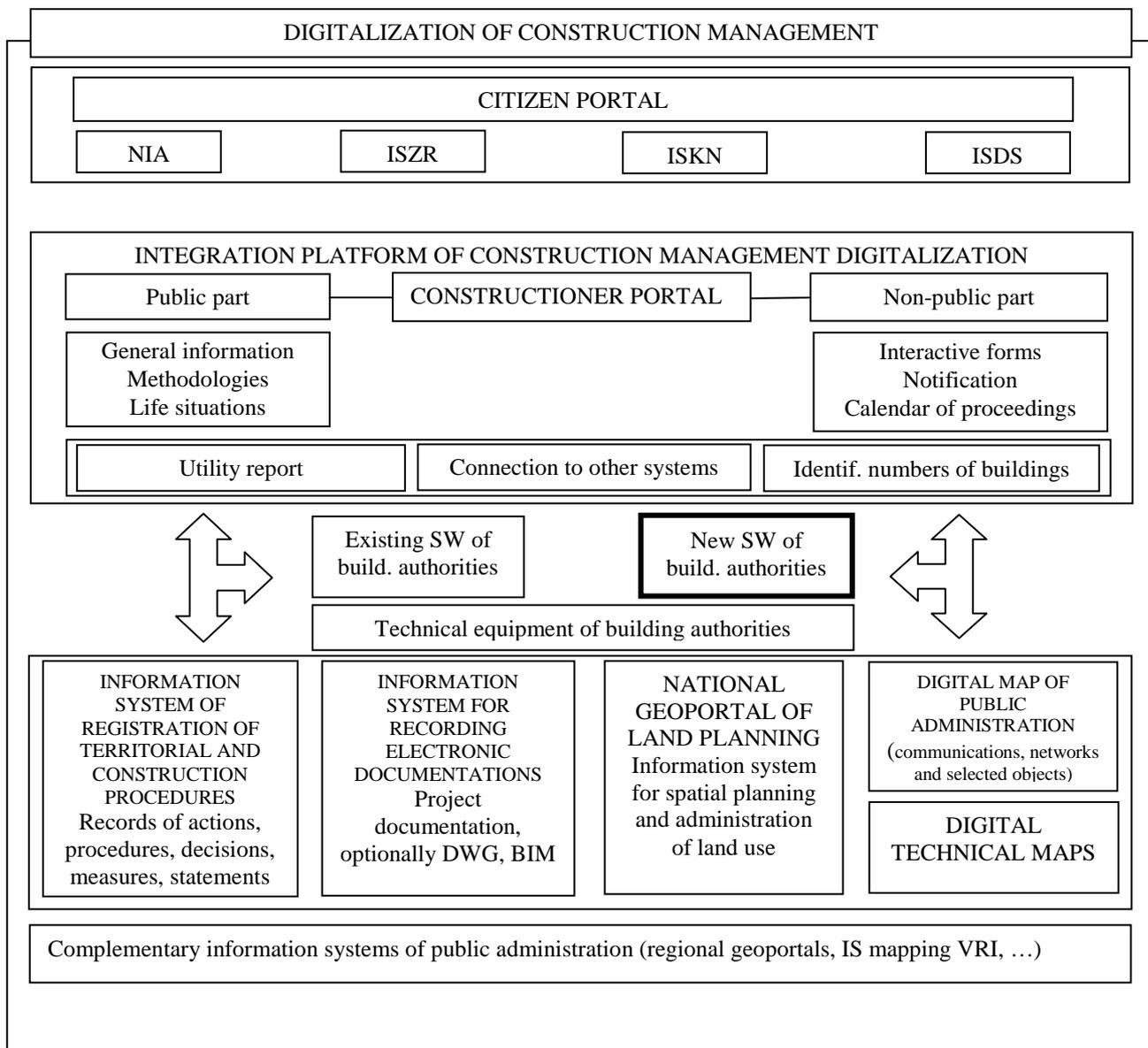


Fig. 1. Concept of digital construction management [3]

Explanatory notes to Fig. 1:

NIA – National point for identification and authentication is information system of public administration supporting process of electronic identification and authentication by qualified system.

ISZR - Information system of basic registers

ISKN – Real Estate Cadastre Information System

ISDS - The information system of data boxes is established and operated on the basis of Act No. 300/2008 Coll. (CR), on electronic acts and authorized conversion of documents, as amended. Its administrator is the Ministry of the Interior of the Czech Republic. The ISDS operator is the holder of a postal license, Česká pošta, s.p. ISDS is a public administration information system in the sense of Act No. 365/2000 Coll. (CR), on public administration information systems, as amended.

The bottom-up method consisted of a survey of the current state of construction management, which had its basis in interviews with actors of public institutions and experts in the field - see Chap. 2. The actual design of a suitable SW was based on a mathematical model of the entire construction process, which can be expressed in relation:

$$P = f(L, T, C, D, R) \quad (1)$$

where

P is a Boolean function that takes 2 values: 0 = construction is not allowed, 1 = construction is allowed,

L is the location where the building is to be located,

T is the time, i.e. the time when the permit is processed,

C are the comments of the participants in the construction proceedings at time T,

D is the project documentation of the construction,

R is the legislation and regulatory measures in force at time T.

Because according to the goal set in the introductory chapter, the subject of the solution is only the assessment of the graphic part of the construction documentation, we can rewrite equation (1) into the form:

$$P' = f(L, T, D, R) \quad (2)$$

#### 4. DESIGN OF THE POSSIBLE SOLUTION

The concept of the design of a suitable SW for the assessment of the graphic project documentation of the construction is shown in Fig. 2. In the input block in Fig. 2 is a collection of graphic documentation in a suitable format that is compatible for further processing in the concept of digital construction management (Fig. 1). One option is to use the IFC (Industry Foundation Classes) format or a special universal interchange format. It is assumed that the documentation will also include a digital technical map and other relevant documents. Block 2 identifies the entities and attributes of the documentation. It is based on the recommended classification of buildings according to the ISO 12006.2 standard, which divides the elements hierarchically as follows: built space - construction complex - construction entity - construction element - attributes. In block no. 3, spatial analyzes are performed. The functions and values of the parameters of these analyzes are contained in the valid legislation or regulations (block no. 5) and can be implemented in the application, for example, in the form of a text file with a line format:

< key word > <relationship> <value>. E.g. < **distance from the border of the neighboring plot** > >= <2m>.

In the next block No. 4, the inspection is carried out according to legislation and regulations, which can be implemented, for example, by a special script in the GIS / BIM environment. The result is a report on whether or not to recommend a building permit. In case of non-recommendation, the project documentation of the construction is returned for revision.

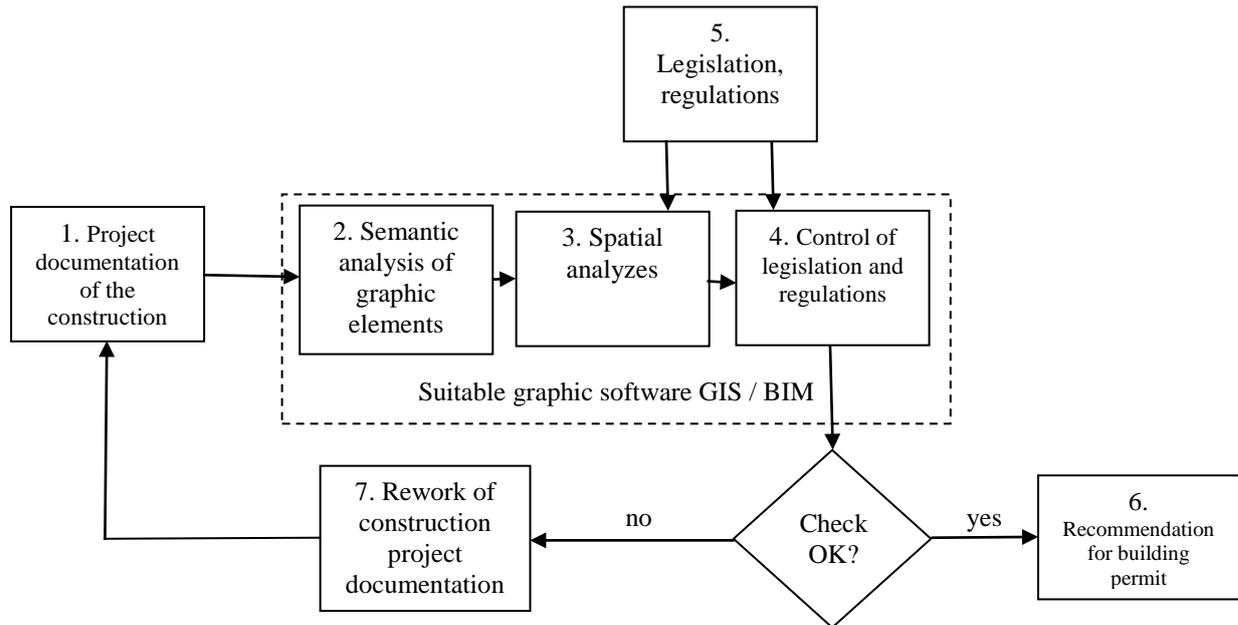


Fig. 2. Digital construction management - assessment of project (graphic) construction documentation

## 5. CONCLUSION

The article proposed one of the possible variants of applications for automated assessment of graphic project documentation in the process of digital construction management. Currently, several projects are underway, where the issue is addressed. One of them is the project CZ.03.4.74 / 0.0 / 0.0 / 15\_025 / 0007522 “Strategy of introducing the methodology of information modeling of buildings for the needs of public contracting authorities”. The final decision depends on the results of this and other relevant projects. In practice, 2 possible variants of the solution can be expected [4]:

1. New application SW + HW for building authorities (addressed in our paper).
  - a. The advantages of this variant lie in the multi-license and in the unified simple and flexible administration and operation.
  - b. The disadvantages of this solution are higher acquisition costs and a new user environment.
2. Use of existing application SW and HW and its modification according to legislative changes
  - a. The positive aspects of this variant are the knowledge of the user environment and thus faster adaptation of officials
  - b. The downsides are the possible vendor lock and the demanding management and operation of the information infrastructure.

Further research will continue in the design of an algorithm for processing comments from participants in construction proceedings, which were not addressed in this article. It is assumed that these comments will be implemented in the form of forms that can be easily and reliably evaluated automatically, eg by a script, and incorporated into the system design in Fig. 2.

## ACKNOWLEDGEMENTS

This paper was elaborated with the support of the project CZ.03.4.74/0.0/0.0/15\_025/0007522 “Strategies for introducing the methodology of information modeling of buildings for the needs of public contracting authorities” and with the theoretical cooperation of Brno University of Technology, Specific Research Project FAST-S-18-5324 and FAST-J-20-6374.

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# TECHNOLOGICAL GIS SUPPORT OF PROPERTY SETTLEMENT OF LARGE STRUCTURES

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## **Abstract**

*The article deals with technological GIS support of property settlement of large structures. The builder is obliged to realize the construction on his land to which he has the ownership right or secured another legal relationship. The process of proprietary settlement begins in the process of planning permission and ends with the issuance of a building permit. Property settlement of a structure includes the identification of existing land parcels and its owners in the area of the boundaries of the future structure, ie. permanent and temporary occupation. The analysis is performed using digital cadastral data. The aim is to generate the necessary data on the participants in the construction proceedings and prepare the documents for writing purchase or lease contracts in favor of the builder, and analysis of price and tax information. For Underground technical infrastructure objects the preparation of documents for marking and recording easements is solved. The data of the occupation report process are part of the structure BIM. Due to the different quality of cadastral and other background data, and related legal links, their analysis is a complicated problem.*

**Keywords:** GIS, BIM, property settlement, construction

## **INTRODUCTION**

The preparation of constructions in the Czech Republic currently takes many years, and a large amount of documents is required. Long preparation hinders the development of construction and therefore the process of digitization of land and construction management is intensively addressed. The main goal is to speed up the whole process of building permits. The most time-consuming is to provide the necessary statements of the participants in official proceedings on the future construction, including the impact on the environment. Within the territorial management process, the preconditions for the sustainable development of the territory are ensured by a systematic and comprehensive solution of the efficient use and spatial arrangement of the territory with the aim of achieving a generally beneficial harmony of public and private interests in the development of the territory. To this end, it monitors the social and economic potential of development. The tool of spatial planning is statistically recorded data on the territory, the so-called territorial analytical documents, the use of which is enshrined in legislation in the Building Act No. 183/2006 Coll. with the aim of continuous monitoring of the state and development of the territory. Spatial analytical data are acquired by the relevant acquirer on the basis of surveys of the territory and on the basis of data on the territory, which are information or data on the state of the territory, rights, obligations and restrictions related to a certain part of the territory, such as area, land, natural formation or building, and which arose or was found out mainly on the basis of legal regulations, as well as information or data on intentions to make a change in the territory. Territorial data also include information on their origin, acquisition, processing, possible approval or entry into force and effectiveness (hereinafter referred to as "territorial data"). The technical map can also be the basis for the acquisition of spatial analysis documents.

The investor is obliged to carry out the construction on his land, to which he has the right of ownership or another legal relationship is ensured. In this sense, every major building cannot do without property preparation. The process of property preparation of buildings begins in the process of land management and ends with the issuance of a building permit. Obtaining a land decision and a building permit is often time consuming and takes several years. Negotiations take place with a large number of owners, technical infrastructure managers, relevant stakeholders and other entities. Digitization of property rights preparation brings the advantages of portability and unambiguity of information, productivity, data timeliness, archiving, etc. The necessary basis for property rights preparation is an occupation report, which determines the scope of property rights preparation of the construction. The aim of the occupation report is to speed up and manage the process of property settlement of the land affected by the construction. In connection with large constructions, especially line constructions, many affected plots enter into the process of property settlement and with it a large number of legal relations that need to be resolved. The state of the cadastral map also plays an important role in this process, especially its accuracy, which is different (decimeters to several meters) and is given by the quality

of source graphic data (directly measured digital geodata or digitized graphic data from historical analog cadastral maps).

## **RELATED WORK**

The issue of using information systems in the construction process is a current topic. A comprehensive description of the construction process in the Czech Republic and its documentation is dealt with, for example, in articles [1], [2]. The dominant information system in the phase of construction preparation is the Real Estate Cadastre Information System, which integrates descriptive and graphic data on real estate and their legal relations. Large cities are building smaller information systems with the aim of their effective use for regional spatial planning and official building permits.

Article [3] presents the use of GIS technology in urban planning and analyzes the factors that affect the orientation of cities. Key factors include the geographical location, natural resources, the international political situation of the city of Altay and at the same time identify the position of the city in the national strategic model. The analyzes of data by the GIS tool showed an upward trend in dynamic orientation.

The issue of the environment and construction is also dealt with in the article [4]. Construction significantly affects our environment. The most effective way to protect the environment and prevent pollution is to use best management practices (BMP) on construction sites. In recent years, intelligent systems have been widely used in a variety of applications, including environmental studies. To reduce environmental pollution from construction activities, the CSBMP expert system software on the Microsoft Visual Basic platform was used, which displayed system recommendations in the form of reports provided and thus informed and supported environmental engineers and decision-makers during construction activities.

At present, BIM modeling technology is intensively penetrating the construction industry [5]. The construction industry is increasingly adopting technologies and methodologies that support the development of buildings with low environmental, economic and social impacts. Current research focuses on the environmental and economic impacts of construction and integrates building information modeling (BIM) technology with life cycle assessment (LCA) and life cycle costing (LCC) methods for the environmental and economic assessment of buildings. Various software tools are used to support decision-making processes, e.g. to verify the feasibility of constructions.

Partial specialized information systems are then used on large and complex constructions, especially in connection with their monitoring, e.g. in tunnel constructions [1]. These information systems integrate electronic implementation project documentation and partial important documents related to the construction. The information systems of buildings include image data (photographic monitoring, video monitoring) and data of geodetic and non-geodetic monitoring. The basic feature of the use of electronic information systems is selective accessibility to selected data and target groups of users with the possibility of online access via smartphones anytime and from anywhere.

The article [6] addresses the issue of estimates of construction costs in connection with the solution of savings in a construction project. During the project life cycle, several estimates are made to allow the project to be decided with stakeholders. Historical data and experience are often used and applied appropriately to future construction activities. The method of building location cost optimization (LCAF) for selected sample sites in North America is described. Spatial interpolation and prediction methods were used. The WEKA and ArcGIS packages were used to develop and test the prediction models. It was found that the prediction models did not outperform the interpolation methods as expected. In addition, between the two prediction models, the GIS-based regression model (GISBR) slightly outperformed the WEKA-based regression model (WEKABR).

In the Czech Republic, in connection with the digitization of the processes of preparation and permitting of constructions, the automation of property rights preparation of constructions is intensively addressed in connection with the information system of the Real Estate Cadastre. Article [7] presents specific applications of a software web solution for asset management and transaction prices. The subject is a comparison of the registered and actual state, the creation of user overviews and analyzes of ownership and context and the use of results in the design of buildings. It deals with the advantages of digitization of property rights preparation, portability and unambiguity of information, productivity, timeliness of data and their effective archiving [8]. In cooperation with the two largest investor state organizations, the Railway Administration and the Directorate of Roads and Motorways, a suitable digital exchange format for occupation reports has been defined [9].

## **PROPERTY PREPARATION OF CONSTRUCTIONS**

The property law preparation of the construction includes the identification of the existing lands and their owners in the area of the boundaries of the future construction, ie. permanent and temporary occupation. The analysis is performed on

digital cadastral data. The aim is to find out the necessary data about the participants in the construction procedure and to prepare documents for drafting purchase or lease agreements in favor of the builder, analysis of price and tax information, etc. In the case of underground technical infrastructure facilities, the preparation of documents for the marking and registration of easements is addressed. The data of the construction preparation process are then part of the construction BIM.

In Fig. 1 are schematically shown on the timeline the phases of the life cycle of a building in connection with the process of property preparation of buildings. The focus of property preparation of buildings is in the phases of land and construction proceedings.

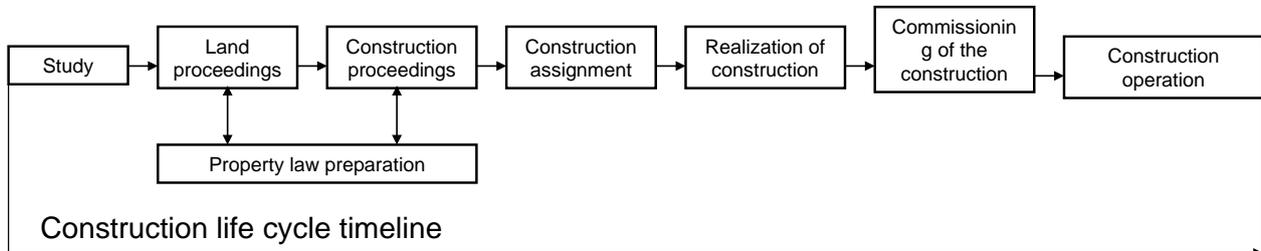


Figure 1. Scheme of partial phases of the construction life cycle on the timeline

In Fig. 2 is an example of spatial analysis of land properties of a part of the territory over digital cadastral data realized in the SYMAP application [7]. Sub-plots are marked in color according to the specified property. From the point of view of construction preparation, important data are data on landowners, which lands are private, which are state, regional, municipal.

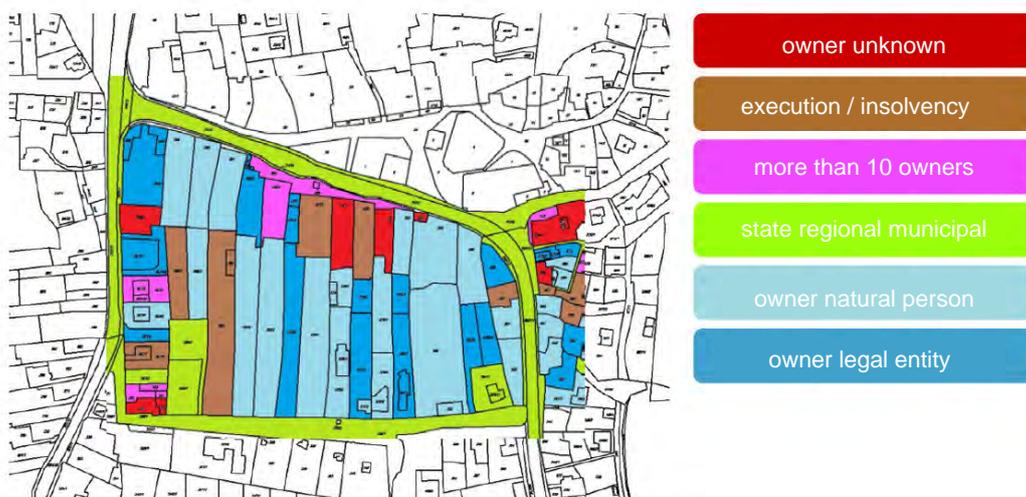


Figure 2. Specification of land properties of the locality of interest from cadastral data

In terms of ownership, it is necessary to distinguish between the ownership of a natural person and a legal person. Complications of property rights preparation are legal relations and encumbrance of land, for example by execution or insolvency. From the point of view of resolving legal relations, ownership by many shareholders is also problematic. Based on the analysis of land properties, it is possible to effectively plan the location of the building in the field.

In Fig. 3 is an example of a spatial analysis of the state of property settlement of the affected lands during the course of line construction implemented in the SYMAP application [8]. The basis is digital cadastral data and the circuit of the projected permanent and temporary land acquisition. It compares the state registered in the real estate cadastre and the actual state. The result is a list of land that must be resolved in property, including the issue of utilities and easements. In conjunction with the Land Register (LPIS), it is also a tool for property settlement with agricultural cooperative administrators. For connoisseurs and appraisers, real estate agents can create output based on location and time variance. The output includes proceedings in the given cadastral area, acreage of the affected plots, acreage of individual types of land and recalculated transaction prices for 1 m<sup>2</sup>.

In order to automate the process, it is necessary to ensure unambiguous and error-free geodata, which has a fundamental influence on the quality of subsequent property rights activities. The quality of cadastral data is crucial. Due to the different quality of cadastral and other background data and related legal links, the analysis is a complicated problem. Any ambiguities and errors in the geodata are then transferred to the contractual documents and must be resolved individually with the landowners. The advantage of the automated solution is the resolution of all discrepancies before the start of construction, which allows you to significantly save time and money.

The output is a color designation of the affected parts of the land and associated information on the status of the legal solution (not yet initiated or negotiated, or already closed legal proceedings, or blocking the land in the form of disagreement or other changes to the affected land).



Figure 3. Identifikace stavu rozjednáni právních vztahů dotčených pozemků liniové stavby

Real estate cadastre data linked to user data subsequently facilitate land administration, tax returns, occupation purchases, and the conclusion of contracts with automated deposits in the real estate cadastre. Data is visualized in ArcGIS over maps, which helps better planning, decision-making, control and risk prevention.

Cadastral data are an irreplaceable source of information for property preparation of buildings, land management, taxes, leases and others, and therefore it is important to work with them effectively in these areas. The aim is to use smart applications to make it easier for interested participants to work with real estate cadastre data, visualize their business or management over the map and reduce the traditional paper agenda. Property law applications combine information from the occupation report and the real estate cadastre, keep the data up-to-date, generate all the necessary documents, monitor deadlines and provide users with a uniform, clear guide throughout the process.

## OCCUPATIONAL ELABORATION

The occupational elaboration is the basic comprehensive basis for property rights preparation of buildings and is created in the phase of zoning or construction proceedings. It integrates spatial geodata on the location of the building given by the project documentation in relation to the spatial geodata of the property boundaries of the lands registered in the real estate cadastre (KN). Thus are identified the plots affected by the construction of in question, for which it is evaluated whether they are subject to exclusion from the land of the agricultural land fund (ZPF) or from land intended for the performance of the forest function (PUPFL). Official land decisions and building permits are issued on the basis of the occupation report.

**The occupational elaboration** indicates the ranges of permanent occupations, temporary occupations and easements. It consists of tabular and graphic parts.

**Permanent occupation** means parts of land for which, as a result of their occupation by the construction of a building, a property settlement must take place through sale or purchase and, as a result, a change of owner or a change in the right of jurisdiction over state property management.

**Temporary occupation** lasting more than one year means the contractual securing of parts of the land for a period longer than one year, without changing the ownership relations to the land. Temporary occupation, which can be limited in time to less than one year, means short-term occupation of parts of land for the needs of, for example, descent to land

or short-term manipulation of land for construction or access for cleaning ditches, handling space during construction of engineering relocations.

**Encumbrance** means a right in rem to another's property restricting the owner of the land, which serves primarily to ensure the access of authorized entities, especially in connection with the construction and maintenance of utilities.

The occupational elaboration serves as a basis for the preparation of the relevant geometric plans, usually in the construction proceedings phase, and is one of the essential components of project documentation. This corresponds to its technical form, factual accuracy and corresponding geometric accuracy. An example of the graphic part of the occupation elaboration is shown in Fig. 4.

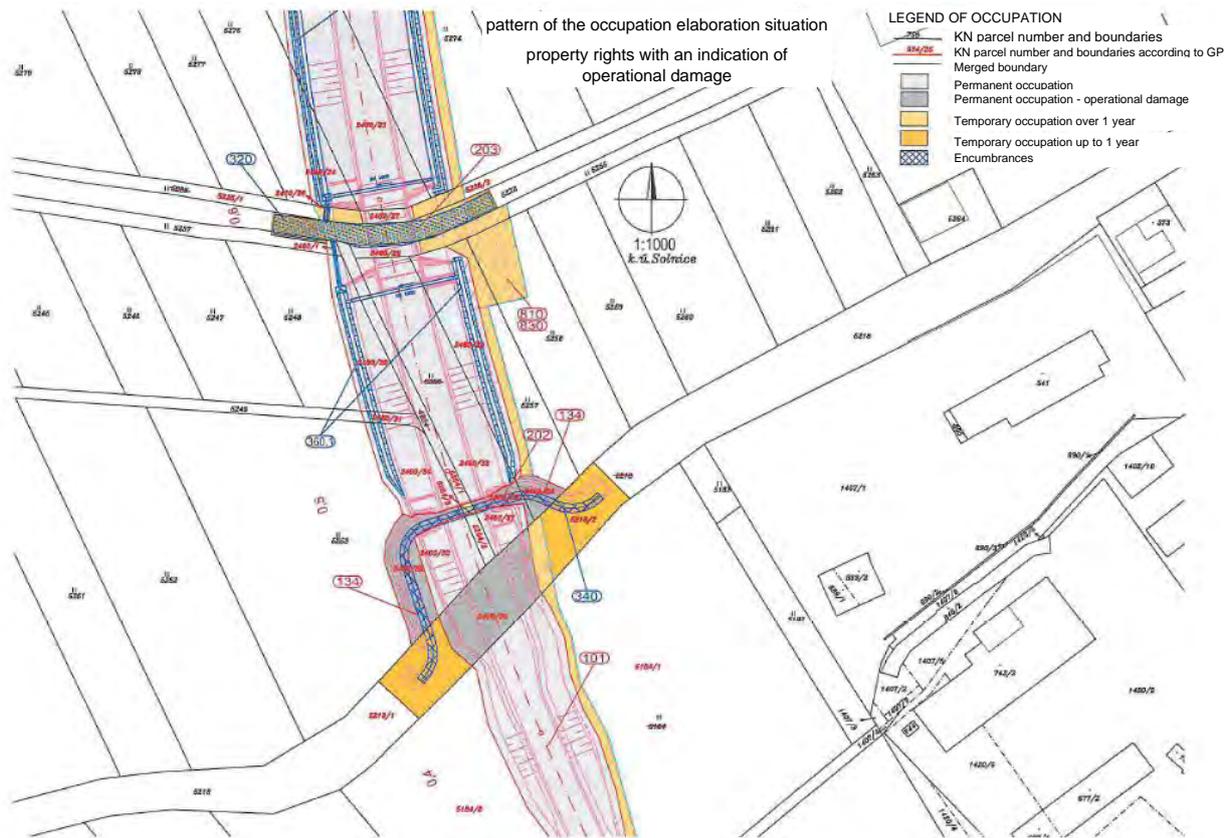


Figure 4. Sample of the graphic part of the occupational elaboration [10]

## EXCHANGE FORMAT OF OCCUPATIONAL ELABORATION

The interchangeable format of occupational elaborations was created for the sake of mutual portability and compatibility between different information systems. It is a format that is to unify and standardize the current digital data of occupation elaboration into one file so that it is machine readable. In addition to their usability in various information systems, it is also possible to use them in a BIM environment. The main goal of creating an interchangeable format was to ensure the automation of data transfer and updating in the process of property settlement.

The interchangeable format of the occupational elaboration contains a graphic part, i.e. the geometry of the drawing of the areas of occupations, easements, buildings and plots and a descriptive part with information on acreage, types of occupations, acquirers and authorized entities. The exchange format also includes meta-information about the construction, the contractor and the export. The interchangeable format is supplemented by predefined code lists of occupation types and levels of documentation. The exchange format does not contain information on real estate cadastre data, but only parcel identifiers linked to the real estate cadastre information system, including the validity of the state of the cadastral data..

The documentation describes the basic scheme and parameters of the format, and especially its mandatory and optional content.

Basic parameters of the exchange format of the occupational elaboration:

1. Custom data is stored in Extensible Markup Language format (XML).
2. The geometries are stored in the formal Geography Markup Language (GML) according to the ISO 19136:2007 standard.
3. Character encoding is allowed only in UTF-8 standard. Elements with the data type string can contain text exclusively in the national language.
4. The geometry can only be stored in the binding East North state coordinate system, which is registered in the GML with the EPSG:5514 code. Coordinates in GML are given to 2 decimal places.
5. The file always contains complete status data. Transmission of difference data to status data is not permitted. It is always necessary to transmit complete data, i.e. to modify the original data according to new facts and submit it as a new unit. Difference data can only be obtained by application comparison of two versions of interchangeable format files.
6. The content of the interchange format is divided into individual data blocks. Not all attributes in individual blocks are required.
7. Export to the exchange format also stores descriptive information, i.e. version of the exchange format, version of the occupation report, validity of the state data of the Real Estate Cadastre, date of export, data on data authorization.
8. Descriptive information about the investment project, including the location of the area and other information, i.e. name, investor, contract, level of documentation.
9. Information on the division of the project into several sections or stages of construction in the event that the investment project is thus divided. Occupations, objects can be distinguished by assigning a number and the name of a section or stage.
10. Information on occupations linked to the land and objects concerned, i.e. description of geometry, acreage, type of occupation, future acquirer.
11. Information on buildings and operating files, i.e. description of geometry, designation, name, acquirer.
12. Information on encumbrances on the affected land, i.e. description of geometry, length and area, connection to the object, connection to the geometric plan.
13. Information on geometric plans, i.e. contractor, number, cadastral area, purpose, verifier and information on future plots from the geometric plan, ie description of geometry, new parcel numbers, acreage, type and method of use.
14. Information on the comparison of the current and new state with the records of legal relations from the geometric plan.
15. Control information on the plots concerned.
16. Description of the geometry of lands managed only by analog.
17. Code lists as fixed values of types of occupations, levels of documentation, types of protection and organizational units.

Files in the XML structure can be easily validated using an XSD template, which verifies the correct structure and content of the file, filling with mandatory and optional data blocks and attributes. The second stage of control is a solution using software, where you can check the correctness of the format of geometry description, rounding, area of occupations and encumbrances, links to code lists, interconnection between data blocks and the valid state in the real estate cadastre information system.

With the introduction of the interchangeable format of the occupation report, there was a clear definition and control of the transmitted digital geodata of the occupation reports with the property of connecting descriptive and graphical data.

Occupational elaboration can be transferred by export / import functions to other SW, which ensure other processes in construction preparation.

## CONCLUSION

A suitable software solution allows you to automate, streamline and improve the quality of individual processes. No software application will replace direct dealing with owners. The newly defined interchangeable format of the occupation elaboration allows to significantly improve and speed up the process of preparation of constructions and by solving all problems even before the implementation of construction saves money and time that would have to be spent on unresolved property rights identified with delays. The new exchange format is therefore incorporated into the internal regulations [10], [11], which are subsequently part of the contractual conditions for the implementation of all constructions of the largest investor state organizations in the Czech Republic, namely the Railway Administration and the Roads and Motorways Directorate. In connection with the use of BIM technology for construction management, the process of property settlement is fully compatible and usable throughout the life cycle of the construction.

## ACKNOWLEDGEMENTS

This paper was elaborated with the theoretical support of the project Specific Research No. FAST-S-18-5324 and FAST-J-20-6374.

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# A COMBINED MODEL OF GIS AND FUZZY LOGIC EVALUATION FOR LOCATING EMERGENCY FACILITIES: A CASE STUDY OF ISTANBUL

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## **Abstract**

*This study presents an approach for integrating GIS with fuzzy logic multi-criteria evaluation for locating emergency facilities in Istanbul region. In the proposed fuzzy logic model, six influencing criteria were fuzzified (or standardized) into appropriate fuzzy membership values by a semantic import (SI) procedure that relied on expert input to define values of criteria suitability. Using these appropriate fuzzy membership functions, values ranging from 0 to 1 were then assigned to each criterion in a GIS environment. Based on these analyses, the criteria layers were subsequently aggregated using the fuzzy OR and AND overlay operators and reclassified to produce a final raster suitability map of Istanbul that could be visualized to show favourable areas for new emergency facilities. The research result provided a model that could be used by decision-makers for enhancing the planning of emergency facility locations and supporting fire disaster mitigation efforts in parallel with future urban growth and developments.*

**Keywords:** *fuzzy logic, fuzzy overlay, geographic information system (GIS), multi-criteria analysis*

## **1. INTRODUCTION**

Urban population growth and infrastructural expansion in tandem with human activities have had wide-ranging impacts on urban environments, worldwide (Dociu and Dunarintu, 2012). Prime among these impacts negatively affecting the sustainable development of urban regions is the increased risk of fires and the occurrence of fire-related incidences in Istanbul, a commercial and cultural centre of Turkey. Istanbul has a population of 15,519,267 people accounting for about a fifth of the country's total population and a large population density of 2,869 people/km<sup>2</sup> registered in the last 5 years (TUIK 2019). Fire incidences surpassing 58,000 have been experienced in the province that had average response times of more than five minutes (IMM 2016). This study, therefore, suggests the use of GIS-based fuzzy logic multi-criteria analytical methods for land-use suitability analysis of selecting new emergency facilities in Istanbul province.

Combined usage of Multi-Criteria Decision Analysis (MCDA) techniques and Geographic Information Systems (GIS), hence referred to as GIS-MCDA, has been motivated by the need to enhance GIS capabilities for decision-making and planning (Sugumaran and Degroote, 2010). The GIS-MCDA integrates geographic data (input maps) and preferences of experts or decision-makers (DMs) to be processed into a decision (output) map (Malczewski 1999; Malczewski and Rinner, 2015). Over the years several multi-criteria or multi-attribute evaluation methods implemented in GIS for land-use suitability assessment applications have included Weighted Linear Combination (WLC) or simple additive weighting (SAW) and its variations (Carver 1991; Eastman 1997), ideal point methods (Jankowski 1995), concordance analysis (Joerinet et al., 2001) and analytic hierarchy process (AHP) (Banai 1993; Nyimbili, Erden and Karaman 2018). In such methods, DMs or experts have been directly involved in assigning criteria weights to each attribute map layer for aggregation using overlay techniques to determine land-use suitability or composite (output) map layer. However, some limitations exist in the GIS-multicriteria evaluations in a decision-making procedure (Jiang and Eastman, 2000) such as the inaccuracy, imprecision, and ambiguity of the input-data (attribute values and expert preferences) that can be resolved by utilizing computational intelligence (AI) approaches, particularly, *fuzzy logic* (Malczewski 2004). Conventional land-use suitability analysis procedures have been criticized due to the unrealistic underlying assumptions that input data is crisp (precise) (Malczewski 2004). In complex real-world scenarios of land-use suitability analysis and decision-making, it is arduous to specify requisite precise mathematical information from conventional techniques based on Boolean algebra. For example, in many cases, attributes related to land use lack natural thresholds or constraints (cut-offs) that define distinct boundaries between suitable and unsuitable areas. There usually exists ambiguity, imprecision, and the assumption that criterion weights are provided in numerical form (contrary to linguistic variables that indicate the importance of weights) when defining such thresholds. Therefore, fuzzy logic and fuzzy set

theory (Zadeh 1965; Fisher 2000) can address these issues associated with ambiguity, vagueness, and imprecision for resolving land use suitability-related decision-making problems (Malczewski 2004; Nyimbili and Erden, 2020).

An extension of the classic binary logic is described by fuzzy logic and is characterized by the likelihood of defining sets without crisp boundaries or partial membership of elements belonging to a particular set (Zadeh 1965). A *fuzzy set* is defined as a class of objects with members having degrees or grades of membership ranging between 0 and 1 whereas the classical set contains elements that must have a membership degree of either 0 or 1. The membership function is the underlying concept of fuzzy set theory and is represented numerically as the degree to which a specified element belongs to the set. The fuzzy set theory describes a framework for resolving uncertainty related to vagueness, imprecision, and lack of information. Three (3) methods for fuzzy membership definition include the *semantic import model*, *similarity relation model*, and *experimental analysis* (Burrough and McDonnell, 1998; Fisher 2000). The semantic import model uses some form of expert knowledge to assign a membership relative to a property measurement while a similarity relation procedure runs data searches for fuzzy membership based on pattern recognition algorithms. Additionally, experiments involving humans can be used to empirically identify membership functions.

Several GIS-based studies utilizing the concept of fuzzy logic and membership function have been reviewed in the literature involving site selection, risk susceptibility mapping and groundwater quality assessment (Ahmed, Rogers and Ismail, 2014; Alves et al., 2018; Charnpratheep, Zhou and Garner, 1997; Çakit and Karwowski, 2018; Loro et al., 2016; Soroudi et al., 2018; Venkatramanan et al., 2015). To the best of our knowledge, no research applying fuzzy logic spatial multi-criteria evaluation techniques has ever been undertaken within the domain of emergency facility selection and suitability analysis for Turkey and Istanbul, in particular. Several advantages of applying fuzzy logic over conventional methods as applied to spatial decision-making problems and land suitability modelling have been stated by some researchers (Hall et al., 1992; Burrough and McDonnell, 1998; Fisher 2000). Burrough and McDonnell (1998) recommended the use of fuzzy membership procedures as ideal for boundary delineation between diverse land-use suitability classes. The authors demonstrated the resultant effects of information loss and an increase in the likelihood of errors when a spatial decision problem comprises imprecise data in conventional methods. Castanho (2005) further reinforced the advantages of using fuzzy logic as being able to mathematically model inaccurate information from natural to human language and the use of values without specifying rigid thresholds between classes. The preservation of complete partial membership information while considering the uncertainty and imperfections is characteristic of the fuzzy logic approaches.

This paper, therefore, proposes the use of a fuzzy-oriented GIS-based multi-criteria analysis approach and fuzzy overlay analysis for suitability mapping of new emergency facilities in Istanbul province.

## 2. RESEARCH METHODOLOGY

### 2.1 Criteria selection, data collection and processing

Based on a previous study by Erden and Coskun (2010) that utilized the AHP method, as well as a literature and project report review (Gay and Siegel, 1987; IMM 1989; Johnston 1999) six criteria/attributes were established as influencing factors for suitability mapping of new emergency facilities in Istanbul province. These selected attributes were the distance from existing emergency/fire facilities (DEF), closeness or nearness to main roads (NMR), distance from earthquake risk-prone areas (DER), high population density (HPD), hazardous material density (HMD) and wooden building density (WBD). Most of the representative attribute data were collected from the Istanbul Metropolitan Municipality Fire Department and were in vector-based polygon data. Using ESRI ArcGIS software, these data were processed, standardized (fuzzified), and analysed in raster criteria map layer formats per sub-district area of Istanbul to a spatial cell resolution of 50 x 50 m<sup>2</sup>. Fuzzy overlay analysis was performed to aggregate the fuzzified criteria map layers into a fuzzy suitability map. Subsequently, defuzzification was carried out by a reclassification using the *natural breaks (Jenks)* classifier and converted into a conventional final suitability map for selecting new emergency facilities of Istanbul.

### 2.2 Conceptual flow chart

Implementation of the GIS-based fuzzy logic suitability modelling approach was conducted in a fuzzy expert system that involved expert knowledge in the structuring of the system elements. A *fuzzy system* is a system containing some or all variables which are fuzzy sets (Klir and Yuan, 1995; Qiu et al., 2014). The conceptual flow chart of this fuzzy model as illustrated in Figure 1, comprises of the selection factors, a fuzzification or standardization procedure for fuzzy suitability membership derivation, a fuzzy inference process, a fuzzy suitability map, defuzzification by reclassification into a final conventional suitability map.

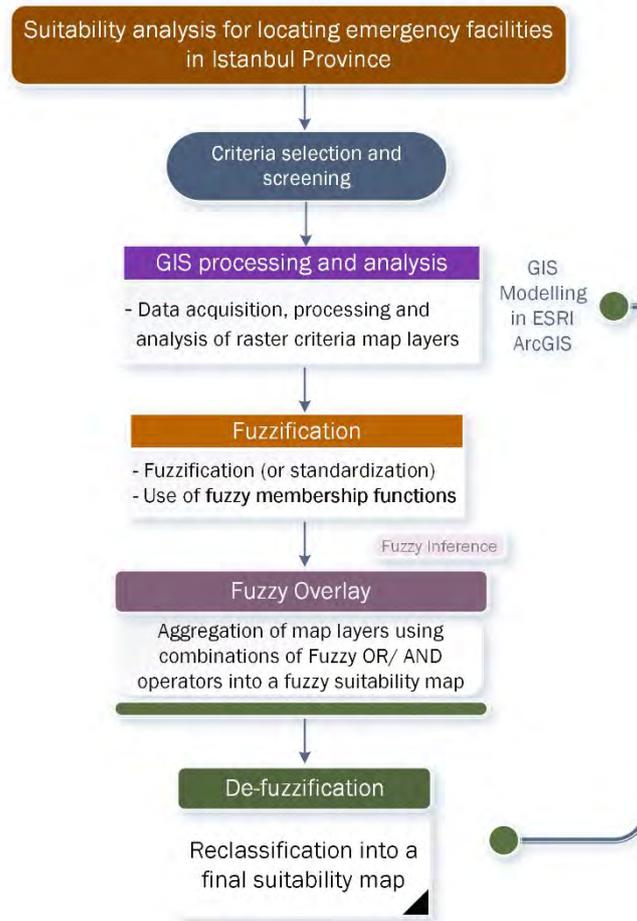


Figure 1. The conceptual model for the study

Within the proposed fuzzy logic model, *fuzzification* is carried out to convert the selection factors under evaluation for suitability mapping of new emergency facilities into the relevant fuzzy set expressed by grades of membership of each land unit respective of the suitability class it belongs to. These fuzzy membership grades acquired for all the six established criteria were then aggregated into a fuzzy suitability map by a fuzzy inference process based on particular fuzzy rules. The aggregated fuzzy suitability map defined the overall measure of suitability for the distribution of the new emergency facilities, ensuring a continuous suitability domain across the entire study region. Such a fuzzy suitability map is said to be more informative than the conventional crisply-defined suitability/unsuitability map (Qiu et al., 2014). In a defuzzification procedure, the fuzzy suitability map may be converted to a conventional suitability map with clearly defined boundaries.

### 2.3 Implementation of the fuzzy logic model approach

As earlier discussed, the fuzzification process is a form of standardization that converts raw criteria measurements into fuzzy membership grades based on fuzzy membership functions defined by an expert for each suitability index ranging from values between 0 and 1. In this study, the *semantic import* (SI) method was selected as appropriate to evaluate the fuzzy membership functions due to the non-availability of training data and the convenience of having a general idea of boundary definition of suitability classes based on expert knowledge (Burrough and McDonnell, 1998). Although difficult to precisely define criteria thresholds of suitability values using the SI approach, the previous study by Erden and Coskun (2010) provided a rationale for delineating the associated suitability boundaries between classes.

Using the fuzzy logic analyses functionality in ArcGIS software, fuzzy membership functions were assigned to the relevant attribute values in the criteria map layers between 0 and 1 and the fuzzy overlay tool was used to merge the multiple fuzzy membership result maps into a composite fuzzy suitability index map (Caniani et al., 2011; Çakıt and Karwowski, 2018). The fuzzy overlay analysis utilizes the fuzzy logic concept and is applied in various GIS-based decision-making problems (Çakıt and Karwowski, 2018; Loro et al., 2016; Qiu et al., 2014; Venkatramanan et al., 2015). The fuzzy overlay procedure permits analysis of the possibility of a phenomenon associated with multiple sets

and their inter-relationships in a multi-criteria overlay analysis in four key steps: collection/processing of source criteria map layers, fuzzy membership value assignment for each map layer, aggregation of the fuzzy criteria map layers into a fuzzy suitability map and result assessment (Çakıt and Karwowski, 2018).

### 2.3.1 Fuzzy membership functions

Comparing with conventional standardization procedures, a broader variety of suitability membership functions were reviewed for use with the *semantic import* (SI) method in this study to derive the fuzzy membership grades that included the sigmoidal shaped functions of fuzzy linear, fuzzy small and fuzzy large. A brief description and formula expression of these functions are given below (Raines, Sawatzky, and Bonham-Carter 2010).

- *Linear*: An increasing linear or decreasing linear membership between two input values depicted by a linearized sigmoid shape.

$$\begin{aligned} \mu_{(x)} &= 0 \text{ if } x < \min, \mu_{(x)} = 1 \text{ if } x > \max, \\ \text{otherwise } \mu_{(x)} &= \frac{(x - \min)}{(\max - \min)}, \end{aligned} \quad (1)$$

where *min* and *max* are user inputs.

- *Small*: Large membership for small input values represented by a sigmoid shape.

$$\mu_{(x)} = \frac{1}{1 + x^{f_1}/f_2} \quad (2)$$

where user inputs  $f_1$  is the spread and  $f_2$  is the midpoint.

- *Large*: Large membership for large input values represented by a sigmoid shape.

$$\mu_{(x)} = \frac{1}{1 + x^{-f_1}/f_2} \quad (3)$$

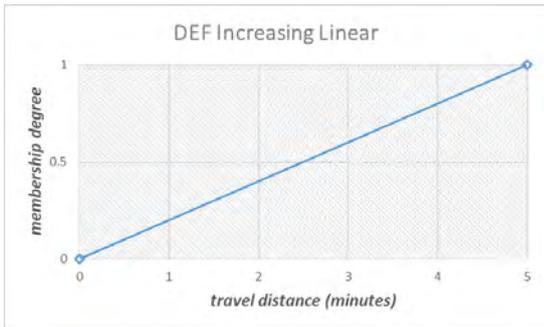
where user inputs  $f_1$  is the spread and  $f_2$  is the midpoint.

Table 1 shows the membership functions subjectively determined for modelling the selected criteria to define the fuzzy suitability membership grades used in this research.

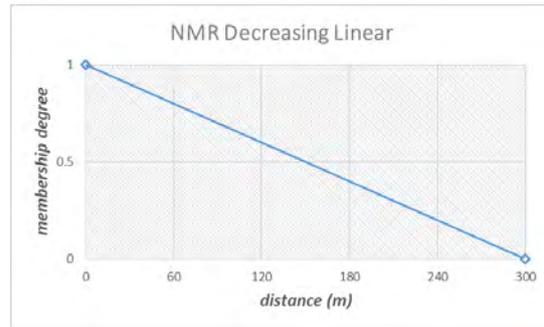
Table 1. Fuzzy membership and respective minimum and maximum suitability values of the selected criteria

Criteria	Fuzzy membership function for fuzzification	Minimum value of suitability	Maximum value of suitability
DEF (coverage area in minutes)	<i>Increasing linear</i>	<i>1</i>	<i>5</i>
NMR (metres)	<i>Decreasing linear</i>	<i>300</i>	<i>0</i>
DER (PGA values in g)	<i>Small</i>	<i>2.38</i>	<i>0.05</i>
HPD (people per hectare)	<i>Large</i>	<i>0</i>	<i>1,333.2</i>
HMD (no. of, per sub-district)	<i>Large</i>	<i>0</i>	<i>153</i>
WBD (ratio of, per total building numbers)	<i>Large</i>	<i>0</i>	<i>1,781.8</i>

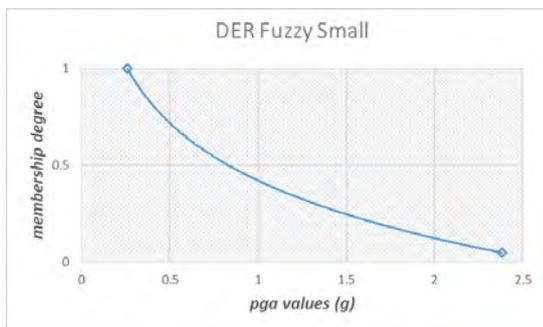
The representative fuzzy membership functions for the criteria are as illustrated in Figure 2 a) – f).



a) DEF (increasing linear)



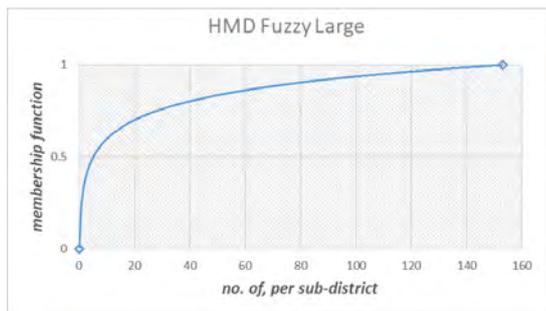
b) NMR (decreasing linear)



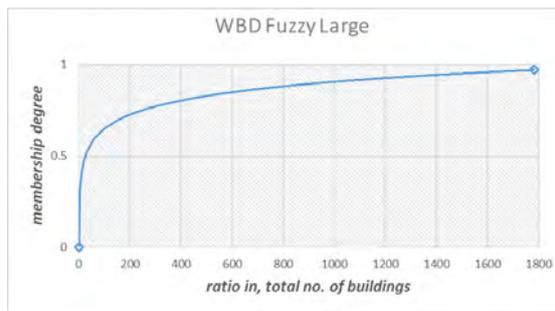
c) DER (small)



c) HPD (large)



e) HMD (large)

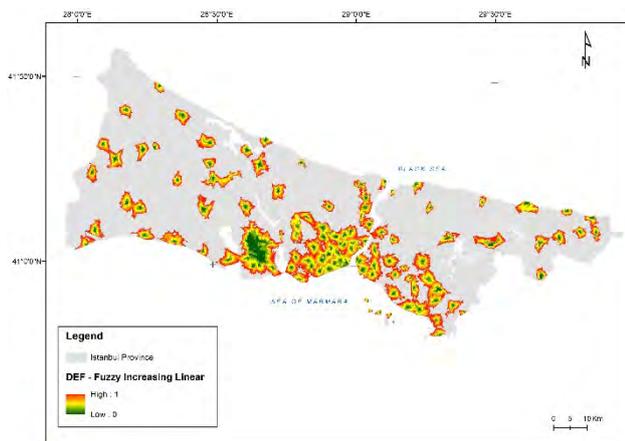


f) WBD (large)

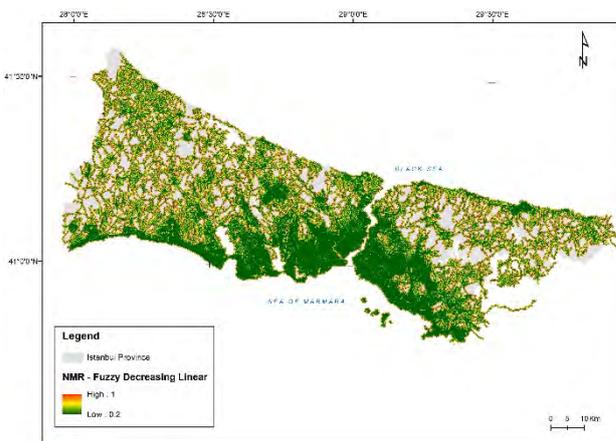
Figure 2. Representative fuzzy membership functions for the a) DEF, b) NMR, c) DER, d) HPD, e) HMD and f) WBD criteria

The *fuzzy increasing linear* function for the DEF criterion assigned high fuzzy membership to large user-specified travel distance values (in minutes) which increase at a constant rate while the *fuzzy decreasing linear* function for the NMR criterion assigned high fuzzy membership to small distance values (in metres) that decrease steadily. Small PGA (peak ground acceleration value in units of gravity) values for the *fuzzy small* function of the DER criterion were allocated high fuzzy membership. The *fuzzy large* function for the remaining HPD, HMD, and WBD criteria distributed high fuzzy membership to their respective large values.

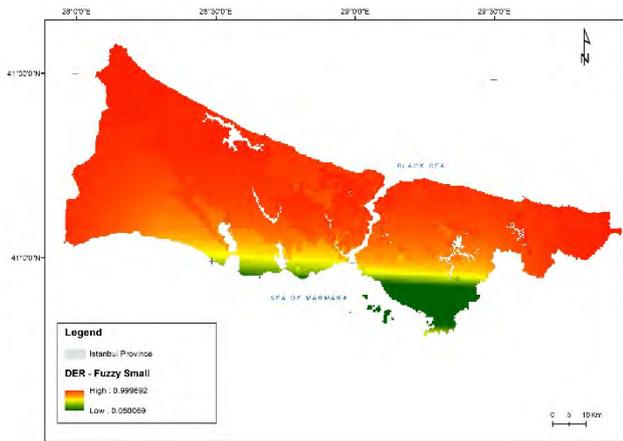
The corresponding fuzzified criteria map layers were as displayed in Figure 3 a) – f).



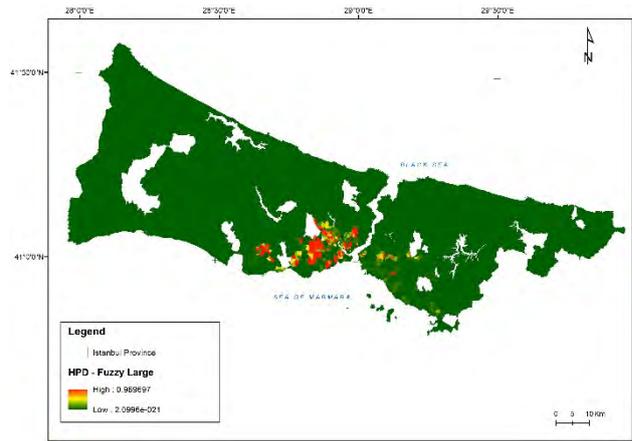
a) Fuzzified DEF criterion map layer



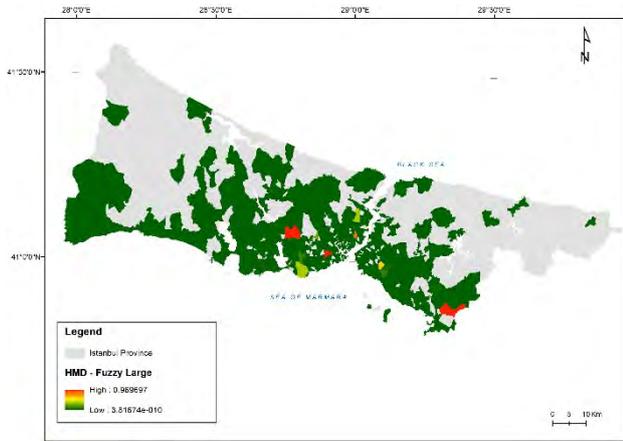
b) Fuzzified NMR criterion map layer



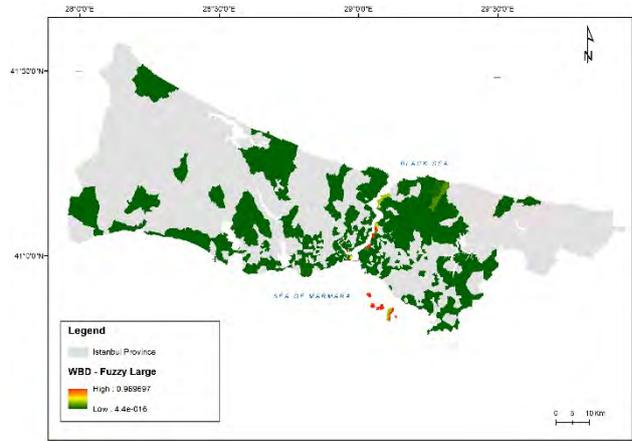
c) Fuzzified DER criterion map layer



d) Fuzzified HPD criterion map layer



e) Fuzzified HMD criterion map layer



f) Fuzzified WBD criterion map layer

Figure 3. Fuzzified map layers for the a) DEF, b) NMR, c) DER, d) HPD, e) HMD and f) WBD criteria

### 2.3.2 Fuzzy overlay operators

The following fuzzy operators were reviewed for use as appropriate overlay aggregator types of each raster cell's membership to the multiple input criteria map layers relative to the desired fuzzy suitability map output: Fuzzy OR, Fuzzy AND, Fuzzy PRODUCT, Fuzzy SUM, and fuzzy GAMMA (Raines, Sawatzky and Bonham-Carter 2010).

#### 1. Fuzzy OR

The Fuzzy OR is a maximum operator described by the union function based on the Boolean OR logic, which takes the maximum (largest) membership value for a particular location of the output map layer.

It is specified by the equation:

$$\mu_{(x)} = \text{Max} (\mu_A, \mu_B, \mu_C, \dots) \quad (4)$$

where  $\mu_{(x)}$  indicates the degree of membership of  $x$  in a specified map layer and  $\mu_{(A)}, \mu_{(B)}, \mu_{(C)}$  etc. are the membership values of the map layers  $A, B, C$  at a particular location.

## 2. Fuzzy AND

The Fuzzy AND is defined by the intersection function, given as the minimum (smallest) membership value for a particular location of the output map layer, expressed by the equation:

$$\mu_{(x)} = \text{Min} (\mu_A, \mu_B, \mu_C, \dots) \quad (5)$$

## 3. Fuzzy PRODUCT

The Fuzzy PRODUCT operator generates an output function at a particular location that is less than or equal to the given lowest function of all the input map layers and therefore has a decreasing effect because of the multiplication of each map layer's membership value.

It is given by the equation:

$$\mu_{product} = \prod_{i=1}^n \mu_i \quad (6)$$

where  $\mu_i$  is the membership value of the  $i^{\text{th}}$  map layer at a specified location and  $n$  is the number of respective maps to be multiplied.

## 4. Fuzzy SUM

The Fuzzy SUM is complementary to the fuzzy product operator and can be described by the following equation:

$$\mu_{sum} = 1 - \prod_{i=1}^n (1 - \mu_i) \quad (7)$$

where  $n$  is the number of map layers to be integrated and  $\mu_i$  is the membership value of the  $i^{\text{th}}$  map layer.

The combined effect of the input map layers is larger (or equal to) the largest membership value and therefore this operator has a resultant increasing effect at a defined location.

## 5. Fuzzy GAMMA

The Fuzzy GAMMA operator is an algebraic product of the two Fuzzy SUM and Fuzzy PRODUCT, which are both raised to the power of gamma therefore moderating the increasing and decreasing effects, respectively.

The general form of the function is characterized by the equation:

$$\mu_{\gamma} = (\prod_{i=1}^n \mu_i)^{1-\gamma} \cdot (1 - \prod_{i=1}^n (1 - \mu_i))^{\gamma} \quad (8)$$

where  $\gamma$  is a user input variable selected from the range [0, 1].

When the specified gamma is 1, the output is equivalent to the Fuzzy SUM and if gamma is 0, the combination is the same as Fuzzy PRODUCT. In-between values permit combinations between these two extremes, thereby establishing relationships between input criteria without returning the value of a single membership function as does either the Fuzzy OR and Fuzzy AND. Therefore, the optimization of membership combination can be achieved by the proper selection of the gamma.

Fuzzy GAMMA can be used when values greater than Fuzzy PRODUCT but less than Fuzzy SUM are desired.

### 3. RESULTS AND DISCUSSION

#### 3.1 Development of the fuzzy overlay model

The fuzzy overlay analysis was implemented in ESRI ArcGIS 10.3 software using the *fuzzy membership* tool for assigning appropriate ratings of 0 to 1 scale for the input criteria raster map layers based on the respective fuzzification algorithms. Aggregation of the multiple fuzzy membership result layers into the fuzzy suitability map was performed using the *fuzzy overlay* tool. Figure 4 shows the fuzzy logic model that was executed using the *ModelBuilder* application of ArcGIS for automating the sequences of geoprocessing tools and workflows.

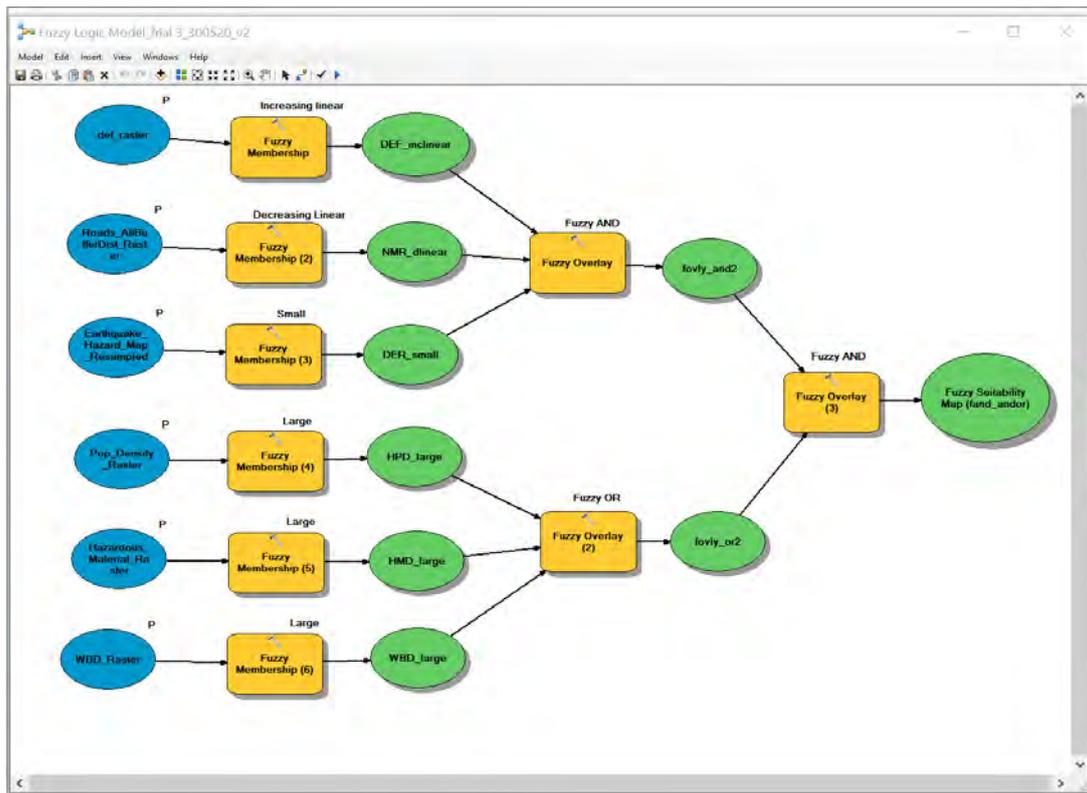


Figure 4. The fuzzy overlay model geoprocessing workflow for fuzzy suitability map generation

In the fuzzy overlay analysis, as shown in Figure 4, the fuzzy AND operator was used to merge the fuzzified DEF, NMR, and DER criteria while the fuzzy OR operator was performed to combine the remaining HPD, HMD and WBD criteria. The selection of the appropriate combinations of fuzzy overlay operators was subjectively done based on the visual inference of outputs and how the evidence rasters interact. The use of these operators provided a greater flexibility level compared to the *weighted-sum* or *weighted-overlay* procedures because they allowed for the incorporation of greater sensitivity based on expert knowledge and inference of desired result rasters (Raines, Sawatzky and Bonham-Carter 2010). For the final procedure, the fuzzy AND operator was used to aggregate the preceding map results from both the fuzzy AND and OR operators to generate a fuzzy suitability map of new emergency facility locations. The fuzzy suitability result map produced in this process is illustrated in Figure 5.

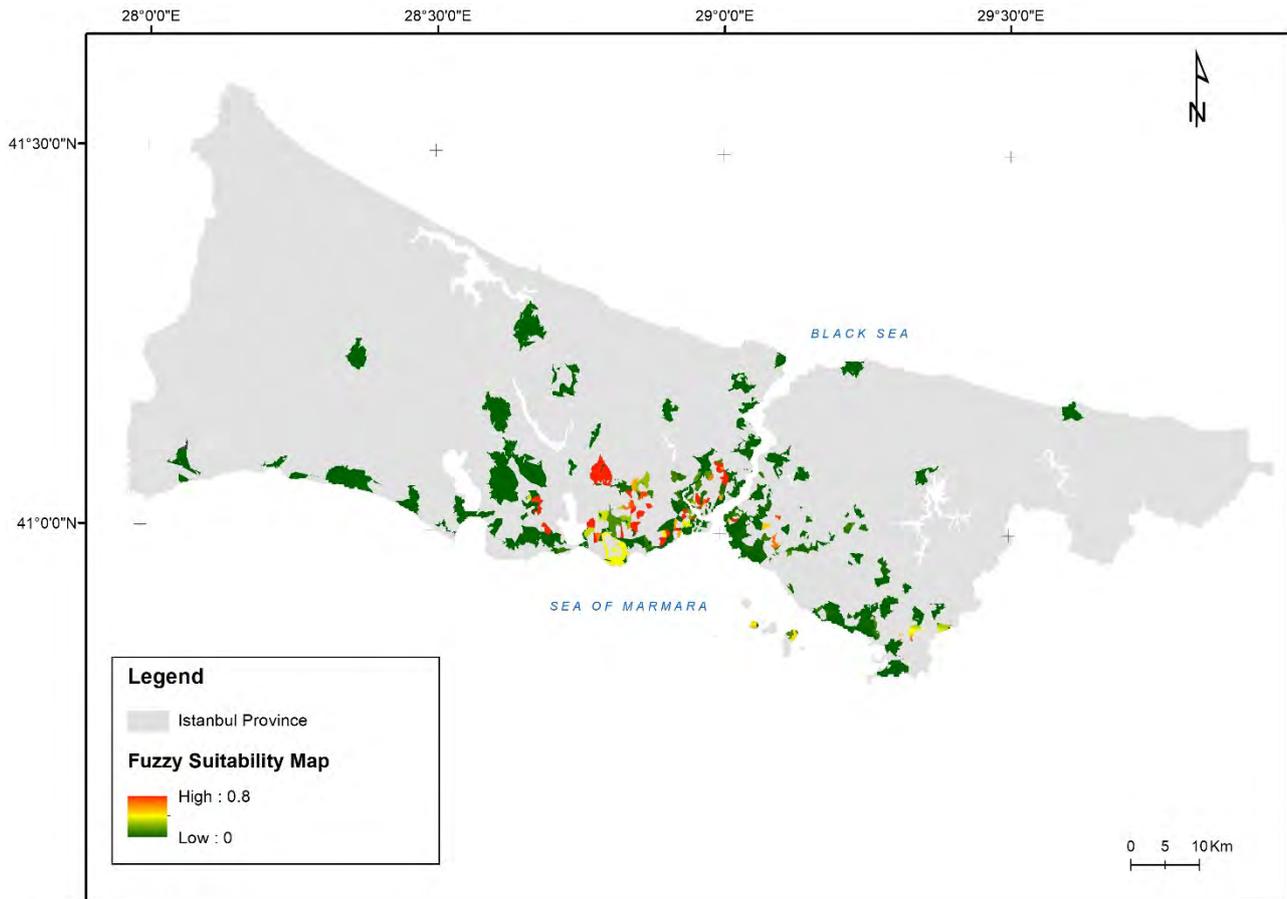


Figure 5. Fuzzy suitability map

As observed from the fuzzy suitability map, the fuzzy values ranging from 0 to 1, represent areas of lowest and highest suitability, respectively which also coincide with corresponding zones of lowest and highest risk of urban fires. This fuzzy map result indicated the continuous spatial variation of the suitability indices for new emergency facility sites as well as the potential urban fire risk phenomenon under investigation in this study. The fuzzy membership methodology was considered appropriate for boundary definitions between the suitability classes and as reiterated by Burrough and McDonnell (1998), is a better approach compared to conventional methods which tend to lose information and increase the likelihood of errors. This is characteristic of spatial problems involving imprecise data.

### 3.2 Final suitability map of new emergency facilities

*Defuzzification* procedure was executed using the *reclassify* tool, to convert the fuzzy scaled values of the map into a final suitability map with the new re-scaled range of crisp values that could be easier to visually interpret by most users. The *natural breaks (Jenks)* classifier method was used to classify the map into five class values ranging from 1 to 5, indicating the least and highest suitability, respectively as shown in Figure 6.

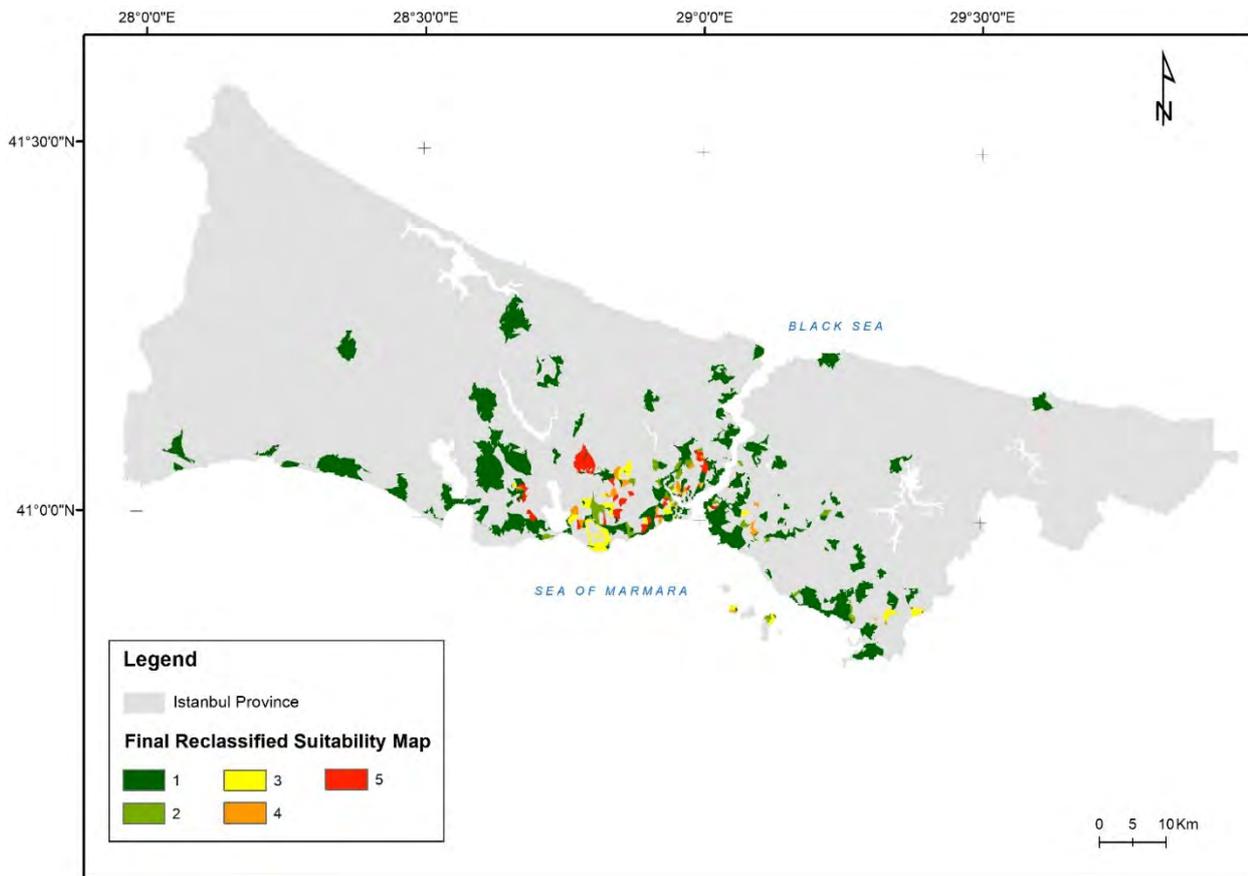


Figure 6. Final reclassified suitability map of new emergency facilities in Istanbul province

From the final conventional suitability map shown in Figure 6, the clear-cut boundary class values labelled 1, 2, 3, 4, and 5 represent classes depicting suitability ranging from *very low*, *low*, *medium*, *high*, and *very high* respectively.

Most of the areas with high suitability shown in yellow, orange, and red colour were concentrated around the most densely populated city centres of Istanbul. These are highly urbanized clusters of large commercial/industrial, trading and tourist activities that are prone to the risk of urban fire and are in urgent need of new emergency facilities for adequate fire protection and related services. Particularly, these potentially high-risk areas are situated in the district regions that include Fatih, Beyoğlu, Şişli on the European side of Istanbul while those on the Asian side consist of Üsküdar, Kadıköy and Ümraniye.

#### 4. CONCLUSIONS

The potential of the use of fuzzy logic multi-criteria evaluation in a GIS-based suitability modelling framework has been demonstrated by mapping the optimal distribution of new emergency facility locations in Istanbul province to augment complex planning and decision-making processes. The fuzzy logic modelling procedures involved data collection and processing into criteria map layers, fuzzification (fuzzy membership assignment) of each raster criterion map layer, aggregation into a fuzzy suitability map by use of fuzzy overlay analysis using a fuzzy inference process, reclassification into a final suitability map and result evaluation.

Visual interpretation of the final suitability map output indicates favourable locations for planning new emergency facilities distributed around the most densely populated and industrial zones of Istanbul. These areas ranging from *moderate* to *very high* suitability shown in corresponding *yellow*, *orange*, and *red* colours which also depict exposure to urban fire risk requiring urgent planning of new emergency facilities as a remedial action.

The effectiveness of the use of the GIS-based fuzzy logic multi-criteria model approach that is easy to implement has been established in providing a suitability map. The model output could be used by decision-makers, planners and policy-makers to reliably and comprehensively plan for the necessary fire protection and emergency services as well as in solving spatial emergency facility location problems within the context of planned future urban growth.

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# GEOSPATIAL ASSESSMENT OF SOIL EROSION ON TIME SERIES USING EROSION POTENTIAL MODEL AND GEOSPATIAL TECHNOLOGIES

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## **Abstract**

*The present study aims to estimate average erosion and investigate spatial distribution of soil loss as well as the calculation of the amount of removed soil in the period between 2000 and 2018. In order to be achieved soil erosion potential and sediment yield in Mitrovica region (Kosova), Erosion Potential Model (EPM) also known as Gavrilovic method has been implemented, as the most used model in our region. The EPM is a quantitative method of estimation soil loss. An approach of Geographic Information System (GIS) and Remote Sensing (RS) have been presented and demonstrated in the present study. The model was implemented in two time series, annually. The input data such as climate parameters (precipitation and temperature) as well as other parameters (geology, topography, land cover) have been collected and recorded from different local and freely available datasets. Unavailable or unreliable data necessary for the model are calculated within the software procedure. Because of the lack of input data according the requirements of the model, the necessary data have been computed. The combination of GIS and RS have enabled to develop the reliable model. The performed results on this study will be  $m^3/km^2/year$ . The spatial-temporal distribution of erosion intensity maps and soil loss map in two time series were generated as thematic maps of 20m spatial resolution.*

**Keywords:** Erosion Potential Model, Geospatial Technologies, Erosion Intensity, Soil Loss, Time Series Maps.

## **INTRODUCTION**

One of the nine leading processes causing soil degradation in the European countries is soil erosion (Dragicevi, 2016). Soil erosion is a process of mechanical detachment of the soil under the influence of erosive agents such as water and wind that consists of a detachment of soil practices, transportation of detached soil and its deposition (Dragicevi, 2016). Blinkov (2012) pointed out that the difference between soil loss and sediment production (erosive material production) is the crucial thing. The main influence on erosion processes are considered to have climate, soil, topography, vegetation cover and antropogenic factors (Dragicevi, 2016). Techniques like remote sensing and GIS are nowadays applied to evaluate erosion risk (Elhag et al., 2019). Erosion rate is very sensitive to both climate and land use, therefore southern Europe and the Mediterranean region is particularly prone to erosion because it is subject to long dry periods followed by heavy bursts of erosive rain, falling on steep slopes with fragile soils (Globevnik et al., 2003). Because of the uncontrolled deforestation, inappropriate land use and due to human impact, the Mitrovica region is highly exposed to erosion. For assessment of soil erosion risk, generally, three types of approaches exist in Europe (Eskelmann et al., 2006): qualitative approach, quantitative approach and model approach, all of which vary in their characteristics and applicability (Milevski, 2015). In last two decades, already developed models and approaches are improved through the

use of geospatial databases developed using GIS technology. There are several well-evaluated empirical models such as USLE, RUSLE, PESERA, etc. Moreover, a widespread empirical model is the Erosion Potential Model (EPM), also known as Gavrilovic method (Gavrilovic, S., 1962; 1970; 1972), as long as its modifications (Lazarevic, 1968a; 1985). The method takes under consideration six factors, depending on surface geology and soil properties (Y coefficient/ erodibility factor), topographic features (mean slope, J), climatic factors {mean annual rainfall (H), mean annual temperature (T)}, land use type and distribution (x coefficient/ soil protection factor) and the catchment's degree of erosion ( $\phi$ , erosion and stream network development coefficient) (Efthimiou et al., 2016). Efthimiou et al. (2016) pointed out that EPM has been widely implemented throughout the Balkans as well as in other countries [Serbia (Gavrilovic Z., 1988), Croatia (Petras et al., 2005), Slovenia (Zemljic, 1971), Germany (De Cesare et al., 1998), Italy (Fanetti and Vezzoli, 2007; De Vente et al., 2006), Argentina (Rafaelli et al., 1998), Belgium (De Vente and Poesen, 2005), Greece (Stefanidis et al., 1998; Emmanouloudis and Filippidis, 2002; Emmanouloudis et al., 2003; Kalinderis et al., 2009)], providing reliable results on qualifying soil erosion severity, estimating mean annual soil loss/ sediment yield as well as implementing torrent regulation and other erosion control measures. The assessment of soil erosion and sediment transport in hydrological catchment is imperative, in different temporal and spatial scales, in order to protect and preserve soil (Efthimiou et al., 2016). Empirical models are widely applied, especially in countries where the availability of input data is often scarce and the validity ambiguous (such as Kosova, Mitrovica), because of their simplicity and ease of use, having less input data and computations demands than the comprehensive ones (Efthimiou et al., 2016). The present study demonstrate the incorporation of EPM into GIS environment, in which was tested and implemented in detail the Mitrovica erosion. Considering the abovementioned issues, the present study aimed to assessment the soil erosion in two time series, 2000 and 2018. The Mitrovica area was selected for this purpose because of the climatic, topographic and anthropogenic parameters. The EPM was implemented into GIS environment in full accordance with its requirements. The remote sensed data were used to compute specific parameters according to model requirements. The erosion process is one of the key issue in the process of environmental monitoring and management, thus it should be taken into account and should be addresses as well.

## STUDY AREA

The Mitrovica is bounded in the north part of Republic of Kosova, only 25 km from the capital Pristina. The study area extends along to shore of the Sitnica river. The study area bounded coordinates are in the North ( $42^{\circ}57'02''$  and  $20^{\circ}54'36''$ ) and the South ( $42^{\circ}52'13''$  and  $20^{\circ}54'19''$ ). The total study area covered  $41\text{km}^2$ , while the minimum elevation is 502m and the maximum elevation is 991m. The annual average precipitation is around 750 mm and moderate winds blowing predominantly from the northeast, average speed ranges 20 m/sec to 4.4 m/sec (Maliqi et al., 2018). Average speed ranges 20 m/sec to 4.4 m/sec. As well as the winters are colder with medium temperatures above  $-10^{\circ}\text{C}$ , but sometimes down to  $-26^{\circ}\text{C}$ . The summers are very hot with average temperatures of  $20^{\circ}\text{C}$ , sometimes up to  $37^{\circ}\text{C}$  (Maliqi et al., 2018). The study area consists of 15 settlements including here urban and rural area. The Republic of Kosova map in which is located study area, is shown in the Figure 1.

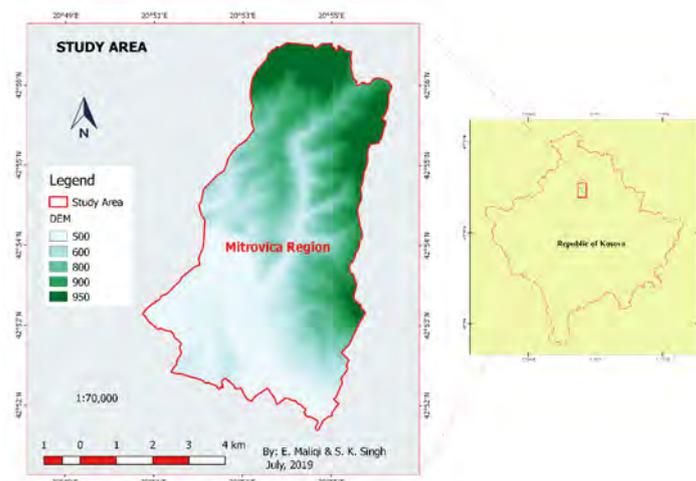


Figure 1. Map of the study area.

## DATA AND METHODOLOGY

It is known that many empirical approaches for the intensity of soil erosion and sediment transport cannot be easily applied in different countries, despite many efforts to make truly ‘universal’ models (Kostadinov et al., 2018). One of the most widely known and accepted model for erosion estimation and sediment transport in the Balkan region, East and Central Europe, is the Erosion Potential Model (EPM), also known as Gavrilovic method.

### The Erosion Potential Model (EPM)

According to the method, the annual volume of detached soil due to erosion has been calculated by the following equation (eq. 1.). The Equation 1 is the average annual erosion, which can be expressed as follow:

$$W = T \cdot H \cdot \pi \cdot \sqrt{z^3} \cdot F \quad (1)$$

Where, W is the average annual erosion ( $m^3 \text{ year}^{-1}$ ), T is the temperature coefficient, h is mean annual rainfall (mm), F is the catchment area ( $km^2$ ).

The equation which calculates the temperature coefficient is (eq. 2.)

$$T = \sqrt{\left(\frac{t^2}{10} + 0.1\right)} \quad (2)$$

Where, t is mean annual temperature ( $^{\circ}C$ ).

The erosion coefficient (z), being the measure of intensity or density of erosion processes (Staut, 2004) was calculated by next equation (eq. 3.) It is known as risk coefficient as well.

$$z = x \cdot y \cdot (\varphi + \sqrt{J}) \quad (3)$$

Where x is the soil protection coefficient, y is the soil erodibility coefficient,  $\varphi$  is the erosion and stream network catchment and J is the average slope of the watershed (%) (Efthimiou et al., 2016).

Zemljic (1971) has classified the z coefficient and the table 1 is presented as follow.

Table 1. Classification of the z coefficient.

Erosion Intensity	z
Very low	<0.19
Low	0.20 - 0.40
Moderate	0.41 - 0.70
High	0.71 - 1.00
Very high	>1.00

Having calculated the total annual soil erosion rates, we calculated the sediment delivery ratio, which is needed for the actual sediment yield calculation (Kostadinov et al., 2018). The appropriate form of the equation in order to determine sediment delivery rate was suggested by Gavrilovic as follow:

$$R_u = \frac{\sqrt{O \cdot D}}{0.25 \cdot (L + 10)} \quad (4)$$

Where,  $R_u$  is the coefficient of retention of the eroded material, O is perimeter of watershed (km), D is average differences of elevation of the watershed (km) and L is length of the watershed (km).

By multiplying the potentially eroded material and the coefficient of the retention ( $W_{\text{year}} * R_u$ ), the average annual sediment transport (G) arriving at the mouth, will be calculated as:

$$G_{\text{year}} = W_{\text{year}} * R_u \text{ (m}^3\text{/year)} \quad (5)$$

## Source data and Data processing

The present study were conducted by using the secondary data. The data sets have been collected and processed to derive soil erodibility factor, mean slope, mean annual rainfall, mean annual temperature, soil protection factor, erosion, and stream network coefficient (Maliqi and Singh, 2019). The secondary data were considered data which are not captured directly from the environment. Numerous source data were obtained and used in the present study (Maliqi and Penev, 2018). The modeling is based on the numerical evaluation of the factors that influence erosion using classification and quantitative methods (Milevski and Ivanova, 2013). The erodibility factor (Y) was obtained on the basis of geological map in scale 1:100000, which was digitized in GIS software. In the appropriate procedure coefficients within the study area were given to the lithology units in form of soil erodibility coefficient (Y).

The dataset images used in the study were obtained from Landsat 7 and Landsat 8 in different time series (2000 and 2018) provided by U.S. Geological Survey. The spatial resolution of Landsat 7 (2000) and Landsat 8 (2018) used has been 30m. The Landsat 7 Enhanced Thematic Mapper (ETM) and Landsat 8 OLI/TIRS were downloaded from U.S. Geological Survey through EarthExplorer ([www.earthexplorer.usgs.gov](http://www.earthexplorer.usgs.gov)). The Landsat 7 ETM datasets for 2000 and Landsat 8 OLI/TIRS datasets for 2018 of Mitrovica have with 30m spatial resolution. The spectral band 3 of Landsat 7 ETM and band 4 of Landsat 8 OLI/TIRS, have been used in order to generate the erosion and stream network catchment coefficient ( $\phi$ ). The Land Cover map was provided by Copernicus Land Monitoring Service ([www.land.copernicus.eu](http://www.land.copernicus.eu)). The CLC 2000 and CLC 2012 datasets were used and in this way the soil protection coefficient (x) has been generated. Because of the lack of updated Corine Land Cover dataset (for 2018), in the present paper CLC 2012 dataset was used instead of the CLC 2018. In order to generate the average slope of the watershed in percentage (%) the J factor, 20m ALOS (Advanced Land Observation Satellite) Digital Elevation Model (DEM) was used. The GIS software has been used to calculate the average slope of the study area in percentage (%) from ALOS DEM. The climate coefficients such as the Temperature coefficient (T) of 2000 (base year), were obtained from 1km resolution WorldClim (v.2.0) ([www.worldclim.org](http://www.worldclim.org)). The 2018 (comparative series) temperature coefficient (T) was calculated by using the algorithm given by Avdan and Jovanovska (2016). The algorithm uses USGS formulas, which in the present paper have been used to calculate Land Surface Temperature (LST) using the Landsat 8 bands. This methodology requires applying a set of equations through raster calculator in any GIS software (QGIS). In particular the methodology requires band 10, band 4 and band 5 to calculate the LST. The same methodology was used, in order to calculate the T coefficient for the 2018. The mean annual rainfall in mm (H) was generated by applying vertical gradient method because the lack of the permanent active meteorological stations in Mitrovica or within the study area. The h factor was prepared by combining the real data from meteorological stations in Republic of Kosovo and corresponding vertical gradient. Due to various sources of input data, which were obtained and collected in different formats and reference systems. Data harmonization process is made at first. The input data were processed in QGIS software and the reference system in which all data were transformed has been KosovaRef01 (Kosovo coordinate system), a local coordinate system in Gauss-Kruger projection in ETRS89 datum. In order to improve the data quality, the satellite imagery geometric corrections were done as well. The cartographic outputs (Erosion Intensity map & Average annual erosion map) were generated for two time series (2000 and 2018) and the digital maps were generated in the GeoTIFF format. The unsupervised classification methodology was selected that the cartographic output to be classified as a multicolor pattern in order to show the maps range values or map classes. It has helped that maps to be interpreted easily. The implementation of EPM in the present study area, was done supporting geospatial technologies such as Remote Sensing (RS) and GIS, thus the maps layout was compiled using the QGIS software tools.

## MODEL IMPLEMENTATION

In order to determine each individual factor according EPM requirements were processed the input data, described in the previous chapter (Chapter 3). According this approach were calculated the model factors, based on mentioned equations (Eq. 1 & Eq. 3). In general this was done into GIS environment and raster calculator in particular. Each factor required by EPM was modeled in the form of digital map (vector and raster). However, the final format of individual factor was converted into the raster format to make suitable for model implementation (Maliqi and Singh, 2019). The EPM flowchart has been sketched in the following diagram, adapted by Efthimiou et al. (2016). This diagram (Figure 5) clearly has expressed the origin of the factors and data modelling according the EPM method, which is based in the input data as well. In order to be analyzed in detail the soil loss and intensity, the model has incorporated two main equations (Erosion Intensity & Average annual erosion), which will be explained in the next sub-chapter. This approach

has been repeated in two time series (2000 & 2018) and cartographic output (Erosion intensity maps & Average annual erosion maps) was performed.

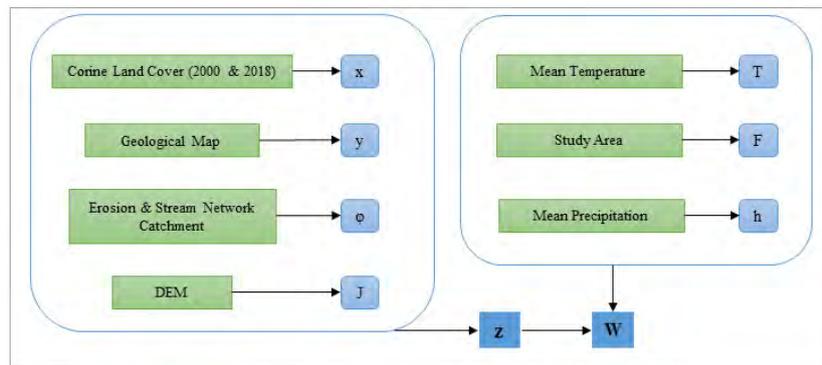


Figure 5. The flow diagram (adopted by Efthimiou et al., 2016).

### Erosion intensity

In order to determine the erosion coefficient ( $z$ ), the calculation of the each individual factor through Equation 3. is required (Efthimiou et al., 2016). The erosion intensity or erosion risk was calculated based on soil protection coefficient ( $x$ ), the soil erodibility coefficient ( $y$ ), the erosion and stream network coefficient ( $\phi$ ) and the average slope ( $J$ ). This derive from empirical composition of the equation (Eq. 1). According the  $z$  coefficient values based on the Zemljic (1971) classification and equal interval classification used into GIS environment, the erosion intensity maps in two time series fall in five categories (Table 1). The most of area for the 2000 erosion intensity map falls in these categories “Moderate” ( $0.41 < z < 0.70$ ), “High” ( $0.1 < z < 1.0$ ) and “Very high” ( $z > 1.0$ ). In the same methodology was acted for the erosion intensity map of 2018, as well as the most of area in 2018 serie falls in these three categories: “Low” ( $0.20 < z < 0.40$ ), “Moderate” ( $0.41 < z < 0.70$ ) and “Very high” ( $z > 1.0$ ). The coefficient translated in the percentage ranges as follow; to the erosion intensity map of 2000 according equal interval classification in GIS the “Moderate” is 23.4%, “High” is 31.7% and “Very high” is 27.5%. The erosion intensity maps of 2018 according equal interval classification as well, has demonstrated that most of the study area fall in categories: “Low” is 19.6%, “Moderate” is 39.7% and “High” is 27.3%. The erosion intensity coefficient ( $z$ ) can be viewd as a soil loss indicator as well.

The following figures (Figure 6) has shown visually the comments explained above. The cartographic outputs (raster maps) have been compiled in full accordance with the EPM equation requirements with 20m spatial resolution using unsupervised raster classification methodology, exactly equal interval classification supported by QGIS software. Then, the  $z$  coefficient will be included in the calculating of the average annual erosion ( $\text{m}^3\text{year}^{-1}$ ) but in the appropriate form that the EPM equation (Eq. 1) requires. In the table below (Table 2), has been calculated and expressed several important data derived from the study. These data were generated in order to validate the erosion intensity coefficient ( $z$ ). In the current form and format, these data including erosion intensity maps in the raster format for 2000 and 2018 (Figure 6) and analytical calculations derived from this, will be used easily for multiple purposes. The erosion insteniry coefficient if one of the most generated parametrs in order to calculate spatial soil loss as a mian objective of the present study and it will be addressed in the following sub-chapter.

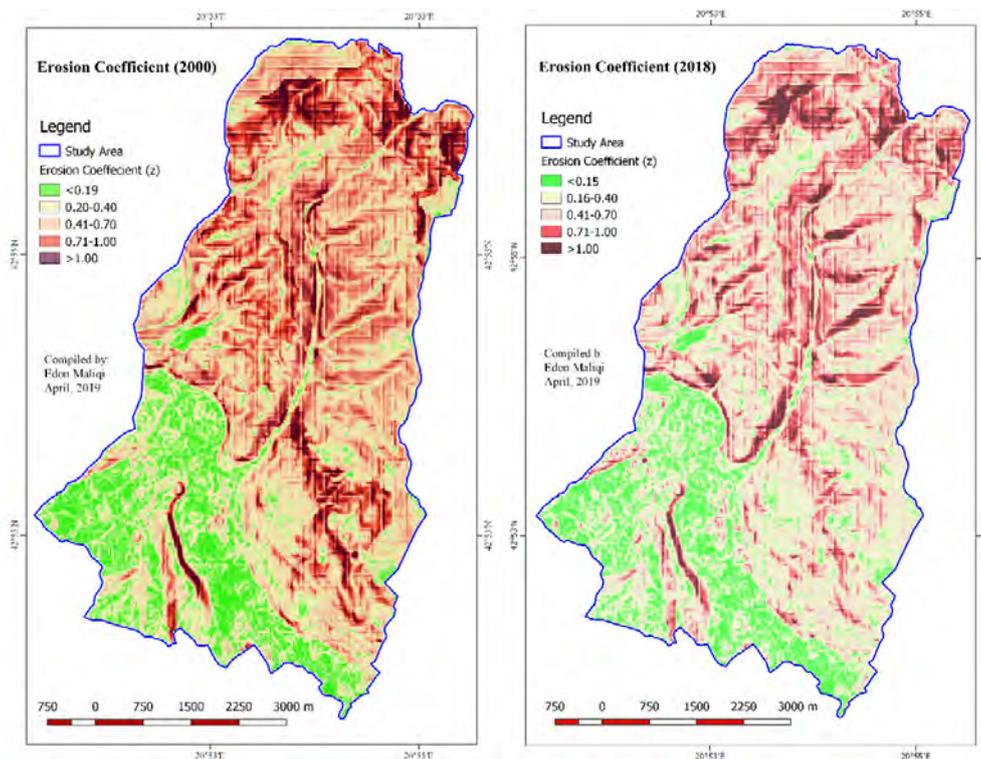


Figure 6. Erosion intensity ( $z$ ) map for 2000 & 2018.

By analysing carefully the below table (Table 2), we can see that there are some decreases and increases throughout the erosion intensity categories, within the study area. The interpretation of the performed results in the table between two time series (2000 and 2018) tell us that the most decrease is in the “Very high” category (16.2%) and the most increase is in the “Moderate” category (16.4%).

Table 2. Time series data of erosion intensity coefficient ( $z$ ) according Equal Interval classification.

EQUAL INTERVAL CLASSIFICATION									
Year	$z$	Area km <sup>2</sup>	Area (ha)	Area (%)	Year	$z$	Area km <sup>2</sup>	Area (ha)	Area (%)
2000	Very low	1.43	143.00	3.49	2018	Very low	0.83	83.00	2.02
	Low	5.70	570.00	13.89		Low	8.05	804.70	19.61
	Moderate	9.60	960.00	23.40		Moderate	16.3	1630.30	39.73
	High	13.00	1300.00	31.68		High	11.21	1121.40	27.33
	Very high	11.30	1130.00	27.54		Very high	4.64	464.00	11.31
	<b>Total</b>		<b>41.03</b>	<b>4103</b>		<b>100</b>	<b>Total</b>		<b>41.03</b>

## Soil erosion potential

Nowadays, various models are being applied for soil erosion assessment. Erosion Potential Model has the potential to estimate erosion and sediment transport in the Balkan region, East and Central Europe (Maliqi and Singh, 2019). There are several classifications of these soil erosion models and one of them is conceptual model in which falls EPM. According to Thiemann (2006), conceptual models provide an indication of quantitative and qualitative processes within a watershed. The present study demonstrate the EPM as a quantitative approach. The methodology for the soil erosion assessment method selection is based mainly on in two criteria: area of the study area and input data availability. The literature has shown that EPM has significant role in the soil erosion assessment in local scale. The evolution of the Gavrilovic (EPM) model has began with the use of geospatial technologies such as GIS and RS. In the present study were generated the soil erosion maps in two time series (2000 and 2018). The raster soil loss maps were compiled with 20m spatial resolution in two time series. The detached soil map of 2000 has shown that the minimum volume of the detached soil was under 100 m<sup>3</sup>/km<sup>2</sup>/year, whereas the maximum volume of the detached soil was above 2000 m<sup>3</sup>/km<sup>2</sup>/year. This raster map were classified in five classes based on (Equal Interval classification) unsupervised methodology supportin by QGIS software (Figure 7). Based on the same methodology was acted in the comparative

serie (2018) and the output raster has shown that the minimum volume of the detached soil was under  $150 \text{ m}^3/\text{km}^2/\text{year}$ , as well as the maximum volume of the detached soil has been above  $2200 \text{ m}^3/\text{km}^2/\text{year}$ . In addition the soil erosion raster map was classified in the five classes as well (Figure 7). The minimum difference of the detached soil volume between 2000 to 2018 series was  $50 \text{ m}^3/\text{km}^2/\text{year}$  and the maximum difference of the soil loss volume was above  $200 \text{ m}^3/\text{km}^2/\text{year}$ . According time series raster maps, the detached soil based on the EPM model between period 2000 and 2018, to the minimum volume was increased about 0.4% and has been decreased 3.4% to the maximum volume in the total soil loss volume within a single serie. It can be expressed as well for year therefore the increased of the detached soil volume is about 5.5% (the rate per year). The annual sediment transport was  $770.55 \text{ m}^3/\text{km}^2/\text{year}$  in 2000 while it amounted to  $968.8 \text{ m}^3/\text{km}^2/\text{year}$  in 2018. In addition the erosion intensity and detached soil are linked with EPM six factors, which have derived from input data and the accuracy of the input data has affected directly the accuracy of the performed results in this paper. Thielen et al. (1999) and Vogt et al. (2003) pointed out that reliability of the final results within GIS is strongly correlated with the accuracy and level of detail of input data. The lack of the Land Cover dataset of 2018, in the present paper was used dataset of 2012 instead of 2018. Therefore, this has affected the finally result of the study. But this research is at the local scale, so the impact in the performed result has been not relevant almost. The figure 7. demonstrates the potential detached soil in millimeter per year ( $\text{mm}\text{year}^{-1}$ ).

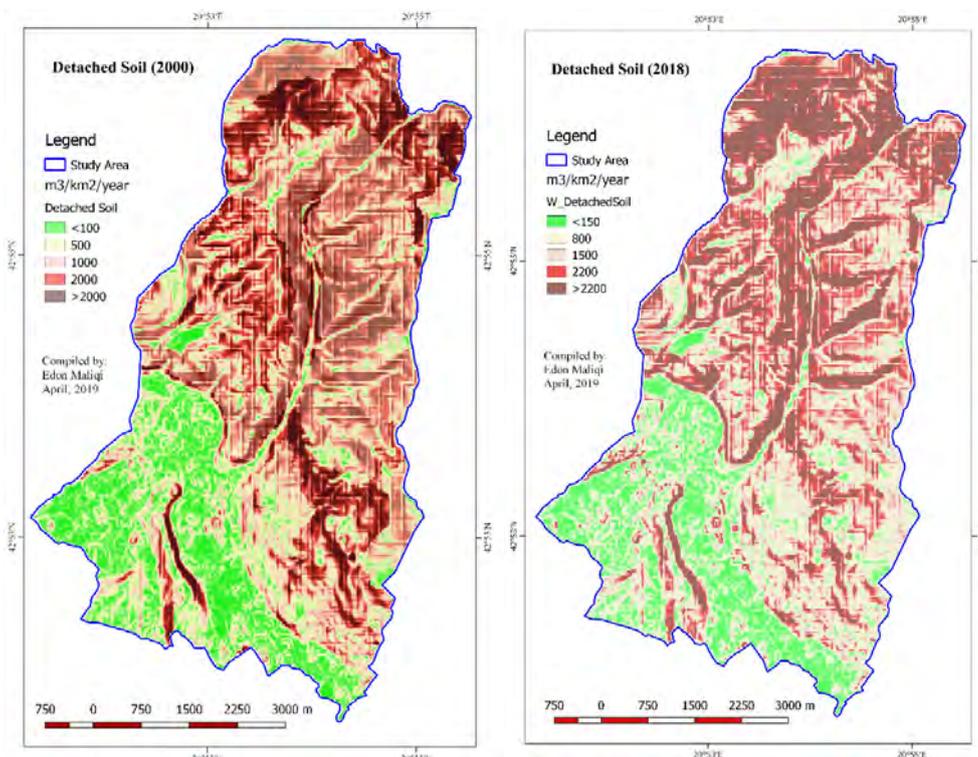


Figure 7. The soil loss map for 2000 & 2018.

## CONCLUSIONS

Geospatial assesment of soil erosion and sediment transport and its mapping is one of the most important technique to determine the changes in environment. There have been no attempts to asses the risk of soil erosion at local and national level in Kosova by using geospatial technologies. The main objective of this study was to apply the Erosion Potential Model (Gavrilovic method) in conjunction with RS and GIS to the Mitrovica region, in order to estimate soil erosion and sediment yield and transport as well as its spatial distribution. The performed results have been in two time series (2000 and 2018) and they were compared as well. In the area of this study from the early years till now, local works on the protection against erosion and torential floods were not carried out ever. Therefore, was chosen to esimate soil erosion and sediment transport in two time series, in two last decades. The erosion is a physical process and control of erosion is a worldwide environmental problem. Hence, the European Commission's Soil Thematic Strategy has defined soil erosion as a significant problem and monitored soil erosion in Europe (Kostadinov et al., 2018). Due to global warming and antropohenic activities such as land use and land cover changes (LULCC), the erosion rate is epected to be increased in this century. The statistics about meteorological conditions in Kosova between 2000 and 2018 has shown that average annual precipitation and mean temperature were increased generally. Beacuse of this, the study has demonstrated that the erosion intensity coefficient and amount of soil loss and sediment yield and transport were increased as well. Numerous data were obtained and used in the present study, which can be named as secondary. These

data were not captured directly from the environment such as erodibility factor, slope, mean annual rainfall, mean annual temperature, soil protection factor, erosion and stream network coefficient. These data were free of charge and the accuracy of the study depends on those secondary data.

The results of the study showed that in 2000 the minimum of the soil loss was under  $100 \text{ m}^3/\text{km}^2/\text{year}$  and the maximum of the soil loss was above  $2000 \text{ m}^3/\text{km}^2/\text{year}$ . As well as the minimum of the soil loss was under  $150 \text{ m}^3/\text{km}^2/\text{year}$  and the maximum of the soil loss was above  $2200 \text{ m}^3/\text{km}^2/\text{year}$  in 2018. Its spatial distribution in two time series was compiled as thematic maps in a raster format with 20m spatial resolution. In the series of 2018, soil erosion was calculated by using the soil protection coefficient (x) obtained from CLC2012 instead of CLC2018 because of the lack of the updated Corine Land Cover dataset (2018), which is expected to be updated soon. As well because of the lack of permanent active meteorological stations within the study area, the vertical gradient method was applied in order to generate the H coefficient. In this way, it was used in two time series. According to field observations, the performed results in the study have been confirmed.

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# MAPPING SOIL PROPERTIES AND RADIONUCLIDES DISTRIBUTION IN POLAR ECOSYSTEMS OF LIVINGSTON ISLAND

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## Abstract

*The purpose of the study is to map the soil properties and distribution of natural radionuclides <sup>40</sup>K, <sup>238</sup>U, <sup>232</sup>Th, and artificial radionuclide <sup>137</sup>Cs along a case study transect in the polar region of Livingston Island (Antarctica). The activity concentrations of radionuclides in surface soil samples collected from 21 experimental sites were analyzed. The studied polar ecosystems are differentiated according to the type of vegetation cover. The results obtained are discussed in relation to soil characteristics such as pH, organic carbon and nitrogen content, mechanical composition. The results for the activity concentration of <sup>137</sup>Cs in the samples are indicative of radionuclide deposition and radionuclide contamination even in the remote polar regions of Antarctica as a consequence of the Fukushima accident (May 2011). The results are visualized using GIS technics generating first soil maps for the polar region of Livingston Island combined with maps of the distribution of the studied radionuclides. The results obtained indicate the presence of great variability of studied indicators and complement the information on polar ecosystem components in the context of radioactive and environmental studies.*

**Keywords:** Soil properties, Radionuclides, Polar ecosystems, Mapping

## INTRODUCTION

Remote and isolated polar areas, such as Livingston Island (South Shetland Islands) are likely to represent pristine environment where the ecological state of the ecosystems are recognized as reference baseline level for concentrations of certain contaminants. In recent years, Antarctica is undergoing rapid and constant environmental changes due to both climate trends and anthropogenic factor. Special interest is paid on distribution of radioactive contaminants, both natural and artificial. The accidents with Chernobyl Nuclear Power Plant (NPP) in 1986 and later with the Fukushima NPP in 2011 resulted in the uncontrolled release of radioactive contaminants into the atmosphere, which affected the environment of the whole world, also the remote Polar Regions. The concentration of the artificially produced radionuclides in Antarctic and sub-Antarctic areas is controlled by their long-range transport. For tropospheric transport, a 30-day transit time of the air masses from distant continental regions to the South Pole has been suggested by Maenhaut et al. (1979). Pourchet et al. (1997) concluded that despite its isolated location, the radioactive fall-out of artificial long-lived radionuclides over Antarctica has been ten times greater than for natural radionuclides. Pourchet et al. (2003) provided a detailed and comprehensive map of the distribution patterns for selected natural and artificial radionuclides over Antarctica and underlining the irregular distribution of the radionuclides and need of more research studies. There is limited knowledge on the distribution patterns and sources of natural and artificial radionuclides in soils of Maritime Antarctica. The distribution and deposition of <sup>210</sup>Pb, <sup>137</sup>Cs and <sup>210</sup>Pb in snow, soil and organisms is mostly studied in the Antarctic Peninsula (Sbrignadello et al., 1994; Roos et al., 1994, Pourchet et al., 1997, 2003). Natural radionuclides such as uranium, thorium and potassium occur in soil minerals and make the major contribution to the total terrestrial gamma-ray flux (Beck, 1972; Kiss et al., 1988). In regards to the artificial radionuclides, the distribution in these remote Polar Regions is related to the airborne transfer of pollutants and nuclear accidents that lead to changes in the radiological status of the components of polar ecosystems.

Knowledge on detail analyses and visualization of soil properties and radionuclides distribution with limited area coverage is needed for further investigations, conservation, and monitoring environmental impacts. Due to atmospheric

conditions remote sensing techniques find limited application for the area of Livingston Island; therefore terrain parameters needed to be obtained on site during the Antarctic summer season. Mapping soil properties such as pH, carbon (C) and nitrogen (N) content, is important to study soil functions, but the spatial resolution and efficiency of statistical models to create accurate soil maps, require a number of samples with an appropriate distribution across the study area.

In this paper, we present methodology for spatial analysis and mapping of a case-study area located in the polar region of Livingston Island in Antarctica based on qualitative biophysical parameters. The applied mapping approach highlights the role of GIS to study the environmental changes in components of the remote polar ecosystems in order to optimize the biomonitoring system in Livingston Island.

## MATERIALS AND METHODS

### Study area description

Livingston Island (62°36'S, 60°30'W) is a part of the South Shetland Islands archipelago and is the second largest after King George Island. The glaciers cover almost entirely the island, where the ice cap occupies 87.6% of the surface and only about 10% of the coastal area is uncovered by ice during the short polar summer (December-February). According to data for Western Antarctic Peninsula, polar territories, characterized by high levels of sensitivity to environmental changes, and give clear picture about the impact and pace of the global climate changes. Over the past 50 years, the average annual temperature has increased by 3.4°C and average winter temperature - by 6.0°C, making the area one of the hottest points of global warming (Bockheim et al., 2013). The average annual temperature on Livingston Island is -1°C and the temperatures are rather constant during the day, reaching 3°C in summer and dropping to -15°C in winter. Strong winds, however, may decrease the real feel and temperatures to drop with 5-10°C lower. The highest daily temperature measured so far is 19.9°C and the lowest is -22.4°C (CEP 2011). The average relative humidity is above 80% and annual wind speed on is 13.3 km/h. The prevailing winds come from south-southwest and maximum wind gust of 150 km/h from east-northeast direction has been recorded in March (Labajo 2008).

The Bulgarian Antarctic Base “St. Kliment Ohridski” (62°38'25.7”S, 060°21'54.9”W) is situated on the northern part of Hurd peninsula and the innermost part of South bay, located on the south part of Livingston Island (Fig. 1). The case-study area represents the ice-free coastal zone near the Bulgarian Antarctic Base (BAB) and sampling sites are selected in terms of accessibility and specific landscape characteristics.

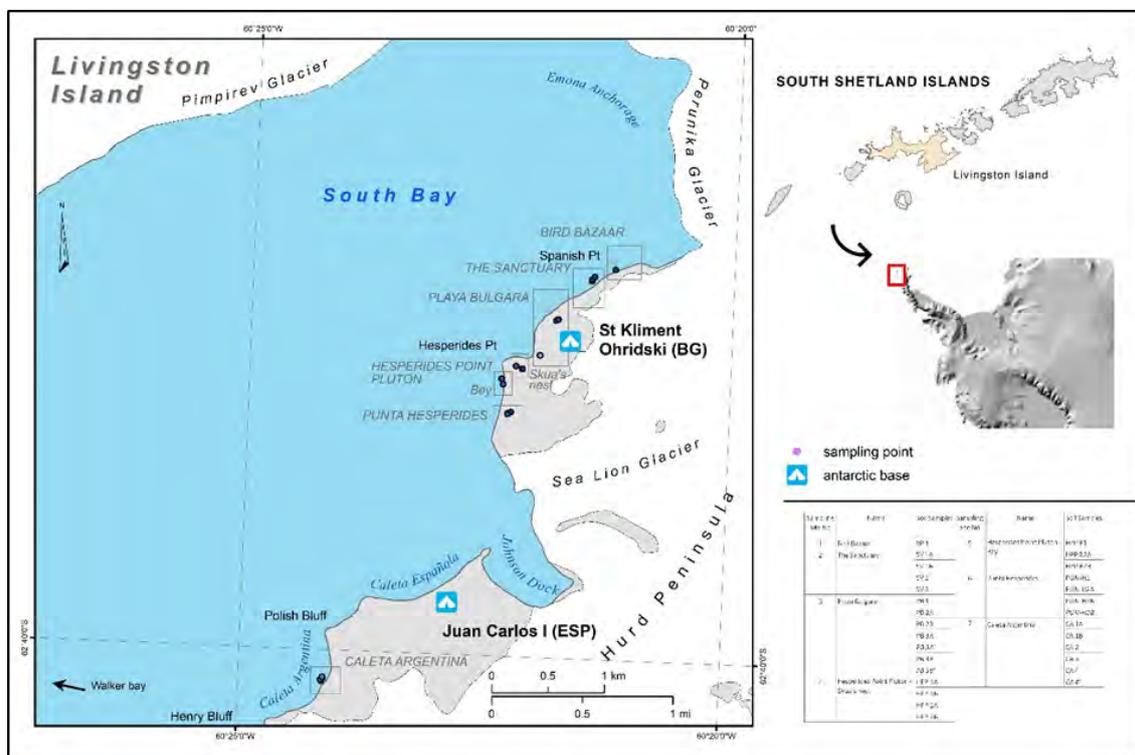


Figure 1. Study plots in the experimental transect of Livingston Island, Maritime Antarctica

All sampled soils referred to the type Gelisols (Latin “gelare” - freezing) and the soil profiles reveals evidence of thaw/freezing processes near the soil surface. Buol et al. (1997) subdivides Gelisols in three groups: Histels, Orthels, and Turbels. Due to very slow soil formation process during the short summer season and limited vegetation growth, most of the soils store large amounts of organic carbon, accumulated in the upper soil layer. In most areas under the influence of glaciation, Gelisols are not very fertile, since nutrients like calcium and potassium are easily leached over the everlasting frost layer (Bockheim, 2015).

### Sampling design and data collection

The sampling was realized during the Antarctic summer season 2018/2019 and the 27<sup>th</sup> Bulgarian Antarctic expedition. An established transect of around 5000 m followed an altitudinal gradient between 0 and 75 m ASL in South Bay starting from Bird bazaar to Caleta Argentina. All selected sampling sites are situated along the transect and are differentiated by the vegetation cover. The sampling sites are located in 7 areas, in the north and south of BAB as follows: Bird Bazaar (BP) - "Bird's Market "(Cape Espanola); The Sanctuary (SV) – “The Sanctuary”; Playa Bulgara (PB) – “The Bulgarian Beach”; Hesperides Point Pluton (HPP) – “The Squa’s nest”; Hesperides Point Pluton (HPP-B) – “The Bay”; Punta Hesperides (PUN-H) - "Todorini Buzi Lake"; Caleta Argentina (CA) - "Caleta Argentina" (Tabl. 1).

The soil samples were collected in December 2018 from the top layer with depth 0-5(7) cm in all sites in 3 repetitions. The soils were sampled using stainless shovel and GPS coordinates in WGS-84 coordinate system were determined for each sampling point. A total number of 21 samples were collected and analyzed.

Table 1 General characteristic of the studied sites

No.	Name /Abbreviation/	Coordinates			Vegetation cover
		S	W	Altitude, m	
1	BP 1	62°38'06.9"	60°21'14.7"	1	<i>Sanionia georgico-uncinata</i>
2	SV 3	62°40'08.8"	60°24'08.7"	2	<i>Usnea antarctica</i>
3	PB 1	62°38'22.3"	60°21'50.6"	45	<i>Leptogium menziesii</i>
4	PB 2A	62°38'21.9"	60°21'49.5"	39	<i>Sanionia georgico-uncinata</i>
5	PB 2B	62°38'21.9"	60°21'49.6"	38	<i>Usnea antarctica</i>
6	PB 3A	62°38'32.5"	60°21'59.9"	71	<i>Sanionia georgico-uncinata</i>
7	PB 3B	62°38'33.4"	60°21'59.7"	70	<i>Usnea antarctica</i>
8	HPP 1A	62°38'36.6"	60°22'10.6"	40	<i>Sanionia georgico-uncinata</i>
9	HPP 1B	62°38'36.4"	60°22'10.5"	39	<i>Usnea antarctica</i>
10	HPP 2A	62°38'35.9"	60°22'14.6"	46	<i>Sanionia georgico-uncinata</i>
11	HPP 2B	62°38'35.7"	60°22'14.4"	47	<i>Leptogium menziesii</i>
12	HPP B1	62°38'39.7"	60°22'23.2"	2	<i>Sanionia uncinata</i>
13	HPP B2A	62°38'39.5"	60°22'23.3"	2	<i>Usnea antarctica</i>
14	HPP B2B	62°38'41.3"	60°22'22.1"	7	<i>Sanionia georgico-uncinata</i>
15	PUN-H1	62°38'49.3"	60°22'16.7"	50	<i>Sanionia georgico-uncinata</i>
16	PUN-H2A	62°38'49.2"	60°22'16.5"	49	<i>Usnea antarctica</i>
17	PUN-H2B	62°38'49.7"	60°22'18.7"	45	<i>Sanionia uncinata</i>
18	CA 1A	62°38'10.5"	60°21'29.3"	11	<i>Sanionia georgico-uncinata</i>
19	CA 1B	62°38'10.1"	60°21'29.1"	13	<i>Sanionia georgico-uncinata</i>
20	CA 3	62°38'10.0"	60°21'29.3"	14	<i>Usnea antarctica</i>
21	CA 4	62°38'09.2"	60°21'27.6"	4	<i>Sanionia georgico-uncinata</i>

### Laboratory analyses

All soil samples have been air-dried at room temperature in the laboratory of the Bulgarian Antarctic Base to reach an air-dry state and later stored in plastic bags in order to be transported to Bulgaria. In the Laboratory of Soil Science in FRI-BAS, Sofia, the samples have been dried additionally, ground to pass a 2 mm sieve and prepared for further analyses. The total weight of the samples, as well as fine and coarse fractions were determined and calculated after dry sieving. Standard soil analyses were performed for pH, organic matter, total carbon and nitrogen content. Granulometric analyses of the sand, silt and clay size fractions was realized.

The radioactivity in soil was determined by means of high-resolution non-destructive gamma-spectrometric analysis of 40 g sample to determine the content of natural and artificial radionuclides  $^{137}\text{Cs}$ ,  $^{40}\text{K}$ ,  $^{238}\text{U}$ ,  $^{232}\text{Th}$ . Gamma spectrometric measurements have been accomplished with H.P.Ge spectrometer product of CANBERRA with 35% efficiency and resolution of 1.8 KeV resolution for  $^{60}\text{Co}$ . The same geometry for all samples is used for calibration at energy rate in energy rate 40-2000keV and measurements were made between 19 and 24h period to obtain well-expressed isotope peaks. The authenticity of results is confirmed by regular successful participation in interlaboratory comparisons and proficiency tests schemes and the use of certified reference materials. The spectra of the measured samples were processed in line with BSS ISO 18589-3:2018, using the specialized software CANBERRA Genie 2000.

### Geospatial analysis and statistics

There are various methods and techniques for spatial prediction and comparative evaluation of soil properties. The initial step is to visualize the data, identify appropriate coordinating system and manipulate inconsistent results. Basic statistics and description of data values is achieved through means, standard deviation, histograms and cluster analysis in order to examine values of data outliers. The sample size and values opted for the application of Kernel density estimation (KDE) to estimate the probability density function of random variables. The Kernel density function produces an empirical surface based on individual locations of all sampled data. The applied algorithm calculates density of values around each neighborhood within predefined search radius and creates smoothly curved surface around each point (sampling plot). The non-parametric estimates of probability density is selected to display the density at each output raster cell, by defining the number of times to count the point value. The bandwidth is a free smoothing parameter that limits the extent of the surface values.

An ANOVA test was used to assess the statistical significance of the differences in the means of the study parameters at a  $p < 0.05$  (Tukey test). Cluster analysis and Pearson correlation were performed in order to clarify the relationship among the variables, especially the influence of soil parameters on distribution of natural radionuclides. Cluster analysis is a useful statistical method, which presents visually the degree of association among different variables.

## RESULTS AND DISCUSSION

### General properties of polar soils

The soils are characterized by higher skeletal content at all sampling sites, while more than 20% of skeletal fraction  $> 1$  mm are established for sites in the Punta Hesperides (PUN-H), the Sanctuary (SV3); Caleta Argentina (CA3 & 4). On Table 2 are presented the results of the physical-mechanical characteristics of the soils in the sites of the polar ecosystems of the Livingston Island.

Table 2 Soil parameters for the study transect

No.	Coarse fractions, %		Granulometry, %			Relative density	C, %	N, %	C:N	pH (H <sub>2</sub> O)
	>1mm	>3mm	clay	silt/sand	fine clay					
			< 0.01	> 0.01	< 0.001					
1	13.04	10.27	10.27	89.73	0	2.4	0.6942	0.0888	7.82	5.76
2	1.19	22.08	6.12	93.88	0	2.9	4.6609	0.4030	11.57	5.29
3	19.2	44.95	10.30	89.70	0	2.4	0.7934	0.0874	9.08	6.03
4	12.41	11.53	7.16	92.84	4.09	2.7	3.1734	0.2608	12.17	6.04
5	11.99	12.34	9.20	90.80	4.07	2.5	1.2892	0.1041	12.38	6.09
6	19.23	36.84	9.15	90.85	4.03	3.7	0.1983	0.0306	6.48	5.93
7	18.67	10.6	5.09	94.91	4.07	2.6	2.1817	0.1305	16.72	5.97
8	1.3	1.54	16.02	83.98	4.11	2.7	1.8842	0.1572	11.99	5.62
9	26.51	3.5	10.27	89.73	0	2.7	0.6942	0.0613	11.32	5.18
10	18.79	27.79	9.25	90.75	0	3.3	0.4958	0.0796	6.23	5.29
11	6.49	-	9.79	90.21	0	2.6	1.7851	0.1871	9.54	5.56
12	41.3	8.26	6.11	93.89	4.07	2.2	0.1983	0.0311	6.38	5.61
13	19.3	14.14	5.42	94.58	0	2.5	0.0992	0.0122	8.13	5.85
14	12.33	30.24	6.11	93.89	4.07	1.4	0.0879	0.0122	7.20	6.08

15	26.52	20.12	2.06	97.94	0	2.6	0.4958	0.0613	8.09	5.82
16	35.42	-	7.16	92.84	4.09	2.5	1.0908	0.1103	9.89	5.78
17	29.28	8064	8.18	91.82	4.09	2.6	2.7767	0.2451	11.33	5.45
18	-	-	5.13	94.87	0	2.6	3.4709	0.3761	9.23	5.75
19	-	-	5.10	94.90	0	2.6	4.1736	0.5852	7.13	7.47
20	36.09	4.37	11.24	88.76	0	2.5	2.1817	0.2389	9.13	4.92
21	28.92	2.99	5.13	94.87	0	2.3	1.5867	0.1896	8.37	4.77

The analysis of the soil samples shows stronger acidification at Hannah Point (HAN) with pH 4.57-4.93, followed by Caleta Argentina (CA) - "Caleta Argentina" with pH 4.77-4.92. In such cases, the influence of climate factors plays a significant role. The decomposition of organic matter cannot reach its final products under these conditions due to the limited temperatures and the high humidity. For all other sites, slightly acidic soils with a pH of 5.5-6.5 predominate.

Carbon and its compounds play an exceptional role in the biosphere. The cold Arctic favors the humus conservation in the soil. The concentration of organic carbon in soil substrates for sites without vegetation is particularly low. These are Hesperides Point Pluton HPP B1 and B2 sites, Playa Bulgara PB1 sites, with organic C not exceeding 1%.

Total nitrogen is also a very important biophilic element in one ecosystem. The biophilicity of nitrogen is high and comparable only to that of carbon. In the soil cover of the Livingston Island polar ecosystems nitrogen content does not exceed 1% in all sites observed, but corresponds, in quantitative terms, to the carbon content.

The C:N ratio, as an indicator of the rate of mineralization processes occurring in the soil cover, range from 9.09 to 19.53 and indicate a biological cycle delay in the soil system of Playa Bulgara (PB) site - The Bulgarian Beach.

### Radionuclides in soils

Until now, no regulatory document that limits the content of natural radionuclides in the soils exists. The detected values for the region of Livingston Island can be assumed as background levels and can be compared with other background values defined after multiple measurements characterizing soils not affected by industrial and commercial activity in other polar regions of the world. The average <sup>137</sup>Cs activity concentration in soils along the studied transect was 5.51±1.38 Bq/kg with a range from 0.51 to 24.27 Bq/kg. These values are much higher than previously reported values by Navas et al. (2005, 2018) for South Shetland Island and for soils developed on moraines and marine platforms of Elephant Island., but are lower than reported by Gwynn et al. (2004) for the environment of Svalbard area, Norway. The concentration of the studied natural radionuclides ranged between 171.19 and 597.60 Bq/kg for <sup>40</sup>K, with average value 275.89±26.52 Bq/kg (Table 3 and 4). The average concentration of <sup>232</sup>Th is 11.46±1.16 Bq/kg with minimum and maximum values 4.81 and 24.57 Bq/kg, respectively. The <sup>238</sup>U was detected in three samples where it ranged from 37.55 Bq/kg to 106.04 Bq/kg, while in all other samples its activity was under the limit of 0.04 Bq/kg. The mean activity values fall within the normal ranges in nature and are comparable with values obtained by Navas et al. (2005, 2018) for soils of Byers Peninsula, South Shetland Islands and Elephant Island (Maritime Antarctica).

Table 3 Radionuclides in soils

No. site	<sup>137</sup> Cs Bq/kg	<sup>40</sup> K Bq/kg	<sup>238</sup> U Bq/kg	<sup>232</sup> Th Bq/kg
1	1.86	477.86	≤0.04	18.97
2	11.15	350.83	≤0.04	19.35
3	0.90	470.48	≤0.04	21.11
4	5.34	375.88	52.85	14.06
5	6.41	286.99	≤0.04	10.26
6	0.51	315.76	37.55	8.85
7	≤0.04	597.60	≤0.04	24.57
8	24.27	174.31	≤0.04	8.22
9	2.04	189.54	≤0.04	8.78
10	1.00	176.46	≤0.04	7.31
11	17.99	189.82	106.04	8.73
12	2.64	171.19	≤0.04	7.83
13	2.43	187.84	≤0.04	4.81
14	0.53	177.38	≤0.04	7.29

15	2.49	231.85	≤0.04	11.70
16	5.94	178.33	≤0.04	7.98
17	13.23	216.25	≤0.04	9.85
18	3.19	343.87	≤0.04	14.21
19	1.64	285.01	≤0.04	10.66
20	6.91	216.03	≤0.04	8.98
21	5.11	180.37	≤0.04	7.09

Pearson correlation coefficients, calculated between radionuclides and main soil properties as grain size, carbon and nitrogen content and pH, have demonstrated that some of them are statistically significant at the level 0.05 – 2-tailed. Concerning the grain size, it is commonly known that radionuclides are adsorbed onto clay surfaces or fixed within the lattice structure (Jasinska et al. 1982; Van den Bygaart and Protz 1995; Van den Bygaart et al. 1999).

Table 4 Pearson correlation coefficients among the radionuclides

	<sup>137</sup> Cs	<sup>40</sup> K	<sup>232</sup> Th	<sup>238</sup> U
<sup>137</sup> Cs	1			
<sup>40</sup> K	-0.212	1		
<sup>232</sup> Th	-0.077	0.938**	1	
<sup>238</sup> U	-0.331	0.200	0.995	1

\*\*Correlation is significant at the 0.01 level (2-tailed)

For good correlations among natural radionuclides and between them and some soil properties, especially carbon content, have been reported by Navas et al. (2002), but they also found significant correlation of <sup>137</sup>Cs with sand and silt content. The pH values showed weak positive correlations with natural radionuclides.

### Mapping the distribution of radionuclides in the study area

The applied GIS analysis in ESRI ArcGIS generated distribution maps of radionuclides within a variable search radius. The graphics on Fig. 2 A-C represent the predicted density values for the sampled soils along the study transect. We used WGS84 coordinate system and Universal Transverse Mercator projection, zone 20S for the spatial analysis. Concentrations of <sup>238</sup>U have are detected only in three samples, therefore the generation of density map was of low contingency in the case.

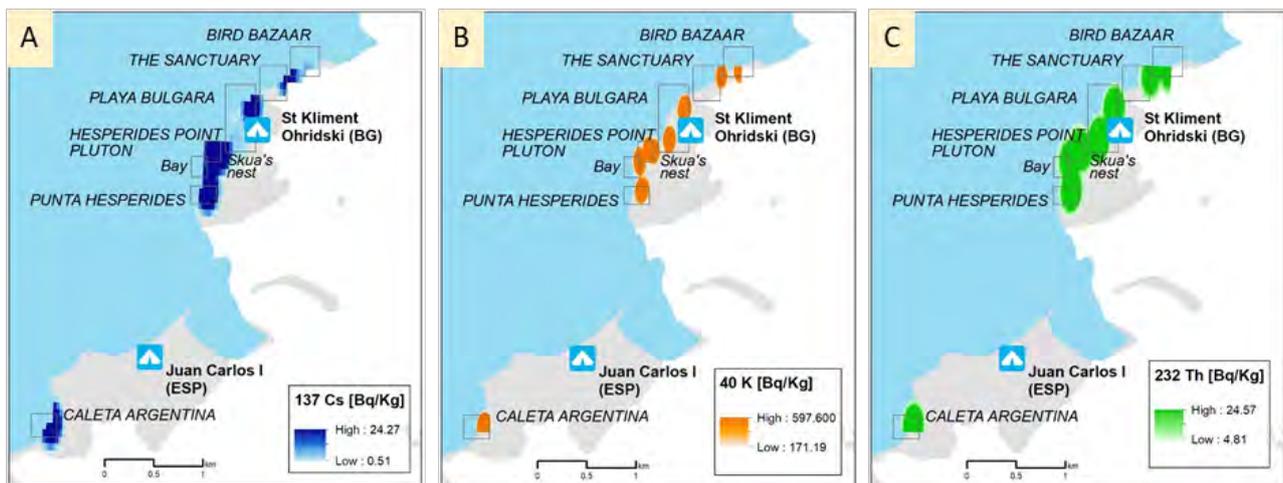


Figure 2. Distribution of radionuclides' concentrations in the experimental transect of Livingston Island

The spatial overlaying has limiting functionality, as it requires complete correspondence of the geometry of the mapping units. Therefore, information on specific soil characteristics has been combined to produce estimates of soil properties, which are not demonstrated in the analysis itself. The underlying information and soil data was aggregated for a specific sampling plot and linked to a single representative value. The statistically aggregated data and lack of information about the mapping unit allows the performance of probability density visualizations over a smoothly tapered surface.

The distribution of radionuclides depends on various factors and the calculated Pearson correlation coefficients between radionuclides and main soil properties define dependences. Higher content of organic matter and carbon were related to higher  $^{40}\text{K}$  and  $^{232}\text{Th}$  activities, indicating positive and statistically significant correlation coefficients ( $r=0.491^*$ ;  $r=0.446^*$ , respectively). The pH values show weak positive correlations with natural radionuclides. At sites where there is soil, moss cover the content of soil organic carbon has highest values. This confirms the close link related to the preferential fixation of the radionuclide by the organic matter as pointed by Gaspar and Navas (2013), Gaspar et al. (2013) and explain its associated redistribution with soil by physical processes (Soto and Navas, 2004).

## CONCLUSIONS

GIS applications have salient analytical capabilities to estimate and visualize area that could be more or less affected by contamination as well to help determine risks to populations. The combination of different sources of quantitative information into a spatial model has various advantages as it allows performing real time analysis, creating, and opening system for geospatial analysis. The study of radionuclides activity provides valuable information on soil factors and processes that affect their spatial patterns in extreme environmental conditions in Antarctic ice-free areas. The results indicate the presence of great variability in the concentrations within the study area. The activity concentrations of natural radionuclides were similar with those reported for Antarctic region and in general comparable with radionuclides activity for other environment. Results of radiometric study on the distribution of natural and artificial radionuclides in polar ecosystems in Livingston Island indicate that anthropogenic radioactive contamination is generally low, as per the Antarctic region. There is significant correlation between radionuclides concentrations and basic soil properties, which confirms the close link in between.

## ACKNOWLEDGEMENTS

The authors are grateful to colleagues from the Institute of Nuclear Research and Nuclear Energy - BAS for the analysis performed. This study was realized under the project "BIOMONITORING OF POLAR ECOSYSTEM COMPONENTS' STATE IN LIVINGSTON ISLAND UNDER GLOBAL CHANGES" at the Bulgarian Antarctic Institute funded through the national Program for Polar Research 2017-2021 with CM Decision No. 718/29.08.2016. Special contribution to the realization of the workflow has the joint collaboration with Saint-Petersburg State University within the scope of the bilateral project ASSESSMENT OF THE REGIONAL CONTRIBUTION OF SOILS OF MARITIME ANTARCTICA ISLANDS TO GLOBAL CARBON BALANCE WITH EVALUATION OF STABILIZATION AND HUMIFICATION RATE OF ORGANIC MATTER (contract No. KP 06-Russia-29/28.09.2019) at the National Science Fund, Ministry of Education and Science. The development of the projects would not be possible without the complete collaboration with the National Center for Polar Studies – Sofia University St. Kliment Ohridski (and Bulgarian Antarctic Institute) and the logistical support during the 27<sup>th</sup> and 28<sup>th</sup> Bulgarian Antarctic Expeditions.

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## BIOGRAPHY



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# MAPPING ECONOMIC VALUATION OF SELECTED ECOSYSTEM SERVICE PROVIDED BY A PROTECTED AREA IN RHODOPES MOUNTAIN

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## Abstract

*The economic valuation of climate-regulation ecosystem services (CRES) provided by forest ecosystems in a protected area (PA) case-study of Western Rhodopes were analyzed and mapped. Assessment and mapping of the current condition of forest ecosystems have been done and analysis of their potential to provide CRES has been performed by processing the available data from Forest Management Plans and Natura 2000 sites Standart Data Forms, and by applying modern GIS-based methods and models. Results show that middle to young-aged forest ecosystems deliver higher value of the CRES, whereas aged forests and shrubland ecosystems have higher capacity to store and sequester carbon. The elaboration of the maps was based on available spatial information for forest stands by: type of forest, total biomass stock and average age. The mapping of the economic valuation of ES can significantly contribute to the integration of PAs in the regional development and support the decision-makers in their planning activities.*

**Keywords:** Forest ecosystems, Ecosystem services, Assessment, Mapping, Economic valuation

## INTRODUCTION

Assessment and mapping of ecosystems and their services is an important activity that can effectively contribute to understanding how ecosystems support human well-being and furthermore to promote the sustainable use of natural resources (Burkhard and Maes 2017). Nowadays, the understanding of the concept of ecosystem services (ES) and the number of studies suggesting the link between biodiversity and the supply of ecosystem services are constantly increasing (e.g. Ingram et al. 2012, Cordingley et al. 2015, Seppelt et al. 2016), and several global, regional and national initiatives have been set up (Schröter et al. 2016). The adoption of the concept by European decision-making bodies (Bouwma et al. 2018), including at the strategic level as illustrated by the 2020 EU Biodiversity Strategy (European Commission 2011) and following the modern approaches for environmental management which highlight ES importance (e.g. de Groot 1992, Daily 1997, Costanza et al. 1997) will contribute to the conservation and restoration of Europe's biodiversity, recognised as one of the major benefits to the society and economy.

The methods for mapping and assessing ecosystem services principally involve measuring and accounting the spatial variation of the economic value of ecosystem services and structuring this information to support decision-making and the design of policy instruments. According to the cascade model of Potschin and Haines-Young (2011) the economic methods operate on the right side of the ecosystem services model to quantify the benefits to humans. Therefore any economic valuation mapping or assessment fundamentally relies on biophysical data and methods to quantify the capacity of ecosystems to supply ecosystem services (Burkhard and Maes 2017). Despite the multiple challenges involved in conservation efforts, the use of economic valuation of ecosystem services as a tool to ensure that economic benefits provided by protected areas (PAs) are properly considered in decision-making process in such a way to guarantee their ecological heterogeneity (Troy and Wilson 2006, Paletto et al. 2015). This could favour to bringing the

spatial dimension of economic valuation as a tool to ensure that economic benefits provided by protected areas are properly considered in the decision-making and help in the integration of PAs in the regional development planning and practice.

The objective of this work is to present an approach for mapping the economic valuation of recognised as important climate regulation ES provided by PAs. The approach was tested by “carbon storage” in a case study of NATURA 2000 site “Yadenitsa”, Western Rhodopes Mt. and could be applied in mapping and assessment of forest ecosystems and their services at a national scale. The recognition and demonstration of the valuation of ecosystem services from the Natura 2000 network can significantly influence stakeholders’ attitudes and help in the integration of the network in the regional development planning, considering the supply of climate regulation by forest ecosystems as integrity.

## MATERIALS AND METHODS

### Study area

The case-study area is a part of Natura 2000 site “BG0001386 Yadenitsa”, designated for conservation of the natural habitats and wild flora and fauna (Fig. 1). It is an important biocorridor between Rila National Park and Western Rhodopes and habitat of great significance for reproduction and migration of bears. The forests territories are almost untouched by human activities, dominated by spruce (*Picea abies* Karst.) and Austrian pine (*Pinus sylvestris* L.), distributed in the range 550-1850 m a.s.l., predominantly (94.3%) in the alpine and less (5.7%) in the continental biogeographical regions (NATURA 2000 Standard Data Form).

The site “Yadenitsa” is located in South Central region of Bulgaria in the temperate climatic zone and Trace forest region, sub-zone of the Western Rhodopes (Sabev & Stanev 1963). The average annual precipitation in the region is 630.5 mm with peaks from May to July, and the mean annual temperature is 7.2 °C. A specific feature of the regional climate is the period of increasing temperatures, which starts from early October to mid-November (Sabev & Stanev 1963). The total area of the site is 17 016.2 ha, and the study area covers about 56.7% (9 642.6 ha), on the territory of Velingrad Municipality.

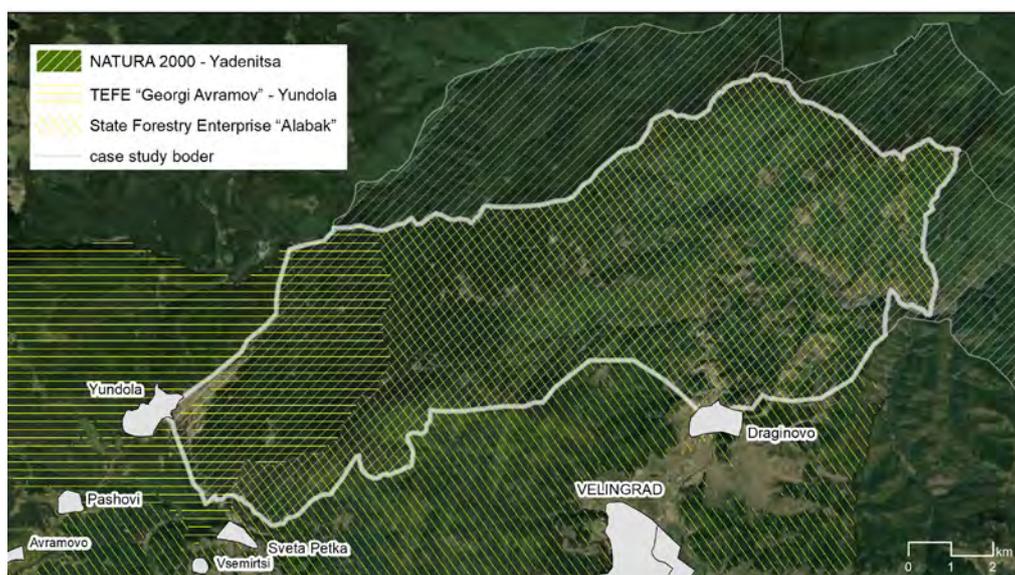


Figure 1. Case-study area in Western Rhodopes Mountain

### Data collection and processing

The data from Forest Management Plans (FMPs) of State Forestry Enterprise “Alabak” and Training Experimental Forestry Enterprise “Georgi Avramov” - Yundola were used for characterization and for assessment of the condition of forest ecosystems and ecosystem services they provide (FMP Alabak, 2018; FMP “G. Avramov - Yundola, 2009). The assessment of the condition of forest ecosystems and ES are based on the “Methodology for assessment and mapping of the condition of forests and forest ecosystems and ecosystem services in Bulgaria” (Kostov et al., 2018), which indicates in detail and step by step the collection and identification of basic data presenting a set of informative indicators with their respective parameters (real and measurable).

The ecosystem service “Mitigation and regulation of the impacts of climate change” belongs to the CICES Class “Regulation of chemical composition of atmosphere” (CICES, 2017) and further used as “climate regulation ecosystem service – CRES” was analysed. The indicator used for the analyses was the carbon storage in forest ecosystems. The service was calculated as a sum of the total carbon stored in different compartments of forest ecosystems - aboveground and belowground biomass, forest floor and forest soils. The total carbon in biomass was calculated using the following formula (IPPC, 2006):

$$C_{BM} = \sum \{ A_i \cdot V_i \cdot BCEFS_i \cdot (1 + R_i) \cdot CF_i \} \quad (1)$$

where:

$C_{BM}$  - total carbon in biomass;

A - area of forests, ha;

V - merchantable growing stock volume,  $m^3 \text{ ha}^{-1}$ ;

i - type of forest (i = 1 to n);

R - ratio of belowground biomass to aboveground biomass, ton dry mass (d.m.) belowground biomass (tonnes d.m. aboveground biomass) $^{-1}$ ;

CF - carbon fraction of dry matter, tonnes C (tonnes d.m.) $^{-1}$ ;

BCEFS - biomass conversion and expansion factor for expansion of merchantable growing stock volume to aboveground biomass, ton aboveground biomass ( $m^3$  growing stock volume) $^{-1}$ .

The data for the merchantable growing stock volume and the area of forests were extracted from FMPs.

For the values of R, CF and BCEFS the data and reference tables from IPCC Guidelines for National Greenhouse Gas Inventories were used (IPCC, 2006), as follows: R coniferous - 0.29, R deciduous - 0.23; CF coniferous - 0.48 t d.m. $^{-1}$ , CF deciduous - 0.51 t d.m. $^{-1}$ , BCEFS coniferous - 0.7  $m^3$  growing stock volume $^{-1}$ , BCEFS deciduous 0.8  $m^3$  growing stock volume $^{-1}$ .

For the calculation of the total carbon in forest floor were used the relevant data from IPCC Good Practice Guidance for LULUCF (IPCC, 2003). The average carbon stock for "warm, moderately moist climates" is 20.3 t C  $ha^{-1}$  for coniferous forests and 28.2 t C  $ha^{-1}$  for deciduous forests. The total carbon in forest soils was determined according to the relevant data from Bulgaria's National Inventory Report 2019 – Submission under the UNFCCC and Kyoto Protocol (MOEW, 2019). The reference carbon stock in forest soils is 78.26 t C  $ha^{-1}$  (0-40 cm). The total carbon absorbed by the forests in studied area was calculated as the sum of the carbon, absorbed by the components of forest ecosystems, using the formula (IPCC, 2003):

$$C = C_{BM} + C_{FF} + C_S \quad (2)$$

where:

C - total carbon;

$C_{BM}$  - total carbon in the forest biomass;

$C_{FF}$  - total carbon in the forest floor;

$C_S$  - total carbon in the forest soils.

The capacity of the forests to utilize  $CO_2$  was calculated in tons of carbon dioxide equivalent (eq $CO_2$ , t) by converting the data for total carbon. The atomic mass of the carbon is approximately 12, and the atomic mass of the oxygen is approximately 16, hence one ton of carbon equals to  $(12+2 \cdot 16) / 12 = 3.67$  t  $CO_2$ . The value of the  $CO_2$  sequestration and storage in the forests in studied area per hectare and for one year ( $CO_{2YV}$ ) was calculated according to the following formula:

$$CO_{2YV} = (eqCO_2 \cdot V / H) / A \quad (3)$$

where:

C - total carbon sequestration and storage in the forests;

H - average age of the trees;

V - price of 1 tone emissions (the reference market price of carbon dioxide emissions for the period from 01.01.2019 to 31.12.2019 is 8.93 EUR / ton  $CO_2$  emissions (the reference market price of carbon dioxide emissions for the period

from 01.01.2019 to 31.12.2019 is 8.93 EUR / ton CO<sub>2</sub> (item 12 of Decision C (2012) 4560 of 06.07.2012 of the European Commission, Order No E-RD-16-436 of 02.08.2018 of the Minister of Energy);  
 A - total area of the forests.

The average age of the forests was calculated using the formula:

$$H = \sum\{H_i \cdot A_i\}/A \quad (4)$$

where:

H - average age of the forest;

A - area of the forests;

i - parcel (i = 1 to n).

### Mapping procedure

The methods applied for mapping and assessing ecosystem's state for Yadenitsa follow the Methodology for assessment and mapping of woodland and forests ecosystems' condition and their services in Bulgaria (Kostov et al., 2017). The generated maps are set in UTM coordinate system WGS84, zone 35N by using ESRI ArcGIS software. Forest data was retrieved from the available Forest Management Plans and transferred into uniform database for further analysis. The afforested territories (completeness ranging from 1-10) of FMP Alabak and FMP "G. Avramov - Yundola, have been considered. We applied the Methodology to assess several indicators by the information provided on parameters and in combination with expert-based assessment.

The mapping procedure comprised 2-tier approach in order to provide flexibility and completeness of the overall assessment. Tier 1 represents assessment based on biophysical indicators. A score from 1 to 5 was assigned to each indicator (such as Plant diversity, Animal diversity, Habitat diversity, Soil heterogeneity, Geomorphological heterogeneity, Matter storage) in regards to the data for the specific parameter per subunit (smallest mapping unit). Tier 2 consists of GIS analysis and application of spatial analysis tools. The territories occupied by forests on subunit level outline polygons that have been related spatially to the corresponding score 1-5. The latter was applied to map the ecosystem state and to map the economic value of the ES. The ES considered in the analysis and the economic evaluation is "Global climate regulation by reduction of greenhouse gas concentrations". According to CICES the indicator for this ecosystem service is the total carbon sequestration and storage in the forest ecosystems that was calculated for forests of different age classes.

### RESULTS AND DISCUSSION

Each habitat type in the site "Yadenitsa" has been attributed to one of the following ecosystem types: grasslands, woodland and forests, heathland and shrub and sparsely vegetated land, in order to assign each habitat type to the relevant MAES level 2 ecosystem types (Table 1).

Table 1. Typology of ecosystems and correspondence of the habitat types with the MAES ecosystem categories and types (Level 1 and Level 2); asterisk (\*) indicates habitat types of conservation priority in Europe

MAES categories		Natura 2000 Habitat types' codes
Major ecosystem category (Level 1)	Ecosystem type (Level 2)	
Terrestrial	Grasslands	62D0, 6520
	Woodland and forest	9110, 9130, 9170, 9180*, 91AA*, 91BA, 91CA, 91DO*, 91EO*, 91MO, 91WO, 91ZO, 9410, 9530*
	Heathland and shrub	5130
	Sparsely vegetated land	8220

According to Corrine Land Cover (CLC, 2018) the forests in the study area are 7507.45 ha. With the largest area was recognized CLC class 312 Coniferous forest – 3123.66 ha, followed by CLC class 311 Broad-leaved forest – 2779.22 ha and CLC class 313 Mixed forest – 1604.57 ha (Fig.2A).

The analysis of the data from FMPs showed that about 74% of the forests are with seed origin, predominantly natural. The forests with recreational functions predominate (4818.28 ha). Catchment areas also cover a significant part of the survey area (1594.96 ha), while the forests for timber production and with environment-forming functions cover a total area of 1188.72 ha). The average age of the forests in the case-study area is 80 years. About 50% of them are aged between 40 and 100 years and about 30% are older than 100 years. The largest area is occupied by forests, dominated by *Pinus sylvestris* (2463.02 ha), *Quercus petraea* (2047.40 ha), *Abies alba* (1362.03 ha), *Picea abies* (1194.63 ha), and *Fagus sylvatica* (919.41 ha). *Pinus nigra*, *Carpinus orientalis*, *Quercus frainetto*, *Quercus cerris*, *Robinia pseudoacacia* and *Carpinus betulus* cover relatively small areas.

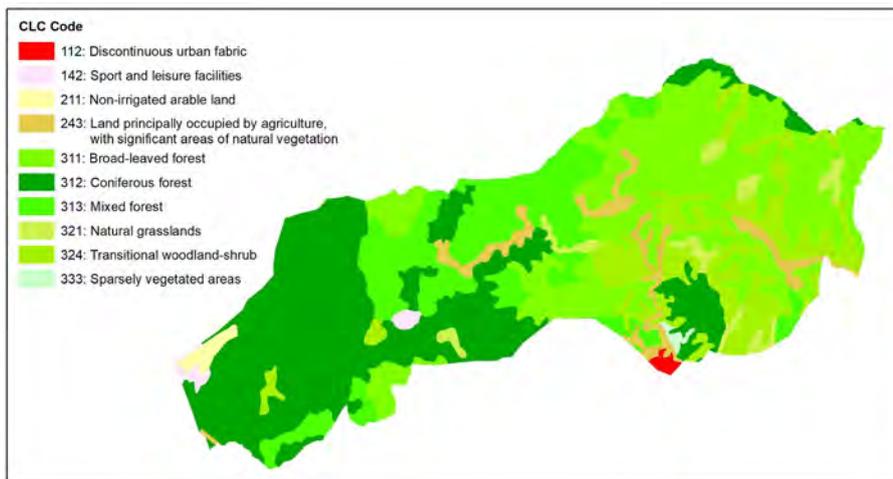


Figure 2. Land-cover characteristics of the forests in the study area

The total merchantable growing stock volume per tree species in the study area is presented in Figure 3. Highest growing stock was obtained for *Abies alba* Mill. (29.0%) followed by *Pinus sylvestris* L. (28.6%), *Picea abies* H. Karst. (17.8%) and *Fagus sylvatica* L. forests (11.7%). The growing stock of other tree species, distributed in the study area does not exceed 10% of the total.

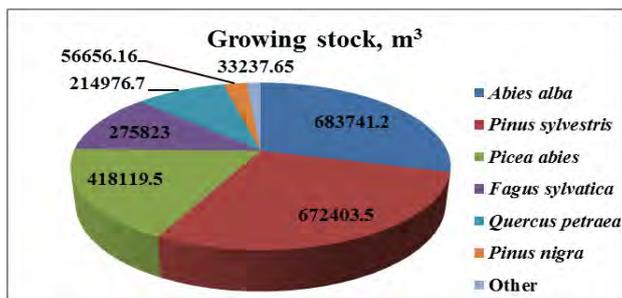


Figure 3. Total growing stock in the study area

The analysis of the results from the assessment of the condition of forest ecosystems in the case-study revealed that 84.35% of them are classified as ecosystems with moderate condition (score 3) (Fig. 3). With bad condition (score 2) are characterized 12.03% of forest ecosystems and only 1% are in the category with “very good” condition (score 5).

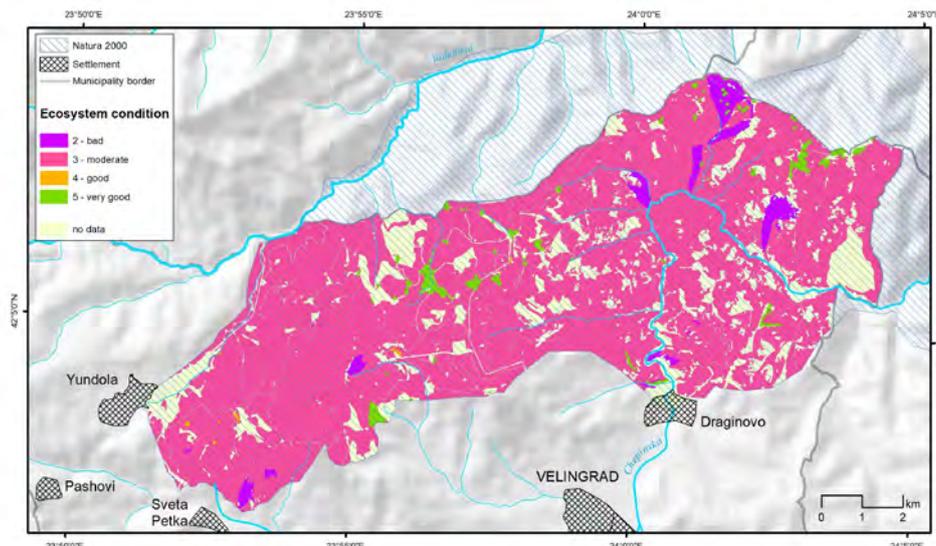


Figure 3. Map of the condition of forest ecosystems in the case study

The total carbon in the forest soils in the case-study of “Yadenitsa” PA is 662 220.40 t with highest values obtained for forest ecosystems over 100 years of age and the lowest for the I<sup>st</sup> age class (0-20 years) in both Yundola and Alabak (Table 2). The total carbon in the forest floor is estimated at 200 163.20 t or 35.08% for forest >100 years old, followed by these from 81 to 100 years old (26.28%) and the lowest amount for the youngest 0-20 years old forests (2.55%). The similar is the distribution among different age classes for carbon storage in biomass with 45.80% for century old forests, followed by forest in V<sup>th</sup> age class (81-100 years) – 22.66% (Fig. 4). The total carbon stored in forest biomass is calculated at 723 461.70 t.

Table 2. Carbon storage in forest ecosystems in “Yadenitsa” case-study area

Yundola							
Age classes	Biomass, t C	Forest floor, t C	Soil, t C	Total, t C	EqCO <sub>2</sub> , t	Carbon storage, t/ha	Value, EUR year <sup>-1</sup> ha <sup>-1</sup>
0-20	563.47	554.19	2136.50	3254.16	11942.77	124.05	244.94
21-40	11331.49	3632.01	13992.89	28956.39	106269.90	162.62	165.30
41-60	22655.21	3840.00	14642.45	41137.66	150975.20	216.74	131.02
61-80	26582.53	3449.91	13092.90	43125.33	158270.00	251.55	107.54
81-100	84454.05	8889.37	34270.05	127613.50	468341.50	274.06	94.45
>100	125782.10	16552.62	63813.20	206147.90	756563.00	240.45	62.87
Alabak							
Age classes	Biomass, t C	Forest floor, t C	Soil, t C	Total, t C	EqCO <sub>2</sub> , t	Carbon storage, t/ha	Value, EUR year <sup>-1</sup> ha <sup>-1</sup>
0-20	2466.82	4546.77	15558.09	22571.68	82838.05	114.56	248.05
21-40	35048.23	17613.45	60870.63	113532.30	416663.60	159.58	147.11
41-60	76238.82	22144.52	75262.64	173646.00	637280.80	189.52	123.73
61-80	53291.41	21562.74	64760.15	139614.30	512384.50	186.43	82.68
81-100	79478.73	43711.34	125709.00	316776.10	1162568.00	167.81	31.33
>100	205568.80	53666.27	178111.90	437700.10	1605063.00	198.36	54.86

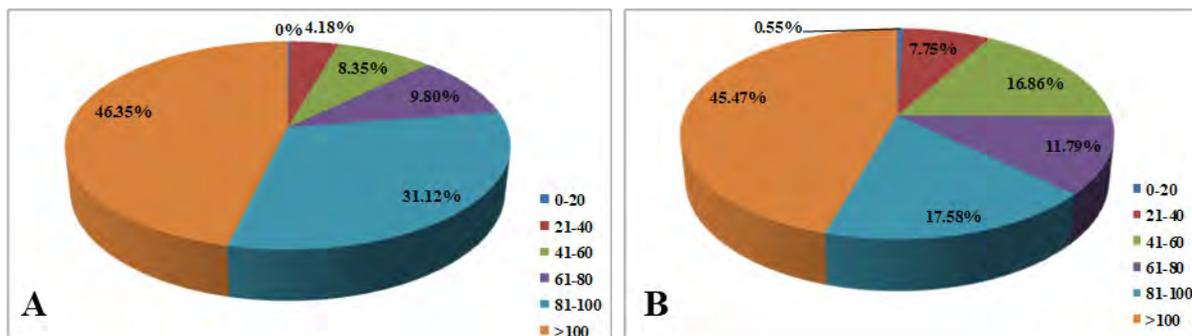


Figure 4. Distribution of carbon storage in biomass of forest ecosystems by age classes (A-Yundola, B-Alabak)

The total carbon stock in forest ecosystems in the case-study is 1 654 075.00 t or 190.45 t/ha. The forests older than 100 years sink 38.93%, followed by the forests, aged between 80 and 100 years – 26.87%. The youngest forests store the lowest quantity of carbon – 1.56%. Such distribution of carbon stock corresponds well to the total areas occupied by each of the forest age classes in the case-study area. The similar trend was also established for the capacity of forests to absorb carbon dioxide, assessed via carbon dioxide equivalent. The total amount for carbon dioxide equivalent calculated for forest ecosystems in the study area is 6 069 160.00 t or 699.01 t/ha.

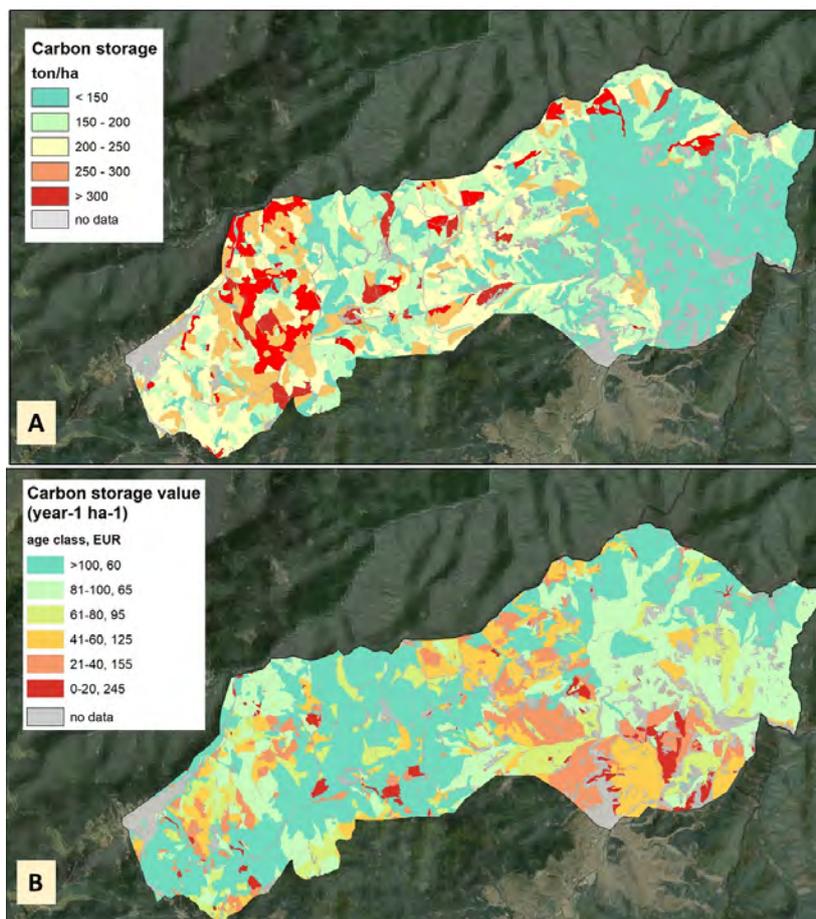


Figure 5. Spatial quantification (A) and economic valuation (B) of Carbon Storage in “Yadenitsa”

The value of the total carbon sequestration and storage in the forest ecosystems in the study area, belonging to the CICES Class “Global climate regulation by reduction of greenhouse gas concentrations” is 124.49 EUR year<sup>-1</sup> ha<sup>-1</sup>. The highest values was calculated for young forests (0-20 years) and the lowest for century old forests (>100 years).

The carbon storage mapping procedure in the case study “Yadenitsa” was realized by assigning the carbon storage estimations to each polygon of forest ecosystems in GIS database (Fig. 5). After clustering the results and analysing

data distribution, all estimates have been grouped in defined intervals, which ensures the most appropriate statistical distribution for this particular case. The map shows that in predominant part of the forest ecosystems the level of carbon storage ranges between 200-250 which corresponds to age classes of forests above 80 years and have the lowest economic values. Results show that middle to young-aged forest ecosystems deliver higher value of the specific ecosystem service (125-245 € per ha per year), whereas aged forests and shrubland ecosystems have higher capacity to store and sequester carbon (over 250 tons per ha).

## CONCLUSION

The demand for monetary estimates of the economic value of ecosystem services (ES) is increasing in many countries in Europe following the expected future integration of ES approach in decision making process and for natural capital accounting. The assessment and mapping of ES is an important activity and can significantly contribute to better understanding of the importance of ecosystems to human well-being and to promote the sustainable use of natural resources. The analysis of the results from the assessment of the condition of forest ecosystems in the case-study revealed that the largest part of them is characterized with moderate condition.

The highest content of total carbon in the forest soils and forest floor in the case-study of “Yadenitsa” protected area was obtained for forest ecosystems over 100 years of age. The similar was established for carbon storage in biomass. The forests older than 100 years sink about 40% of carbon, followed by the forests aged between 80 and 100 years and have the lowest economic values. Results show that middle to young-aged forest ecosystems deliver higher value of the specific “climate regulation ecosystem service – CRES”, whereas aged forests and shrubland ecosystems have higher capacity to store and sequester carbon. The mapping of the economic valuation of ES in the case study “Yadenitsa” can significantly contribute to the integration of PAs network in the regional development and directly support the decision-makers in their planning activities.

## ACKNOWLEDGEMENTS

This study was performed under the project "MAPPING AND COMPARATIVE ASSESSMENT OF ECOSYSTEM SERVICES IN MOUNTAIN PROTECTED AREAS IN RHODOPE (BULGARIA) AND ALTAI (RUSSIA)" – MOUNTPRO, funded by Bulgarian National Science Fund, under grant agreement KP-06-Russia-26/28.09.2019.

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# GIS SUPPORT OF CARBON SEQUESTRATION, EMISSIONS AND BALANCE ASSESSMENT FOR RUSSIAN FORESTS

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## **Abstract**

*The Paris Agreement provides a good opportunity for revising methodology and improving the practice of net carbon sink assessment for Russia's forests. The upgraded methodology, of which GIS is an integral part, has been developed. The test calculations performed with state forest statistical data as of 01/01/2018 and presented on maps. The cartographic service designed for interactive viewing and visualizing the carbon stocks in forest biomass by pools, annual carbon absorption in forest biomass by pools, carbon losses caused by disturbances, net carbon sink (balance) has been developed. Cartographic service operates with the set of maps created by ArcGIS. The map sets are grouped in thematic sections and subsections. The structure of thematic sections and subsections is identical to that of the website and represents a hierarchical system of HTML-pages. The map sets have been converted using the open source JavaScript "Leaflet" library and the R 3.5.2 programming language in an interactive form and then combined with HTML-pages in an atlas-like hierarchical structure.*

**Key words:** Russian forests, GIS, web-GIS technologies, carbon sink assessment.

## **INTRODUCTION**

The role of forests in the global carbon cycle could hardly be overemphasized. The removal of carbon dioxide from the atmosphere by biomass of forest ecosystems is an important component of climate regulation services. Stocktaking and mapping of forest ecosystem services are in demand for a better understanding of climate change and for the implementing the policies and decisions to mitigate and adapt for predicting changes. Ecosystem services are seen as non-commodity outputs provided by ecosystems that contribute directly or indirectly to human well-being (TEEB, 2012). Forest ecosystem services are increasingly valued in today's world (Barredo et al., 2015).

In the forestry sector, carbon storage and carbon sequestration are the most studied ecosystem services. Assessment and mapping of the forest ecosystem services for climate change mitigation and indicators of the forest carbon budget is a popular research area (Barredo et al., 2015). Information on forest biomass and carbon stocks in biomass are available from various sources, including FAO national statistics on forests of the world, data sets based on a combination of satellite observations and in-situ data, model outputs (Kindermann, 2008). Remote sensing datasets describing biomass of terrestrial vegetation and changes in biomass over time are widely available. As an example, the Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC) holds numerous regional databases and presents digital maps of aboveground biomass storage for tropical and boreal forests<sup>1</sup>. The European Space Agency (ESA) via GlobBiomass project provides data and maps of forest growing stock volume and aboveground biomass derived from radar images with calibration by field data. The outcome products consist of global datasets including estimates of average growing stock volumes and aboveground biomass<sup>2</sup> (Santoro et al., 2018). Under the frame of Global Carbon Project, the Global Carbon Atlas had created as a platform to explore and visualize the most up-to-date data on carbon fluxes resulting from fossil fuel emissions, human activities and natural processes<sup>3</sup>. Despite the tens of thousands of completed research on assessment of carbon balance components and their mapping, there are still many uncertainties in understanding the carbon cycle, carbon sinks and CO<sub>2</sub> emissions associated with land use change and forest disturbances (Le Quéré et al., 2018).

At the regional scale, the National Forest Inventories data from measurements on permanent sample plots in-situ are widely used for assessments of the forest carbon parameters. Quantitative indicators and their spatial representation on maps usually published in National Greenhouse Gas (GHG) Inventory Reports submitted by countries in accordance with their international obligations to the United Nation Framework Convention on Climate Change (UNFCCC)<sup>4</sup>. At the regional and local levels, researchers proposed the integrated methods that combine the satellite imagery and sample plots data with lidar based data for assessment and spatial distribution of forest biomass (Boisvenue et al., 2016, Kennedy, 2017, Neety, 2016, Margolis et al., 2015). It should be noted that only studies on temperate and boreal forests in climate-like countries to Russian forests are mentioned here.

The aboveground biomass and carbon stocks in biomass are more consistent than other forest carbon parameters - absorption, losses and outcome balance. However, calculations of the carbon balance require not only accounting for incoming stocks and removals, but also for consumable items, i.e. annual losses of carbon stocks and reduced removals caused by disturbing factors, including timber harvesting and wood removal, fires, forest insect and diseases damages. This item of the carbon balance at country and sub-regional level is taken into account with great uncertainty.

In spite of multiple studies and broad range of instruments and observations, there is no consensus in understanding the magnitude of land-use change emissions and terrestrial ecosystems CO<sub>2</sub> flux in boreal and temperate climatic zones (Le Quéré et al., 2018). There is the very reason to believe that carbon uptake by boreal ecosystems is undervalued. Comparison of the results of mathematical modelling with data from the national inventory reports on the climate convention shows significant discrepancies in the estimation of carbon balance components (Grassi et al., 2018). The problem of a consistent assessment of the carbon balance components at the national, regional, sub-regional and forest biome levels therefore remain relevant (Erb et al., 2018).

Spatially referenced information is needed to implement coherent policies for climate change mitigation and adaptation at the national and regional scales. With regard to counting the carbon balance parameters of Russian forests, the picture is the same as on a global level. Estimates of living biomass and carbon stocks in living biomass that the derivative of merchantable growing stock volume are the most consistent. Assessments of forest carbon sinks, carbon losses and finally carbon balance obtained by different groups of researchers vary greatly (Dolman et al., 2012, Pan et al., 2011, Shvidenko, 2014, Vsaganov et al., 2005, Kurganova, 2015). Therefore, the issue with an unbiased assessment of net carbon sequestration in the Russian forests is still relevant and requires further research. With regard to assessment of net carbon sequestration by the Russian forests, the group of scientists from the Institute for Applied Systems Analysis (IIASA) is the most active and internationally recognized. This group is well known for its multifaceted and in-depth research aimed at assessing all components of the carbon balance in Russian forests. The results of many years' research are widely published. The Integrated Land Information System IIASA provides with the facility to download and process the field, remote sensing and etc. data for counting and mapping the carbon parameters of Russian forests (Shvidenko, 2014, Schepaschenko et al., 2019).

Officially published data on carbon stocks in biomass, absorption, emissions and balance are included in the National Inventory Reports (NIR) and National Communications presented by the Russian Federation under the UNFCCC

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<sup>1</sup> [https://daac.ornl.gov/cgi-bin/theme\\_dataset\\_lister.pl?theme\\_id=5](https://daac.ornl.gov/cgi-bin/theme_dataset_lister.pl?theme_id=5)

<sup>2</sup> <http://globbiomass.org/products/global-mapping>

<sup>3</sup> <http://globalcarbonatlas.org/en/content/welcome-carbon-atlas>

<sup>4</sup> <https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-un>

commitments<sup>5</sup>. Such reports in Russia are prepared by research institute and regional subdivisions of the Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet), which also develop procedures for estimating greenhouse gas emissions by sources and removals by sinks. The procedure used to calculate carbon absorption in forest biomass and biomass carbon losses has a number of disadvantages noted in our earlier publications (Filipchuk, 2018). Shortcomings in the procedure regarding to carbon absorption assessment in forest biomass lead to a significant understatement of the sequestration capacity of Russian forests. GIS support of the national reporting methodology remains limited and extremely simplified. It reduced to visualizing the results of the evaluation in cartographic form<sup>6</sup>. The aim of the research presented in the publication concerns the 3 key pillars: 1) to improve the national reporting under the climate agreement through the application of an enhanced methodology for stocktaking the carbon in forest biomass; 2) to discuss the contribution of GIS to assessment methodology; 3) develop the set of maps and cartographic service for ease of use and spatial presentation of the carbon assessment results.

GIS is an integral part of the methodology and procedure for counting the CO<sub>2</sub> absorbed by the Russian forests further referenced as Methodology (Methodology, 2017). The Methodology based on the Intergovernmental Panel on Climate Change (IPCC) guideline for GHG inventories in Land Use, Land-Use Change and Forestry sector (LULUCF) (IPCC Guidelines, 2006).

## MATERIALS AND METHODS

The Methodology provides for using annual state statistic report's data on the Russian forests. A two level-data are involved in the counting procedure: once local (the forest management unit data) for the assessments of carbon stocks and carbon absorption in biomass and once regional (the region's data) for the assessment of carbon losses in biomass and net carbon sinks. Local level data provided by State Forest Register deal with forest quality and quantity parameters, such as the dominant tree species, age groups, the forest growing stock volume, forest growing stock increment, etc. Regional level data provided by annual forestry statistic include the volumes of timber harvested in forests, areas and volumes of the losses caused by forest fires, forest pests and diseases. The distinctive features of the revised Methodology were described in the paper (Filipchuk, 2018). Here, we will focus on the features of the Methodology concerning GIS and the most important outcomes.

In forest biomass calculations based on the merchantable growing stock volume, the biomass conversion and expansion factor to specify the volume in term of mass is used. The factor is functionally dependent on the specific site-growing conditions and varies for different tree species and age of forest stands. The use of input data on growing stock volume and on the increment of growing stock for forest management units and the precise linking of these data to strata allows counting required parameters and doing final estimates with less uncertainty. Optimization of the forest stratification on the site-growing (site-specific) conditions rely on an available map of forest vegetation zoning (Kurnaev, 1973) and regulative documents of forestry (An Order of Ministry of Natural Resources N 367 and ed. N 83 dated 21/03/2016). Standard ArcGIS tools allowed to combine information from different cartographic sources and to prepare a map of homogeneous strata with similar forest site-growing conditions (Malysheva et al., 2018).

The next innovation of the methodology is the use of GIS tools for more explicit referencing the source data on forest management units to strata. GIS overlay operations made it feasible to superpose the polygons of forest management units over the strata polygons and referenced the initial forest quality and quantity parameters to the strata. For each of the defined strata, the reference table with a set of necessary parameters for carbon calculations has been compiled. Thus, geographic reference the data to the strata allows evaluating the parameters for all forest carbon pools such as aboveground and belowground living biomass, dead wood and litter.

Another advantage of GIS tools used in the final stage of the study is the visualization of the outcomes on maps. A mask with forest land polygons have been created to visualize the results. The map of forest vegetation of the Russian Federation, where forests are differentiated by dominant tree species and forest cover density, was transformed by GIS routines to be used as a mask of forest land polygons. The initial map was drawn up using the results of interpretation of MODIS satellite images, geo-referenced and available in raster formats (Bartalev et al., 2004). We converted these data into vector format using ArcGIS and divided the polygons into two groups: forest lands and non-forest lands. The produced base mask of forest lands was further applied to visualize the estimates of carbon stocks, annual carbon absorption, annual carbon losses caused by disturbances, and finally net carbon sink (carbon balance) in Russia's forests. The procedure with GIS support tested by processing the initial data as an example of 01/01/2018.

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<sup>5</sup> <https://unfccc.int/process>

<sup>6</sup> <http://www.igce.ru/performance/map-data/status-and-trends-of-carbon-balance-etc/carbon-budget-parameters-of-russia-s-managed-forests/carbon-budget-of-russian-forests-2018/>

## RESULTS AND DISCUSSION

### *GIS for spatially explicit presentation of the assessment outcomes*

Experimental testing of the developed procedure made it possible to carry out the estimates of carbon stocks in the forest biomass in total and in separate carbon pools; annual carbon absorption by forest biomass in total and by separate pools; annual carbon losses caused by disturbances; and net carbon sink (carbon balance) in the forest biomass. All the parameters are spatially referenced with the forest land polygons, that represent CO<sub>2</sub> inventory units in LULUCF sector. The results presented on maps were prepared by ArcGIS. Figures 1-3 illustrate the outcome parameters of assessments. The spatial distribution of the calculated parameters allows tracing their regional particularities and provides the synthesis of the findings.

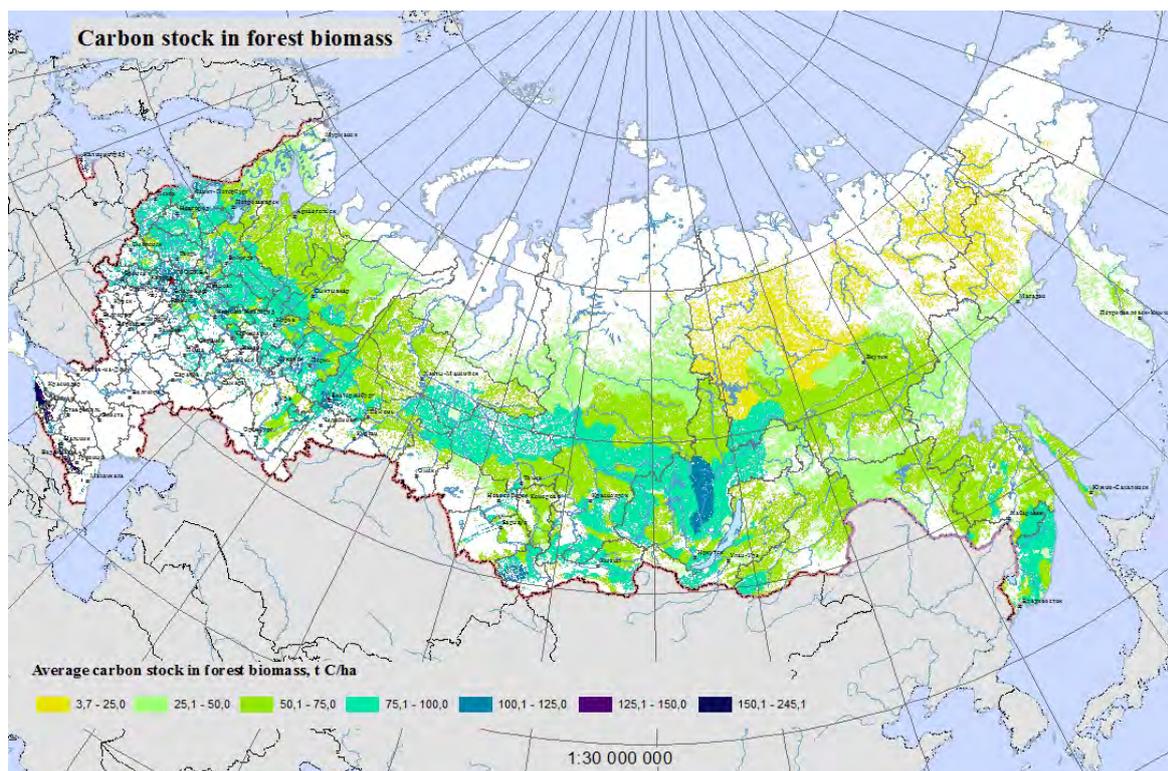


Figure 1. The carbon stocks in biomass of the Russian forests as of 01/01/2018

The carbon stock in forest biomass clearly depends on the forest site-growing (site-quality) characteristics. Russia's forests grow in a variety of forest vegetation zones, from sub-tundra woodlands and rare taiga in the north to semi-desert woodlands and, further south, forests that grow in a subtropical climate on the Black Sea coast of the North Caucasus. Therefore, the spatial distribution of carbon stocks in biomass clearly reflects a latitudinal zoning and diverse of site-growing conditions. The average carbon stocks in forest biomass are varied greatly from 3.7 t C/ha in semi-desert zone and 8.9 t C/ha in sub-tundra woodlands and rare taiga in the north of European part and Siberia up to 245.1 t C/ha in broad-leaved-coniferous stands of the North Caucasus area. Spatially explicit presentation of assessed data on maps shows the distinct longitudinal gradient of carbon stock changes in biomass, depending on the forest site-growing conditions (Figure 1). The total and average carbon stocks in forest biomass referenced by forest site-growing zones are shown in Table 1.

Table 1. Carbon stocks in forest biomass by forest vegetation (site-growing) zones as of 01/01/2018

Zones	Carbon stocks in biomass			Forest lands, million ha
	Subtotal, Mt C	Average carbon stock, t C/ha	Standard deviation of average carbon stock	
Zone of sub-tundra woodlands and	5073.2	29.9	17.1	214.82

Taiga zone, inter alia	32075.5	-	-	505.95
northern taiga sub-zone	12146.3	53.4	15.5	230.65
middle taiga sub-zone	14311.4	70.8	14.8	203.69
southern taiga sub-zone	5617.7	81.6	12.8	71.60
Coniferous-broad-leaved (mixed)	3764.1	90.6	16.6	44.58
Forest-steppe zone	2764.8	88.2	30.5	37.84
Steppe (prairie) zone	133.0	59.5	27.9	2.08
Semi-desert zone	4.0	22.4	16.7	0.01
Mountainous zone of the North	470.8	132.2	50.9	3.11
South Siberian mountainous zone	5465.0	70.4	15.7	81.83
<b>Total</b>	<b>49750.5±9614.3</b>	<b>66.6*±10.8</b>	<b>16.8**</b>	<b>890.21</b>

\* weighted average of carbon stocks

\*\* weighted average deviation of carbon stocks

The average carbon stock in biomass increases from 29.9 t C/ha in sub-tundra and rare taiga to 90.6 t C/ha in temperate broad-leaved forests, then decreases to 22.4 t C/ha in semi-desert woodlands of the south. In mountainous forests of the North Caucasus due to excellent climatic and growing conditions, carbon stock in biomass reaches its maximum values, which averages 132.2 t C/ha with a large variation, as shown by the weighted average deviation from the sample average (Table 1). In total, the carbon stocks in the biomass of Russian forests (for all IPCC recommended pools – aboveground and belowground living biomass, deadwood and litter) estimated at 49750.5± 9614.3. The magnitude of the indicator variation is related to the diversity of climatic and site-growing conditions and to the sizable areas of forest lands both. The total area of forest lands is 890.21 million ha as of 01/01/2018. Boreal forests contribute most to the total carbon stock in biomass (85.7% of total carbon stock and about 90% of total forest land area). We refer to boreal forests as those located in the following forest vegetation zones: sub-tundra woodlands and rare taiga, taiga zone subdivided into three sub-zones and South Siberian mountainous zone. These are the forests growing in the severe climate of the arctic and sub-arctic regions and mountainous regions of the South Siberia with the high-altitude zoning.

As noted above, biomass and carbon stocks in biomass are the most commonly agreed indicators, with estimates consistent among many researchers. A comparison of our estimates with those of the NIR 2019 shows their consistency. The average carbon stock in Russia's forest biomass without soil pool is 55.2 t C/ha (National Report, 2019). Our estimate gives a weighted average carbon stock in biomass of 66.6 ± 10.8 t C/ha representing a likelihood of 95% that true value is in the confidence interval. The average value of carbon in forest biomass is slightly lower in the NIR, but taken into consideration the weighted average deviation of carbon stock value in our estimates, sample means is comparable.

We estimate the annual growth rate in carbon absorption of forest ecosystems as net ecosystem production (NEP) index. The annual accumulation of carbon stock in biomass is due to the rate of growing stock increment, which in turn is related to climatic conditions and soil productivity, depends on the tree species and age of forest stands and the degree of anthropogenic disturbances. The carbon sequestration in forest biomass per unit area is comparatively small at 1.3± 0.14 C/ha year<sup>-1</sup> due to Russia's climatic conditions. The value also varies considerably across Russia and the trend of change has longitudinal gradient. The average value increases from the sub-tundra woodlands and rare taiga zone to the coniferous-broad-leaved forest zone and decreases further in semi-desert woodlands of the south. On average, the biomass carbon absorption in sub-arctic woodlands and rare taiga forests in the European part of Russia is 0.33 t C/ha year<sup>-1</sup>, and in the Chukotka region in Asian part is 0.11 t C/ha year<sup>-1</sup>. The indicator increases up to 1.87 t C/ha year<sup>-1</sup> on average in coniferous-broad-leaved forests and decreases further to 0.45 t C/ha year<sup>-1</sup> in the rare woodlands of the semi-desert zone of Kalmykia. The maximum carbon sequestration in biomass per unit of area occurs in high-yielding coniferous broad-leaved forests of the North Caucasus - 2.2 t C/ha year<sup>-1</sup> (Republic of Adygea and Republic of North Ossetia). However, their share in the total area of forest lands is small, amounting to only 3.1 million hectares or 0.35% (Table 1) and the contribution to the total annual sequestration is about 1%. The boreal forests contribute the most to the total carbon sequestration of about 81%.

Timber harvesting and wood removals, forest fires, forest insects and diseases cause the losses of forest biomass carbon. The annual carbon losses in biomass pools have been calculated based on the area and stock of dead stands in the current year, allowing for the correlation of biomass losses with a magnitude of disturbances, the identification of causes and the spatial distribution of biomass losses across regions. As of 01/01/2018, maximum carbon losses in forest biomass from all factors were observed in Eastern Siberia and Far East, and in the northwestern European part of Russia (Arkhangelsk Oblast) (Figure 2). The role of factors disturbed forests varies from region to region. In the north of the European part, the carbon losses in forest biomass relate to timber harvesting and wood removal. The forests in the

Eastern Siberia were most affected by the fires and timber harvesting that caused the biggest carbon losses in forest biomass. Forest fires are main factor caused the biomass losses in the regions of the Far East. Total carbon losses in forest biomass were estimated at  $88.95 \pm 23.2$  Mt C/year as of 01/01/2018. The regions of the Eastern Siberia and the Far East contribute about 61% to the total losses, and 74% of the total area. The findings of estimated annual carbon losses in biomass are clearly correlated with the reported forest losses in the regions collected from field surveys, data from state forest pathological monitoring, forms of annual reporting on sanitary and health measures and measures to eliminate hotbeds of harmful organisms (Review of Sanitary..., 2018).

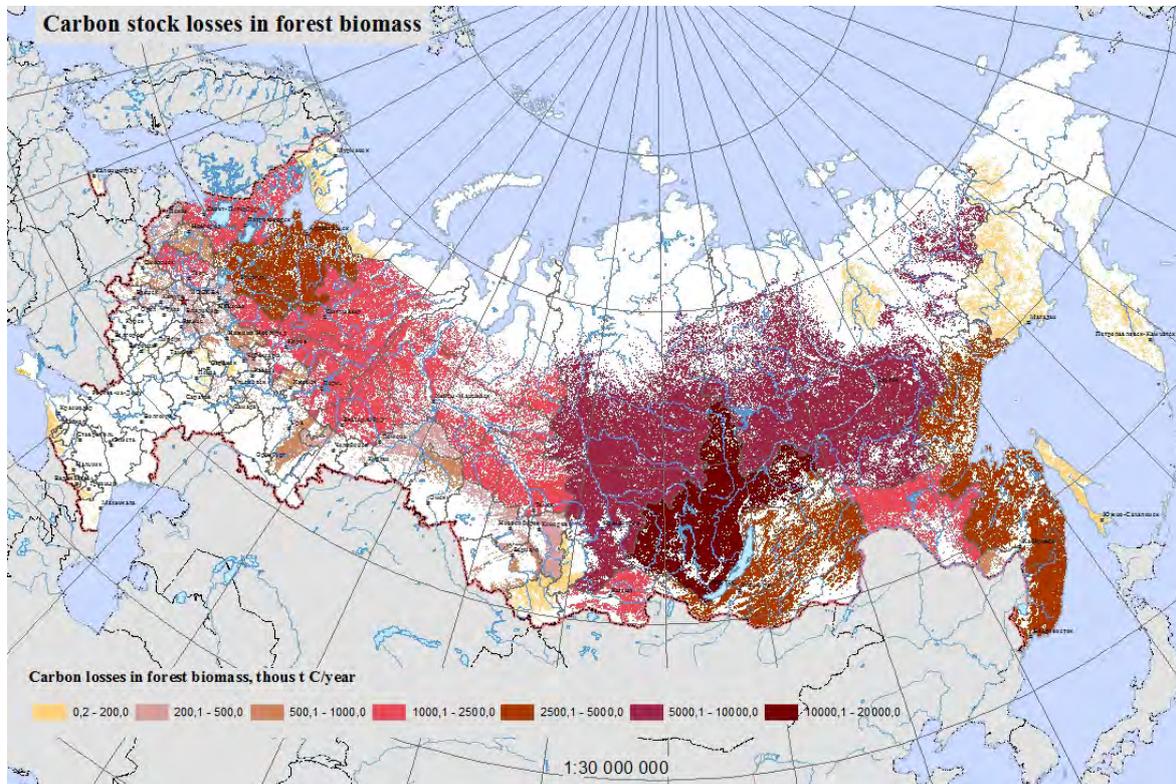


Figure 2. The annual carbon losses in biomass of the Russian forests as of 01/01/2018

Overall, for all forests, annual carbon sequestration in biomass exceeded losses caused by timber harvesting, forest fires, forest pests and diseases and other forest-related negative factors. The increase of the carbon sequestration in the living biomass pool compensated for the losses, and as a result, Russia's forests served as a carbon sink as of 01/01/2018. The weighted average net carbon sink in forest biomass in the study is estimated at  $0.81 \pm 0.14$  t C/ha year<sup>-1</sup>. The spatial distribution of total carbon sink by regions shows that the values are the highest in the regions of Siberia and the Far East, despite the significant biomass losses caused by fires, timber harvesting and wood removals (Figure 3).

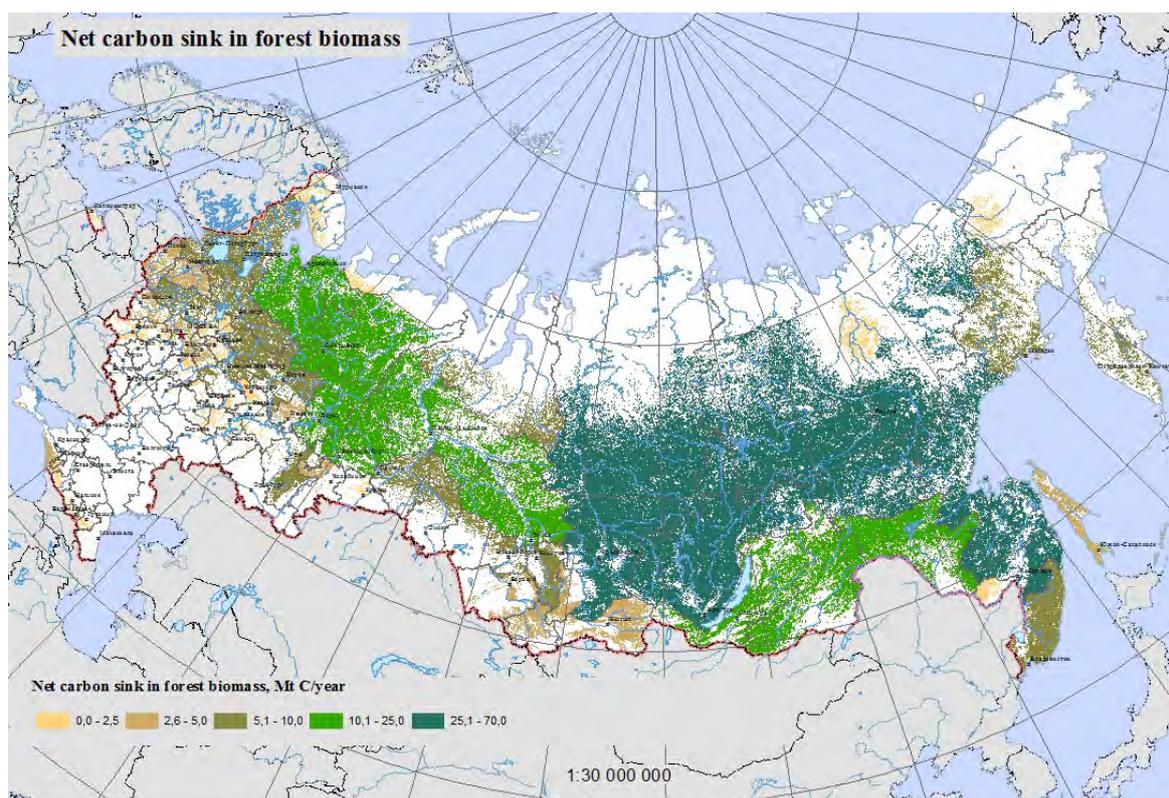


Figure 3. The net carbon sinks in biomass of the Russian forests as of 01/01/2018

### ***The map service for ease of use and spatial presentation of the carbon assessments***

Our Cartographic Service (or set of interactive maps) is the result of the integration of GIS functionality, software, and multimedia solutions. As in the traditional atlas, our service is a systematic set of spatial data in electronic form, having a semantic load and aimed at experts as well as non-specialists. The user interface has interactive functions and geographical navigation. At this stage, the implementation of queries is not provided, it is possible only to view and obtain information on the forest carbon stock indices by pools, forest carbon absorption by pools, forest carbon losses and the carbon balance of Russia's forests in the context of two-level mapping — local (forest management units) and regional (subjects of the Russian Federation).

Since thematic maps were created with the estimated data at the forest management unit level, and the map with forest land borders was used as a basis. The method of refined cartogram (choropleth) in the ArcMap environment was chosen as a method of visualizing the amplitude and density of forest carbon indices. In this case, the thematic load is distributed only within the forest land boundaries, which are located within the forest management units or subjects. Great importance was given to the classification and scale selection. Relative values were used for the subsequent comparative analysis of the mapped indices, due to the large variety of both the values themselves and the areas of the considered units. To achieve an aesthetic and at the same time informative results, the selection of scales and selection of color palettes for design was produced in the ArcMap environment.

Further maps were visualized in the R programming environment with the help of the Leaflet library (Cheng, 2018), which allows us to create interactive choropleths. As a base map layers we added a list of the ESRI map tiles using the `addProviderTiles()` function, many other free third-party basemaps can be added using this function, i.e. Stamen, Carto, Open Street Map and etc. Created shape files were added to the map with the `addPolygons()` function. We used the same one legend for the leaflet polygons created in ArcMap. The `htmltools` library (R Studio, 2019) was used to add small boxes containing arbitrary HTML, that point to a specific polygon on the map (popups). Every popup contains information about forest management units, subjects of the Russian Federation, quantitative characteristics of carbon stock, annual carbon removal, emission, and carbon balance for the selected object. The `rmarkdown` (Allaire et al., 2020) and `flexdashboard` (Iannone, 2018) libraries were used to export maps to HTML-pages. The main steps of the cartographic service creation are shown in Figure 4. The code sample is available at the link <https://github.com/atsyplenkov/forestry-carbon>.

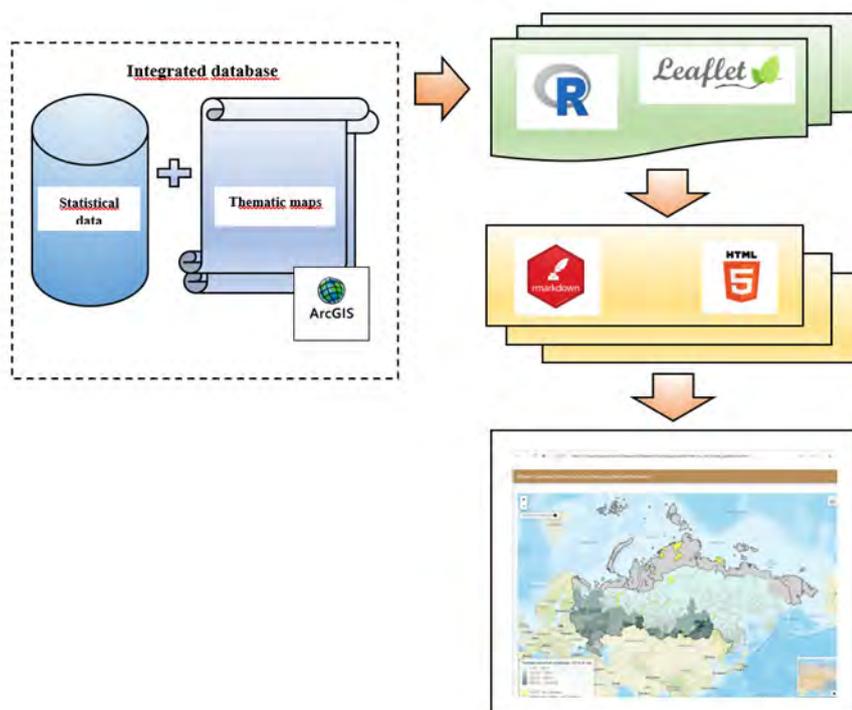


Figure 4. The main steps of the cartographic service creation

The maps in the service are grouped into four thematic sections: carbon stock in forest biomass, annual carbon absorption in biomass, annual carbon losses in biomass, and net carbon sink (carbon balance) in biomass. Each thematic section includes subsections with maps showing the values differentiated by carbon pools: aboveground living biomass, belowground living biomass, deadwood (detritus), and forest litter. It is possible to obtain numerical values for a certain spatial object working with maps in interactive mode. When the viewer places the cursor on any spatial object, a pop-up window will appear with quantitative characteristics of carbon stocks, annual carbon removals, emissions, and net carbon sink (carbon balance) for the selected object. Work with the map service in interactive mode is possible on any computer using a WEB-browser. To view the maps and get information about the forest carbon indices does not require the installation of special software on your computer, this product is software-independent.

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# **ANALYSIS OF LAND-COVER CHANGE CAUSED BY SHEEP HERDING IN THE CENTRAL BOHEMIAN HIGHLANDS (CZECHIA) USING THE ARCHIVAL AND CURRENT REMOTELY SENSED DATA**

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## **Abstract**

*The sheep herding is a typical way of subsistence helping to preserve the steppe character of The Central Bohemian Highlands (in the region of Louny, Czechia). After 1989, herds were liquidated without replacement by other suitable forms of farming. As a result, shrubs started to grow in the steppe areas in the analyzed region. Since 2010, the traditional sheepherding began to return to the Central Bohemian Highlands Protected Landscape Area. The archival remotely sensed data (aerial imagery, satellite imagery) were used to analyze the land-cover change. The archival aerial images for the period 1953 – 2014 were processed to analyze the landscape change. Each of the processed orthophotos was analyzed with a focus on the not original shrubs and trees. Several thousands of points were digitized to analyze the influence of the sheep herding on the land-cover of the steppe grasslands.*

**Keywords:** *landscape change, sheepherding, archival aerial images, analysis.*

## **INTRODUCTION**

Human activity changes the surrounding landscape in many ways. All over the world, we may find large areas affected by heavy industry, open-pit mining, intensive agriculture, or growing cities. In this paper, we would like to introduce the analysis, how human activity helps to keep the original state of the landscape. The Central Bohemian Highlands (the Czechia) has in the Louny region a typical steppe character. Here we can find rare animals and plants typical for the steppe environment. The sheep herding is a typical way of subsistence helping to preserve the steppe character of this region. The sheep herding tradition in this region was kept for centuries.



*Figure 1 Raná Hill and the landscape of the Central Bohemian Highlands (Toman, 2020)*

After 1989, in connection with changes in Czech agriculture, herds were liquidated without replacement by other suitable forms of farming. As a result, shrubs (as the not original plants) started to appear in the steppe landscape in the analyzed area. Moreover, the loss of short-lived dry grasslands, habitat uniformity, and the reduction of species diversity occurred. In 2010 the traditional ways of farming (including the sheepherding) started to return to the Central Bohemian Highlands Protected Landscape Area with a significant effect on the non-original plants in this region.

The main aim of this paper is to analyze, with the use of spatial data, whether the renewed pastoralism has a positive effect on the preservation of the original steppe landscape. The landscape change may be analyzed with the use of different types of archival spatial data. The old maps and archival aerial photographs are mainly used for such a type of analysis (Brůna et al., 2014; Pacina et al., 2012; Skaloš et al., 2011; Vuorela et al., 2002). Only archival aerial photographs captured with sufficient overlap may be processed using the standard ways of photogrammetry or Structure from Motion (SfM) modeling (Cantoro, 2015; Puligle and Fava, 2013; Sevara et al, 2017). The archival aerial photographs are stored in repositories or national aerial image archives (Cantoro, 2015; Cowley and Stichelbaut, 2012; Cowley et al, 2013; Pacina et al., 2020).

The archival remotely sensed data (aerial imagery, satellite imagery) were used to analyze the land-cover change. The archival aerial images from different periods were processed to cover the entire period – the year 1953 (historical state of the land-cover), 1998, 2004, 2008 (regular periods after the sheep herding stopped), 2011, and 2014 (the sheep herding was renewed).

## **METHODOLOGY**

### **Study area**

The Protected Landscape Area of Central Bohemian Highlands lies in the north of Bohemia. With an area of 1266 km<sup>2</sup>, it is the second-largest protected landscape area in the Czech Republic. The relief of the Central Bohemian Highlands is the result of volcanic activity in the Tertiary, as well as subsequent weathering and erosion processes. Characteristic are the conical and cumulus shapes of hills, short ridges, often with rubble fields on the slopes. (AOPK, 2020).

Among the most interesting and beautiful peaks of the Bohemian Central Mountains are the areas of the Raná and Oblík hills analyzed in this paper. The analyzed area, in the Louny region, covers 1 577 hectares (see Figure 2).

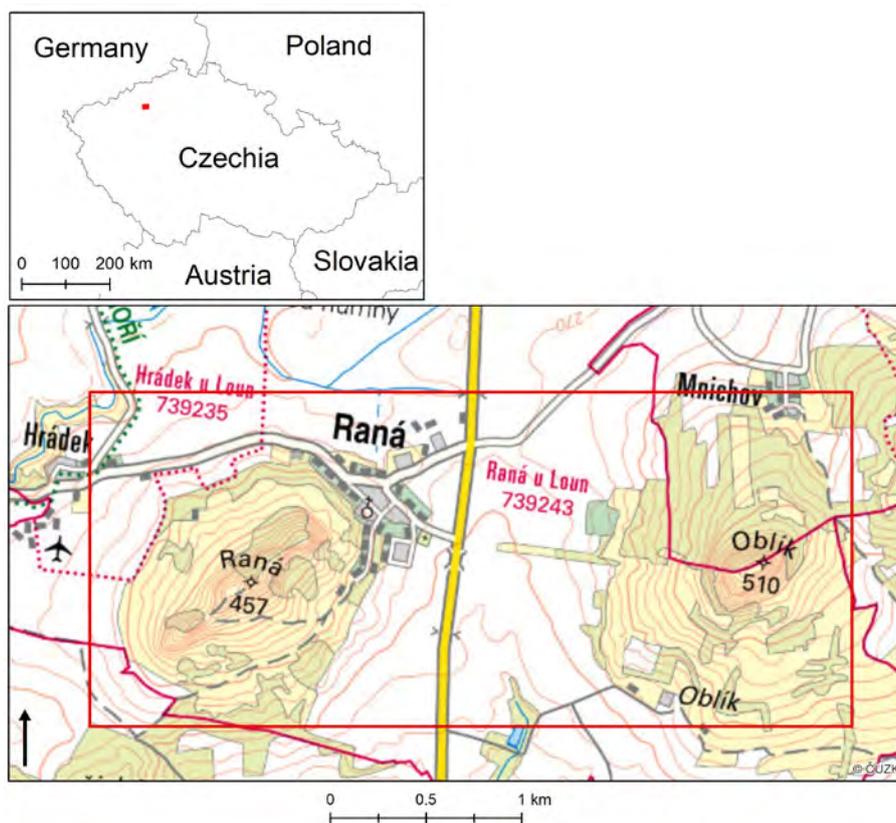


Figure 2 Area of interest - Raná and Oblík hill

## Archival data

Several types of spatial archival data may be used for landscape development and change analysis. Concerning the studied phenomenon and the scale, the archival aerial images were chosen as a relevant data source. Within the old maps, we are unable to identify the single trees (studies in this area). The archival satellite images offered by the USGS (Landsat) are available back to 1972 and are a very valuable source of the data with worldwide coverage. Unfortunately, the spatial resolution is too rough to be used for our purposes.

In the Czech environment, the archival aerial images are available in the national archives managed by the Military Geographical and Hydro-meteorological Institute in Dobruška (VGHMÚř) or the Czech Office for Surveying and Cadaster (ČÚZK). The aerial images for the year 1953 were obtained from VGHMÚř and the aerial images for 1998, 2008, 2011 and 2014 were obtained from ČÚZK. The aerial images were, based on the accuracy analysis performed in (Pacina and Popelka, 2017), processed in Agisoft Photoscan (v. 1.5.0). Selection of Ground Control Points (GCP) is crucial for quality data processing (Pacina et al., 2020). The catalogs of the GCPs used for the original processing of the aerial images are not available – thus the GCP has to be identified both on the archival aerial photograph and the contemporary processed orthophoto. The elevation information is further derived from the *Digital Terrain Model of the Czech Republic of the 5th Generation* (DTM 5G) available for the whole Czech Republic. The DTM 5G is acquired with LiDAR and is available for the public as an irregular set of points, with a 1 point/m<sup>2</sup> average density (ČÚZK, 2020).

## Landscape change analysis

The landscape change analysis is based on a comparison of two or more processed time series of data. Within the area of interest, two different types of analysis were performed: 1. landscape change analysis based on the differences in the land cover and 2. the higher (non-original) vegetation identification. The manual identification and hand digitalization were used for both of the analyses.

## RESULTS

### Archival data processing and interpretation

The selected archival aerial photographs were processed for the defined years – the total number of 13 images for the year 1953, 5 images for 1998, 4 images for 2008, 6 images for 2011, and 6 images for 2014. All of the images were processed using the Agisoft Metashape software. For most of the images, the GCPs were identified on the 2018 orthophoto available as a WMS service at <http://geoportal.cuzk.cz> (see an example in Figure 3). The regular distribution of the GCPs is requested to produce an accurate digital surface model (DSM) based on the raw archival aerial images (Pacina et al., 2020). Approximately 10 GCPs for each of the processed time series of archival aerial images were used. The only exception was the year 1953. The total number of 25 GCPs were defined and in field measured with RTK GPS as the derived DSM was subjected to accuracy analysis in (Pacina and Popelka, 2017).

The land-cover on processed archival orthophotos was manually digitized (classified) into six categories: bosk, grassland, field, built-up area, forest, and orchard. As a bosk is classified as an overgrown area where it is impossible to identify single trees or bushes. The non-original higher vegetation (trees, bushes) was digitized as a single point for detailed vegetation analysis. See the significant years (1953, 1998 and 2014) in Figure 4.



Figure 3 Example of Ground Control Point identification. A – contemporary orthophoto available as WMS. B – processed orthophoto from 2008.

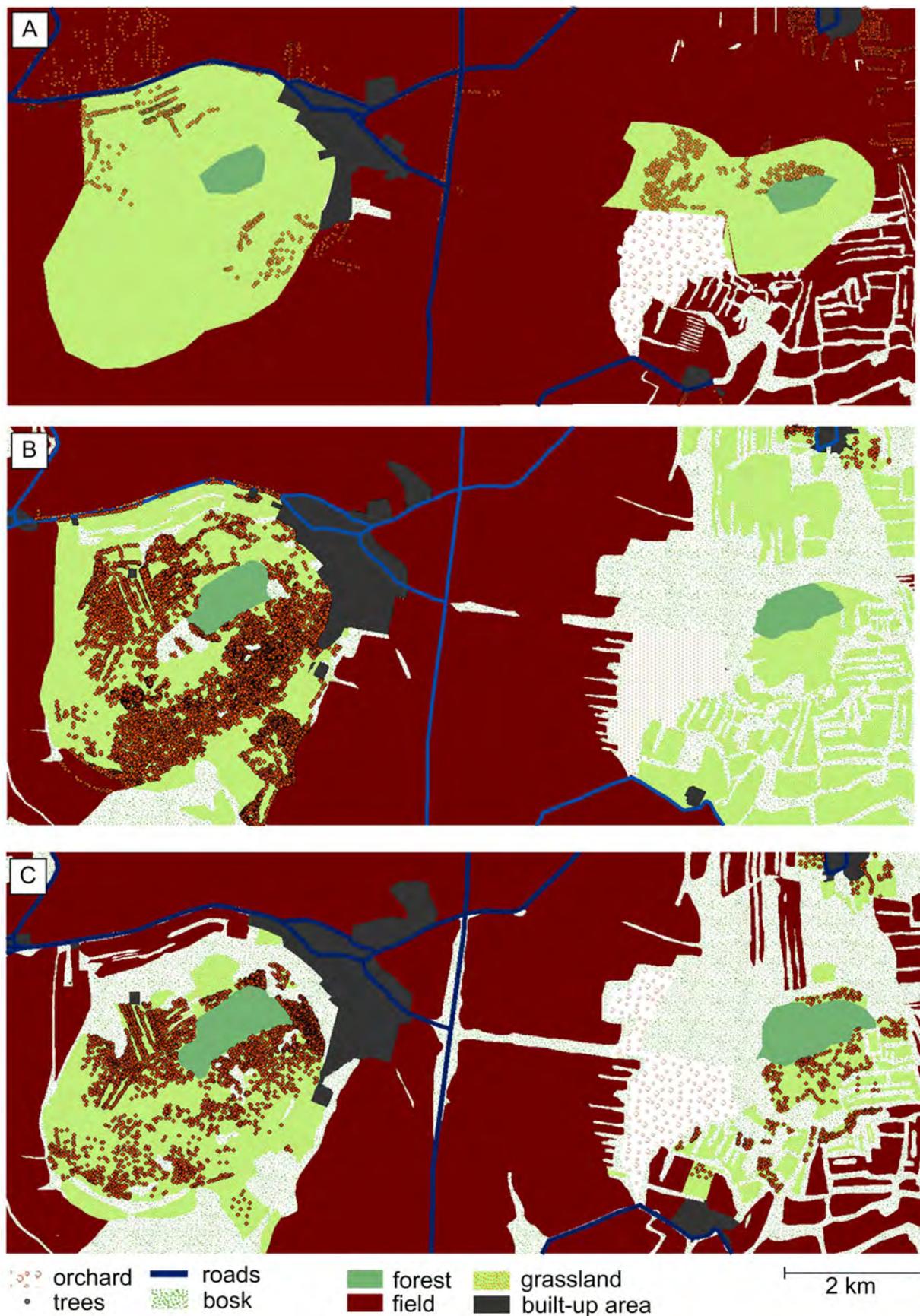


Figure 4 Land cover digitalization within the area of interest. A - the year 1953. B - the year 1998. C – the year 2014.

## Non-original plants identification and landscape change analysis

The non-original plants (trees, higher bushes) identification/visualization was performed using two types of analysis. The area of interest was divided into a regular square grid. Different grid sizes were tested – 30 x 30 m, 50 x 50 m, 75 x 75 m and 100 x 100 m. The 50 m sized grid was selected for further analysis. The *Create Grid Index Feature* function, implemented in ArcGIS was used for the grid creation. The tree density was then recorded within each of the grid cells. In Figure 5 is presented the tree density of the year 2014 with a detailed inset. In Figure 6 and Figure 7 are presented results for years 1953 and 1998.

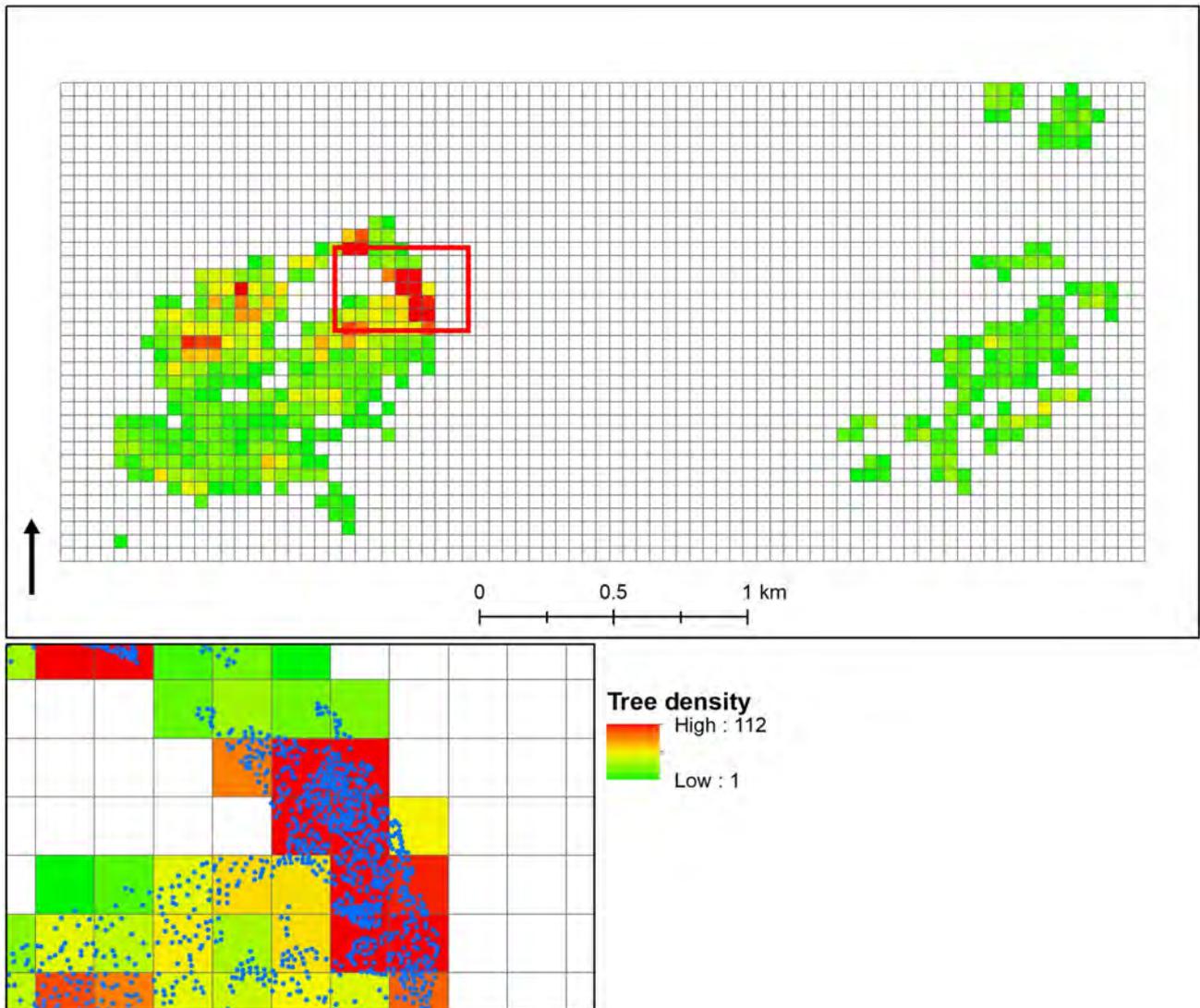


Figure 5 The “higher vegetation” density expressed with 50 x 50 m grid for the year 2014. Blue dots in the inset represent single identified trees.

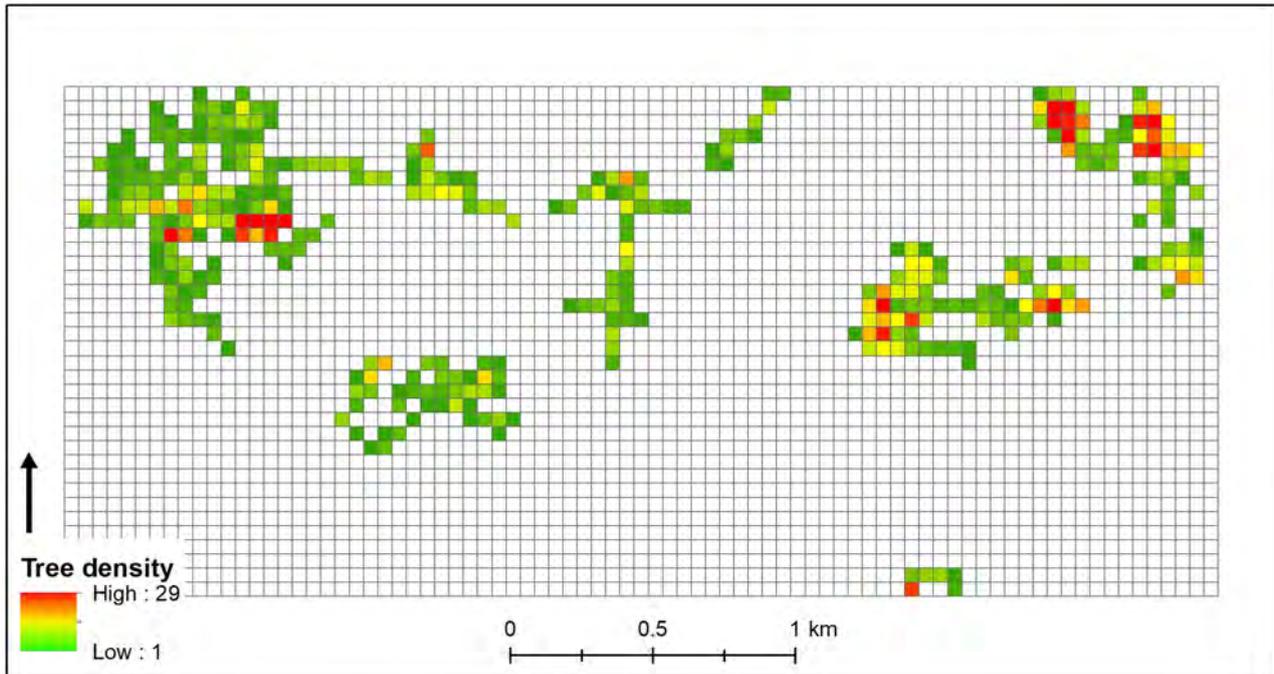


Figure 6 The “higher vegetation” density expressed with 50 x 50 m grid for the year 1953.

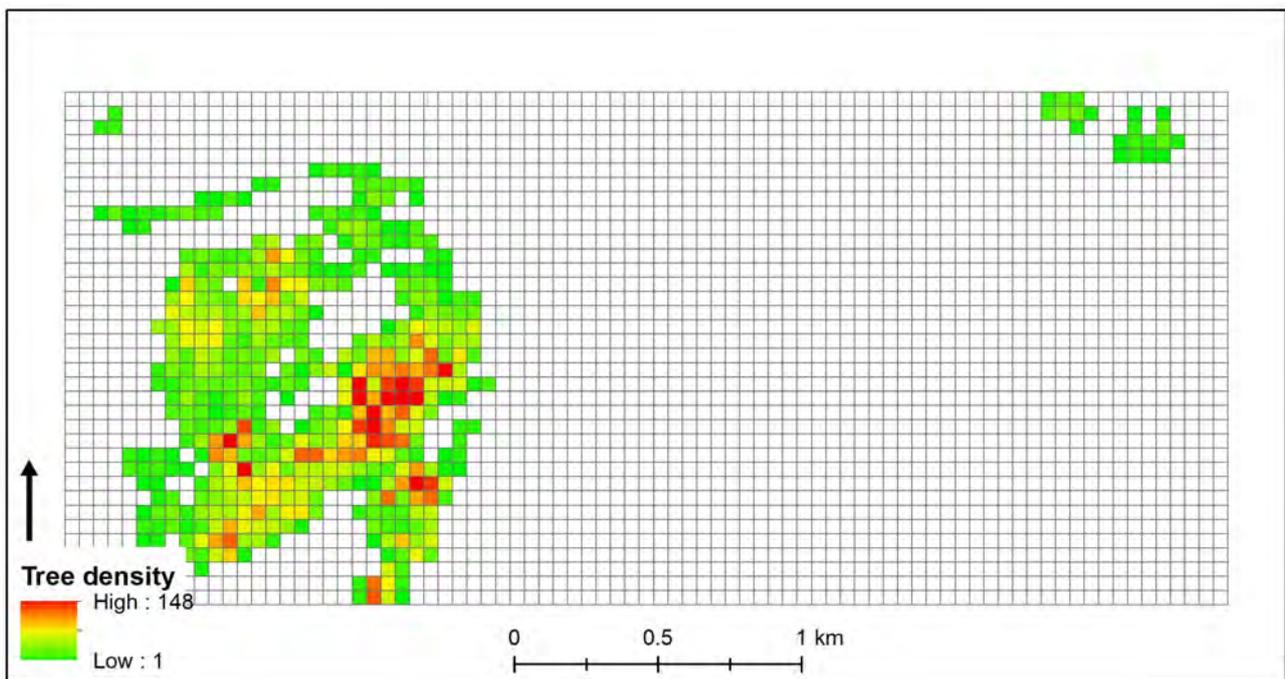


Figure 7 The “higher vegetation” density expressed with 50 x 50 m grid for the year 1998.

In Table 1 are presented the maximum tree density values in the defined 50 m square and the total number of identified trees/bushes for the defined year. It is visible that in 1953 there is a significantly low number of trees and bushes within the area of interest. Between 1998 and 2004, there was a decrease in individually growing higher vegetation, there was also a decrease in the total number of individually growing trees and shrubs, but this decrease could occur by pruning higher vegetation or rather by growing this vegetation and merging into wholes. In 2008, the largest range of individuals is evident. In 2014, there are almost 2/3 fewer individuals than in 2008.

*Table 1 Identified higher vegetation in the defined periods.*

	Analyzed period					
	1953	1998	2004	2008	2011	2014
Highest tree density in a square	29	148	69	112	230	112
Total number of trees	1931	9369	8556	11356	8947	4312

As a further analysis, a comparison of the development in individual years for bosks, forest, grass area, and field in the given localized area was performed. All continuous vegetation was marked as a bosk, where it was no longer possible to classify individuals of trees or shrubs. The results are presented in

As can be seen from the table, when comparing individual years, the development of bosks corresponds to the growth and merging of individuals of higher growth. The fewest of them were in the first year of monitoring, the largest increase occurred in the years 2008 - 2011. Since then, there has been a slight decrease, which has also caused pruning of this vegetation. This fact was also verified by field research.

Grasslands do not differ significantly in the monitored years, the differences between the areas in individual years are not so great. The forest is also growing, especially on the northern sides of both hills. The area of the fields decreased slightly from 1953 to 1998, in 2004 the area of the fields increased again and in 2014 there was a slight decrease again.

*Table 2 Landscover in the studied periods (in hectares)*

	1953	1998	2004	2008	2011	2014
Bosks	28.30	121.14	128.88	182.56	184.51	170.12
Grassland	170.13	221.04	172.27	116.84	124.84	120.02
Field	466.13	319.91	332.38	508.19	498.16	340.39
Built-up	19.87	28.12	28.67	32.54	34.33	32.82
Forest	16.18	12.72	17.55	20.51	16.05	18.77
Orchard	21.49	21.51	21.57	21.61	21.52	21.36

## CONCLUSIONS

Within this paper, there are presented standard ways of landscape change analysis focused on the sheep-herding effect on the plants in the studied region. The archival aerial photographs were used as the most suitable data for this type of analysis. A time series of aerial images from 1953 to 2014 was processed to cover the period of the land-use change. The research was focused mainly on the “higher vegetation” – the non-original trees and bushes in the steppe environment of the Central Bohemian Highlands. More than 40 000 points representing the “higher vegetation” were hand digitized in the defined time-periods. The research data support the theory, that the sheep herding keeps the natural state of the steppe environment. In 1950’ when sheepherding was a natural part of this region, there was a very low number of higher vegetation individuals. The tradition of sheepherding was disconnected in the early 1990’. The first data analyzed after this point are from the year 1998. Here we have identified a significant increase in the higher vegetation and the year 2008 represents the peak. In 2010, the sheepherding tradition was renewed and the analyzed data from the years 2011 and 2014 show a significant decrease.

The manual identification of the trees requires a precise digitalization technique and a lot of time. In future research, we would like to focus on automatic digital image processing and machine learning for faster (and possibly) more robust tree identification.

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## ACKNOWLEDGMENT

This work was supported by Project No.: UJEP-SGS-2019-44-001-3 covered by student grant competition at UJEP - Jan Evangelista Purkyně University in Ústí nad Labem.

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# ASSESSMENT AND MAPPING OF MOUNTAIN FOREST ECOSYSTEM SERVICES: THE CASE STUDY OF PIRIN NATIONAL PARK

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## Abstract

*Protected areas (PAs) are widely recognized for their potential to protect biodiversity and to secure ecosystem services (ES). We selected a system of informative indicators for assessment of ecosystem condition, related to biodiversity dynamics, landscape fragmentation, and habitat loss, considering their particular sensitivity to global change and the importance of specific services they provide. The analysis of the potential of the forest ecosystems in the case-study area was done by processing the available data from the Management Plan of NP Pirin and the data for Natura 2000 sites, by applying modern GIS-based methods and models. The prioritization of ES provided by forests in NP Pirin has been conducted based on expert assessment and questionnaires. The elaboration of ES maps allows the proper understandings of the impacts of mountain forest ecosystems on human welfare and support decision-makers for sustainable management of these services.*

**Keywords:** Mountain ecosystems, Ecosystem services, Assessment, Mapping, Management

## INTRODUCTION

Mountain ecosystems have an important role in conservation of biodiversity, water resources, regulation of global climate, soil erosion prevention etc. They are known as "hot spots of biodiversity" and encompass a high species diversity, diversity of ecosystem types and a remarkable diversity of economic activities, which provide a wide range of ecosystem services (ES) and benefits to the society (Körner and Ohsawa, 2005). Their exceptional role in supplying a vast variety of provisioning, regulating and cultural ES at the European level and globally has been acknowledged in the recent years (Maes et al., 2011; Grêt-Regamey et al., 2012), regardless mountain ecosystems are highly sensitive and vulnerable to climate change (Beniston, 2003; Löffler et al., 2011).

Key Biodiversity Areas and protected areas provide value to humanity not only for the biodiversity they contain, but also because they sequester and store carbon, purify water, provide recreation and tourism opportunities, contain cultural or spiritual values, and deliver a range of other benefits (Neugarten et al., 2018). Quantifying and mapping these benefits is an important tool and could help decision makers to justify the importance of these sites for conservation, to attract new sources of funding and manage the sites more effectively.

Pirin Mt. is a significant element of the natural capital and society with vast territories within protected areas (PAs), regarded as important for maintaining species and habitat diversity, as well as protecting specific landscapes. For many years PAs have been recognized as successful management tool to achieve the long term conservation of nature with associated ecosystem services and cultural values' and able to effectively contribute to improving the quality of life of residents. Despite providing an unprecedented abundance of ES, mountain protected areas still remain among the poorest documented ecosystems. The implementation of ES approach for assessment and mapping of mountain forest ecosystems and ecosystem services they provide could help to properly understand the large-scale view of the unique 'multifunctionality' of mountain PAs and could help managers and decision-makers to identify stakeholder preferences for sustainable management of these services.

In this paper we present the results from spatial analysis and mapping based on qualitative biophysical assessment of forest ecosystems and their services in high-mountain territories in National Park Pirin.

## MATERIALS AND METHODS

### Case study area

National Park “Pirin” encompasses the larger part of Pirin Mt. in southwestern Bulgaria, spanning an area of 40 332.4 ha (Order No. RD - 395 of 15 October 1999 of the Ministry of Environment and Water). In 1983 NP “Pirin” was included in the list of the Convention on the Protection of World Heritage by UNESCO, confirming the exceptional value of the nature in the park.

NP Pirin is characterised with specific alpine territories, rich biodiversity, with many endemic and relict plant and animal species. On the territory of the park a total of 1341 species and intraspecific taxa have been identified, which represents about 32.6% of the flora of Bulgaria (MP, 2004). Forests cover around 57.3% of the total area of the park, from which 95% coniferous and 5% deciduous forests. The largest area is dominated by dwarf mountain pine (*Pinus mugo* Turra), followed by Norway spruce (*Picea abies* Karst.), European beech (*Fagus sylvatica* L.) and Bosnian pine (*Pinus heldreichii* Crist.). In the zone between the upper tree-line and timberline, mostly situated between 1900 and 2250 m a.s.l., are distributed two subendemic tree species, Macedonian pine (*Pinus peuce* Gris.) on silicate sites and Bosnian pine (*Pinus heldreichii* Crist.) on carbonate rock.

The proper identification of ecosystems types requires the use of reliable typology. The MAES typology is organized in two main levels and its structure enables applying CORINE Land Cover (CLC) data for spatial delineation and is also adjusted with the European Nature Information System (EUNIS) habitat classification types. The main classes of the typology proposed by MAES were used for the differentiation, assessment and mapping of the condition of mountain ecosystems and the services they provide in NP “Pirin” (Maes, 2013). The ecosystem types in high mountain territories in NP “Pirin” at Level 2 are determined as follows: Urban, Grassland, Woodland and forest, Heathland and shrubs, Sparsely vegetated land, Rivers and lakes. The case study area covers high mountain forest ecosystems (Fig.1).

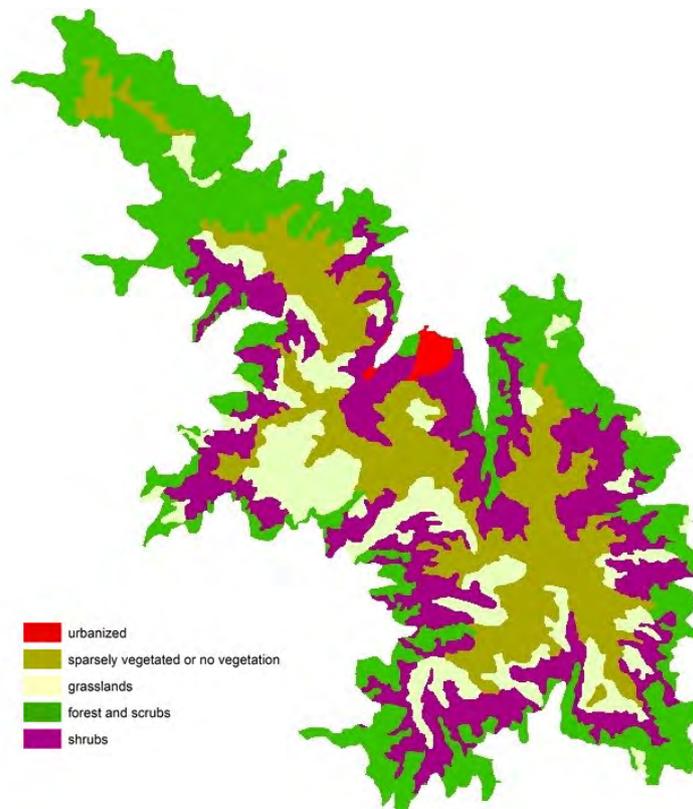


Figure 1. Ecosystem types in the case study area – National Park “Pirin”

## Data collection and processing

The data from Management Plan of “Pirin” National Park (MP, 2014) were used for characterization and biophysical assessment of the condition of forest ecosystems. The informative indicators to quantify the condition of an ecosystem were chosen, based on the “Methodology for assessment and mapping of woodland and forest ecosystems condition and their services in Bulgaria” (Kostov et al., 2017). The indicators have to be able to provide useful information to policy makers and the wider public on the current state and changes in the conditions of the environment. The set of selected indicators include the main five indicator groups: biotic diversity, abiotic heterogeneity, energy budget, matter budget, water budget. Each of them contains particular number of individual indicators with specified parameters.

The condition of the ecosystems was assigned with scores from 1 (bad condition) to 5 (very good condition), depending on the measured/assessed values of every indicator (by expert evaluation for each specific polygon). In order to collate all separate indicator scores into one single measure of ecosystem structural-functional condition, the Index of Performance (IP) for a particular ecosystem was used. The IP was calculated as the ratio of the sum of the indicator scores to the maximum possible indicator sum:

$$IP = Sni/Sni(max) \quad (1)$$

where:

Sni – sum of the scores, assigned to every indicator;

Sni – sum of the maximum possible indicator (score 5) for every indicator.

The IP takes values between 0 and 1, according to the following scale: IP = 0.00 ÷ 0.20 – very bad condition; IP = 0.21 ÷ 0.40 – bad condition; IP = 0.41 ÷ 0.60 – moderate condition; IP = 0.61 ÷ 0.8 – good condition; IP = 0.81 ÷ 1.00 – very good condition.

The importance of various variables underlying the ecosystem services in mountainous protected areas (PAs) were assessed based on perception evaluation of scientists and local stakeholders by questionnaire and further prioritisation. The relevant ES delivered by NP “Pirin” were selected. After the selection, the appropriate for assessment and mapping ecosystem services were determined, based on: readily available information for each of them; opportunity to measure this service; ability to collect data (availability of information, accessibility, completeness and appropriate format of information).

## Mapping procedure

The assessment and mapping procedure rely on the integration of two consecutive approaches. The Methodology for assessment and mapping of woodland and forests ecosystems’ condition and their services in Bulgaria (Kostov et al., 2017) provides detailed description of the assessment of the forest ecosystem’s condition. After finalizing scoring of the proposed set of biophysical parameters - indicators, geospatial analysis is applied in order to develop maps of the provision of ES. The application of GIS method is advantaging, therefore we used ESRI ArcGIS software and the working environment in UTM WGS84, zone 35N for the final step. GIS ensures the application of analysis tools set to perform overlay analysis and to optimize and manipulate the results of the assessment. The next step was to spatially link the datasets to the forest subunits, delineated by polygons. The final map represents the condition of forest ecosystems in NP “Pirin” in a uniform visualization.

## RESULTS AND DISCUSSION

The distribution of the afforested area in the case study by tree species showed that 36.81% are occupied by *Pinus mugo*, followed by *Pinus peuce* (35.2%) and *Pinus sylvestris* (10.1%). This distribution well corresponds to the distribution of afforested area on the whole territory of NP “Pirin”. The analysis of the data revealed that 11 177.8 ha (69.3%) is the area of forests growing on medium-rich habitats, followed by those on poor habitats – 4081.3 ha (25.3%). On rich habitats an area of 564.0 ha (3.5%) covered by high-mountain forests are located. The forests in the case study have a relatively high mean age, as 88.0% are above 80 years old, most of them are above 100 years old and those above 120 years old are 31.3%. The oldest are *Pinus heldreichii* and the youngest are *Pinus sylvestris* forests. The average growing stock is 232.47 m<sup>3</sup>/ha.

Three main subtypes of forest ecosystems at Level 3 have been identified in the case study area (Table 1): G 1 (High

deciduous forests, G 3 (Coniferous forests) and G 4 (Mixed deciduous and coniferous woodland). To the level 4 are attached 6 subtypes of forest ecosystems, corresponding to respective Natura 2000 habitat types' code. Heatland and shrub ecosystems are presented by 1 subtype F 2 (Arctic, alpine and subalpine) corresponding to habitat type 4070\*, which is of conservation priority in Europe. The most widely distributed in the case study are the ecosystem subtypes F 2.4 (Conifer scrub close to the tree limit) and G 3.6 (Subalpine Mediterranean pine woodland), followed by G 3.4 (Scots pine woodland south of the taiga).

Table 1. Typology of ecosystems and correspondence of the habitat types with the MAES ecosystem categories and types (Level 2, 3 and 4); (\*) indicates habitat types of conservation priority in Europe

Level 2	Level 3	Level 4	Natura 2000 Habitat types' codes
Woodland and forest	High deciduous forests - G 1	G 1.6.	9110, 9130
	Coniferous - G 3	(G 3.1+G 3.4+G 3.5+G 3.6)	91BA, 91CA, 9410, 95AO, 9530*
	Mixed deciduous and coniferous woodland - G 4	G 4.6.	
Heatland and shrub	Arctic, alpine and subalpine – F 2	F 2.4.	4070*

The analysis of the results from the biophysical assessment of the condition of forest ecosystems in NP “Pirin” showed that almost all ecosystems are characterised with “good” condition – 94.80%. The proportion of the ecosystems with “moderate” condition is 4.76% and with “very good” – 0.44% respectively (Fig. 2). The largest part (80.0%) of the ecosystems with “very good” condition are *Pinus peuce* forests, most of them located on the territory of the reserves “Bayuvi Dupki- Dzhindzhiritsa” and “Yulen”.

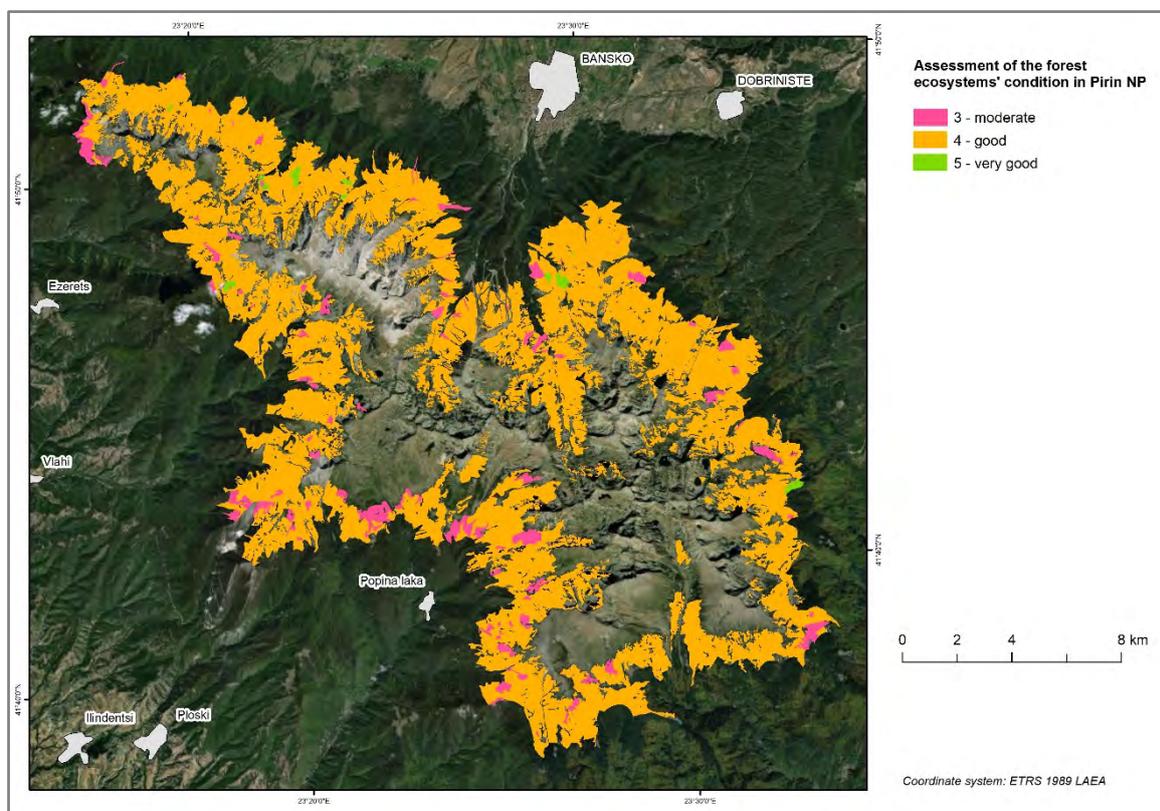


Figure 2. Mapping of the condition of forest ecosystems in NP Pirin

The ES concept was designed to be included in the decision-makers' agenda through various tools for environmental and natural resources management (MEA, 2005) but still more effort is needed for its actual inclusion in natural resource management and decision-making process (Kienast et al., 2009). It was recognised that this inclusion strongly depends on institutional capacity and the credibility of generated information (Ruckelshaus et al. 2013) and in order to inform and support decision making trust needs to be gained to scientific evidence (Rae et al. 2007; Willemen et al. 2015).

The analysis of the result from the perception evaluation of scientists and local stakeholders revealed that the forest ecosystems in the case study are of a major importance for the provision of Regulating and Maintenance services and for Cultural services (Table 2). Mountains play an important role in the water cycle, with significant feedback to the regional climate regulation. They are often called nature's "water towers" storing water in various ways, including the formation of snow and ice, which is later released as melt-off during warm seasons. Water storage and modulating runoff regime or so called "waterholding capacity" of mountain ecosystems reduces peak stream flow. Mountain vegetation and soils play a significant role in reducing or mitigating risks from natural hazards, e.g. avalanches and rockfall. Mountain ecosystems play crucial role in protection of fragile mountain slopes from erosion and leaching processes.

Mountain ecosystems have intrinsic spiritual and religious value, especially for local inhabitants. Species diversity with many endemic or charismatic animals and plants together with spectacular landscapes are of strong aesthetic value. Traditional mountain ways of life and the landscape mosaics that have been created result in a strong sense of place and cultural heritage. Scenic landscapes and clear air make mountains target regions for recreation and tourism – often seen as an engine for economic development. Mountain populations have high diversity of cultures, incl. languages and traditional agricultural knowledge that commonly promote sustainable production systems.

From the Provisioning ecosystem services "genetic resources" are recognised as being of key importance in mountain ecosystems in protected areas. As sources of all major and many smaller rivers they supply water to human population and some of the rivers are also used for hydropower production.

Table 2. Ecosystem services, provided by mountain PAs

Ecosystem service	Key contribution	Some contribution
<b>Provisioning services</b>		
Food and fibre		x
Timber/fuel/energy		x
Freshwater	x	
Ornamental resources		x
Biochemical/natural medicines		x
Genetic resources	x	
<b>Regulating and services</b>		
Pollination		x
Seed dispersal		x
Pest regulation		x
Disease regulation		x
Climate regulation	x	
Air quality regulation	x	
Erosion regulation	x	
Natural hazards regulation	x	
Water flow regulation	x	
<b>Cultural services</b>		
Spiritual and religious values		x
Education and inspiration	x	
Recreation and ecotourism	x	
Cultural heritage	x	
Aesthetic values	x	
Sense of place	x	

Generally, scientists put more emphasis on the biotic and abiotic (system related) ES, whereas stakeholders put more emphasis on the socio-economic and cultural ES. For example, considering the ES with key contribution in mountain PAs, the scientist indicated ES such as carbon sequestration, flood mitigation, or erosion control whereas the stakeholder's preferences are for leisure activities. The difference in the perception of scientists and stakeholders may be due to the fact that the scientists pay more attention to the long term processes, while stakeholders give more weight to issues they deal with in their daily work, such as anthropogenic disturbance or managing tourist numbers (Hein et al., 2014; Bagstad et al., 2014). The observed differences in views may also be an effect of the more in-depth and theoretical view of scientists on ecosystems, and the more general and practical view of managers (Fisher and Brown, 2014). Nevertheless the stakeholders' involvement in decision making on PAs management is of the utmost importance as success of conservation and management measures relies on their acceptance by local stakeholders (Niedzialkowski et al. 2018, Sterling et al. 2017)

After the identification of relevant ES we identified a set of 3 ES to which biophysical dimension could be spatially quantified, based on data availability and readiness of its use for the specific purpose. The set included: Erosion Regulation (ER), Carbon Sequestration (CS) and Biodiversity as cultural heritage (Biodiversity Heritage - BH) (Table 3).

Table 3. Selected set of ES (classification following CICES)

Selected ES			
ES classification following CICES (v5.1)			Specifications
Section	Section	Class (Code)	ES Designation
Regulating	Regulation of physical, chemical, biological conditions	Stabilisation and control of erosion rates [2.2.1.1]	Erosion regulation (ER)
		Global climate regulation by reduction of greenhouse gas concentrations [2.3.5.1]	Carbon sequestration (CS)
Cultural	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Heritage, cultural [3.1.2.3]	Biodiversity (as heritage) (BH)

The methods for quantifying and mapping of each of the selected ecosystem service have to be based on the data collection and processing and guided by the availability and readiness of its use. For the purpose of our study we propose for assessment and mapping of ES "Erosion Prevention" the Universal Soil Loss Equation (USLE) to be used, integrated in a GIS platform. USLE allowed the difference between erosion rates in the current scenario (i.e. erosion rates given actual land cover type) and erosion rates for a worst-case scenario (considering a cover type with maximum erosion - bare soil under mobilisation) to be determined as first suggested by Guerra et al. (2014). Our suggestion for mapping ES "Carbon Sequestration" is to be based on input/output balances in biomass (above and below ground). Annual emission and retention coefficients for each land-use have to be estimated based on the National Inventory Report results (MOEW, 2019). Biodiversity (as heritage) can be mapped on the basis on presence (area) of protected habitats listed under the Annex I of the Council Directive 92/43/EEC (CEC, 1992).

## CONCLUSION

The present study provides information on assessment on the condition of high-mountain forest ecosystems in NP "Pirin" and revealed that the majority of ecosystems are characterized with good condition. The forest ecosystems in the study site are characterised with relatively large size and could supply multiple ES. Mapping of ecosystem condition highlights potential hot-spots of ecosystem services supply in the case study area.

Studied forest ecosystems preserve high biodiversity and have high potential to provide regulating and cultural ES. The methods for quantifying and mapping were proposed for selected ecosystem service: “Erosion Prevention”, “Carbon Sequestration” and “Biodiversity as heritage”. Regarding policy- and decision-making support, this study provides one of the initial steps needed for the kick-off actions of the MAES implementation in protected areas in Bulgaria.

The approach presented in this study for mapping of the selected ES can be further developed for economic valuation of ES (as proposed by the EU 2020 Biodiversity Strategy) and the elaborated maps can be useful tool to bring the analytical framework adopted into the practice of PA management.

## ACKNOWLEDGEMENTS

This study was performed under the project "ASSESSMENT AND MAPPING OF ECOSYSTEM SERVICES IN HIGH-MOUNTAIN TERRITORIES IN RILA AND PIRIN FOR SUSTAINABLE MANAGEMENT OF NATURAL RESOURCES" - MAPESMOUNT, funded by Bulgarian National Science Fund, under grant agreement No KII-OIIP 03/6/17.12.2018.

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## BIOGRAPHY



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# SLOPE TYPE CLASSIFICATION WITH RANDOM FOREST METHOD IN THE GERECSÉ HILLS, HUNGARY

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## **Abstract**

*The Gerecsé (average elevation ~400 m) in Northern Central Hungary has a highly variable morphology, consisting of horsts, hillslopes, stream valleys, and loessy riverside bluffs. The rocky surfaces are composed of Mesozoic and Cainozoic limestones, marls, and sandstones, and are covered by thick layers of unconsolidated Quaternary fluvial, lacustrine, and aeolian sediments. Main elements of the morphology have been formed by the constant and relatively rapid fluvial and colluvial erosion. Landslides are also present, especially in the large, loess-covered areas of the northern part of the hills. Landslides occur even in inhabited and agricultural areas and may cause serious damages. There have been attempts to map these landslides and the observations were documented in the National Landslide Cadastre (NLC) inventory. However, these documentations are sparse and often inaccurate. Our aim was to complete and correct the landslide inventory by slope classification modelling. We used the Random Forest classification method to sort the slopes of the area into six categories: scarps, debris, transitional area, stable accumulation areas, stable hilltops, and stable slopes. The analysed input datasets were terrain indices (4) derived from the MERIT DEM and categorized geological data from local geological maps. Training areas for each slope category were delineated by using the local landslide inventory, geological maps, and the previous field experience of the team. The model was tested on 12 m resolution raster data covering 480 sq. km, yielding an error of ~20%. The results of the model showed that the probable location of landslide-prone slopes is not restricted to the areas marked in the National Landslide Cadastre inventory, and unstable slopes might be present on a much larger area. For example only 6% of the estimated location of the scarp areas fall within the NLC polygons in the modelling area.*

**Keywords:** Landslides, random forest, slope stability, terrain categorization, Gerecsé

## **INTRODUCTION**

The morphology of the Gerecsé Hills in north-central Hungary is characterised by the fluvial terraces of the Danube River, Neogene tectonism and Quaternary erosion. Gravitational mass movements are regularly detected on the agricultural (vineyards) areas, and on the built-in slopes of the local villages. The hazardous areas are mainly those, where unconsolidated sediments are present, or loess cover is characteristic. To estimate the level of hazards, several studies and mapping campaigns were done, concentrating on those areas, where human activity is high (Pécsi et al., 1976; Szabó, 1996;). Small-scale nation-wide maps were also compiled, indicating the high level of geohazards in this region (Gábris et al, 2018; Józsa et al., 2019). These studies refer to an event-based mass movement inventory, which dates back to the early 1970s. Although such inventory is essential in geomorphological studies and to determine the spatial probability of hazardous mass movements, it often contains inaccurate records (Gerzsenyi and Albert, 2018).

The systematic recording of gravitational mass movement events in Hungary has started in 1972 (Szabó et al., 2008). A National Landslide Cadastre (NLC) was established and files were created for all event. Each documentation contains a map excerpt in 1:25000 scale and a description. Later this data has been digitally processed and a geodatabase was

created by the Geological Institute of Hungary. Additional records have been added to the digitized core data and the database was made accessible online in KML-format.

The problem is that the NLC is not complete. Many of the records do not contain information about the actual state and the cause of the slope movement. Moreover, none of the map inlets of the archive records differentiated the landslide body into source/scarp and deposit/debris area, and this also stands for the added records. The latter is rather composed of point-like records without any areal delineation. Distinction of the scarp, the debris and the transitional areas of a landslide is crucial for predicting the landslides by means of modelling (Petschko et al., 2016).

In previous years we have concentrated on the landslide susceptibility mapping of the area (Gerzsenyi and Albert, 2018). The method was the likelihood ratio function (Chung, 2006), based on the NLC polygons and combined with on-site validation. The extensive fieldwork drew our attention to the incompleteness of the NLC. It occurred that only the close vicinity of the villages and agricultural areas were represented in the database records. According to a pan-European study, which included the NLC data as well, such incompleteness of the database produces unreliable regional estimations (e.g. Günther et al. 2014).

In the present study the NLC has been used as base data, but extensive fieldwork improved the original documentation and new observations were also recorded. The aim of the present study was to complete and correct the landslide inventory by creating a map of classified slope types in the study area using machine learning method, namely the random forest classification (RFC), for modelling.

## MATERIALS AND METHODS

The study area covers ~480 km<sup>2</sup> containing mainly moderately steep foot-hill areas dissected by loessy valleys, gullies and riverside bluffs. The hilly regions are represented by horsts, hillslopes, stream valleys, and usually covered by forests (*Figure 1*). The rocky surfaces are composed of Mesozoic and Cainozoic limestones, marls, and sandstones, and are covered by thick layers of unconsolidated Quaternary fluvial, lacustrine, and aeolian (wind-blown) sediments. Although the road network in this area is dense, the access to the outcrops was sometimes complicated with vehicles due to the lack, or closure of viable roads.

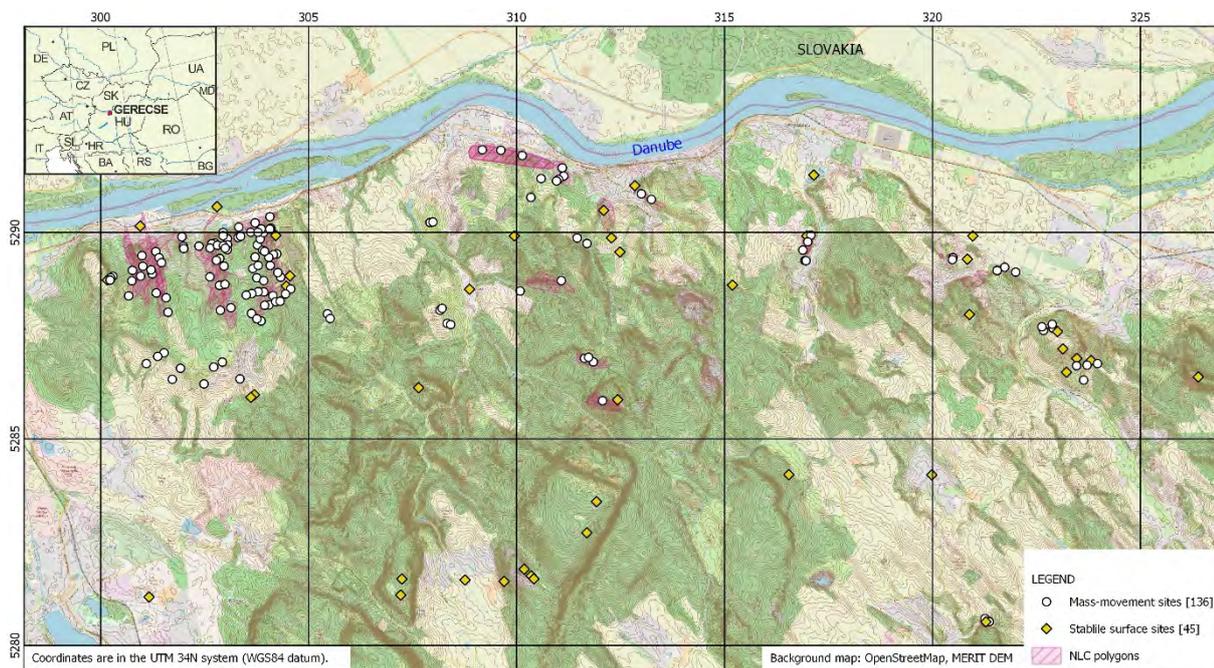


Figure 1. The map of the study area comprising the Gerecse Hills nearby the Danube River.

### Digital elevation data

The slope-type classification required digital elevation data, which is appropriate for producing morphometric derivatives. In the present study the latest high-precision, global coverage terrain model, the MERIT (Multi-Error-Removed Improved-Terrain) DEM was used. This database was created using mainly the SRTM 3" resolution database,

and the JAXA (Japan Space Agency) AW3D30 (ALOS World 3D - 30 m) DEM model, but compared to these sources it was corrected to represent the terrain instead of the surface elevations (Yamazaki et al. 2017).

The terrain indices were derived from the MERIT DEM and a morphometry-based analysis was done prior to slope classification to select the appropriate derivatives. The analysis focused on the rate of difference between the landslide-affected and the non-affected areas, and included the correlation of the frequency distributions for each variables. A total of seven morphometric variables were analysed (*Table 1*). The correlation values (r) refer to the rate of difference between the two area-types: if the value is low the distribution functions are different, but if the value is high, the distribution functions are quite similar. For finding the landslide-prone slopes we need variables, which has different distribution function in the two area-types, so the variables with lower coefficients are preferred.

*Table 1. Morphometric variables, their ranges in the landslide-affected and the non-affected areas, and the correlation coefficients of their frequency distributions in the two area-types.*

Morphometric variable	Range of non-affected areas*	Range in landslide-affected areas*	Correlation coefficient (r)
elevation [m]	108-306	123-276	0.20
aspect [°]	1-109; 183-359	0-88; 243-360	0.66
slope angle [°]	0-14	1-17	0.52
profile curvature	-0.0022-0.0022	-0.0025-0.0020	0.93
TWI (topographic wetness index)	5-10	5-10	0.97
mean upslope area	0-58	0-58	0.62
normalized height [%]	0-100	0-100	0.84

\*Larger than 0.2% of the examined area was involved.

Since the aim of this study was not only focusing on the distinction of sliding and non-sliding areas, we had to consider other aspects of the possible morphometric variables. The area-specific variables (such as the *elevation* and the *aspect*) may produce unwanted bias in the morphology classification by reducing the chance to detect morphological types outside the range of the “most frequent” elevation and aspect values. So despite having appropriate correlation values for landslide detection, the *elevation* and the *aspect* variables were omitted as possible predictor variables in the classification. The remaining five parameter were all considered usable, but sometimes one of them was excluded from the list of predictor variables during the modelling process.

## Geological data preparation

The geological data of the area was extracted from a medium-scale geological map (Gyalog and Síkhegyi 2005). The polygons of this map are categorized differently for the Quaternary and the pre-Quaternary formations: the Quaternary is classified based on the genetics of the sediment (e.g. wind-blown, fluvial, gravitational, etc.), while the older units are categorized as formations. Neither of these classifications is appropriate when doing modelling based on physical parameters of the rocks and sediments, because both categorization methods unites different lithological units (e.g. the Eocene Tinnye Formation contains marls, limestone, loose sand, and sandstones).

The reclassification of the geological map polygons aimed to create categories containing physically similar sediments and rocks. Among the created 14 categories mixed types also exist representing those formations which are inhomogeneous (*Table 2*). The preliminary analysis of the lithological categories on the landslide-affected (NLC polygons) and non-affected areas suggested that the lithology is not a good predictor for landslides in the studied region for RFC because the different categories have quite similar distribution functions. The correlation of the two distribution was high ( $r=0.98$ ). However, the similarity may be caused by the geological classification derived from the medium-scale source map.

*Table 2. Criteria of our map evaluation system and the rate of categories in non-landslide and landslide areas.*

No.	Lithological category	Rate in non-landslide areas [%]	Rate in landslide areas [%]
1	clay	2.28	0.1
2	silt	60.05	75.08
3	travertine	0.86	0.06
4	sand	3.89	0
5	sand and silt	4.15	0

6	sand-silt-clay	0.93	2.59
7	old carbonates	8.85	0.25
8	gravel	0.14	0.02
9	gravel-sand	0.02	0
10	gravel-sand-silt-clay	13.03	16.85
11	consolidated mixed debris	0.01	0
12	layered sandstone	0.68	0.48
13	layered mixed debris	1.35	1.18
14	loose mixed debris	3.75	3.38

## Reclassifying the landslide cadastre into morphological categories

In the Gerecse Hills the NLC contains 47 polygons, each representing a gravitational mass-movement event. Since occasional renewal of a landslide was recorded as a distinct event, the polygons sometimes overlap with each-other. The outlined body of the moving landmass was drawn on a small map and attached to the files of the original documentation. The polygons were later digitized from the map inlets of the paper-based files of the NLC (Szabó et al., 2008). The recorded events date from 1972 to 1980. The geometry of the polygons are not appropriate for modelling due to the crude digitization technique and the inaccurately georeferenced manuscript maps. These polygons served as an initial “itinerary” to give clues where to look for landslides on the field.

Using objective criteria, the records of the NLC and additional sample locations (a total of 136 sites) were sorted into three morphological categories: scarps, debris, transitional area. The criteria, which were used to differentiate the landslide bodies into three categories consist of visible markers, which can be determined on the field:

*scarp*: fresh outcrop usually exists, in situ revealing the base geological formation. Vegetation is usually undisturbed above the outcrop, but often dying or non-existent on the scarp itself due to the erosion.

*transitional*: outcrops are small, or do not exist, and the revealed material is not intact (i.e. the original sedimentary markers are blurred, disturbed, non-existent). The material is more loose than in the scarp, and wet clayey matrix is usual. Vegetation shows disturbance (e.g. trees leaning towards the slope).

*debris*: the material is disturbed, loose, clayey and often wet. Original sedimentary markers are nonvisible, the morphology is hummocky and the vegetation cover may also be disturbed (e.g. trees are fallen, or leaning to different directions).

The non-hazardous morphological categories were also sorted into three types: stabile accumulation areas, hilltops, and stabile slopes. A total of 45 pieces of polygons of these categories were designated to the geodatabase records. These polygons were selected from previously visited parts of the Gerecse Hills aiming for wide coverage and uniform density. The categorized map of the observations (181 polygons) served as training data for the subsequent random forest classification (RFC). The composition of the training data was the following: 35 scarp; 62 transitional; 39 debris; 15 hilltop; 15 stabile accumulation area; 15 stabile slope.

## THE RANDOM FOREST CLASSIFICATION (RFC)

Random forest is a powerful tool for multivariate classification that uses several decision trees, each one with a prediction, where the most popular one will be the overall result (Liaw and Weiner, 2002). In spatial predictions this method can reach high accuracy to classify raster-type objects, but it is sensitive to the precision of the training area (Belgiu and Drăguț, 2016). We also used raster-type spatial data as subject of RFC predicting a result for each pixel.

Rasters were created from the DEM in the form of the five morphometric derivatives: 1) *slope angle*, 2) *profile curvature*, 3) *mean upslope area*, 4) *TWI* and 5) *normalized height*. The reclassified polygons of the geological map were also rasterized. Using these rasters, a multi-band .TIF file was created, in which each predictor variable was represented as a raster-band. The resolution of the multi-band raster was increased using b-spline, and nearest neighbour<sup>1</sup> resampling method (~12x12 m) to better fit to the shape of the landslide polygons. The polygons of the slope types were also rasterized during the classification process with the same parameters. For deriving the morphometric variables and rasterizing the geological variables the SAGA program was used, and the rasterization of the slope-type polygons was done with RStudio, using R 3.5, and the rgdal, sf, sp and raster libraries.

<sup>1</sup> The NN-method was used only for the geology, since having discrete values.

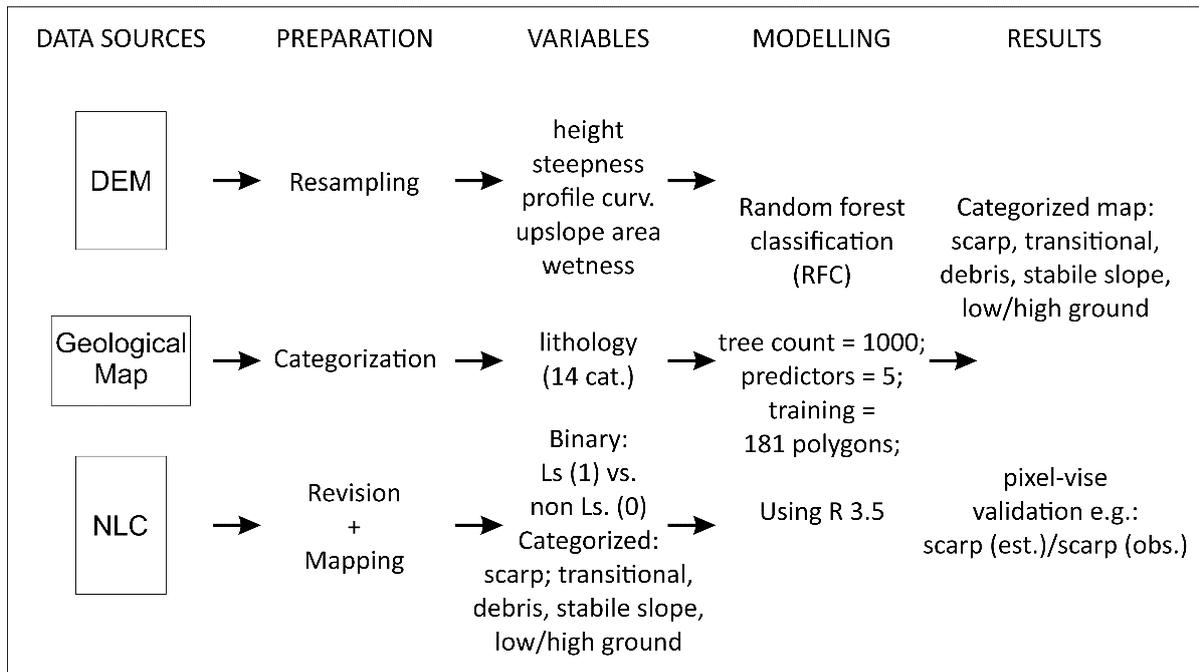


Figure 2. An overview of the modelling methodology using RFC

The random forest classification process was also done in RStudio, and the R-script used the caret library. The data sources were represented as one single georeferenced TIF-file with six bands, and a SHP-file containing the 181 training polygons, each of them categorized into one of the six slope-types (Figure 2). The parameters of the RFC were defined in the script to have 500-1000 randomly selected decision trees (which determined the size of the “forest”). The modelling result was a single-band georeferenced raster, in which the pixel values represented the predicted slope-types (Figure 3 C).

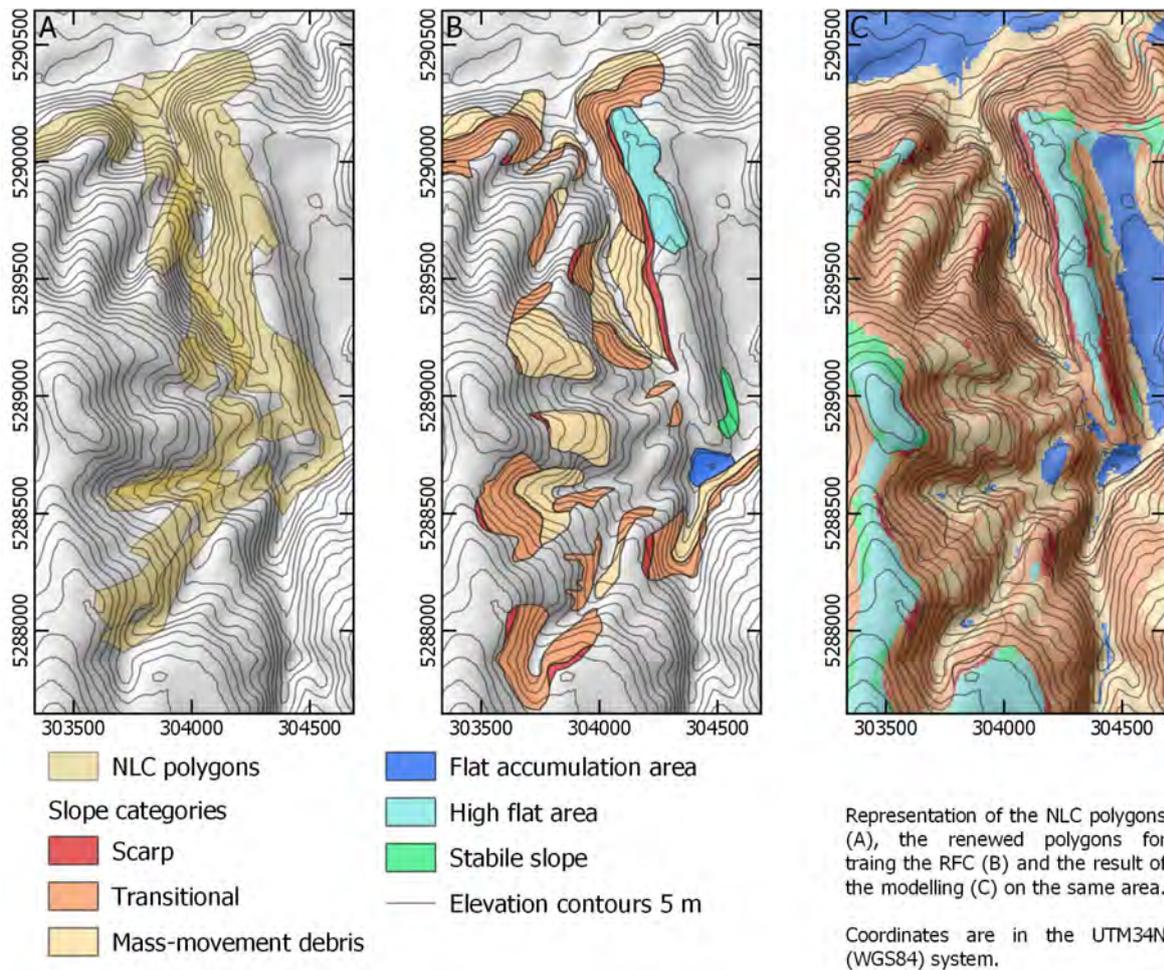


Figure 3. A series of excerpt maps of the study area representing the geometry of the NLC, the renewed polygons, and the modelled slope categories.

## RESULTS

The results of the RFC were inserted into QGIS (v. 3.14) to compare with the training data. Since several combination of modelling was executed, the GIS environment was prepared to be able to run repeated tasks (e.g. in the form of python scripts). The varying number of training polygons in each of the six category was a disadvantage in the validation process, and because of this we executed a pixel-wise comparison of the observed and the modelled slope categories (Table 3).

Table 3. Results of the pixel-wise comparison of the training polygons and one of the models (model no. 6).

Type	Polygons*			Pixels			Modelled area [pixels]	Rate of detection [%]	Rate of category in model [%]
	Fit	Missed	Error [%]	Fit <sup>1</sup>	Missed <sup>2</sup>	Error [%]			
Scarp	18	17	0.49	899	1099	0.55	37026	5.4	1
Transitional	56	6	0.1	18107	3244	0.15	1016111	2.1	28
Debris	20	19	0.49	8378	5349	0.39	579529	2.4	16
Flat accumulation	13	2	0.13	7654	515	0.06	1517486	0.5	42
Hilltops	14	1	0.07	3757	673	0.15	270747	1.6	8
Stabile slopes	9	6	0.4	2740	1563	0.36	180870	2.4	5
Median:			0.27			0.25		2	

\* A polygon was considered "fit" when the right category-type cell was the most occurring

<sup>1</sup> Fitting pixels in fit & missed (but correct category) polygons

<sup>2</sup> Missed pixels in fit & missed (but correct category) polygons

The modelled area covers 480 sq. km and the training area was only 2% of it. Throughout the modelling a total of seven realizations were executed and tested with different combinations of the predictor variables and the RFC's tree count parameter. The best result was achieved with the model no. 6 (Table 3) which used all the six predictor variables and 1000 decision trees.

The prediction of the model (in the case of no. 6) was successful in 75% if looking at the pixel count in all the training polygons. In the case of two other models (no. 4 and no. 7), using similar tree-count in the RFC, this rate was 70% and 73% respectively. Comparing the rate of success with the rate of error, we have a slightly better, ~82% result. For this, we calculated the count of "missed" cells in those polygons, which do not have the majority of the fitting category, and compared to the count of "fit" cells in those polygons, which have the majority of fitting cells (Table 4).

*Table 4. The rate of success of the prediction in different models using the same number of decision trees (1000) but different morphometric variables. In model 4 the mean upslope area was excluded; in model 6 all variables were used; in model 7 the TWI was excluded.*

	Scarp	Transitional	Debris	Flat accumulation	Hilltops	Stabile slopes	Median:
Model 4	66%	99%	55%	94%	100%	64%	80%
Model 6	38%	97%	64%	95%	97%	68%	82%
Model 7	49%	96%	71%	96%	97%	73%	85%
Average:	51%	97%	63%	95%	98%	68%	82%

## CONCLUSIONS

According to the models ~45% of the area falls within one of the three gravitational mass-movement category (scarp, transitional, debris), which does not mean that such a large area is prone to landslides. In the study area many types of mass movement are present (e.g. debris slides, rotational slides, topples, creeps, rock falls and slumps), and not all of them are hazardous. The results of our study suggest that only 1% of the area is "scarp" which refers to those locations, where the mass-movement is the most intense.

However, this 1% is high, if the location of the scarp lies in a built-in or on an agricultural area. The results showed that the probable location of landslide-prone slopes is not restricted to the areas recorded in the National Landslide Cadastre inventory. Only 5.4% of the highly unstable slopes (scarps) fall within the NLC polygons in the study area.

From our results and field experience we conclude that the landslide inventory (NLC) records require refinement and corrections before using them for modelling. The refinement primarily should include the distinction between scarp, debris, and transitional areas of the landslide locations. The results of our modelling serve as the base of an ongoing regional geohazard mapping project.

## ACKNOWLEDGEMENT

The project was partly supported by the Thematic Excellence Program, Industry and Digitization Subprogram, NRD Office, project no. ED\_18-1-2019-0030 (from the part of G. Albert), and the ÚNKP-19-3 New National Excellence Program of the Ministry for Innovation and Technology (from the part of D. Gerzsenyi).

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# GIS-BASED ASSESSMENT OF THE HAZARD OF HEAVY METAL POLLUTION OF SOIL BY FLOODING FROM DANUBE IN THE OSTROVSKA LOWLAND

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## **Abstract**

*The aim of this study is GIS-based assessment of the hazard of heavy metal pollution of soil in the Ostrovska lowland (Bulgaria) in case of inundation from the Danube. For this purpose, a GIS-based model is elaborated and applied to the study area. The assessment takes into account the following two parameters: degree of heavy metal pollution of river sediment (Me) and topography (To). The first step produces files into raster format for each of the two parameters of the MeTo index. The second step of data processing includes a reclassification of the resulting maps of the two factors considering the rating of the predefined intervals for each factor. The third step uses the Spatial Analyst Tools - Map Algebra - Raster Calculator of ArcMap to combine all the factor maps into one preliminary map. The latter is reclassified in the last step of data processing taking into account the predefined hazard classes.*

**Keywords:** GIS, Spatial Analyst Tools, Map Algebra

## **INTRODUCTION**

In recent years the geographical information systems (GIS) have been used increasingly in assessing natural hazards (Carrara et al., 1995; Aleotti & Chowdhury, 1999; Temesgen et al., 2001; Metternicht et al., 2005; Huabin et al., 2005; Fell et al., 2008; Westen et al., 2008; Galderisi et al., 2008; Lari et al., 2009; Tarolli & Cavalli, 2013; Suh et al., 2017; Ashournejad et al., 2019). In this regard, different methods have been applied, e.g. statistical and mathematical - cluster analysis and regression analysis (Aleotti and Chowdhury, 1999; Clare et al., 2016), geostatistical and simulation methods (Horspool et al., 2014), and hybrid methods which are a combination of the above mentioned. GIS is a computer-based technology handling geospatial and non-spatial data and its geospatial analysis and modelling. According to Thapinta and Hudak (2003), the application of GIS methods has the following advantages over the statistical and simulation methods: usage of publicly available data and the requirement of less resources. The important benefit of using GIS is the user-friendly visual access and display, the performance of spatial analysis and application of standard GIS functions such as thematic mapping, buffer zoning, charting, network-level analysis, simultaneous access to several layers of data and the overlay, data management, and user-specific functions. Recently GIS has often

been combined with analytical models using machine learning and data mining methods (Tarhan and Saygýn, 2006; Suh et al., 2017).

Ore extraction and processing, as well as industrial and municipal activities, are considered to be the main sources of trace metal and metalloid (TMM) pollution of the Danube Valley (Macklin et al, 2006; Milacic et al., 2010; Pavlović et al., 2015). TMM load of rivers is presumably associated with particulate matter and fluvial deposits (Bird et al., 2003; Macklin et al, 2006). The transport of contaminated sediment from mining-affected sub-basins to the Danube can be intensified during torrential rainfalls and flood waves due to increased erosion of mine wastes at the mining sites and activated river bank erosion of contaminated floodplains. Some of the major point sources of contemporary trace metal pollution in the Lower Danube are located in the sub-basin of the Timok River (Brankov et al., 2012; Kotsev, Zhelezov, 2014). The impact of the contaminant load from the tributary can be traced more than 100 kilometers downstream the Danube, both in its channel and floodplain sediment (Bird et al., 2010a; Bird et al., 2010b; Bird 2010c; ICPDR, 2002, 2008, 2015). During flood events, the Danube floodplain between Timok and Vit rivers seems to be threatened by receiving certain loads of hazardous substances (Stoyanova et al., 2018; Stoyanova et al., 2019). Therefore, it is necessary to assess the risk of heavy metal contamination in the lowlands in this section of the Lower Danube. Such preliminary GIS-based assessment is elaborated for one of the lowlands, named Ostrovska, located in the Bulgarian part of the Danube Valley between Ogosta and Iskar rivers. The results of the study are presented in this paper.

## STUDY AREA

The Ostrovska Lowland extends over part of the floodplain of the Lower Danube, NW Bulgaria, between the villages of Leskovets and Ostrov (Figure 1). The approximate geographic location of the study area is 24°0' - 24°8'E and 43°38' - 43°43'N. It covers an area of 25.05 km<sup>2</sup> with a mean altitude of 28 m and an average inclination of slopes about 2°. The Ostrovska Lowland has a length up to 12 km in West-East direction and a maximum width of 4 km in North-South direction.

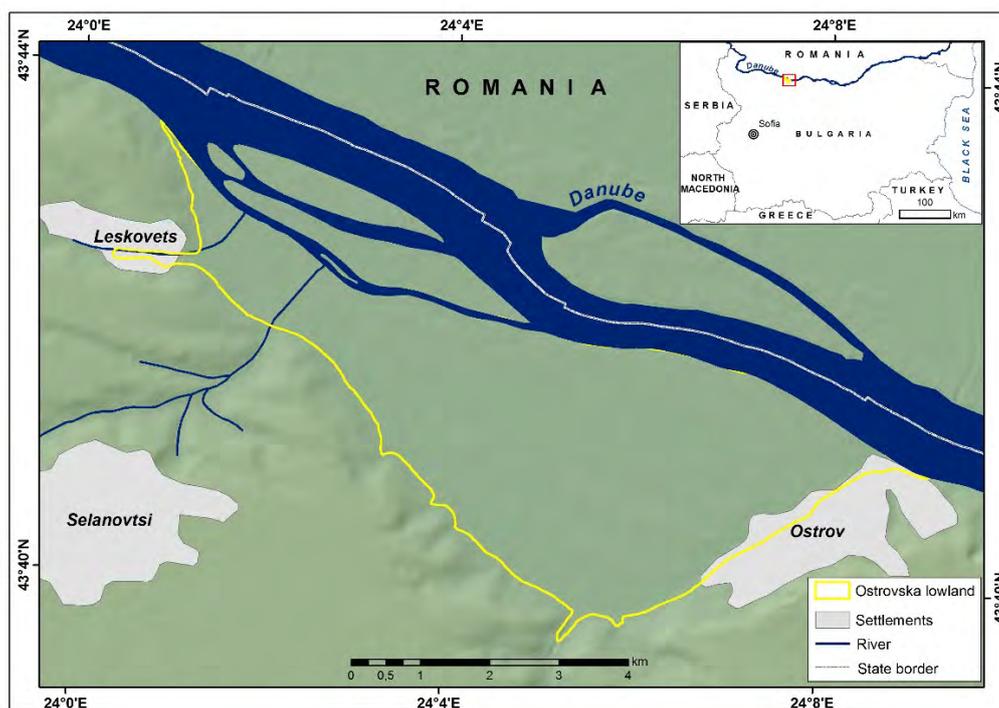


Figure 1. Location map of the study area

From a geological point of view, the investigated area is a part of the Moesian Platform overlain by several sedimentary deposits formed during various cycles of the Palaeozoic, Mesozoic and Neozoic, basically during the Miocene, Pliocene, and Quaternary. The study area is constructed at the top of quaternary alluvial sands, clays and gravels, and contemporary alluvial and loess deposits (Balteanu et al., 2013).

The climate of Ostrovska Lowland is temperate continental with a relatively cold winter and hot summer. The mean temperature in January is -2.2°C, and the average minimum extreme reaches -15°C, while the mean temperature in July is 24.3°C, often with temperature values exceeding 35°C. The area is characterized by westerly and northwesterly

winds. The annual amount of precipitation varies between 518-592 mm with a maximum in May and June, and a minimum in February (Velev, 2002).

The floodplain of Ostrovska Lowland is covered with alluvial soils, primarily Eutric Fluvisols (FAO, 2006) and Eutric Gleysols (FAO, 2006) (Figure 2). The sandy ridges are characterized by sandy soils - Arenosols (FAO, 2006) (Balteanu et al., 2013).



Figure 2. Photographs of the soils of the Ostrovska Lowland: (A) Eutric Gleysols, FAO; (B) Arenosols, FAO; (C) Eutric Fluvisols, FAO (photos V. Stoyanova, October 2017)

According to the CORINE Land Cover nomenclature (CORINE Land Cover, 2018), the agricultural areas take the biggest share of the territory equal to 50,3% (211 - Non-irrigated arable land), followed by wetlands 16,05% (411 - Inland marshes), agricultural areas with natural vegetation 15,81% (243 - Land principally occupied by agriculture with significant areas of natural vegetation), forests 12 % (311 - Broad-leaved forest), and mixed forests and shrubs 1,10% (324 - Transitional woodland-shrub), as well as artificial surfaces 3,98% (112 - Discontinuous urban fabric) (Figure 3). No large industrial plants are operating within the study area at present.



Figure 3. Photographs of the Ostrovska Lowland: (A) Low floodplain with arable land; (B) Sandy ridges with agricultural land and significant areas of natural vegetation; (C) Depressions in the low floodplain with marsh vegetation

There are three protected sites in the Ostrovska Lowland - Gola Bara, Kochumina, and Kalugerski Gred-Topolite, with a total area of 10,705 ha.

According to the administrative division of Bulgaria, the study area is located in the municipality of Oryahovo in the Vratsa District and includes parts of the lands of the villages of Leskovets, Selanovtsi, Ostrov, Galavo, as well as of the town of Oryahovo. The settlements of Leskovets and Ostrov are located within the lowland, and their total population of 1836 inhabitants is distributed as follows: Leskovets - 547 people; Ostrov - 1289 people (GRAO, 2019).

## METHODS AND MATERIALS

### Methodology

To generate a hazard map of heavy metal pollution of soil in the Ostrovska Lowland by flooding from the Danube, a newly developed index method named MeTo (Stoyanova and Kotsev, 2020) has been applied. The acronym of the index is created from the first letters of the included parameters. These are a degree of heavy metal pollution of river sediment (Me) and topography (To). Each parameter is characterized by the following elements: weight (W), ranges, and ratings (R). The relative importance of the three variables is evaluated by comparison between one-another. The

highest weight is given to the indicator ‘degree of heavy metal pollution of river sediment’ followed by the ‘topography’ and ‘distance to the river’. Their weight coefficients are 2 and 1, respectively. The scale of ranges of the parameters characterizes the variety of environmental settings throughout the wetland for the accumulation of heavy metals in soil. A rating (R) from 1 to 4 is assigned to each of the ranges of the individual variables.

The degree of pollution of the river sediment (Me) is calculated by the index  $C_d$  proposed by Backman et al. (1998) as follows:

$$C_d = \sum_{i=1}^n C_{fi}$$

$$C_{fi} = \frac{C_{ai}}{C_{ni}} - 1$$

where:

$C_{fi}$  = contamination factor for the i–th component;

$C_{ai}$  = analytical value of the i–th component;

$C_{ni}$  = upper permissible concentration of the i–th component.

To calculate the index  $C_d$ , the measured concentration of heavy metals is compared against the target values for sediment used in the consecutive Joint Danube Surveys organized by the International Commission for the Protection of the Danube River (ICPDR, 2015). The ranges of  $C_d$  are determined as follows:  $C_d=0$ , no pollution;  $C_d (0, 1]$ , low pollution;  $C_d (1, 3]$ , moderate pollution;  $C_d>3$ , high pollution. The intervals have ratings 1, 2, 3, and 4, respectively.

The topography (To) is assessed by the major geomorphological forms identified in the lowland, which are rated as follows: high floodplain, R=1; sandy ridges, R=1; low floodplain, R=2; old river channels, R=3; marshes, R=4.

The MeTo index is calculated as the sum of the products of ratings (R) and weights (W) assigned to each of the parameters:

$$MeTo = Me_w * Me_R + To_w * To_R$$

where:

MeTo – name of the index method;

Me - degree of heavy metal pollution of river sediment;

To - topography;

R – ratings;

W – weights.

The minimum MeTo index value is 3 and the maximum is 12. It resulted in dividing the whole range into the following six classes: 3 (negligible hazard), 4-5 (very low hazard), 6-7 (low hazard), 8-9 (moderate hazard), 10-11 (high hazard), and 12 (very high) (Table 1).

Table 1. Rating and weighting values for the parameters of the MeTo index (Stoyanova and Kotsev, 2020)

Parameters	Range	Rating R	Weight W	Total Score
Me - degree of heavy metal pollution of river sediment	0	1	2	2
	0-1	2		4
	1-3	3		6
	>3	4		8

To - topography	high floodplain, sandy ridges	1	1	1
	low floodplain	2		2
	old river channels	3		3
	marshes	4		4

To elaborate on the hazard assessment, the MeTo is applied to produce maps for each index, as well as an integrated hazard map in the final step (Figure 4). ESRI ArcGIS, ArcMap 10.6.1 software is used in this study. GCS\_WGS\_1984 is applied as the Geographic Coordinate System and projected to WGS\_1984\_UTM\_Zone\_35N in all maps of this survey.

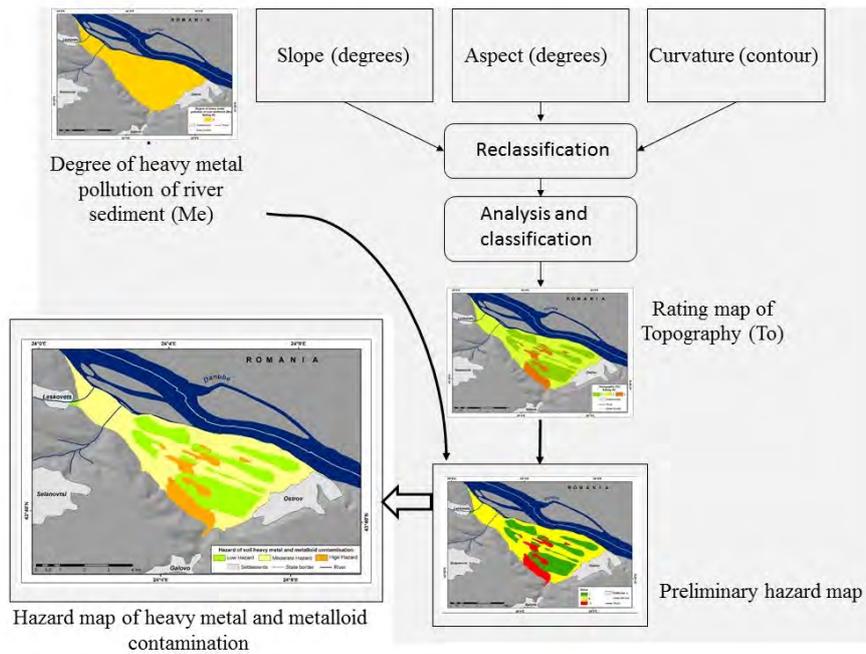


Figure 4. Flowchart of hazard map of heavy metal and metalloid contamination

The first step produces files into a raster format for every three parameters of MeTo. The second step of data processing includes the reclassification of the resulting raster files for the three indices considering the rating of the predefined intervals for each parameter. The values of the rated maps are then multiplied with the relevant weight factors to produce the final maps of each index (Table 1). The third step combines all the index maps into one preliminary hazard map. The latter is reclassified in the last step of data processing, taking into account the predefined hazard classes. The map of the hazard is then reclassified with the relevant values for each class, which is characterized by a different color (Table 2).

Table 2. Hazard classes

Range	Colour	RGB	Hazard
3	Dark Green	38/118/0	Negligible
4-5	Green	10/204/0	Very low
6-7	Light green	170/255/0	Low

8-9	Yellow	255/255/135	Moderate
10-11	Orange	255/168/0	High
12	Red	255/0/0	Very high

## Materials used

To elaborate the raster file of the river sediment contamination, we used data on the concentration of As, Cu, Zn, Pb, Cr, and Ni in one representative sample of Danube overbank sediment deposited in the Ostrovska Lowland. The sampling was a part of a field campaign which covered the whole Bulgarian section of the Danube between the Timok River and the town of Silistra in the period 29 August – 01 September 2013. The sediment was deposited in the spring of the same year during a high flow event of Danube. Pellets are prepared from 4 g of the fine fraction of the sediment (<0.063mm) and 0.9 g of an amide wax (N,N-bis-stearyl ethylenediamine, Licowax C, Clariant). Total contents of the trace elements are measured in the pellets by X-ray fluorescence spectrometer Spectro X-Lab 2000 of the Spectro Company.

The raster files of topography are derived from a digital terrain model (DTM) with a spatial resolution of 1x1m. The DTM has been generated from high-resolution airborne laser scanning data obtained within the project DanubeFLOODRISK (2009-2012). The files of the DTM are provided by the Directorate of Water Management to the Ministry of Environment and Water of Bulgaria. Additionally to the terrain model, topographic maps of a scale of 1:25 000 are also used for delineation of the major geomorphological features of the lowland.

## RESULTS AND DISCUSSION

### Degree of heavy metal pollution of river sediment (Me)

Index  $C_d$  is calculated to be 1.29 for the Danube overbank sediment in the Ostrovska Lowland. This value falls in the range 1-3 of the index and is rated to 3. The limited number of sites with information on the trace elements in overbank sediment in the lowland did not allow us to do interpolation, and the score of 3 is set for the entire study area. The raster file for the degree of heavy metal pollution of river sediment (Me) is created with the tool Spatial Analyst Tools - Conversion Tools - To Raster - Polygon to Raster (Figure 5).

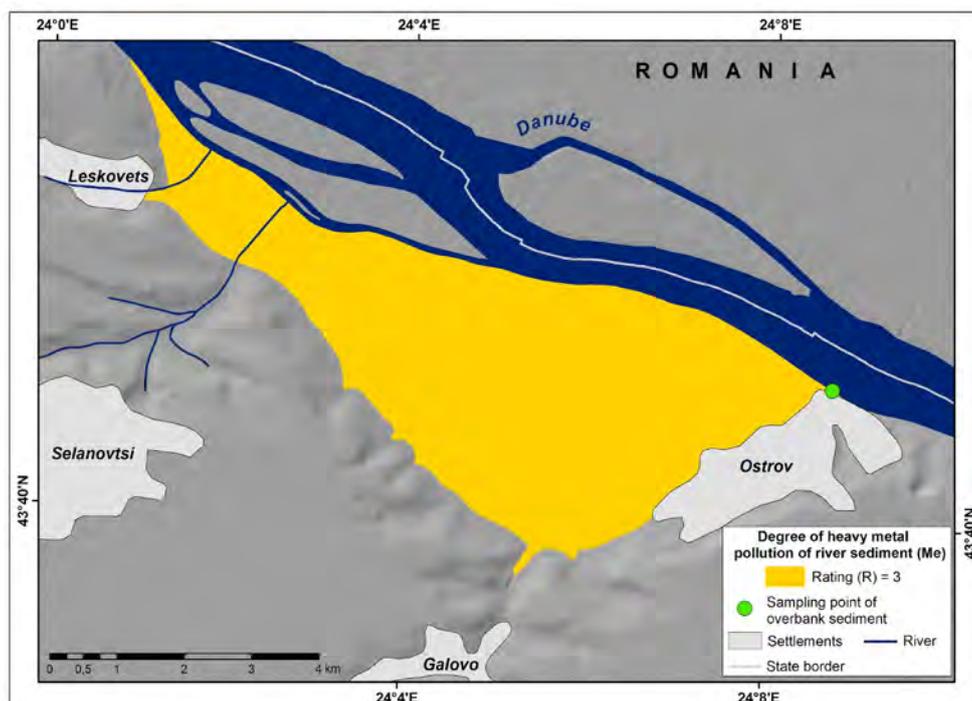


Figure 5. Rating map of Degree of heavy metal pollution of river sediment (Me) in the Ostrovska Lowland

**Topography (To)**

To delineate the limits of the lowland and the geomorphographic landforms, we extracted the slope, aspect, curvature contour, and hillshade from the DTM using the Spatial Analyst Tools - Surface in ArcGIS. After classifying and analyzing these indicators and comparing them with topographic maps, the following geomorphographic units are defined: marshes, low floodplain, high floodplain, and sandy ridges (Figure 6). The categories of the geomorphographic units are defined according to the classification of Mishev (1959).

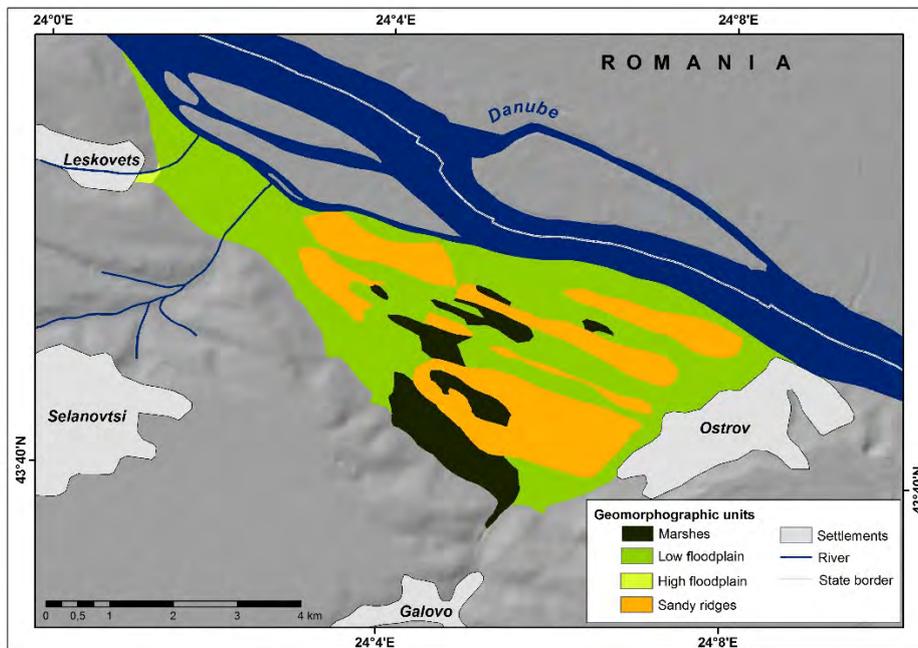


Figure 6. Geomorphographic units of the Ostrovska Lowland

The geomorphographic map is then transformed into a raster format and reclassified with the ratings of the predefined intervals for the parameter Topography (Table 1, Figure 7) applying the Spatial Analyst Tools - Reclass - Reclassify.

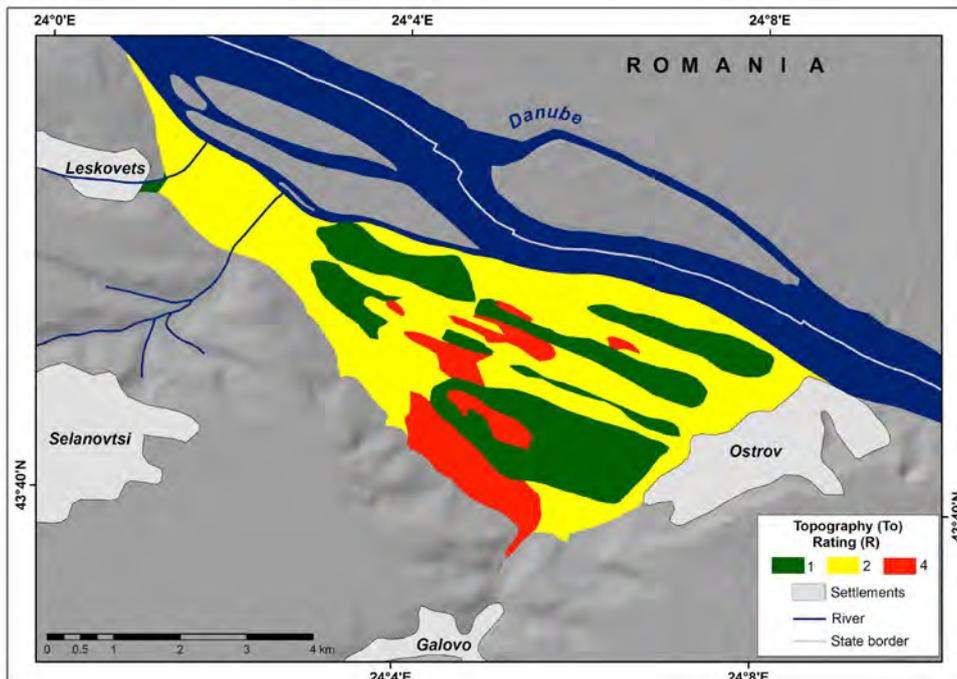


Figure 7. Rating map of Topography (To) of the Ostrovska Lowland

## Map of the hazard

The hazard map is created with the Spatial Analyst Tools - Map Algebra - Raster Calculator of ArcMap.

The calculated values of the MeTo index for the Ostrovska Lowland are within the range 7-10 and fall into three classes of a hazard: low hazard (34% of total area), moderate hazard (48% of total area), and high hazard (18% of total area) (Figure 8).

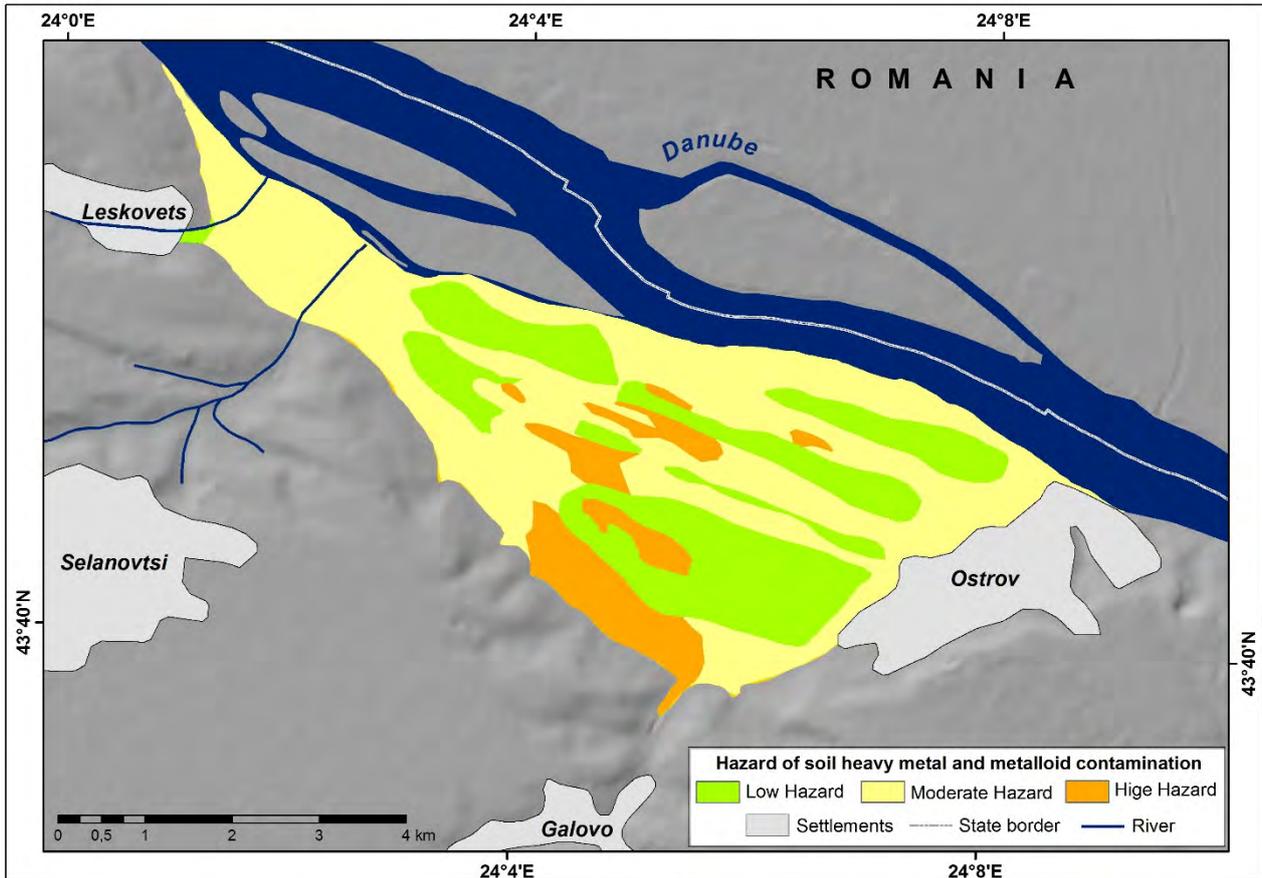


Figure 8. Hazard map of heavy metal contamination of soil in case of inundation

## CONCLUSIONS

The elaborated map shows levels of hazard which are closely associated with the morphology of the lowland. The marshes are highly threatened by metal contamination if flooded, while the hazard of metal contamination of the sandy ridges and high floodplain is determined to be low. The Danube floods represent a moderate threat to the predominant part of the lowland in which the low floodplain is developed. The evaluation elaborated with MeTo can be incorporated as a step in the risk assessment of soil pollution with heavy metals and metalloids in the Danube lowlands. The produced map of the hazard will be provided to local authorities to optimize land use and reduce the health risk to the local population following a flood.

## ACKNOWLEDGEMENTS

This work was supported by the Bulgarian Ministry of Education and Science under the National Research Programme "Young scientists and postdoctoral students" approved by DCM # 577 / 17.08.2018

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# 3D MODELLING IN GIS ENVIRONMENT FOR THE PURPOSE OF DEBRIS FLOWS ANALYSIS – A CASE STUDY OF THE EASTERN RHODOPES (BULGARIA)

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## **Abstract:**

*Debris flows, described as a rapid movement of water saturated soil, sediments and rock debris down slopes, are one of the most dynamic environmental hazards in mountain areas. The geomorphometry and studying the changes in the topographic surface take an important part in prevention and mitigation of debris flows risk. For this purpose, the geospatial technologies provide powerful tools for data acquisition, modelling and analyses.*

*In the current research two different in size and type debris flows are considered – debris flow in a gully and in a low part of a stream system. Terrestrial laser scanning (TLS), combined with GPS/GNSS was performed to obtain adequate georeferenced 3D models of selected debris flows. Digital elevation models (DEM) of the debris deposition areas are derived from the TLS data. The vegetation was removed from the point clouds by open-source filters and manual interaction. The 3D models are elaborated and analysed in standalone, server and web-based GIS environment. As a result of the analyses the erosion and debris flows deposition areas are characterized. Morphological features of the study areas are described. The impact of the vegetation on the results of the TLS as well as the impact of the point density in the cloud and the models resolution on the results of analysis are considered too.*

## **1. INTRODUCTION**

Modeling as a methodology for processing geographical (spatial) data with application computer algorithms is increasingly used in geomorphological research. With the development of geoinformation technologies DEMs became the basis for determining and calculating a number of morphometric indicators, visualization and tracking of changes in the topographic surface. In this relation the quality of the initial data and the spatial resolution of DEMs are of great importance for the reliability of the results of modelling. Many publications analyze geomorphological processes and landforms in different scale using geoinformation technologies and data acquired by UAS, aerial LiDAR and terrestrial laser scanning (Staley et al., 2006; Ghuffar et al., 2013; Kociuba et al., 2014; De Haas et al., 2014, Pearson et al., 2017; Schwendel and Milan, 2020 etc.). The influence of DEM resolution on the results of geomorphological studies is considered by (Žabota et al., 2019; Kasprak et al., 2019 etc.). Analysing the geomorphic changes due to the debris flow Kim et al., 2016 use DEMs derived from airborne LiDAR data acquired at a spatial resolution of 56 cm and then interpolated to 1 m resolution. Investigating rockfall Zabota et al., 2019 determine that spatial resolution of 1 m is the most suitable for modelling on a local scale; resolutions of 5, 12.5 and 25 m are appropriate for modelling on a regional scale and a resolution of 100 m should not be used for rockfall modelling.

The literature review shows that the choice of the DEM resolution depends not only of the territorial scale of the research but also on the purpose of the modelling and the characteristics of the modelled phenomena. For example, DEMs in different resolution could give equally reliable results in modelling different types of debris flows. As a general methodology for studying the changes in the relief and assessment of debris flows dynamic, analysis and comparison of DEMs before and after the occurrence of the phenomenon or by comparing the topographic differences of the two successive terrain surveys and derived DEMs is applied. (Loye et al., 2016; Kim et al., 2016, Morino et al. 2018). In the current study, DEMs of the debris deposition areas of two types debris flows are generated from TLS data. The spatial distribution of the changes of the topographic surface of the both areas is presented by slope raster and topographic profiles derived from DEMs. This is the first stage of the research of debris flows in the Eastern Rhodopes (Bulgaria) using TLS and the presented results refer to the morphometric properties of the studied areas, and do not consider the time dynamics of the debris flows. The 3D modelling was performed of the depositional areas at two sampling locations - a gully induced debris flow near to village Golyama Bara and debris flood deposits of the river

Damdere, few kilometers before it flows into a river Varbitsa. The main activities at this stage of the project are presented on Fig. 1.

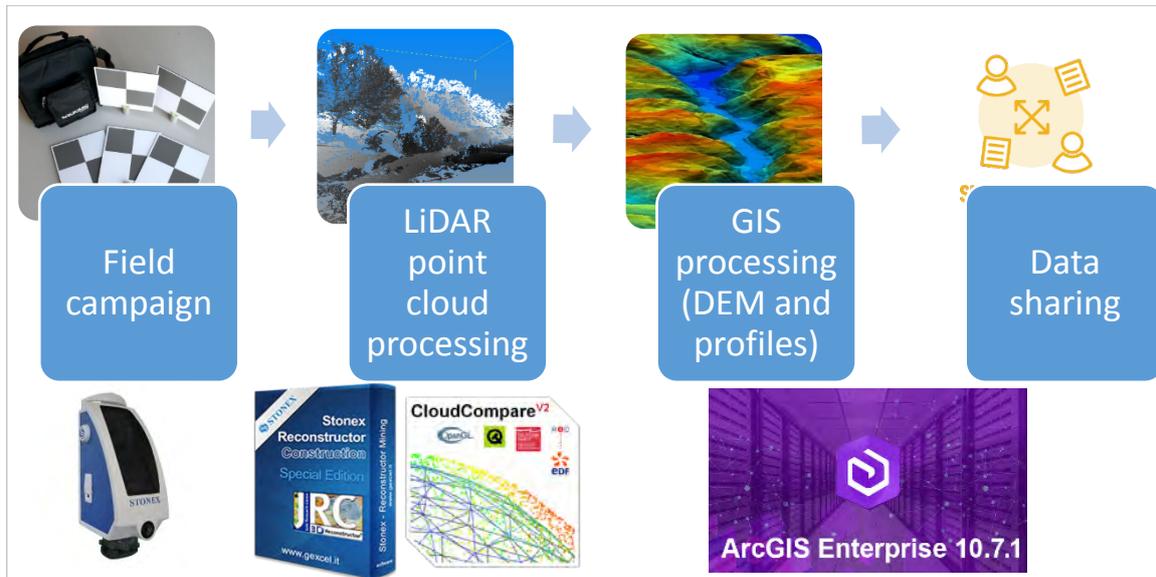


Figure 1. Workflow of the project operations

## 2. TERRESTRIAL LASER SCANNING

Terrestrial laser scanning (TLS) field campaign was organized to derive point cloud data for the areas of debris flow deposition and the erosion. The TLS data was derived using Stonex X300 laser scanner - a mid-range (1.6 – 300 m) laser scanner, able to detect color and intensity information alongside three-dimensional data (Fig. 2). It has a 32 GB internal memory, capable of storing up to 50 scans at maximum resolution. The instrument has a built-in Wi-Fi interface, which was used for field setup via Android smartphone. The 3D geospatial dataset is obtained via five 3D-scans at standard resolution. Paper targets were deployed onto characteristic terrain features for georeferencing purposes. The scanned areas are of relatively small scale - the Damdere debris flood area was covered with three point clouds, while the gully - Golyama Bara with just two.



Figure 2. Stonex X300 laser scanner at operation in Damdere debris area

### 2.1. Data preprocessing

During data collection, all raw point cloud data were recorded in Stonex .x3a archive format. They were subsequently converted to Stonex .x3s grid (structured) point cloud, and imported into the Stonex 3D Reconstructor software. Preprocessing and noise removal were applied for data optimization. Two filtering techniques were incorporated in the preprocessing:

- Range & Reflectance Gate - all pixels outside the instrument scanning range were filtered, plus all measurements with intensity values outside the [0-1] interval;
- Median filter and relative depth discontinuity filter;

Computation of normals was performed through a local surface tangent plane for each point, based on the neighborhood of the pixel (local plane fitting).

Edge detection was applied via two types of geometrically significant line features, calculated from the point cloud data: edge discontinuities (features when there is a sudden change in the object orientation), and depth discontinuities (features where the scanner hits an occlusion and therefore the measured range jumps from a foreground to a background value).

Confidence computation was incorporated through a dedicated new layer, containing confidence values for each measurement, based on the incident angle between the laser beam and the tangent plane of the target, the distance to the target and the material of the object (respectively, the intensity of the reflected signal). The confidence value is computed as a weighted sum of the surface normal, the range value and the reflectance value.

Afterwards, the preprocessed scans are registered manually via pairs of homologous points - paper targets, as well as distinctive terrain features – stones, trees, etc. (Fig. 3 and 4). Every registration is performed via at least three homologous points, with RMS of less than 2 cm. The models were approximately georeferenced via autonomous GNSS measurements at the scanning positions and paper targets locations with submeter accuracy. The data is subsequently exported in ASCII (XYZ) colored-reflectance point cloud format for further processing, mainly for vegetation removal.

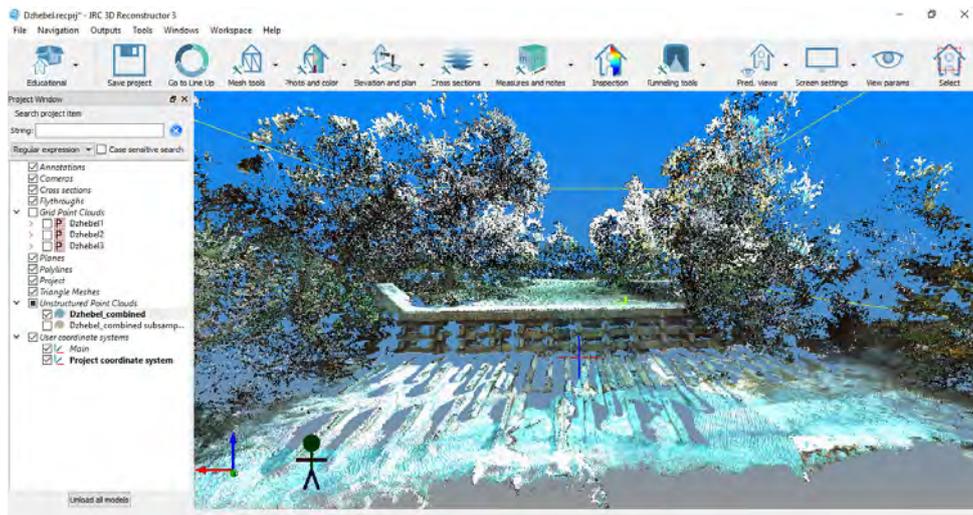


Figure 3. Overview of the three point clouds for Damdere, including overlying forest canopy that needs removal

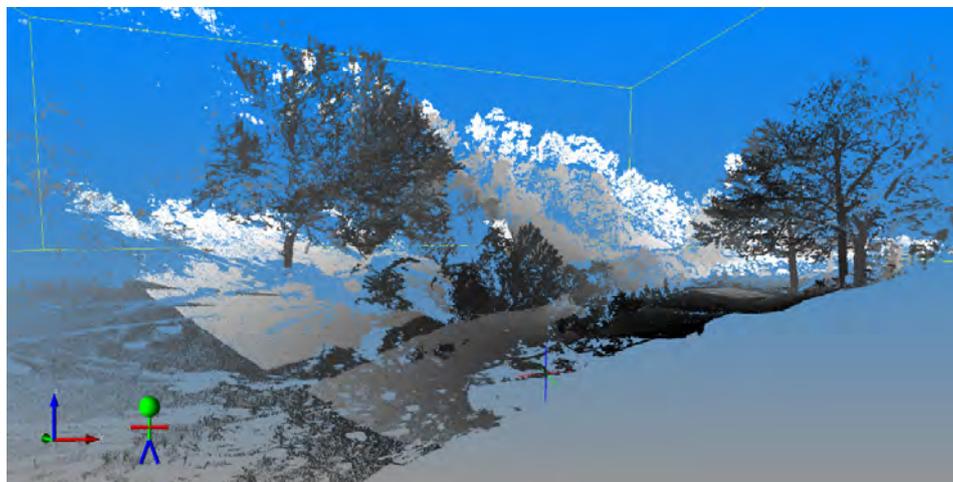
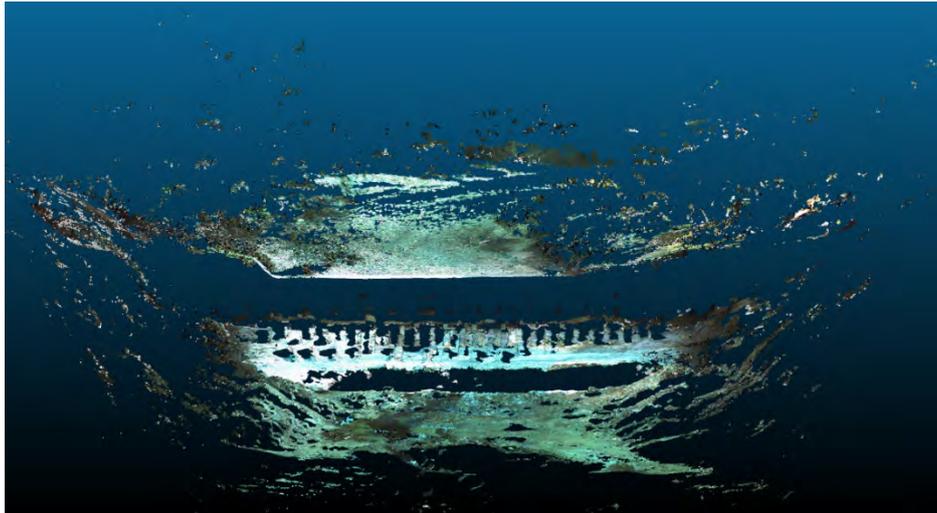


Figure 2. Combined dense cloud for the gully - Golyama Bara, where plenty of vegetation needed to be removed.

## 2.2. Vegetation removal

Separating point clouds into ground and non-ground measurements is an essential step to generate digital elevation models (DEMs) from LiDAR data. Many filtering algorithms have been developed. However, even state-of-the-art filtering algorithms need to set up a number of complicated parameters carefully to achieve high accuracy. The vegetation was removed to a satisfactory degree using both automatic filtering and manual cropping. The relatively simpler Cloth Simulation Filter (CSF), available in the open software CloudCompare, was used instead. Various settings were tested until acceptable noise removal factor was achieved. CSF is based on cloth simulation, which is a 3D computer graphics algorithm and is used for simulating cloth within a computer program tool to extract ground points from LiDAR point clouds. The detailed theory and algorithms of this filter may be found in Zhang W. et al (2016). In addition to the processing with the filter, some densely forested areas are removed manually (Fig. 5).



*Figure 5. Damdere after vegetation removal with the CSF filter*

## 3. MODELLING IN GIS ENVIRONMENT

The point cloud data was processed in GIS environment in several stages. First, the point clouds were imported in ArcGIS Pro 2.5.1, where a set of DEMs, profiles (longitudinal and cross-section) and surfaces of slopes were created for further geomorphologic analyses. Then, a web map was deployed in ArcGIS Portal 10.7.1 within the university GIS portal. Finally, a web application was developed using the Operations Dashboard tool.

### 3.1. DEM and profiles

DEMs in 5 cm horizontal resolution are generated. For this purpose point feature class is created from the point clouds and terrain is built. Using ArcGIS Pro Conversion tool the terrain is converted in DEM raster. To smooth the model ArcGIS Spatial Analyst Tools – Neighborhood – Focal Statistics is used with neighborhood type (moving window) 20 x 20 cells, statistics type “Mean (Fig. 6).

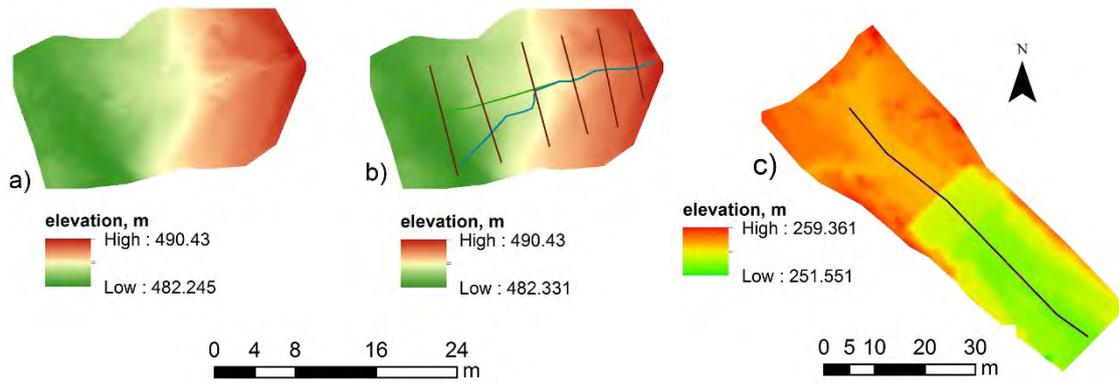


Figure 6. DEMs of the studied areas: a) low part of gully – Golyama Bara without smoothing; b) low part of gully – Golyama Bara smoothed, profile lines are outlined - green line shows the general downslope direction; blue line – the greatest flow convergence; c) Damdere debris deposition area, smoothed DEM and profile line

Profile lines are interpolated by 3D Analyst Tool (Interpolate Shape) to create 3D lines and profile graphs. The z-values are interpolated from the DEM to analyze the changes of the topography and the second interpolation of these lines is done taking into account the values of the slope surface. Changes of the slope of longitudinal profiles indicate changes in erosion and accumulation. Steeper lines are related to the increasing of deep erosion while more slopping lines show calmer conditions or accumulation (Fig. 7)

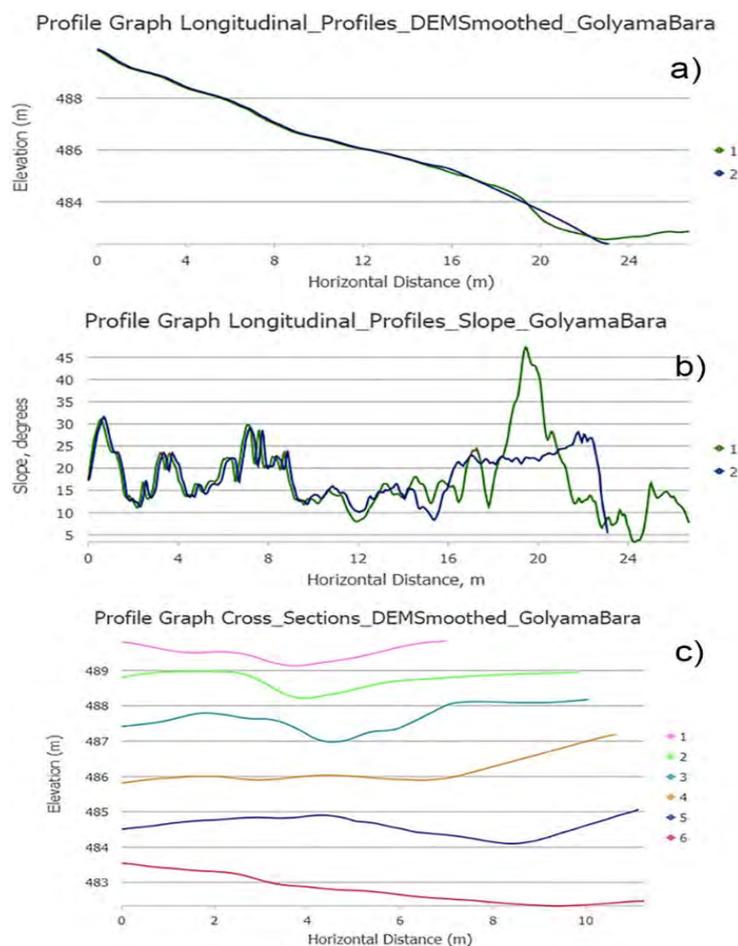


Figure 7. Profile graphs at gully – Golyama Bara area: a) longitudinal profile of the topography (line 1 – on the general downslope direction; line 2 – the greatest flow convergence); b) changes of the slope through the profile lines (line 1 and line 2 – the same as previous); c) cross-section profiles of the topography

If we compare the longitudinal profile lines through the DEM and these ones through the slope surface (Fig. 7a and 7b) we could suggest a relatively high erosion to the 8<sup>th</sup> m of the profile lines. More calm environment could be seen from 8<sup>th</sup> m to 18<sup>th</sup> m and after the 18<sup>th</sup> m it is visible the deviation of the flow convergence line from the general downslope direction which could be an indicator for debris fan forming. The changes of the cross-section profiles (Fig. 7c) show the decreasing of deep erosion from upper to the lower part of the gully.

The rapid decrease in the elevation at the Damdere longitudinal profile indicate the position of the check-dam (Fig. 8a). The cross-section profiles clearly outline the character of the topographic surface before and after the check dam (respectively the top and bottom of the graph), Fig. 8b. The higher variability of the cross-section profiles after the check-dam shows greater flow variability and accumulation of debris deposits in the sides of the flow bed.

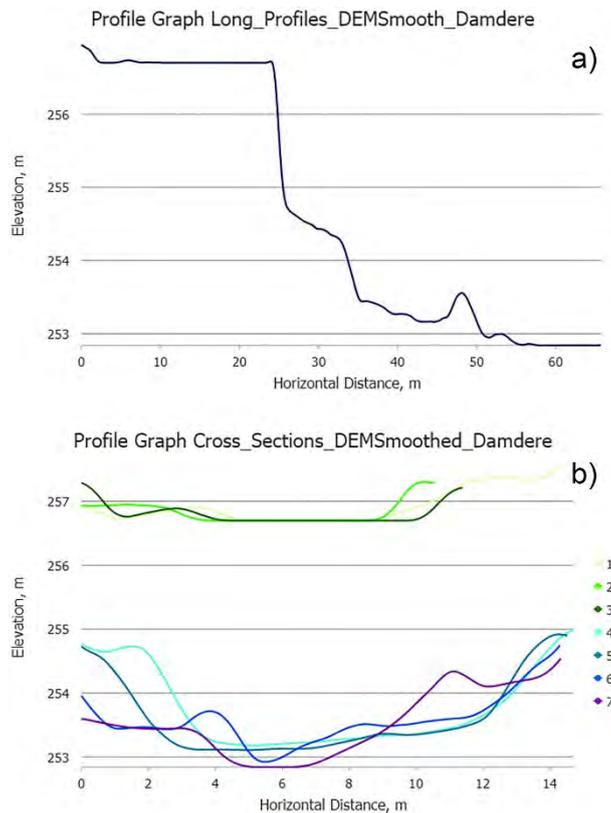


Figure 8. DEM Profile graphs at Damdere debris flood deposition area: a) longitudinal profile; c) cross-section profiles

The profile graphs were exported as raster images (.jpg format) and uploaded into the Portal to be used as pop-up images in the web map.

The slope surfaces of the both studies areas are generated from the DEMs. Nearly 50% of the studied area of the gully - Golyama Bara are with slope range between 15 and 30 degrees, while at the Damdere area slopes from 5 to 15 degrees predominate (32% of the studied area), followed by slopes in a range between 15 and 30 degrees ( 23%).

### 3.2. Web map deployment

The project, created in ArcGIS Pro, is shared as a web map and uploaded in the university GIS Portal, licensed for education and research by ESRI Bulgaria. The web map provides an interactive display of the project locations and is composed of web layers that can be visualized in any standard web browser. The portal incorporates several ArcGIS Enterprise products – ArcGIS Server, ArcGIS Database, ArcGIS Web Adaptor and ArcGIS Portal 10.7.1., installed on a Windows Server 2016-amd64-10.0 machine with Intel i7-6700K CPU @ 4.00GHz, 32 GB DDR4 RAM and NVIDIA GeForce GTX 1060 6GB video card. The server is federated to ArcGIS Portal as hosting server, named MAPS.MGU.BG. The GIS environment is available online, configured using the default Windows web server (Internet Information Services) with free Let'sEncryptAuthorityX3 HTTPS certificate.

The slope DEMs are uploaded into the Portal server as web tile layers, corresponding to 4 map image services, while the 8 profiles – as web feature layers, grouped together into a single hosted feature service. Slope surfaces are also uploaded as web tile layers (a collection of predrawn map images) and provide appropriate elevation basemap. Two default ArcGIS Server databases are used: a managed database for the vector features and a tile cache database for the raster DEM tiles. It has to be noted that the server machine video card is not able to render 3D scene view.

### 3.3. Web application development

The web application is configured and shared publicly using the Operations Dashboard tool, available within the ArcGIS Portal platform (Fig. 9). ArcGIS Dashboards is an application that enables users to convey information by presenting location-based analytics using intuitive and interactive data visualizations on a single screen.

Several dashboard items were incorporated in the home interface: the web map, developed in the previous step, plus six list items – one for each main feature layer.

The web application is available on the following address:

<https://maps.mgu.bg/arcgis/apps/opdashboard/index.html#/28d0ae553971416899edd450dd25483e>

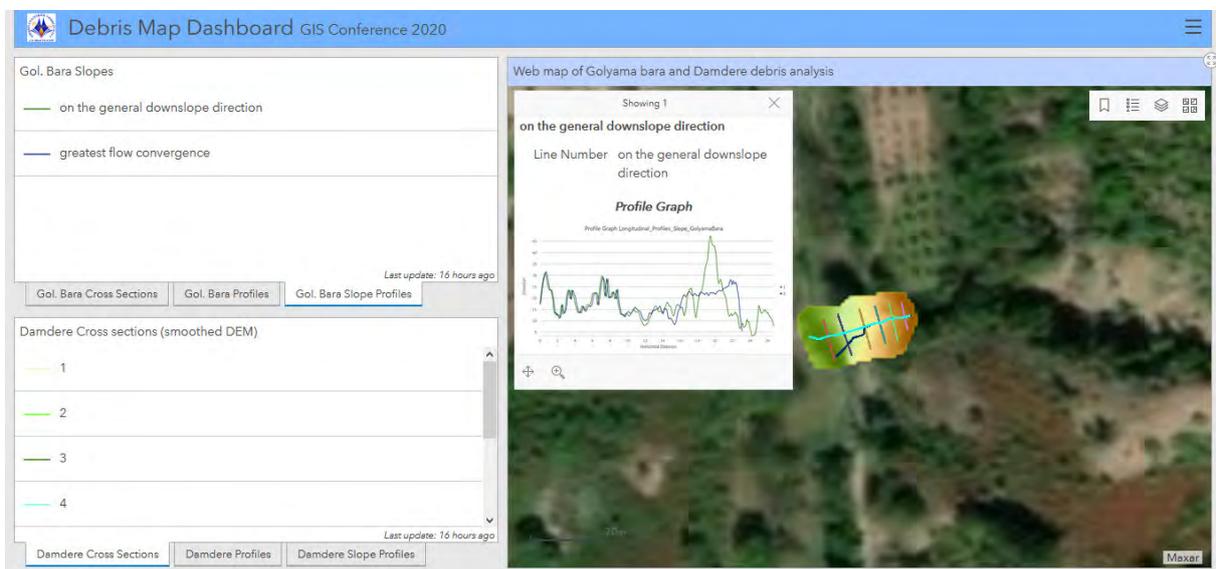


Figure 9. Main interface of the web application with gully - Golyama Bara DEM and profiles visible

## 4. CONCLUSION

The study shows good results with the vegetation removal filter, with some 80% of the data processed correctly (compared with photos of the area). The generated models of the debris deposition areas allow assessing the spatial changes of the topographic surface as well as the morphometric characteristics of the gully induced debris flow and debris flood section. The results set the beginning of the debris flow monitoring in this part of the Eastern Rhodopes Mountain and can be used for debris flow susceptibility and hazard assessments. The subsequent surveying of the territory related to the current results will give an information about the spatio-temporal dynamic of this geomorphological hazard. Further data collection may include aerial photogrammetry (drones) for even larger coverage. However, terrestrial laser scanning may still be needed inside the dense forest canopy.

The web application (operations dashboard) will be updated with new data collation campaigns of the presented debris areas. The app may be also used in real-time on mobile device for better navigation within the area.

## ACKNOWLEDGEMENTS

This work has been carried out in the framework of the National Science Program "Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters", approved by the Resolution of the Council of Ministers № 577/17.08.2018 and supported by the Ministry of Education and Science (MES) of Bulgaria (Agreement № Д01-322/18.12.2019).

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# LANDSLIDE SUSCEPTIBILITY MAPPING USING GIS: A CASE STUDY ALONG BULGARIAN BLACK SEA COAST

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## **Abstract**

*The Bulgarian Black Sea coast is a region where a considerable part of the deep complex landslides in the country are distributed. More than 200 landslides affect only urban areas, resorts and villa zones. Depending on the depth range, geological and tectonical structure and the engineering geological properties of the geological units, the Bulgarian Black Sea coast can be divided into three landslide areas: Northern, Middle and Southern zone. In this study, the Mora and Vahrson method was applied to estimate the landslide susceptibility. This method is based on evaluation of various local factors for slope instability which are estimated. The article incorporates contemporary rainfall data that have a direct relationship on climate changes in recent years. The purpose of the study is to produce landslide susceptibility maps of a landslide-prone area located at the Black Sea coast of Bulgaria using updated GIS-based data for the region.*

**Keywords:** *Landslide susceptibility, Landslide mapping, Black Sea coast, Bulgaria*

## **INTRODUCTION**

Landslides are the most common destructive geological processes in Bulgaria. Landslide activities along the Black Sea coast cause concern in the whole society in the country with large material losses and human casualties.

The Bulgarian Black Sea coast is a region where a considerable part of the deep complex landslides in the country are distributed. More than 200 landslides affect only urban areas, resorts and villa zones (Frangov et al., 2011; Berov et al., 2013; Dobrev et al., 2013; Ivanov et al., 2014; Ivanov et al., 2017). The main triggering factors are: rainfalls and groundwater level fluctuation, abrasion, erosion and earthquakes (Frangov et al., 1998; Berov et al., 2002; Bruchev et al., 2007; Ivanov et al., 2019).

In general, the Black Sea coast is one of the regions of the country where catastrophic landslides periodically occur. Favorable conditions for this are the geological-tectonic structure, the geomorphological conditions, the engineering-geological properties of the rocks and the soils (Varbanov et al. 1997, Lakov et al., 2002; Evlogiev, Evstatiev, 2016; Evstatiev et al., 2017; Atanasova, Nikolov, 2019; Nankin, Ivanov, 2019).

The Bulgarian Black Sea coast can be divided into 3 parts based on the geological and tectonic structure - Northern, platform, built of almost horizontally lying sedimentary rocks of Tertiary and Quaternary age; Middle – within the Stara Planina structures, composed of differently inclined tectonic processed Upper Cretaceous and Tertiary sediments with predominance of flysch facies; South – covering the structures of the Burgas synclinorium with a pronounced predominance of the Upper Cretaceous sedimentary volcanogenic complex, cut in places by young plutonites with imposed Tertiary depressions and small spots of Middle and Upper Miocene sediments. Under this geological fact, more suitable conditions for landslides exist on the Northern part of the coast.

Geomorphologically, the terrain in the coastal part of the Varna Depression has a plateau-like character. In the section North of Varna there are 2 plateaux - Frangya and Dobrudzha, separated by the valley of the Batova River. The altitude of the edges decreases in a northerly direction. The eastern edge of the Frangya plateau is 200-250 m above sea level, Dobrudzha – from about 200 m on the left bank of the Batova River to Balchik, 60-70 m in the area of Cape Kaliakra, 40 m near the village of Kamen Bryag and up to 11 m near the village of Krapets. The valley of the Batova River is cut 200-250 m into the Miocene sediments, has a flat bottom and relatively steep valley slopes.

Subhorizontal Tertiary and Quaternary deposits have been deposited on the Moesian platform, sinking to the northeast at an inclination of up to 5°. As a result of the general slope of the young sediments in the area around Varna, the lower floors of the Miocene are revealed, represented by clayey-calcareous and sandy facies – clays, loose sandstones and sandy limestones, which sink to the north and reveal the clayey-calcareous sediments at the surface. This has led to the development of circus, delapsive landslides near Varna, complex landslides in the region of Balchik to typical block landslides – in the area of the resort complex Rusalka. The almost continuous landslide strip north of Varna to Kavarna has a length of about 30 km and a width of up to 2-3 km.

Landslides are distributed mainly in the Northern part of the coast between the towns of Varna and Kavarna. Most of the landslides are complex and deep-seated. This part of the Bulgarian Black Sea coast has a high degree of landslide hazard in economic loss, social and environmental consequences. Landslides are also spread in Cape Galata, around the towns of Byala and Obzor, near Cape Emine, Ravda, Sarafovo, Chernomorets and Tsarevo villages. Most prone to landslide processes are slopes in the areas of Varna and Balchik and parts of the Eastern Balkan Mts (mostly southern slopes).

In this study, the Mora and Vahrson (1994) method was applied to estimate the landslide susceptibility along the Bulgarian Black Sea coast, which is strongly affected by landslides. This method is based on evaluation of various local factors for slope instability which are estimated. Some new data on rainfall and soil moisture distribution that have a direct relationship on climate changes in recent years are incorporated. Landslide susceptibility maps of a landslide-prone area located at the Black Sea coast of Bulgaria using updated GIS-based data for the region are produced in the study.

## **MAPPING OF THE TERRAINS TO SUSCEPTIBILITY OF LANDSLIDES**

Knowledge of landslide processes and their dynamics is important in engineering risk management and land use planning. Their study can be associated with the slope movements of the past that could be reactivated. Landslide susceptibility mapping methods are varied and numerous and often vary depending on the country, terrain, objectives and finances available for the project. Susceptibility is the tendency and predisposition of geological space to generate landslides. In mathematical form, landslide susceptibility is the probability of the spatial manifestation of a certain slope prone to landslides, under a certain set of engineering geological conditions (Guzzetti et al., 2005). It is assumed that in the future landslides will occur under the same conditions as in the past (Guzzetti et al., 1999) and the susceptibility estimates made in this way can be used to predict the geographical location of future landslides. Landslide susceptibility mapping does not predict "when" or "how often" landslides will occur or how large and destructive they will be (Guzzetti et al., 2005). The study presents the results using GIS and the methodology given below of a research on landslide susceptibility mapping along the Bulgarian Black Sea coast.

## METHODOLOGY

The Mora-Vahrson method (Mora, Vahrson, 1994) is a simple and effective procedure for zoning landslide-prone regions. It has been used in various countries in Latin America such as Guatemala, Salvador, Nicaragua, Costa Rica with good results, according to the published studies (Roman, Boraschi, 2018). Mora and Vahrson (1994) describe this model as a system designed to allow the classification of landslide risks in seismically active tropical areas. In the model are inputted five factors, which are divided into two groups: susceptibility by passive elements (slope, lithology, soil moisture) and susceptibility by active elements (seismic intensity and intensity of rainfall). For each factor, an influence index is defined. The relative level of threat (H) is obtained by multiplication and sums of the indices by using the following equations:

$$H = (Sr * Sl * Sh) * (Ts + Tp) \quad (1)$$

Where:

Sr – slope factor

Sl – lithology factor

Sh – soil humidity factor

Ts – seismicity triggering factor

Tp – precipitation triggering factor

An additional factor - Te – erosion/abrasion triggering factor, was proposed by Berov et al. (2016). This factor takes into account the specific conditions along the Bulgarian Black Sea coast. In this way, the supplemented formula of Mora and Vahrson acquires the form:

$$H = (Sr * Sl * Sh) * (Ts + Tp + Te) \quad (2)$$

The following explanations are given in more detail regarding the abrasion and erosion factor (Te). The criteria are specific for the Bulgarian shoreline. The values of the factor are different respectively for sea-side strip and cliff. For the accumulation zone the value of Te is 0. For rocky cliff, with abrasion and erosion processes Te=1. For soft soils cliff, with abrasion and erosion processes Te=2.

This additional method allows to outline the areas of landslide susceptibility along the Bulgarian Black Sea coast both according to the individual factors and to give an integral interpretation of all factors.

## EXTREME MONTHLY PRECIPITATION AS AN ACTIVATION FACTOR

In the present article the precipitation data for the period 1931-2019 were taken under consideration with the accent on the last 30 years.

The territorial distribution of landslides depends on specific geological-geomorphological and hydro-climatic conditions, and could also be associated with anthropogenic activity that does not comply with the hydro-geological conditions of the territory.

The climate influences the occurrence of landslides with precipitation, which can lead to a decrease in the stability of the territory through surface runoff or an increase in the groundwater level. Due to the high frequency of extreme weather events during the last decades the interest in the investigation of climate impact on the landslides formation increased. The relationship precipitation – landslides was analysed in a number of publications (Crozier, 2010; Polemio, Petrucci, 2010; Wasowski et al., 2010; Stoffel et al., 2014; Gariano et al., 2015).

The analysis of the precipitation for the investigated territory was made on the basis of monthly values for the period 1931-2019 measured at the meteorological stations Varna and Burgas which are representative for the north and the south part of the Bulgarian Black Sea coast. We calculated the number of extreme wet and extreme dry months. As extreme wet months we consider the months with precipitation totals greater than or equal to the 95<sup>th</sup> percentile of the

empirical distribution of data for the entire investigated period. Extreme dry are the months with precipitation less than or equal to the 5<sup>th</sup> percentile.

The results of the analysis of the extreme precipitation months show that for the period 1931-2019 in both investigated stations the number of extreme dry months is higher than the number of extreme wet months (Table 1).

Table 1. Number of extreme precipitation months for the period 1931-2019

Investigated stations	Extreme wet	Extreme dry
Varna	51	68
Burgas	48	55

Despite the higher number of extreme dry months compared to the extreme wet months an increase in the number of extreme wet months was observed during the last 30 years (1990-2019), (Fig. 1). This fact is better established for the north part of the Black Sea coast (station Varna). The increase of extreme wet months is among the factors for initiation of landslides.

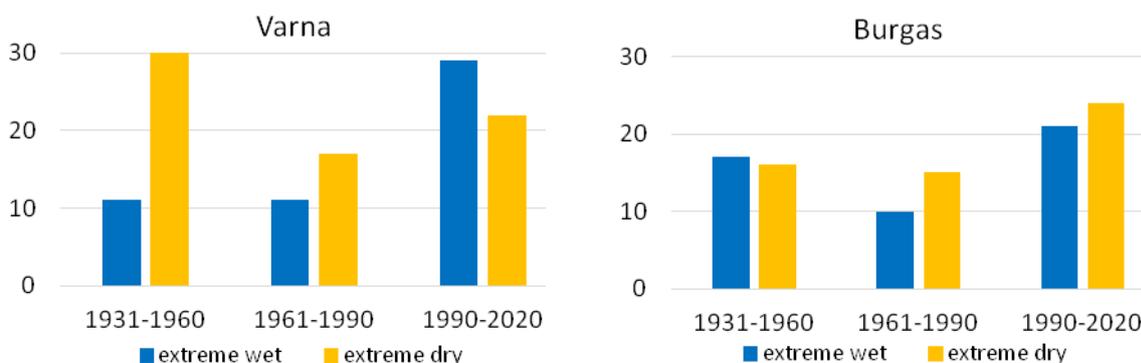


Figure 1. Distribution of extreme dry and extreme wet months for various 30-years periods

In most of the cases monthly precipitation totals for the months with landslide occurrence vary between 70 and 110 mm. According to Polemio and Petrucci (2010) rainfall-induced landslides are related to the extreme rainfall in the month before the events. A similar situation was found in the present study – often the landslides were observed in the months following the months with extreme precipitation (Fig. 2). For the investigated stations 6-months cumulative precipitation (for the month with landslides and 5 months prior to the event) is between 230 and 580 mm. Gariano et al. (2015) show that during the period 1981-2010 landslides were triggered by the less cumulated event rainfall in comparison to the period 1951-1980.

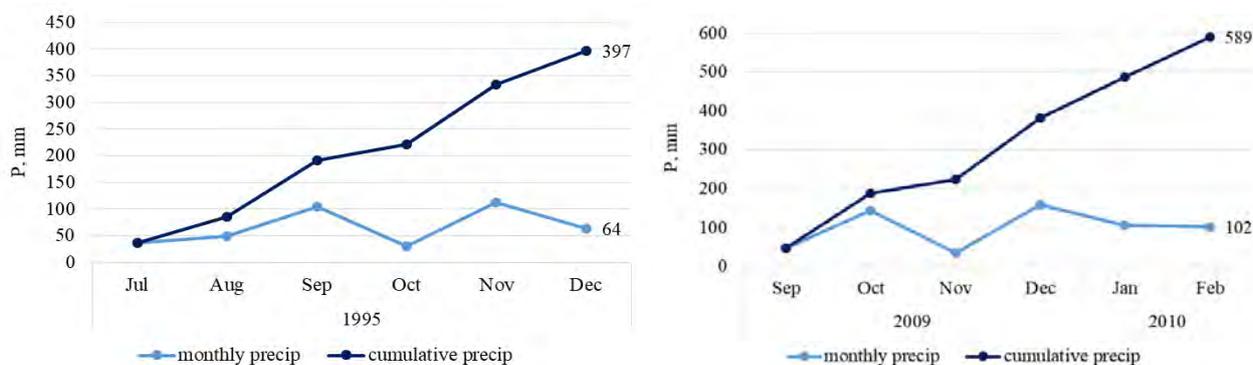


Figure 2. Monthly and cumulative precipitation at station Varna (a landslide was observed in December, 1995 and in February, 2010)

The landslide susceptibility map was compiled in GIS using up-to-date precipitation data based on monthly values for the last 30 years (1990-2019).

## **MAPPING LANDSLIDE SUSCEPTIBILITY USING GIS**

Maps have been compiled taking into account the above-mentioned factors that affect landslide susceptibility along the Bulgarian Black Sea coast and a set of layers has been created with the use of GIS techniques. Factors influencing the activation of landslides on the Black Sea coast are unequally distributed. Their spatial location is determined by some features of the geological development of the basin and the nature of the processes. In the Northern Black Sea coast more landslide activations are observed in recent years (Fig. 3).

### **Endogenous factors**

Earthquakes and slow tectonic movements are endogenous processes that have a direct impact on landslide activations. The formation of high shores and slopes in the Northern part of our Black Sea coast is predetermined by the positive slow vertical tectonic movements. Long rows of large and complex landslides are attached to these areas. Earthquakes with seismic foci in the areas of the town of Shabla and Cape Kaliakra have a significant impact on landslides in Varna and the Dobrudzha coast. The earthquake zone of Shabla, which is located in the Black Sea and it is parallel to the shoreline is the most dangerous (Dimitrov et al., 2003). The strongest earthquake was registered on March 31, 1901 with a magnitude of 7.2. Deep-focus earthquakes in the Vrancea region of Romania also affect some of the landslides on our northern Black Sea coast (Avramova-Tacheva et al., 1998; Dobrev et al., 2014).

Slow vertical tectonic movements are negative in the Southern coast of the country and the Burgas depression is slowly sinking. The seismic impacts until now in the Southern part of the Bulgarian Black Sea coast are not very pronounced and are rarely observed. The strong earthquakes coming from the territory of Turkey so far have not affected the local landslide events in our Black Sea coast.

### **Exogenous factors**

Abrasion, erosion, precipitation and fluctuations in groundwater levels are the main exogenous factors influencing landslides. Abrasion directly affects landslides in areas devoid of wide beaches. Its spatial impact is along all the rest of the Black Sea coast. Deep erosion has affected the steep slopes in the Eastern Stara Planina (around Cape Emine and to the west) as well as the periphery of the Momin, Frangya and Dobrudzha plateaux.

The complex nature of landslides triggering factors makes it difficult to answer the question how climate change affects landslides. However, the existing research works show that there is a high confidence that climate and changes in the amount and intensity of precipitation will affect landslides in various regions (IPCC, 2012). Short-term and intense precipitation causes mainly small and shallow landslides, while extensive and deep landslides are associated with fluctuations in groundwater caused by the specifics of the precipitation regime and the amount of monthly and seasonal precipitation (Crozier, 2010; Dijkstra, Dixon, 2010).

### **Data used and GIS mapping**

Free data obtained from NASA, 30 m DEM, were used for the slope factor (Sr). The classification was made following the approach given by Mora and Vahrson (1994).

Data from the Geological map of Bulgaria in scale M 1:10000 are used for the main lithological units. Approximate to the original approach are the criteria used to determine the lithology factor (Sl). The geology of the sea area is very complex. Mostly in the sector from Varna to Cape Emine and also in the Strandzha mountain. Geological units can be classified into 3 groups.

Data published by Koleva and Peneva (1990) for 15 sites in Bulgaria are used to determine the soil humidity factor (Sh). The range of precipitation time for the Black Sea region is mainly from 1 to 1.5 hours (for 24 hours). In the southern part of Burgas district the values are less than 1 hour, namely Strandzha district.

The data for precipitation are taken also from the Meteorological yearbook and the Bulletins of National Institute of Meteorology and Hydrology (Bulgaria). The data for the last decades are from the Statistical Yearbook of the National Statistical Institute (Bulgaria) as well as from the specialized websites (i.e. <https://www.stringmeteo.com/> and <http://www.tutiempo.net>). The Bulgarian Black Sea coast and in particular its northern part (the region of Balchik and Shabla) is one of the driest territories in Bulgaria. On the other side, in the investigated area (mainly the region of Varna) the intense precipitation which exceeded the monthly climatic norm by 120-150% was observed.

The data for seismicity are taken from Codes for design of buildings and facilities in earthquake regions (2007) which are reported for a period of 1000 years. The seismicity triggering factor ( $T_s$ ) varies along the Bulgarian Black Sea coast. For Burgas region it is equal to 5 ( $T_s = 5$ ), but in area of Shabla and Kaliakra towns will have value of 7 ( $T_s = 7$ ).

The data for abrasion (sea erosion) are used from Shuiskij and Simeonova (1982) and erosion data (surface and linear) are from the Map of the geological hazards in Bulgaria (Iliev-Bruchev (ed.) et al., 1994). For the erosion and abrasion factor ( $T_e$ ) are accepted results following Berov et al. (2016).

All collected data are used to make the maps given in Fig. 4. The landslide susceptibility map was compiled with the ArcMap program, tool Raster Calculator.



*Figure 3. Landslides along North Black Sea coast – Balchik area: a) Ikantalaka view from Thracian Cliffs Golf & Resort, b) Villa zones Fish-Fish, c) Momchilski rid (Photos taken by Plamen Ivanov, 2019)*

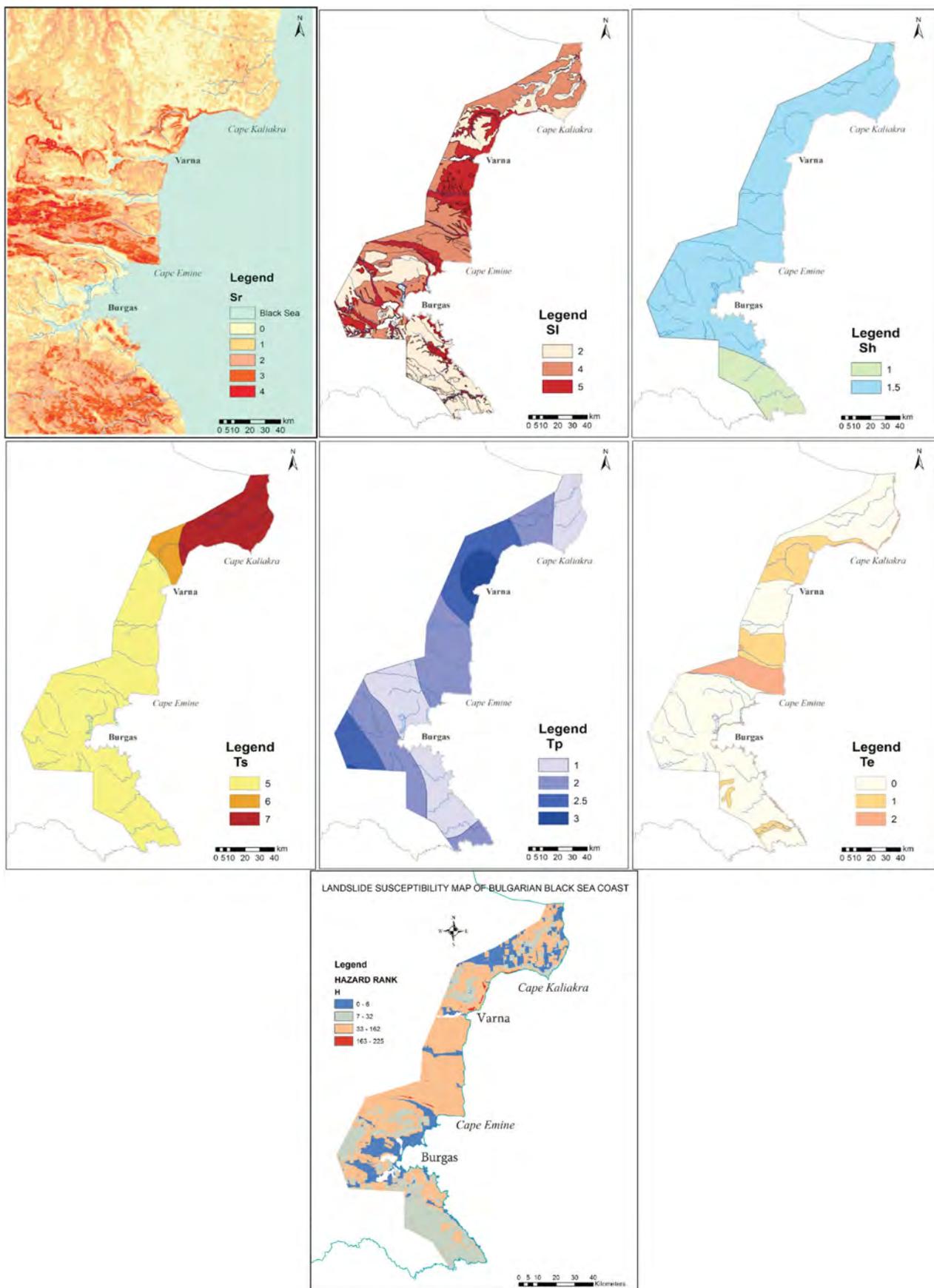


Figure 4. Maps of the Bulgarian Black Sea coast made by factors: Sr, Sl, Sh, Ts, Tp, Te and the compiled map of landslide susceptibility (modified after Berov et al., 2016)

## CONCLUSION

The study presents an updated assessment of the landslide susceptibility along the Black Sea coast and its surroundings in Bulgaria using GIS and the Mora and Vahrson method (1994). Special attention is paid to precipitation in the last 30 years, as during this period there is a proportional increase in landslide activity. The study gives an example of the visual expression of the data for the different factors (Sr, Sl, Sh, Ts, Tp, Te) related to slope stability along the Bulgarian Black Sea coast in a GIS environment. This allows seeing and analyzing the results in a geospatial context. The comparison of the susceptibility maps with that of the already manifested landslides – the inventory map of the landslides, shows coincidences. However the areas where the occurrence of new landslides is possible are also depicted. The created maps are basic tools for land-use planning. The obtained information can be useful and applied by the local authorities in the process of decision making in order to develop preventive measures to reduce the damage caused by landslides. It is suitable for engineers to pay attention to where and when the landslide problems can occur and to reduce losses by means of appropriate mitigation procedures. The study also shows that using GIS to assess field conditions and characteristics gives better results.

## ACKNOWLEDGEMENTS

This work has been carried out in the framework of the National Science Program "Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters", approved by the Resolution of the Council of Ministers № 577/17.08.2018 and supported by the Ministry of Education and Science (MES) of Bulgaria (Agreement № Д01-322/18.12.2019).

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# ASSESSMENT OF LANDSLIDE HAZARD IN BULGARIA USING GIS

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## **Abstract**

*The territory of Bulgaria has a high degree of landslide hazard with possible economic losses, social and environmental consequences. The Landslides are widespread throughout the country's territory. They form the most serious part of the geological hazard in Bulgaria.*

*The main factors for landslide activity (rainfall, impact of surface and ground water, abrasion (sea erosion), erosion and earthquakes) around different regions in Bulgaria using the GIS data analysis are presented in this study.*

*The purpose of the study is to provide an analysis for the assessment, forecasting and prevention of natural and anthropogenic risks and disasters and for inclusion in European networks and projects for the development of Earth sciences. Work is underway on structuring the database, collecting information on dangerous geological processes in the country and introducing them into the GIS environment.*

**Keywords:** *Landslide distribution, Landslide Hazard, Landslide mapping, Landslide factors, Bulgaria*

## **INTRODUCTION**

The territory of Bulgaria has a high degree of landslide hazard with possible economic losses, social and environmental consequences. The landslides are widespread throughout the country's territory. They form the most serious part of the geological hazard. All known landslide types of internationally accepted classification of Varnes (1978) are represented there. Mapping the landslides is one of the main activities in the overall spectrum of geological hazards and the main step towards landslide risk assessments in Bulgaria.

The present analysis is composed of available data for landslides, which are registered in the National Program for Prevention and Mitigation of Landslides in Bulgaria (2014) and in the Elaboration of Analysis, Evaluation and Mapping of Geological Risk (2017). The projects are supported by the Ministry of Regional Development and Public Works in Bulgaria (<http://gis.mrrb.government.bg/KGR/>).

The purpose of the study is to provide an analysis for the assessment, forecasting and prevention of natural and anthropogenic risks and disasters and for inclusion in European networks and projects for the development of Earth sciences. Work is underway on structuring the database, collecting information on dangerous geological processes in the country and introducing them into the GIS environment.

## **METHODOLOGY AND RESULTS**

### **Main factors determining the dynamics of landslides**

There are many endogenous and exogenous factors exerting impact on the process of landslide origin and activation. The influence of earthquakes, neotectonic movements, river and sea erosion (abrasion), surface and ground water level fluctuations, precipitation and technogenic activity is strongly expressed (Kamenov, Iliev, 1963; Konstantinov et al., 1992; Iliev-Broutchev, ed., 1994; Berov et al., 2002; Lakov et al., 2002; Bruchev et al., 2007; Dobrev et al., 2013; Stoynev, 2018; Atanasova, Nikolov, 2019, Ivanov et al., 2019).

The complex geological structure and intensive tectonics determine the activation of erosion-abrasion processes in the coastal zones and the triggering of landslides of various types and mechanisms, which occur in sloping terrains – river valley slopes, sea shores, hilly lands, peripheries of the plateaux, foothills and mountain slopes. Most of the settlements, villa areas and resorts in highly urbanized areas are located on slopes with active or potential landslides.

Important conditions for the development of erosion, abrasion and landslide processes on the slopes are: specific diversity of rocks and soils, inclination of the layers, the presence of clay layers, weak layers, tectonic disturbed areas, the presence of groundwater. The physico-mechanical properties of the various lithological types – grain size distribution, density, natural water content, consistency, peak and residual shear strength, have a leading role in the formation of slope resistance. The groundwater regime – a way of feeding and drainage, depth, amplitude of seasonal fluctuations in the groundwater levels, have a multifaceted impact on landslide activity.

The slopes are influenced by natural and man-made factors, which contribute with varying degrees to the landslide occurrence. Natural factors are associated with the undercutting of the foot of the slopes caused by the erosive action of rivers, ravines and their tributaries and sea abrasion. There is a close relation between the areas with active erosion and abrasion and the occurrence of gravitational processes – landslides, rockfalls, and slope creeping.

According to their depth range, contemporary activity and possibilities for prevention or reduction of their unfavorable influence, landslides can be divided into three groups – shallows with cyclic activity; deep, conditionally stabilized; deep, with periodic activation of individual parts of them. The most numerous are the landslides from the first group. Their depth range is up to 6-8 m and they have areas up to 2-3 dka. They are developed everywhere and are triggered under the impact of precipitation, erosion, abrasion and man-made activity. They cause relatively little damage and the consequences are easily solved.

The second group includes landslides that occurred in the past. Their dimensions are large – depths up to 30-40 m, and areas over 10 dka. They are currently in a state of temporary stabilization. Large landslides of this type are distributed along the Danube and Northern Black Sea coasts, in the central Fore-Balkans, Western and Eastern Balkan Mts., and the Rhodopes Mts. The danger they pose is potential, but it can occur in extreme situations – after strong earthquakes, storms, or intense erosion.

Most dangerous are the landslides from the third group. These are large, complex landslides with depths of the main slipping surface of up to 50-60 m and more, and areas of tens of decares. The slopes on which they are manifested are in a state close to the limit equilibrium. Just a small impact of some destabilizing factor is enough to trigger the landslide process, such as abrasion, erosion, prolonged precipitation or snowmelt, seismic and man-made activity. Deep landslides move (creep) at a slow, relatively constant speed along the deepest sliding surface, and shallower local modern activations occur in their range. The consequences in these cases are the most severe, and countermeasures are difficult, expensive and not always successful. Serious problems are created by the landslides of this group in the region of the Danube River bank between the village of Slivata and Orsoya, the village of G. Tsibar, the towns of Oryahovo, Svishtov, Tutrakan, the coastal strip along the northern Black Sea coast between the resorts St. St. Constantine and Helena, Golden Sands and Albena, the areas at the town of Balchik, the Maritsa-Iztok Basin, along the valleys of the rivers Iskar, Struma, Mesta, Arda, Vacha, Kamchia.

## **Criteria reflecting some basic regularities in the occurrence of landslides, the acting factors and their consequences**

The assessment of the geological hazards caused by gravitational phenomena (as rockfalls, mudslides and especially landslides) is always given a special place in Bulgaria as well as in the World practice. For this reason, the analysing of the regularities and factors that play a key role in determining the landslide hazard is also taken into account (Konstantinov et al., 2003; Ivanov et al., 2017a,b).

### ***Frequency of occurrence of large landslides***

This criterion reflects landslide activity in relatively homogeneous engineering geological conditions. Depending on the cyclicity when reaching the active stage in the triggering of the landslide process in a given area, three groups of terrains are separated, respectively with:

- High frequency – 1 landslide for a period of 10 years;
- Average frequency – 1 landslide for a period of 30 years;
- Low frequency – 1 landslide for a period of 100 years.

### ***Landslide velocity***

The danger of landslides increases as a function of the rate of deformation and displacement during the active stage of the process. According to this criterion, the landslide dynamics are assessed at 3 levels:

- High degree – speed >10 m/a;
- Moderate degree – speed 1-10 m/a;
- Low degree – speed <1 m/a.

### ***Influence of destabilizing factors***

The complex impact of the more important factors is reflected. It is graded in 3 levels:

- High degree – combines active erosion or abrasion with speed > 1 m/a, seismicity I > VIII degree (MSK-64), intensive technogenic activity (opencast mining, water saturation, etc.), large amplitudes in the water level of open reservoirs or rivers.
- Medium degree – erosion or abrasion of the banks with a speed of 0.1-1 m/a, seismicity I = VII-VIII degrees, prolonged precipitation, etc.
- Low degree – weak erosion, seismicity I <VII degree, separate excavations or embankments.

### ***Consequences of landslide processes***

The caused direct and indirect damage, as well as the potential losses from the active landslides are divided into 3 groups:

- Severe consequences – destroyed groups of buildings, large facilities and communications, discontinued extraction of minerals, disruption of transport links;
- Medium consequences – destroyed single buildings, deformed facilities, temporary suspension of mines or enterprises;
- Weak consequences – potential threat to settlements, industrial enterprises, periodic deformations on roads and railways, cracks in buildings, etc.

## **Landslide hazard assessment**

The assessment of the landslide hazard is in accordance with the criteria set out in the National Program for Prevention and Limitation of Landslides on the territory of the Republic of Bulgaria, erosion and abrasion along the Danube and Black Sea coast 2015-2020 (2014) and in the Elaboration of Analysis, Evaluation and Mapping of Geological Risk (2017) supported by the Ministry of Regional Development and Public Works in Bulgaria

(<http://gis.mrrb.government.bg/KGR/>). The main indicator is the condition of landslides (S), which is determined by the equation:

$$S = S1 + S2 \quad (1)$$

where S1 is a parameter depending on the degree of activity according to Table 1, S2 is according to the area of the landslide according to Table 2. An example (in QGIS) of the final assessment of the landslide hazard used in the current mapping is shown in Table 3, Fig. 1 and Fig. 2. The location and parameters of the landslides during the mapping are according to data provided from the Geoprotection organizations – Varna, Pleven and Pernik.

*Table 1. Landslides by degree of activity*

Definition by degree of activity, S1	scores
Active, with periodic activity	4
Potentially landslide-prone terrain (dormant)	3
Stabilized	1

*Table 2. Scope of landslide processes (according to Ordinance 12 and the Methodology for prioritization of landslides)*

Types of landslides by area, S2	scores
Area over 20000 m <sup>2</sup> (class I)	4
Area from 10000 to 20000 m <sup>2</sup> (class II)	3
Area from 1000 to 10000 m <sup>2</sup> (class III)	2
Area less than 1000 m <sup>2</sup> (class IV)	1

*Table 3. Landslide hazard characteristics*

Total Points, S=S1+S2	Degree of Hazard	Class of Hazard
2	very low	1
3-4	low	2
5	moderate	3
6-7	high	4
8	very high	5

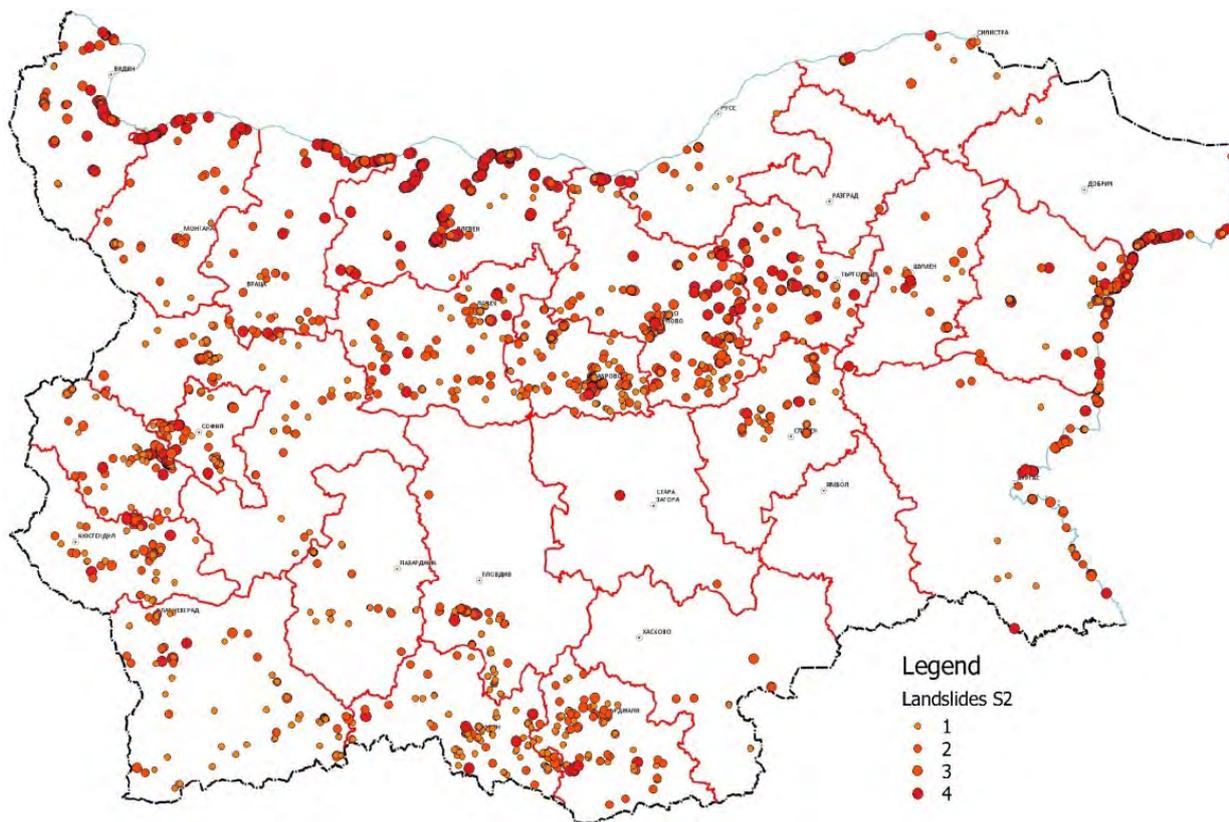


Figure 1. Landslide hazard of Bulgaria by S2

Lands\_points : Features total: 2118, filtered: 2118, selected: 0

	nomer	selishte	местонахождение	состояние	A_LS	S1	S2	S	Class_LS	L_LS	H_LS
1	GA805.73290....	Трачито	път III-4404 "Габрово - Трачито - Дебел дял - Муга - Габр...	Периодично активно	5396	4	2	6	4	0.80	0.142
2	VTR04.10447....	Велико Търново	На път пред входа на мн."Св.Троица", на 5.3 км от разкл...	Стабилизирано	948	1	1	2	1	0.20	0.036
3	VTR04.10447....	Велико Търново	Преображенски манастир	Потенциално	308	3	1	4	2	0.40	0.071
4	VTR04.10447....	Велико Търново	Преображенски манастир	Стабилизирано	1417	1	2	3	2	0.40	0.071
5	VTR04.10447....	Велико Търново	Преображенски манастир	Стабилизирано	13971	1	3	4	2	0.40	0.071
6	VTR04.10447....	Велико Търново	северен вход, мелниц.	Периодично активно	210	4	1	5	3	0.60	0.107
7	VTR04.10447....	Велико Търново	Път за мн."Св.Троица", на 2.3 км от разклона.	Стабилизирано	332	1	1	2	1	0.20	0.036
8	VTR04.10447....	Велико Търново	път за мн."Св.Троица", на 2.2 км от разклона	Стабилизирано	1103	1	2	3	2	0.40	0.071
9	VTR04.10447....	Велико Търново	северен вход	Периодично активно	1201	4	2	6	4	0.80	0.142
10	VTR04.10447....	Велико Търново	северен вход	Потенциално	1194	3	2	5	3	0.60	0.107
11	VTR04.10447....	Велико Търново	северен вход	Потенциално	26437	3	4	7	4	0.80	0.142
12	VTR04.10447....	Велико Търново	северен вход	Периодично-активно	4195	4	2	6	4	0.80	0.142
13	VTR04.10447....	Велико Търново	в района на Радиозавода	Потенциално	2715	3	2	5	3	0.60	0.107
14	VTR04.10447....	Велико Търново	в района на Радиозавода	Периодично-активно	35182	4	4	8	5	1.00	0.178
15	VTR04.10447....	Велико Търново	Северно от несокомбинат в. Търново, над пътя за мн. "С...	Периодично активно	12156	4	3	7	4	0.80	0.142
16	VTR04.10447....	Велико Търново	район на Месокомбината	Потенциално	3494	3	2	5	3	0.60	0.107
17	VTR04.10447....	Велико Търново	сев.вход	Периодично активно	167	4	1	5	3	0.60	0.107
18	VTR04.10447....	Велико Търново	ул.Опълченска, срещу входа на скривалище на "Гр.защит...	Потенциално	979	3	1	4	2	0.40	0.071
19	VTR04.10447....	Велико Търново	ул.Опълченска №75, 3 от сграда на Д-ция "Гр.защита"	Стабилизирано	148	1	1	2	1	0.20	0.036
20	VTR04.10447....	Велико Търново	ул.П.Тилгографов, имота 1282 и 1283	Стабилизирано	64	1	1	2	1	0.20	0.036
21	VTR04.10447....	Велико Търново	На откос, от югоизточната страна на ул. "Опълченска", ср...	Потенциално	532	3	1	4	2	0.40	0.071
22	VTR04.10447....	Велико Търново	източно от Месокомбината	Периодично активно	69354	4	4	8	5	1.00	0.178

Figure 2. Attribute table with information of landslides (QGIS)

### General characteristics of the terrains with different degree of landslide hazard

We separate the regions of landslide hazard into 3 categories (high, moderate and low degree of hazard) based on an analysis of the overall impact of the existing geological-tectonic, geomorphological, engineering-geological and hydrogeological conditions on the territory of the country (Frangov et al., 1996). The impact of various destabilizing factors and the retrospective analysis of landslide activity over a long period of time are the basis of forecast zoning according to the degree of hazard of activation of large landslides (Fig. 3).

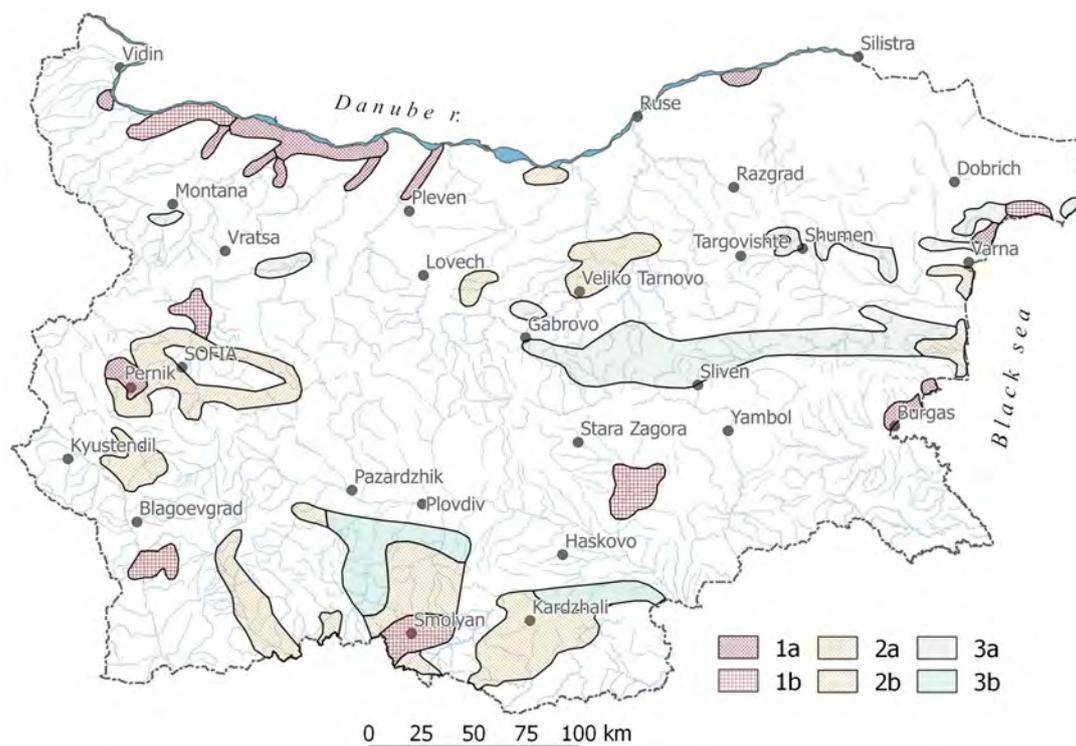


Figure 3. Regioning of the territory of Bulgaria according to the degree of the landslide hazard (according Frangov et al., 1996). 1 – high degree; 2 – moderate degree; 3 – low degree (a – landslides with a volume of up to 10 million m<sup>3</sup>; b – a volume higher than 10 million m<sup>3</sup>)

The country's territory is highly threatened by large landslides. Such is the shoreline of the Danube River between the town of Dunavtsi and the Iskar River (Iliev-Brouchev, ed., 1994; Frangov et al., 1996; Dobrev et al., 2014; Tcherkezova, 2019). In this zone, the landslides are developed here in the Pliocene clayey deposits within the Lom depression. They are characterized by large volumes – over 15 mln m<sup>3</sup>. Activation stage is characteristic with a long preparation period, during which a formation of a prism of active pressure is observed years before the active stage. In the area around Tutrakan, the Danube River bank is built of Neogene clays with a predominance of the calcareous component. Here the landslides are shallower. The depths vary in the range between 10 and 25 m. Key factors here are groundwaters and man-made water saturation (Frangov, 1990). The loess and the Neogene sediments take part in the landslide processes on the Danube river bank.

Along the Black Sea coastal area, the sections Balchik-Kavarna, Golden Sands-Kranevo, Ravda, and Sarafovo have a high degree of hazard (Varbanov et al., 1997; Frangov et al., 1998; Berov et al., 2013; Atanasova-Zlatareva et al., 2019; Chapanov et al., 2019; Nankin, Ivanov, 2019). Mainly Neogene sediments with different lithological structure are involved in landslide processes. Main destabilizing factors are abrasion and groundwater level fluctuations. Along the Northern Black Sea coast, seismic impacts from near and far foci (Shabla, Vrancea) also have an impact on activation.

The landslides near the villages of Sarafovo and Ravda (northward from Burgas) have relatively shallow slip surfaces (about 15 m); along the Northern Black Sea coast they are more complex and have a storey layout – a deep sliding surface and 1-2 shallower slip surfaces, with activations occur mainly in the upper levels.

Another dangerous landslide area is situated in the Rhodopes Mts., mostly in the valley of the Cherna River (Iliev-Brouchev, ed., 1994). On its steep slopes, made of eluvial-deluvial materials, sudden landsliding phenomena can occur, with high speed and difficult predictability in the absence of visible marks during the preparatory stage.

In the Iskar Gorge (northward from Sofia City), whose steep slopes are composed of Paleozoic metamorphic rocks covered with a thick layer of eluvial-deluvial materials, landslides are also difficult to predict and can have severe economic consequences.

Large landslides affect the areas with intensive coal mining exploitation (Maritsa-Iztok, Pernik, Oranovo, Brezhani). They have a man-made origin and arise both on the sides of the open pit mines (Maritsa-Iztok, Pernik, Brezhani, Nedelishte) and as a result of collapse over mine galleries (Pernik, Oranovo, Brezhani). The landslides involved mainly

Neogene (Maritza-Iztok, Simitli valley) and Paleogene sediments (Brezhani and Pernik valley). Suitable conditions also exist in the Simitli valley (Dobrev, 1997; Dobrev, Boykova, 1998), where the danger of large landslides is due to the high seismic activity and the presence of active faults, linear erosion and changes in groundwater levels.

Areas of moderate hazard are as follows: the peripheral parts of the Sofia valley, the southern part of the Pernik valley, the region of Bobovdol, the valley of the Mesta river, parts of the Central and Eastern Rhodopes, the Black Sea coast between Galata Cape and Emine Cape, the valley of the river Dvojnitsa in the Eastern Balkans, the volcanic complex in the Rhodopes Mts., the areas around Veliko Tarnovo, Alexander Stamboliyski Dam and near the town of Svishtov. The geological formations that make up these terrains are mainly of Paleogene age: such are the areas along the valley of the Dvojnitsa River, the volcanogenic complex in the Rhodopes, the Mesta Graben, the Pernik and Bobovdol areas. The rocks in the peripheral parts of the Sofia valley, the coast around Galata, around Dospat, the southern part of the Mesta graben are of Neogene age. There is also a moderate degree of landslide hazard in the marl deposits of Cretaceous age – around the Alexander Stamboliyski Dam, Veliko Tarnovo region and near Svishtov. The main destabilizing factors here are earthquakes (Svishtov landslide, landslides in the regions of Veliko Tarnovo, Strazhitsa, Oryahovo and Gorni Tsibar), groundwater, erosion and abrasion.

The areas with a low degree of hazard from large landslides include mainly the peripheral parts of the plateau in Northeastern Bulgaria (Shumen, Madara, Provadia, Frangya, Batova River valley, etc.) and the marly slopes in the Fore-Balkan and the Paleogene and Mesozoic flysch formations in the Central and Eastern Balkan Mts. The latter are a favorable environment for the occurrence of landslides with volumes up to 1 mln m<sup>3</sup>. Conditions for the occurrence or activation of larger landslides exist in the Central Rhodopes. The block landslides along the Northern Black Sea coast – Rusalka (Taukliman), Yailata and others are also slightly dangerous.

In the rest parts of the map there are also conditions for manifestations of landslides – in many of them there are shallow landslides. However, under certain new terrain conditions, the occurrence of single large landslides is not excluded.

## CONCLUSION

The current analysis is composed of available data on registered landslides in Bulgaria. Maintaining GIS-based information and a landslide database is an important activity that can be used for zoning by landslide hazard and risk in the country. Landslide hazard zoning will be subject to periodic updating and improvement in the future after supplementing the register of landslides, taking into account the conditions, factors, impacts, consequences, results of monitoring measurements, the effects of landslide countermeasures etc. These activities are expensive, but worth doing, given the huge losses caused by landslides. The analysis and mapping of the landslide hazard is part of the assessment of the general geological hazard and risk for the territory of Bulgaria.

## ACKNOWLEDGEMENTS

The present study has been carried out in the Project "National Geoinformation Center (NGIC)" ([www.ngic.bg](http://www.ngic.bg)), which is financed by the National Roadmap for Scientific Infrastructure 2017-2023 under Contract No D01-161/28.08.2018 with the Ministry of Education and Science.

Some of the data used comes from the projects "National Program for Prevention and Limitation of Landslides on the territory of the Republic of Bulgaria, erosion and abrasion along the Danube and Black Sea coast 2015-2020" (2014) and "Elaboration of Analysis, Evaluation and Mapping of Geological Risk" (2017) supported by the Ministry of Regional Development and Public Works in Bulgaria (<http://gis.mrrb.government.bg/KGR/>).

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# DEVELOPING MULTIBAND RASTER DATASETS FOR UTILIZATION OF GLOBAL EARTH GRAVIMETRICAL MODELS FOR THE REPUBLIC OF KOSOVA

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## Abstract

*Due to current situation in Kosova with the national geoid, which is still under development, utilization of global EGM's is more than necessary. In this research, multiband raster datasets with 1km spatial resolution of existing EGM 2008, 1996, and 1984 have been developed. Maximal and minimal differences between the models, range of extreme values of geoid heights in three geoid models, mean heights and other data calculations, are given in this paper.*

*Calculation have been performed with online geoid calculator GeoidEval, in grid of 10893 points. Based on developed multiband raster model dataset and calculated differences between the models, three maps for the territory of Kosova were compiled.*

*Main purpose of performed research analyses and developed GIS datasets for geoid heights, is free and open for usage by the geo community in Kosova, till the establishing of state gravimetical network and model.*

**Keywords:** EGM, geoid, multiband raster, geoid undulation, earth gravitation, geoid height, Kosova.

## 1. INTRODUCTION

A precise local geoid model constitutes one of the most challenging research subjects of geodesy, particularly since 1980s. Geoid modelling deal with the determination of geoid undulations between the geodetic heights obtained from the Global Navigation Satellite Systems (GNSS) techniques and the orthometric heights, or levels, relative to the Mean Sea Level (MSL). Thus, geoid models are crucial for the utilization of GNSS (particularly the Global Positioning System: GPS) in civil engineering projects (Al-Krargy etAll 2015). Recent advances in GNSS techniques make it possible to measure ellipsoidal heights with an accuracy of a few centimeters. Therefore, if a well-established geoid model is available, orthometric heights can be derived precisely by GNSS positioning, and accordingly a reference height system can be established via the geoid model (Matsuo and Kuroishi 2020).

The basis of the theory of gravity field stands in the definition that a body on the Earth's surface experiences Earth's gravitational force as well as centrifugal force due to the rotation of the Earth, and this is what we call gravity (Bajrami Lubishtani and Idrizi 2020). In geodesy three basic surfaces are encountered: the physical surface of the earth, the geoid and the reference ellipsoid. In relation to these three surfaces another three entities are defined: the orthometric height (h), the ellipsoidal height (H) and the geoidal separation/undulation (N) (Das etAll, 2017). All geodetic measured quantities from the physical surface of the Earth are reduced to the geoid and to the surface of adopted reference ellipsoid through applying corrections on the measured values, as well as into the map projection (Idrizi etAll 2018). There are a number of mathematical models to relate the geoidal separation N with corresponding locations in order to

define the geoid surface. Such models include simple polynomials, radial basis functions, multilayer perception neural network methods etc (Cakir and Yilmaz, 2014). Though classical geoid determination is restricted to regional computations using the astro-geodetic techniques (Drews and Adam 2019), by grace of the enhancement of space geodesy techniques, are mainly used to determine the figure of the geoid globally and regionally as well in recent decades. The true geoid is not directly observable and estimating it may vary as current knowledge improves. Hence, there may be many models of the geoid surface and, consequently, many geoid height models (Roman etAll 2010). The new gravity satellite missions provide new global solutions that allow modeling the long and medium wavelengths of the Earth's gravitational field (Soycan 2014). There are global geoid models such as EGM 84, EGM 96 and EGM 08 which supports the conversion of ellipsoidal heights to orthometric heights with accuracies varying between few centimeters to even a meter.

After establishment of the Kosovo geodetic datum in 2001, the 1<sup>st</sup> order network has been exaggerated with additional 450 points covering whole territory of Kosovo with an approximate distance of 10 to 15km between neighbor points (Kohli 2003). Currently, these points are serving as height reference surface, however their deviation in some areas exceed  $\pm 50$  cm and need to be considered (Ameti, Jaeger 2016). Until now, there is no official state geoid model for the area of the Republic of Kosova developed by the Kosova Cadastral Agency as national responsible institution. A model developed for the Kosova area was calculated by Ameti and Jaeger in year 2016 at the Karlsruhe University in Germany, which unfortunately still is not in official use by the state institutions in Kosova. Aimed to offer three alternative models for the area of the Republic of Kosova, three national models based on three global models (EGM 84, 96 and 08) have been developed within research study performed by this paper authors in collaboration between three institutions: Geo-SEE Institute from Skopje (based on the previous experience for developing three models for North Macedonian territory in year 2013 (Idrizi 2013)), geodesy department of the University of Prishtina (where first and second authors are employed) and geodesy department of the Polytechnic University of Tirana (where the first author is finalizing her PhD thesis on developing of Albanian geoid model). This database in national level has to be developed, and it has to be open and free for usage by geo community (Idrizi 2014). Part of calculations for geoid heights based on EGM for the territory of Kosova have been performed on year 2018 within the research study of length differences from topography to map projection within the state coordinate systems for some countries on the Balkan Peninsula (Idrizi etAll 2018).

## 2. EARTH GRAVITATIONAL MODELS (EGM)

The Earth Gravitational Models (EGMs) are geopotential models of the Earth consisting of spherical harmonic coefficients, developed and published by the Office of Geomatics at National Geospatial-Intelligence Agency (NGA) [2], as responsible for collecting, processing, and evaluating gravity data (free-air and Bouguer gravity anomalies) as well as computing gravimetric quantities such as mean gravity anomalies, geoid heights, deflections of the vertical, and gravity disturbances [1]. EGM96 from 1996 is used as the geoid reference of the World Geodetic System [2]. Three versions of EGM are published: EGM84 with  $n=m=180$ , EGM96 with  $n=m=360$ , and EGM2008 with  $n=m=2160$ . “ $n$ ” and “ $m$ ” are the degree and orders of harmonic coefficients; the higher they are, the more parameters the models have, and the more precise they are. EGM2008 also contains expansions to  $n=2190$  [1]. Developmental versions of EGMs are referred to as PGMs, Preliminary Gravitational Models (Pavlis etAll 2012).

EGM84 geoid (code 5203) is a vertical datum first defined in 1984, with its geoid origin in WGS 84 ellipsoid. EGM84 geoid is a vertical datum for Geodesy, defined by information from US National Geospatial-Intelligence Agency [4]. Data of EGM84 today have historical importance, without practical utilization (Idrizi 2013). Differences between geoid heights of EGM 84 with two newest models EGM 96 and EGM08 are used in our research just for comparing with two newest models of years 1996 and 2008, and not as a model that can be used at the present time.

EGM96 (code 5773) is a geopotential model of the Earth consisting of spherical harmonic coefficients complete to degree and order 360. It is a composite solution, consisting of a combination solution to degree and order 70, a block diagonal solution from degree 71 to 359, and the quadrature solution at degree 360. It is a result of collaboration between the National Imagery and Mapping Agency (NIMA), the NASA Goddard Space Flight Center (GSFC), and Ohio State University [3]. This gravitational model is complete to spherical harmonic degree and order 2159, and contains additional coefficients extending to degree 2190 and order 2159.

EGM2008 (code 3859) is complete to spherical harmonic degree and order 2159, and contains additional coefficients extending to degree 2190 and order 2159. Computing the geoid undulation values are realized with respect to WGS 84 ellipsoid [1]. Over areas covered with high quality gravity data, the discrepancy between EGM 2008 geoid undulations and independent GPS/levelling data is of the order of  $\pm 5$  to  $\pm 10$  cm (Nikolaos et al., 2012). The EGM2008 model gives stable result for the root-mean-square-error (RMSE) of the residuals in terms of relative geoid heights accuracy (Kim, Yun and Choi 2020).

The International Center for Global Earth Models (ICGEM) continuously analyzes the performance of every new released GGM model over several GPS/Levelling check points worldwide. Table 1 presents the statistics of evaluation of the selected seven GGM models in terms of the Root Mean Square error (RMS) of the undulation differences. It can be seen that the overall accuracy of EGM2008 over the entire 12036 check points indicates that it is the most precise GGM (Al-Krargy etAll 2015).

Table 1. RMS of Differences of GGM-Based Geoid Undulations over GPS/Levelling Check Points (m)

Test area	USA	Canada	Europe	Australia	Japan	Brazil	All
No. of check points	6169	2691	1047	201	816	1112	12036
EGM08	0.248	0.128	0.125	0.217	0.083	0.460	0.240
EGM96	0.379	0.353	0.493	0.298	0.364	0.730	0.427

Source: <http://icgem.gfz-potsdam.de/ICGEM/ICGEM.html>

Three global gravitational models are open for download and utilization through the official web page of NGA [1], as well as from many other web pages. One of the WEB GIS based free product via internet is the geoportal of surveying.org web page, where can be found very wide range of special spatial data, such as weather, NGS (national geodetic survey), USGS maps, geoid heights, magnetic declination, state plan systems, UTM zones etc (Idrizi 2013).

### 3. SOURCE DATA AND BASIC TEST MODEL

Since the possibility for usage of official data by responsible institution for geospatial information is very limited, as source data have been used test model developed for analyses of length differences between topography and geoid as well as between geoid and referent ellipsoid, with 10893 points with Cartesian/geographic coordinates in the state coordinate system in ground resolution of 1km shown in figure 1 (Idrizi etAll 2018), while for elevation dataset the ASTER global DEM [6] with 30m spatial resolution have been used.

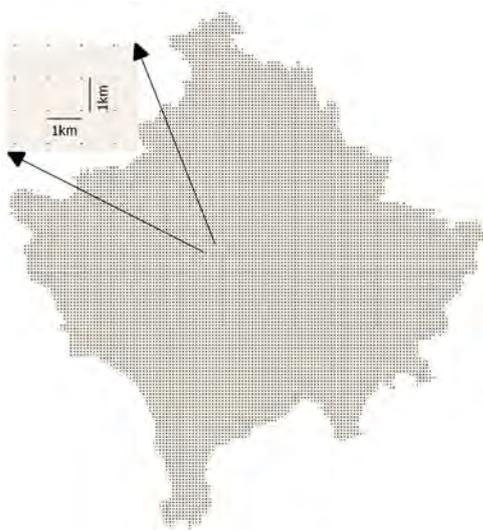


Figure 1. Dataset for test model with 10893 points

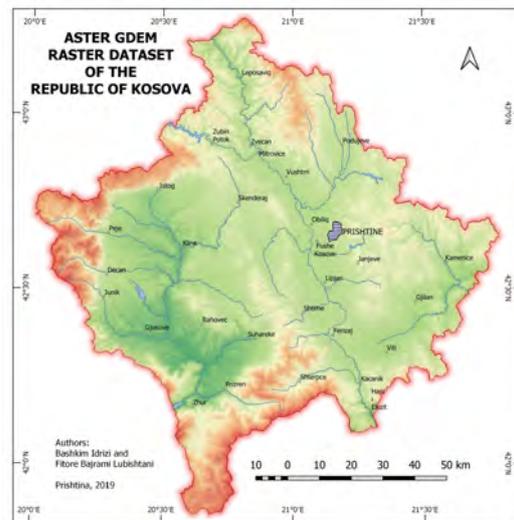


Figure 2. Relief of Kosova based on ASTER GDEM

Aimed to calculate empirical values for three geoid models and differences between them (steps 9, figure 3), as output for each of 10893 points should be calculated:

- Maximal values,
- Minimal values,
- Differences between maximal and minimal values,
- Mean values, and
- Standard deviations.

#### 4. DEVELOPING EGM MODELS 2008, 1996 AND 1984 FOR THE KOSOVAS TERRITORY

Three EGM models (2008, 1996 and 1984) for the national area of the Republic of Kosova are developed as separate point vector datasets with 1km ground resolution (Idrizi etAll 2018), while later converted to raster datasets, and finally merged into multiband raster dataset based on obtained elevation values, obtained geoid heights for three models, and calculated values between geoid heights and with elevations. Schema for whole process is given in next figure 3.

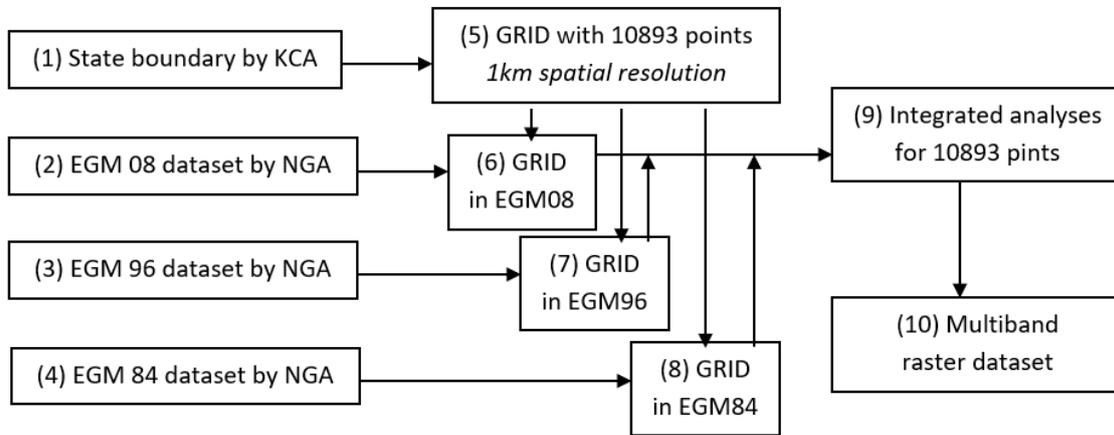


Figure 3. Scheme of developing multiband raster dataset of EGM 08, 96 and 84 for the Republic of Kosova

Test model used from previous research of Idrizi etAll 2018 (steps 1 and 5) contain cartesian/geographical coordinates and ASTER elevation [6] data for each of 10893 points. Data for steps from (2) to (4) were extracted directly from official web page of NGA [1], which then have been used for calculation of geoid heights [5] for all test model points (steps 6 to 8).

Three grids of 10893 points (6, 7 and 8) with values for coordinates, elevations, and geoid heights for three EGM models, at final step of calculation, before developing multiband raster dataset, have been used for calculation of differences between geoid heights of three models and ellipsoidal heights based on difference between the elevations and geoid heights of three models (step 9). With this, input grid of 10893 points with coordinates and elevations (5) is extended with nine new columns for geoid heights of three EGMs, difference between them and ellipsoidal heights based on each EGMs (9).

Final output database of test points with three obtained values for coordinates and elevations (step 5), as well nine calculated values (steps 6 to 9), as final product has been converted to single multiband raster dataset with ten bands and 10893 cells of 1km spatial resolution. Meaning of bands are given in bellow table with description:

Table 2. Description of bands in developed multiband raster dataset

BAND	DATA	BAND	DATA
1	ASTER elevation	6	Difference between geoid heights of EGM 08-96
2	Geoid height (EGM 84)	7	Difference between geoid heights of EGM 08-96
3	Geoid height (EGM 96)	8	Ellipsoidal heights based on EGM 84 and ASTER
4	Geoid height (EGM 2008)	9	Ellipsoidal heights based on EGM 96 and ASTER
5	Difference between geoid heights of EGM 08-96	10	Ellipsoidal heights based on EGM 2008 and ASTER

##### 4.1. EGM 2008 for the national area of Kosova

In step 6 of above given schema, the geoid heights for all points have been calculated for the entire area of Kosova. Calculation of geoid heights have been realized with precision of 4 decimals after meter (0.1mm), and 1mm RMS of interpolation of geoid heights in points of test model. From the calculated results, maximum value of geoid heights within EGM08 is 46.433m, while the minimum is 43.9215m. The difference between extreme values within the territory of Kosova of EGM08 geoid heights is 2.5115m, while the mean geoid height is 45.5391m, shown in table 3. In figure 4 [9], compiled map of geoid heights based on EGM2008 for the national area of Kosova is given.

### 4.2. EGM 1996 for the national area of Kosova

The identical procedure as in a case of using EGM 08 for the territory of Kosova, have been implemented for EGM96 also (step 7), by calculation of geoid heights with precision of 4 decimals after meter (0.1mm), and 1mm RMS of interpolated geoid heights of points of test model. The largest value of geoid heights within EGM96 is 45.8281m, the lowest one is 43.1571m, mean height is 43.9581m, and the difference between extreme values is 2.671m, given in table 3. With the same methodology as in a previous case of EGM2008, the GIS raster dataset with 1km spatial resolution of EGM96 for Kosova is compiled, which is shown in bellow figure 5 [10].

### 4.3. EGM 1984 for the national area of Kosova

Procedure and methodology for calculation of EGM84 geoid heights for the territory of Kosova (step 8) and their representing in a compiled map (figure 6) [11], were same as in a cases for EGM08 and EGM96. Greatest value of geoid heights within EGM84 is 47.198m, the smallest one is 43.9867m, the mean height is 45.5669m, while the difference between extreme values within the EGM84 geoid heights is 3.2113m, given in table 3.

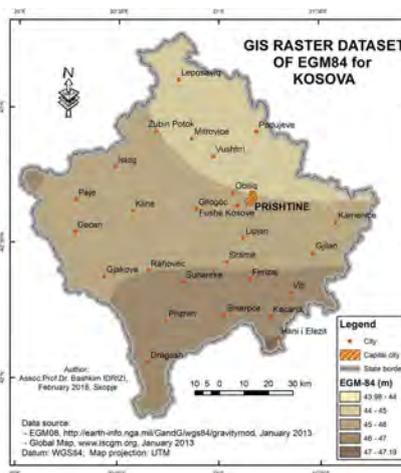
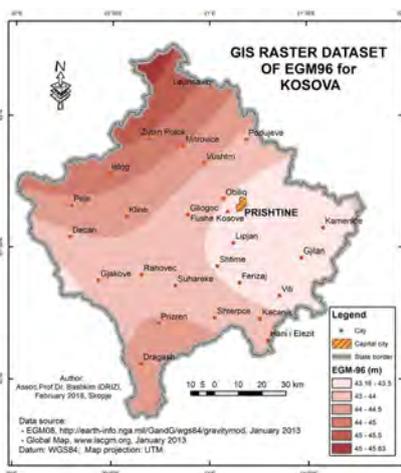
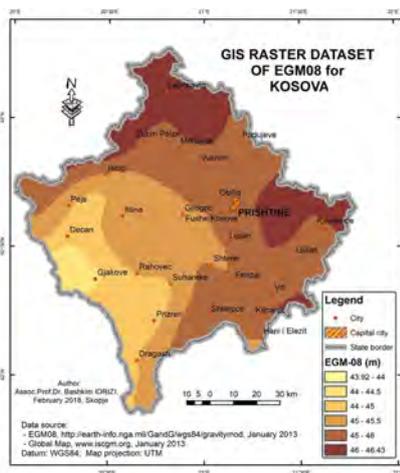


Figure 4. GIS raster dataset with 1km spatial resolution of EGM2008 for Kosova

Figure 5. GIS raster dataset with 1km spatial resolution of EGM96 for Kosova

Figure 6. GIS raster dataset with 1km spatial resolution of EGM84 for Kosova

Table 3. Geoid heights and differences between EGM 08, 96 & 84 in the territory of Kosova

	Geoid heights (m)			Difference between two geoid heights (m)		
	EGM84	EGM96	EGM2008	EGM 08-96	EGM 96-84	EGM 08-84
<b>Max value (m)</b>	47.198	45.8281	46.433	2.9344	1.1018	2.1423
<b>Min value (m)</b>	43.9867	43.1571	43.9215	0.2611	-3.259	-2.0307
<b>Diffe Max-Min (m)</b>	3.2113	2.671	2.5115	2.6733	4.3608	4.173
<b>Mean value (m)</b>	45.56692	43.95809	45.53911	1.581024	-1.608835	-0.027811
<b>Stand.Dev. (m)</b>	0.690377	0.572147	0.493465	0.6974836	1.003411	1.04026

### 4.4. Multiband raster dataset for geoid heights for the national area of Kosova

In the last step 10 (figure 3), according to ASTER elevation data and calculated values for all 10.893 points, as are presented in table 2, in GIS software multiband raster dataset with 10 bands was established. Each cell of raster image contains 10 values, per one in each band, which means that multiband raster image with 10.893 cells contain 108.930 values/calculations. Developing multiband raster image instead developing separate raster images for each calculated value, i.e. one instead ten raster images, is intended for multipurpose usage and creating suitable environment for further analyzes in this subject for the area of the Republic of Kosova. In bellow figure 7, three bands (EGM 08, 96 and 84 geoid heights) out of ten are shown as example/extract from developed multiband raster dataset, followed by the short description of each band.

It is open for further improvement by adding additional bands with geoid heights data developed by other researchers. A new band with official geoid model of the Republic of Kosova after its development by the responsible national mapping institution (Kosova Cadastral Agency), will be added by our side, in order to put into one place many geoid

models for multipurpose usage, for everyday professional up to research purposes. If the national digital elevation model will be available free of charge by the KCA, it will be added to this multiband raster dataset, and some data as ellipsoidal heights (bands 8, 9 and 10) will be recalculated and updated.

Main objective of developed multiband raster is to fill current gap in this field in the Republic of Kosova, as well as to establish platform that will be used for performing multipurpose research analyses in a period post developing of official national geoid model.

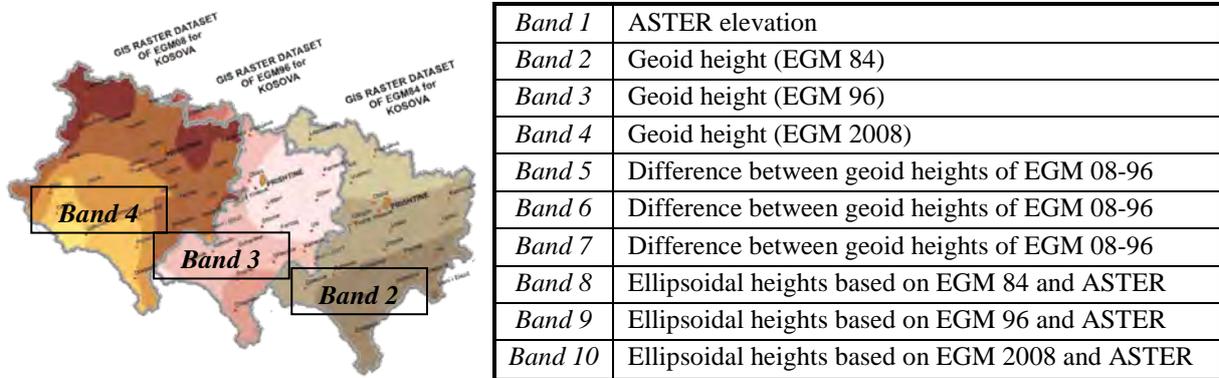


Figure 7. Multiband raster dataset for EGM 08, 96 and 84 geoid heights for Kosova

## 5. CONCLUSIONS

Model for utilization of existing global Earth Gravitational Models (EGM) for entire area of the Republic of Kosova through developing GIS dataset is given in this paper. Due to current situation in Kosova with the national geoid, which is still under development process by the Kosova Cadastral Agency [7], usage of global EGM's for issues related to geoinformation is more than necessary.

Three existing global models EGM 2008, EGM 96 and EGM 84 [1] have been used for performing this research study. Comparing of the results between three models, were calculated based on joint GRID model with 10893 points which covers all national area with 1km ground resolution. Maximal and minimal differences between the models, maximal and minimal geoid heights (height of geoid above/bellow the WGS84 ellipsoid) in three geoid models, mean differences, standard deviation, ellipsoidal heights and other data-calculations, followed by developing of multiband raster dataset, are main outputs of performed research in this study.

Based on three developed models and differences between the models, nine maps for the territory of the Republic of Kosova were compiled. For map background, such as data for cities and boundaries, open and free Kosova Global Map data has been utilized, as official data developed by the national mapping authority of Kosova [7], while for the elevation data the ASTER global Digital Elevation Model (DEM) with 30m spatial resolution [6] has been used. Within the paper, only three maps EG models with geoid heights as layouts of three bands are shown.

Calculation with online geoid calculator GeoidEval [5], gave us feedback and insure for calculated geoid heights for three models. Control points were selected by criteria to cover entire national area of Kosova. Based on the calculated values, the differences between calculated geoid heights with online geoid calculators and those exported from models in GIS platform have been evaluated, which resulted with very low differences.

Main purpose of analyses and developed GIS dataset for geoid heights and other data, is their open usage by geo community in Kosova, mainly for direct obtaining of elevations during field measurements and further research projects, till the establishing and formalization of national gravimetric network and national geoid model.

Multiband raster image with ten bands in 1km spatial resolution, which contain 108.930 values stored in 10.893 cells, is the main output of this research study. It is open and extendable raster dataset, that is intended for multipurpose usage and update its content, as well inclusion of new band with the official national geoid model of the Republic of Kosova as soon as it is developed by the Kosova Cadastral Agency. Until the official national geoid, this model will fill the current gap in geo sector in the Republic of Kosova as contribute of academic community for professional and research usage of global geoid models for national purposes.

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- [9] [https://www.researchgate.net/publication/323116877\\_GIS\\_dataset\\_with\\_1km\\_spatial\\_resolution\\_for\\_GEOID\\_HEIGHTS\\_base\\_d\\_on\\_Earth\\_Gravitational\\_Model\\_2008\\_for\\_KOSOVA\\_Total\\_number\\_of\\_calculated\\_grid\\_points\\_10893\\_EGM2008forKOSOVA](https://www.researchgate.net/publication/323116877_GIS_dataset_with_1km_spatial_resolution_for_GEOID_HEIGHTS_base_d_on_Earth_Gravitational_Model_2008_for_KOSOVA_Total_number_of_calculated_grid_points_10893_EGM2008forKOSOVA) (March 2020)

- [10] <https://www.researchgate.net/publication/323117149> GIS dataset with 1km spatial resolution for GEOID HEIGHTS based on Earth Gravitational Model 1996 for national areas of KOSOVA Total number of calculated grid points 10893 EGM96forKOSOVA (March 2020)
- [11] <https://www.researchgate.net/publication/323116880> GIS dataset with 1km spatial resolution for GEOID HEIGHTS based on Earth Gravitational Model 1884 for national areas of KOSOVA Total number of calculated grid points 10893 EGM84forKOSOVA (March 2020)

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# LAND COVER AND LAND USE ASSESSMENT IN RELATION TO TOURISM DEVELOPMENT IN THE MUNICIPALITY OF TROYAN IN BULGARIA

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## **Abstract**

*Tourism is a priority sector in the local economic development of the municipality of Troyan in Bulgaria. The municipality's tourism resources are characterized by a combination of unique natural landmarks, cultural and historical heritage, attractive landscapes, as well as favorable climate, waters and geographical location. However, how tourism destinations should be planned properly using land cover resources to enhance community well-being and sustainability has not yet been extensively elaborated issue. This study aims to explore and analyze the structure of land cover and land use in relation to tourism development in the municipality of Troyan. Spatial analysis of land cover and land use state is based on quantitative assessment of Corine Land Cover data and thematic mapping in GIS environment. The interrelation of land cover and tourism development is discussed. The results presented in this study can be used in defining priorities for long-term land use planning and sustainable tourism development.*

**Keywords:** Land cover, Land use, Tourism, Spatial analysis, GIS

## **INTRODUCTION**

Tourism is an economic sector that is highly dependent on natural resources. Therefore, the sustainable development of tourism is closely related to environmentally friendly land cover and land use long-term plans. This study aims to explore and analyze the structure of land cover and land use in relation to tourism development. The municipality of Troyan in Bulgaria was selected as a case study.

Tourism is a priority sector in the local economic development of the municipality of Troyan. This municipality has unique natural resources, well-preserved nature and rich biological diversity, as well as favorable geographical location, climate and waters, which are prerequisites for the development of various forms of tourism. However, how tourism destinations should be planned properly using land cover resources to enhance community well-being and sustainability has not yet been extensively elaborated issue.

The major source of spatial data about land cover and land use is remote sensing technology. Remote Sensing (RS) and geographic information systems (GIS) currently provide new tools for advanced land cover mapping and monitoring. RS has the advantage to cover large geographical areas, to perform systematic observations for a long time period, and

to offer cost-effective approaches for change detection. Both RS and GIS are powerful tools for monitoring, mapping and spatial analysis of land cover change at various spatial and temporal scales, as well as for identifying trends of change patterns. A series of studies present wide range of RS and GIS applications in the fields of landscape change and land cover/land use mapping and modelling in last decade (Gillanders et al., 2008; Feranec et al., 2010; Kopecka, 2011; Sohl, Sleeter, 2012; Feranec, Soukup, 2013; Vatsveva, 2015; Goga et al., 2019, etc.).

## STUDY AREA

The study area is the Municipality of Troyan in Lovech District in Bulgaria (Figure 1). It is located in Central-North Bulgaria, 160 km northeast of Sofia, at coordinates  $42^{\circ}71' - 43^{\circ}03'N$  and  $24^{\circ}43' - 24^{\circ}89'E$ . The municipality covers a territory of 894.82 km<sup>2</sup> with a population of 28,195 inhabitants, as of December 2019 (NSI, 2019).

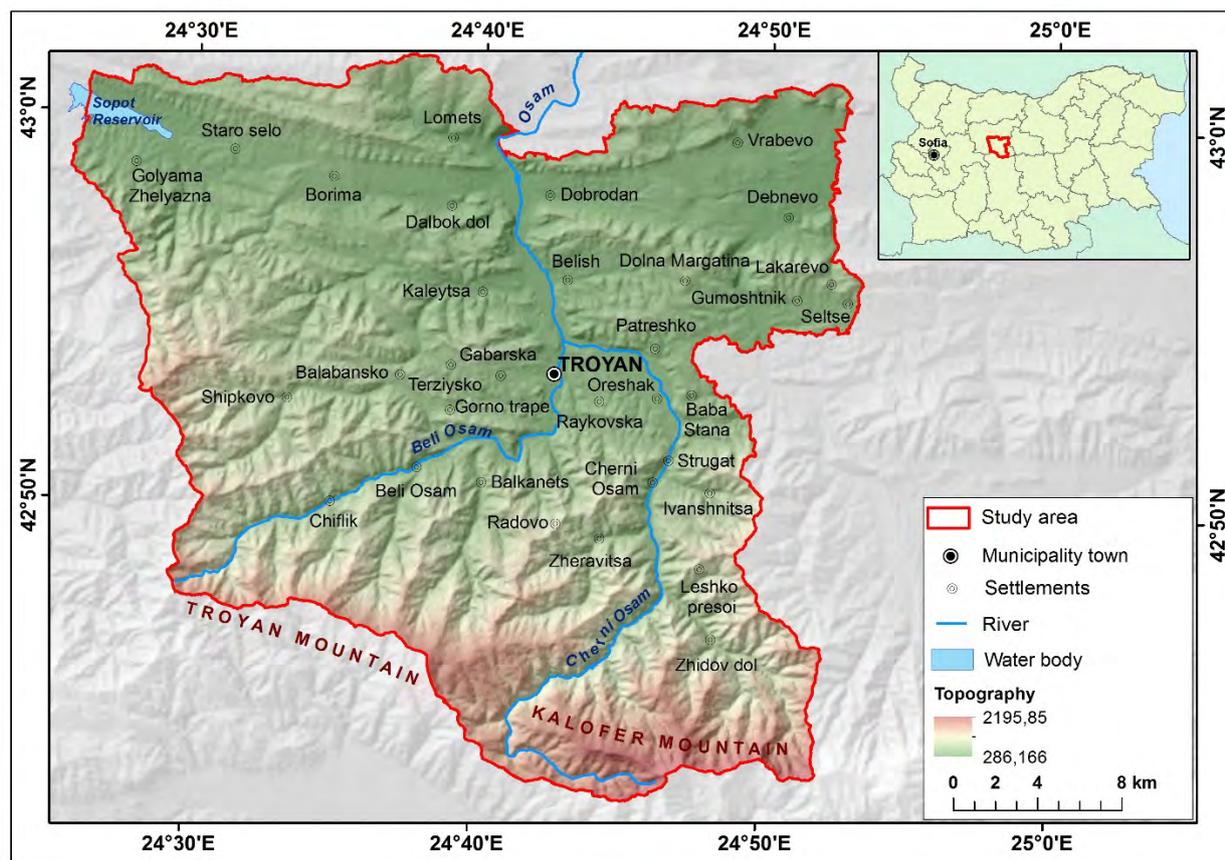


Figure 1. The municipality of Troyan - study area

The territory of the study area covers a part of the longest and highest part of the Central Balkan Mountains (Central Stara Planina) – the Troyan-Kalofer Mountains, as well as adjacent parts of the Central Fore-Balkan (Georgiev, 1979). The northern part of the Troyan municipality is located in the Central Fore-Balkan, where the dominant terrain is a hilly – ridge, formed by normal folds and slopes to the north. These are relatively low landforms with an average altitude of about 350 m. The southern part of the Troyan municipality is located on the steep northern slopes of Balkan Mountains. The relief is typically mountainous and is characterized by strong dissection. The slopes on most of the territory are steep and very steep to the precipices, and the ridges are sharp and slightly rounded. The terrain is heavily rugged with a well-developed and dense hydrographic network. The largest rivers in the municipality are Beli Osam and Cherni Osam, uniting in the Osam River.

The natural resources of the municipality of Troyan provide good opportunities for the development of tourism as a priority sector in the local economic development. The municipality of Troyan has an appropriate combination of unique natural landmarks, cultural and historical heritage, attractive landscapes, as well as a favorable climate, waters and geographical location.

## MATERIALS AND METHODS

Geospatial data and information about the land cover / land use and tourism in the municipality of Troyan were provided by available remote sensing data, vector data, topographic maps and technical documents.

The remote sensing data used include digital orthophoto images provided by the Bulgarian Ministry of Agriculture, Food and Forestry (MAFF, 2017). The orthophoto images (Figure 2) were acquired in 2014 and 2016 with spatial resolution of 0.4 m.

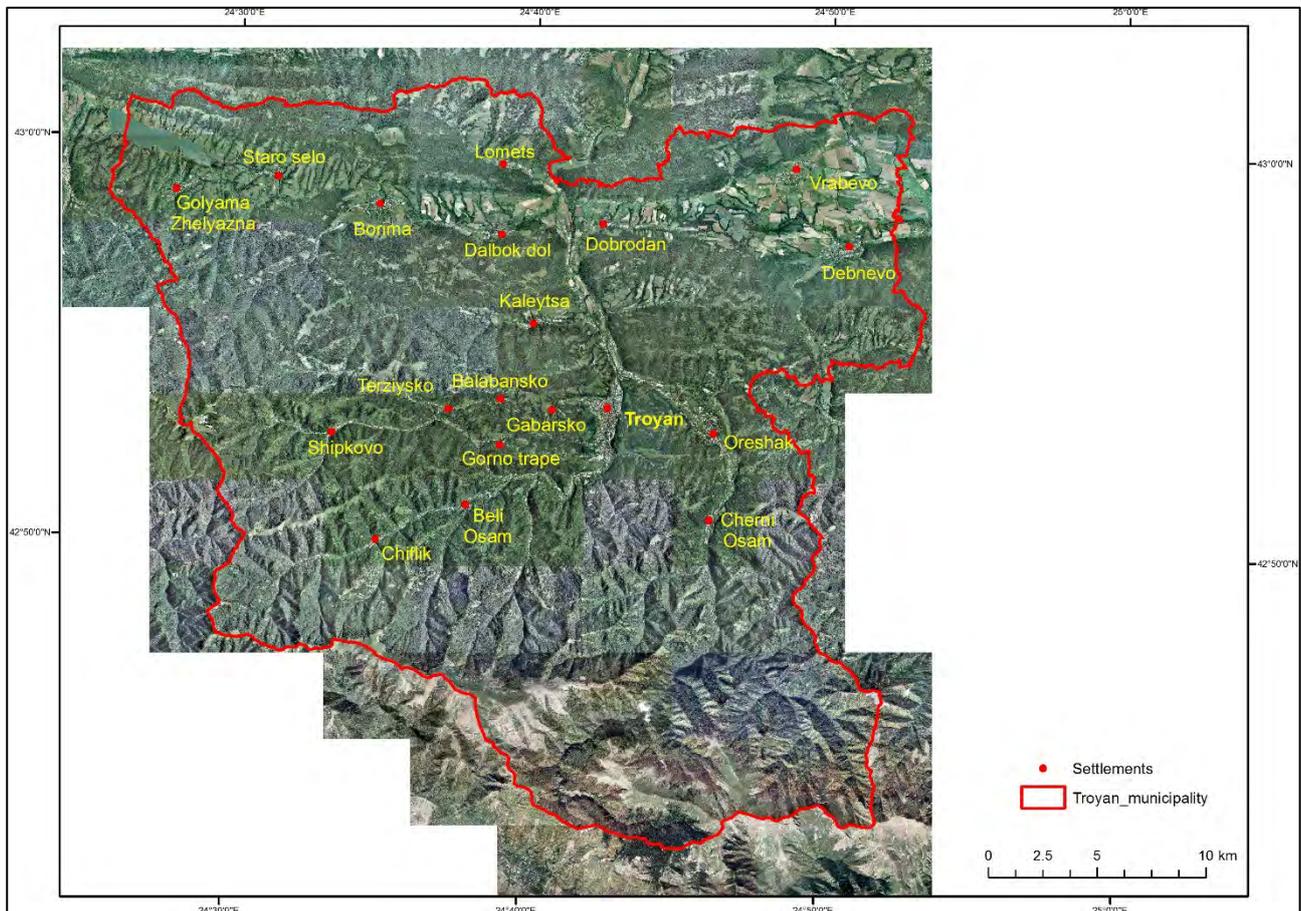


Figure 2. Orthophoto image coverage of the municipality of Troyan

CORINE Land Cover (CLC) 2018 data (ExEA, 2020) was used to assess land cover/land use of the municipality of Troyan. The land cover and land use mapping is produced through the CLC project based on application of computer aided visual interpretation of high resolution remote sensing data in GIS environment according to the CLC methodology (CEC, 1995, Bossard et al., 2000; EEA, 2007). Further, in our study CLC data was combined with available orthophoto images as reference data in order to provide more detailed land cover / land use data with high spatial accuracy.

The additional data includes digital topographic maps 1:50000, thematic maps, technical documents (Municipal development plan, 2013), expert knowledge and fieldwork.

The applied methodological approach for land cover mapping includes the next main methodological procedures:

1. Image processing
2. Additional data processing
3. Identification and classification of land cover by visual image interpretation
4. Fieldwork for verification of the interpretation done using the imagery
5. Application of GIS procedures for control and correction of the land cover database.

In this study, the mapping and assessment of land cover and land use state in the municipality of Troyan includes statistical analysis of the spatial distribution and the quantitative assessment of presented land cover classes.

**RESULTS AND DISCUSSION**

The produced map of CLC in Figure 3 visualizes the structure and spatial distribution of land cover and land use in the municipality of Troyan in 2018. The reference ellipsoid of map is WGS 84, cartographic projection: Universal Transverse Mercator (UTM) Zone 35N, geographical coordinates. The Table 1 shows registered land cover classes (see also Legend in Figure 3) according to CLC nomenclature.

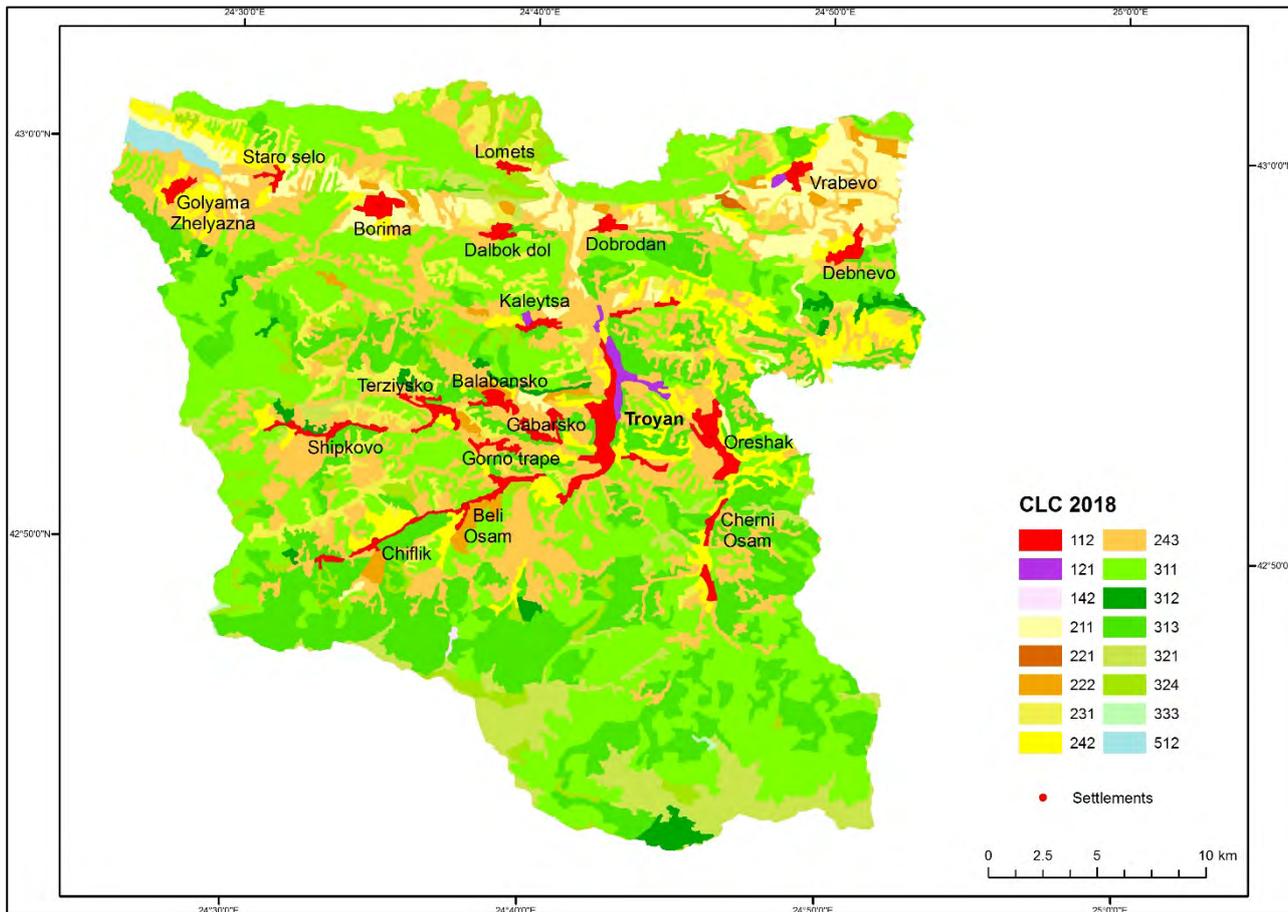


Figure 3. CORINE Land Cover (CLC) map of the municipality of Troyan in 2018

Table 1. CORINE Land Cover classes in the municipality of Troyan

Level 1	Level 2	Level 3
1. Artificial surfaces	1.1. Urban fabric	1.1.2. Discontinuous urban fabric
	1.2. Industrial, commercial and transport units	1.2.1. Industrial or commercial units
	1.4. Artificial non-agricultural vegetated areas	1.4.2. Sport and leisure facilities

2. Agricultural areas	2.1. Arable land	2.1.1. Non-irrigated arable land
	2.2. Permanent crops	2.2.1. Vineyards
		2.2.2. Fruit trees and berries plantations
	2.3. Pastures	2.3.1. Pastures
	2.4. Heterogeneous agricultural areas	2.4.2. Complex cultivation patterns
2.4.3. Land principally occupied by agriculture with significant areas of natural vegetation		
3. Forest and semi natural areas	3.1. Forests	3.1.1. Broad leaved forest
		3.1.2. Coniferous forest
		3.1.3. Mixed forest
	3.2. Scrub and/or herbaceous vegetation associations	3.2.1. Natural grassland
		3.2.4. Transitional woodland scrub
	3.3. Open spaces with little or no vegetation	3.3.3. Sparsely vegetated areas
5. Water bodies	5.1. Continental waters	5.1.2. Water bodies

The statistical analysis of land use and land cover of the municipality of Troyan in 2018 represents the distribution of forest and semi-natural areas (62.17%), agricultural areas (34.08%), artificial surfaces (3.33%), and water bodies (0.42%) (Table 2).

Table 2. CORINE Land Cover 2018 in the municipality of Troyan

Land cover and land use	CLC code	CLC level 3	Area (ha)	Percentage (%)
1. Artificial surfaces	112	Discontinuous urban fabric	2645.11	2.96
	121	Industrial or commercial units	301.21	0.34
	142	Sport and leisure facilities	32.53	0.04
2. Agricultural areas	211	Non-irrigated arable land	4504.64	5.04
	221	Vineyards	53.59	0.06
	222	Fruit trees and berries plantations	978.84	1.09
	231	Pastures	4294.51	4.80
	242	Complex cultivation patterns	5027.23	5.62

	243	Land principally occupied by agriculture with significant areas of natural vegetation	15619.05	17.47
3. Forest and semi natural areas	311	Broad leaved forest	29428.39	32.91
	312	Coniferous forest	1024.67	1.15
	313	Mixed forest	17505.52	19.57
	321	Natural grassland	4847.86	5.42
	324	Transitional woodland scrub	2730.39	3.05
	333	Sparsely vegetated areas	57.90	0.06
5. Water bodies	512	Water bodies	377.88	0.42
		<b>Total</b>	<b>89429.32</b>	<b>100.00</b>

For the purposes of this study, CLC data was combined with available orthophoto images as reference data in order to verify land cover and land use data in the fieldwork and to provide data with high spatial accuracy (Figure 4).

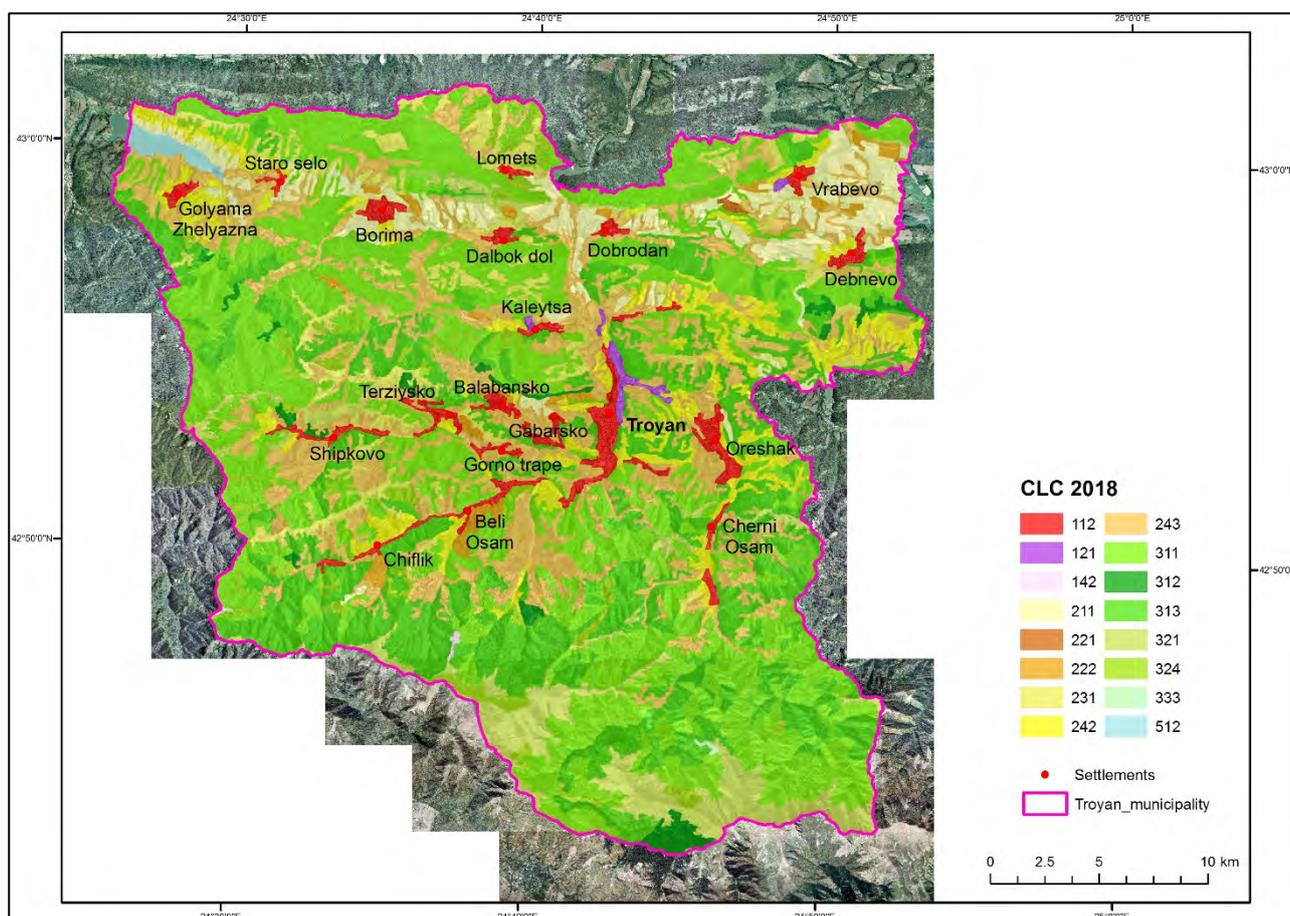


Figure 4. Combined orthophoto images and land cover data for the municipality of Troyan

The analysis of the land cover and land use state is focused mainly on the CLC classes that represent natural resources for tourism development, such as forest and semi-natural areas and water bodies.

Forest and semi-natural areas predominate in the municipality of Troyan covering 62.17% of its total area. The following tree species are observed (Municipal development plan, 2013): oak, maple, ash, hornbeam, poplar are widespread. Over 800 m above sea level beech communities are located, which significantly give the general appearance of the forest vegetation. Within the beech belt in the higher mountain parts there are firs, spruce, white pine and other conifers. Forests play a significant role in the formation of the local climate, protect soils from erosion,

regulate the water regime of rivers, reduce wind strength, have great aesthetic value and are important for the realization of tourism and recreation of people.

The floristic diversity is represented by about 2337 species and subspecies of plants, of which about 1900 species and subspecies of higher plants. The number of conservation-significant plants is as follows: local endemics - 10 species, Bulgarian endemics - 10, Balkan endemics - 67, protected by Bulgarian legislation - 30, included in the national Red Book - 81, in the Red List of Europe - 9, endangered worldwide - 10 species. An extremely large number of medicinal plants are found in agricultural areas and forests (Municipal development plan, 2013). Plant species of conservation importance are located in three protected territories: the National Park "Central Balkan", the "Steneto" Biosphere Reserve and the "Kozya stena" Reserve.

The water wealth of the municipality in connection with the land cover is presented in a study by Gartsianova (2016). It includes the largest rivers Beli Osam and Cherni Osam, which merge into the river Osam, as well as their tributaries. The Sopot Dam has been built in the northwestern part of the municipality. There are 5 mineral springs in the village of Shipkovo. The water was captured in 1936. The total flow of all water sources is 62 l / s, the temperature is 18-38 °C. The water is weakly mineralized, hyperthermal hydrocarbonate-sulphate calcium-magnesium. It is used for medicinal purposes - for drinking and baths. There is also a mineral spring in the village of Chiflik.

Tourism is a well-developed industry, influencing the overall vision of the municipality of Troyan. The main factors for development of tourism sector in the municipality are the favorable combination of natural resources and recreational resources with religious and cultural-historical landmarks, as well as the attitudes of the population for development of tourism business. Based on this, the following types of tourism are developed in the Troyan municipality: cultural and cultural-historical; religious; cognitive; mountainous; hiking, eco and green tourism; ski tourism; SPA and balneal tourism; extreme tourism and alternative tourism. The most important for the municipality development are religious tourism, SPA and mountain tourism. The main natural landmarks for tourism development include: the century-old tree "Kartsov beech", a stone bridge "Crali markova dupka", the vertical "Pticha Dupka" cave, the precipice "Raychova Dupka" cave, the "Toplya" cave, the rock chapel "St. Peter and Paul", and waterfalls (Brambar skok, Koman, Lopushnitsa, Bankovski skok).

## CONCLUSIONS

Tourism is a sector in which almost all activities and services depend on nature itself. In this regard, the presented study of land cover and land use is needed to achieve environmentally sound land use plans and tourism development. Analysis of land cover and land use state is focused mainly on the CLC classes that represent natural resources, such as forest and semi-natural areas and water bodies. The distribution of forest and semi-natural areas in the municipality of Troyan in 2018 represents 62.17%. The following types of tourism are developed in the Troyan municipality: religious; cultural and cultural-historical; cognitive; mountainous; hiking, eco or green tourism; ski tourism; SPA and balneal tourism; extreme tourism and alternative tourism. The most important for the municipality development is religious tourism, followed by SPA and mountain tourism.

The modern geoinformation technologies can provide new knowledge and can ensure a scientific support for an informed decision-making on sustainable tourism development. The research results can be used in defining priorities for long-term land use planning and development of tourism in the municipality of Troyan.

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# MAPPING TOURISM INFRASTRUCTURE IN TROYAN MUNICIPALITY (BULGARIA) USING GIS TECHNOLOGIES

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## **Abstract**

*This article analyzes the tourism infrastructure and superstructure of the Troyan municipality. Tourism infrastructure is an element of overall infrastructure. It is comprised of basic facilities and services necessary to develop tourist area (accommodation, catering, transport, information, museums, and tourist attractions). Bulgaria is a tourist destination that has invested heavily in improving and expanding tourism material base. There has been a new trend of interest in tourist regions. Tourism resources are really important, but increasingly scarce for tourists when choosing their destination. Tourism superstructure and tourism infrastructure are becoming more essential elements of tourism supply. This study aims to collect data and to create a GIS database of tourism infrastructure, as well as to map tourism infrastructure with tourist attractions using GIS technologies. The collected data is analyzed and structured into GIS datasets for relief, hydrography, land cover, settlements, roads, and tourist infrastructure. The results are presented with produced maps and tables.*

**Keywords:** *Tourism, Mapping, GIS, Cartography*

## **INTRODUCTION**

The topicality of the article is related to the importance of tourism infrastructure for the development of tourism and competitiveness of the destination, as well as the ability of GIS to meet the information needs of a wide range of users: potential infrastructure investors, local and central authorities, tourism organizations, non-governmental organizations as well as tourists themselves.

Modern tourism no longer relies solely on natural resources or cultural and historical heritage to attract tourists. Tourism resources are important, but in themselves insufficient for tourists when choosing a destination for their stay and recreation.

Increasingly essential elements of tourism are the tourist superstructure and tourist infrastructure, as well as information provided for them. For tourism infrastructure and many definitions, a very small part of them is included in this article. According to Neshkov and Dabeva, 2014, the tourist infrastructure "is built to develop the resort area, the tourist place and provide communications and access to them" (Vasileva and Sabrieva, 2018). The tourist infrastructure in a broad sense includes "auxiliary and additional means, equipment, systems, processes and resources that are necessary for the functioning of any tourist destination" (Jovanović and Ilić, 2016; Vasileva and Sabrieva, 2018). The tourist infrastructure in a broad sense includes "auxiliary and additional means, equipment, systems, processes and resources that are necessary for the functioning of any tourist destination" (Jovanović and Ilić, 2016; Vasileva and Sabrieva, 2018). In the broadest sense, the tourist infrastructure includes places for accommodation and meals, intermediary activities in tourism, advertising, information and marketing activities, commercial sites, legal, banking, and accounting institutions, sites satisfying cognitive, entertainment and other interests, control and administrative bodies (Vasileva and Sabrieva, 2018). The tourist superstructure is also a key element in the tourism system. Most authors do not

distinguish the tourist infrastructure from the tourist superstructure and the available definitions of tourist superstructure are significantly less (Vasileva and Sabrieva, 2018). Other authors (Neshkov and Dabeva et al, 2014) distinguish between the two concepts and consider them as the two components of the material base of tourism (Vasileva and Sabrieva, 2018). The concept of the superstructure in tourism science was introduced in 2003 by Ritchie and Crouch (Vasileva and Sabrieva, 2018). The tourist superstructure includes various congress, sports, gambling and SPA centers, shopping malls, accommodation buildings, restaurants and entertainment, offices of tour operators and travel agents, tourist information centers, airports, ports, stations, etc. (Vasileva and Sabrieva 2018 ).

Indeed, tourism infrastructure and superstructure are key drivers of tourism. Without their construction, renovation, and development, it is difficult, even impossible, for the tourist to absorb the territory, as well as the subsequent competitive positioning of the destination. The construction of the material base of tourism requires significant investments, and their return is guaranteed by the increasing attractiveness of the respective tourist destination. Most of the innovations in tourism are related to tourism infrastructure. Innovative solutions in terms of tourism infrastructure and superstructure create competitive advantages and are an important prerequisite for the development of new tourist destinations. In this regard, the issue of the state of the tourist infrastructure in our country, as well as the information provision for this infrastructure is topical. It is about the following: To carry out effective investment and innovation activities in the field of tourist infrastructure, it is necessary to provide information regarding the condition of this infrastructure, its specifics, the location of individual sites, etc. The following should also be taken into account: the development of various processes, such as the orientation of modern tourists to self-organized travel, as well as the development of short-term (weekend) travel programs and initiatives stimulates and deepens tourists' need for up-to-date and up-to-date information. of various aspects of their stay - opportunities for accommodation, meals, recreation and entertainment, opportunities for alternative forms of tourism, various experiences, and more. Various guides related to individual tourist areas, as well as tourist maps, are periodically published in the country. Given the modern development of technology, this option (information provided on paper) is no longer sufficient to meet tourist demand. The same applies to the development of infrastructure: the availability of traditional media is not sufficient for its renewal and future development. Geographic information systems (GIS) are the answer to these problems. The main task of any geographic information system is to collect, store, analyze, and visualize spatial data and related information about the presented objects. Most often, the information is presented in the form of digital maps that can be easily searched, analyzed, and edited. The use of digital maps in GIS has some advantages: they are much easier to process, unlike traditional paper maps; easily edited, updated, summarized and analyzed; easily edited, updated, summarized and analyzed; provide an opportunity for historical visualization of geospatial information, which is a means of tracking and analyzing the dynamics in the development of geographical objects; can be superimposed in the form of layers in maps of different purposes and thus get a complete picture of the analyzed geographical object in each specific study.

The consumer of geoinformation is the whole of society, and geoinformation technologies are needed to manage organizational and social change in it. Their main function is to provide quality information services to customers. The Geographic information systems (GIS) contains three aspects - a geographic database (geodata), maps (interactive maps showing the objects on the Earth's surface, and links between them) and models (Tcherkezova et al., 2019).

GIS analyzes the output and assigns x, y, and z coordinates (length, width, and height) to each object, serves to map, provide consumer-oriented products from a specific geographical area, and develop applications that support the operation of the state administration (Popov, 2012). The objective of this study is to analyze the tourist infrastructure of the municipality of Troyan and to present the infield GIS database for the tourist infrastructure. Despite the presence of the line ministry, as well as the National Statistical Institute (NSI), Bulgaria lacks a single database regarding statistical information related to accommodation and their attendance, especially when it comes to individual regions and municipalities. The survey shows that there are differences in the data from the municipality of Troyan and the National Statistical Institute regarding the accommodation facilities in the municipality.

## **STUDY AREA**

The study area is Troyan Municipality, Lovech District (Central North Bulgaria) (Figure 1). The study area coincides with the area of the municipality.

In physical-geographic terms, the territory of the study area covers a part of the longest and highest part of the Central Balkan Mountains – the Troyan-Kalofer Mountains, as well as adjacent parts of the Central Fore-Balkan (Georgiev, 1979). The dominant terrain in the Central Pre –Balkan is a hilly – ridge, formed by normal folds and slopes to the north. These are relatively low landforms. The average altitude is 364 mm. The highest point is Vasilyov peak (1490 m) in the Vasilyovska Mountain, in the middle of the Pre – Balkan.

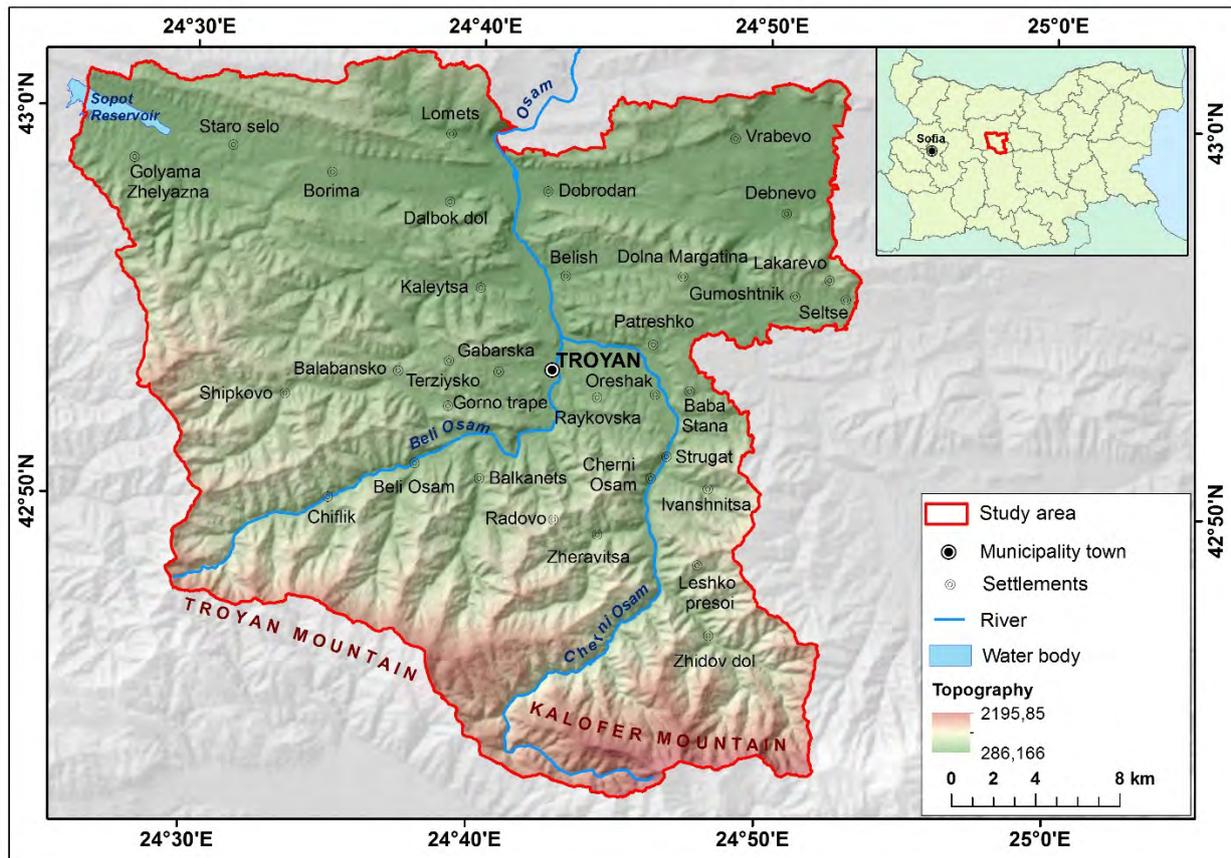


Figure 1. Study area - the municipality of Troyan

## DATA AND METHODS

To compile the geodatabase of the tourist infrastructure of the municipality of Troyan, digital information layers in GIS have been prepared, using the following sources of information: topographic maps M 1:50 000; available thematic and administrative maps (in various scales, analog or digital) and field research (measurements with GPS – Garmin) to collect the necessary information.

The following digital input data were used: 1. Relief; 2. Settlements; 3. Border of a municipality; 4. Road network; 5. Hydrography (rivers, water bodies); 6. Tourism infrastructure 7. Objects of cultural and historical heritage.

The applied main methods and tools are the cartographic method, spatial and statistical analyzes, and GIS technologies. The cartographic method was used for the purpose of design (choice of the coordinate system and map projection), generalization (reduction of the content according to the selected scale), and visualization (depiction of point, linear and area objects). Spatial and statistical analyzes are related to determining the thematic content of maps.

GIS technologies are related to the use of desktop GIS software to collect and process digital data, drawing and editing objects, validation (verification) of data, storage (preservation of geographic information layers), analysis (interpretation of data for geographical objects) and visualization (cartographic presentation of thematic content). The maps and the database comply with ArcGIS 10.6.1 software (ESRI, 2017). The geographical coordinate system GCS\_WGS\_1984 and projection WGS\_1984\_UTM\_Zone\_35N were used.

## RESULTS AND DISCUSSION

From topographic maps in M 1:50 000 in ArcGIS, the tourist trails are digitized, the information is supplemented with the data downloaded from GPS when mapping them. There are paths on the territory of the Troyan municipality. Shapefiles have been created for tourist attractions, which are divided into natural (parks) and anthropogenic (monasteries, churches, fortresses), as well as for the available infrastructure (hotels - number of rooms, beds, chalets - number of rooms, beds). The database is supplemented with data from the JICA project - settlements, roads.

The accommodation places are located unevenly on the territory of the municipality, which is logical, given the available resources and the demand for the respective tourist product. The highest share of the bed capacity is concentrated in the villages of Chiflik and Shipkovo, given the availability of resources for the development of spa and spa tourism in these areas. The presence of various places for accommodation on the territory of the municipality is impressive, which allows tourists to make their choice according to their specific preferences and capabilities. The specified number of accommodation places is constantly changing, given different macroeconomic conditions and changes in demand.

Thus, according to the announcement by the municipality, in 2018 57 sites are subject to categorization, of which: restaurants and entertainment - 18 sites, and 70 applications for categorization have been submitted, incl. restaurants and entertainment - 24 sites. For 2019, 46 sites are subject to categorization - 18 restaurants and entertainment. (Report of the Program for the development of tourism on the territory of the Municipality of Troyan in 2018). From the information provided in this way, in practice, no conclusions can be drawn regarding the number of places for eating and entertainment in the municipality, much less in terms of their quality and opportunities to satisfy consumer tastes. The personal opinion is that this is a big omission on the part of the municipal authorities. The central location of the municipality of Troyan, relative to the territory of Bulgaria, provides easy access to the tourist and other sites of the municipality of Northern Bulgaria. In autumn, spring, and summer, the access from Southern Bulgaria is through the Troyan-Karnare pass, as there are months in winter when this pass is closed and those wishing to visit the municipality should choose alternative routes. The main parameters of the national and municipal road network on the territory of the municipality are: (Municipal Development Plan of Troyan Municipality, 2014-2020. Adopted by Decision of the Municipal Council № / ... 11.2013): no highways and first-class roads pass through the municipality, although a first-class road E-772 passes near it in the direction Sofia - Veliko Tarnovo - Varna; the local road network is 256 km long, as it is formed by the re-categorized fourth-class road network with a length of 136.2 km and local roads - 120.1 km. Much of this network is in poor condition, with 35.8 km without permanent pavement; most of the settlements are served by roads from the national road network, which cover over 80% of the settlements; The transport service in the municipality is provided by the second class road 11-35 Pleven-Lovech-Troyan - 1-6, which passes meridian through the territory (length 40.4 km) and leaves it shortly after Beklemeto, serving the town of Troyan and the settlements of the central part of the municipality and those in its immediate vicinity.

On the territory of the municipality, there are third-class roads with a total length of 79 km, and the second-class roads are about 1% of the total length of the second-class road network in the country, while the third-class roads represent 0.7% of those in the country. The information service of the tourists in the municipality is a priority for most of the local government. An Information and Cultural Center has been established at the Municipality of Troyan, where, according to the official web page, information is offered regarding the sites for accommodation, meals, and entertainment; available natural and cultural landmarks; the current cultural calendar and the events that are organized on the territory of the municipality, the various sports events and opportunities for active recreation, the tourist routes and the maintained eco-trails, the transport structure. Free materials such as brochures, guides, maps, etc. are available at the Center, as well as a monthly newsletter for organized events. Additional services offered by the Center are in terms of accommodation assistance, as well as connections with mountain guides, local craftsmen and artisans, and others. At the same time, there is good information provided in terms of transport opportunities, cultural events, and festivals, and an extremely good impression is made by the section "150 years of the city of Troyan. 15 reasons to visit it". The section has a complete marketing and communication character and presents the main opportunities for practicing various forms of tourism that the municipality offers. The territory of the Troyan municipality is a place where many natural and anthropogenic resources are located, allowing the development of different types of tourism (Figure 2).

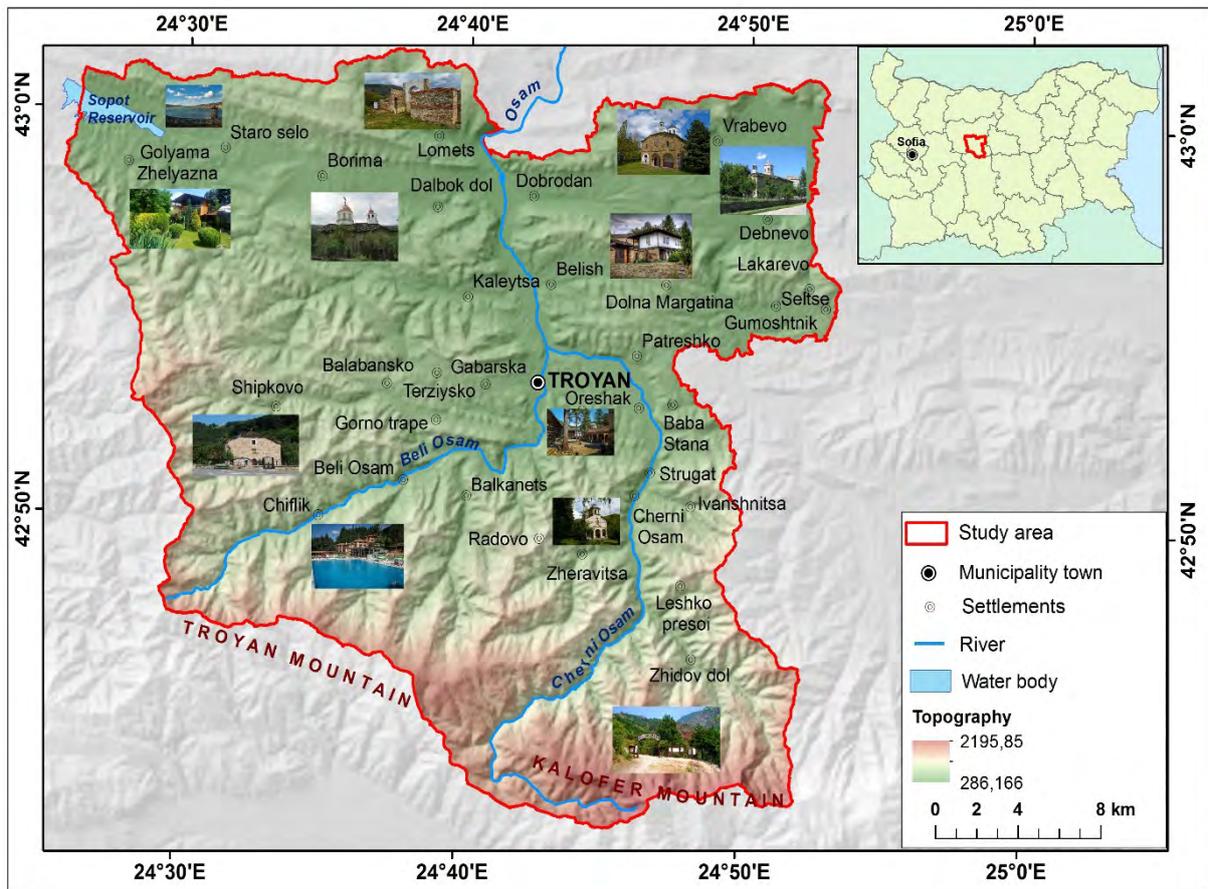


Figure 2. The most popular natural and anthropogenic tourist resources in Troyan municipality

According to the various resources of the municipality of Troyan, the following classification of the types of tourism has been made (Table 1):

- Cultural tourism and cultural-historical tourism;
- Religious tourism;
- Cognitive tourism;
- Mountain tourism;
- Hiking;
- Eco or green tourism;
- Ski tourism;
- SPA and balneal tourism;
- Extreme tourism;
- Alternative tourism.

Table 1. List of part of the tourist natural and anthropogenic resources (tourist infrastructure) and the type of tourism in the municipality of Troyan

Object	Location	Type of Tourism
Museum of Arts and Crafts	Troyan	Cultural tourism and cultural-historical tourism
National Exhibition of Arts and Crafts	Oreshak	Cultural tourism and cultural-historical tourism
Art gallery Seryakova house	Troyan	Cultural tourism and cultural-historical tourism
Museum collection	Vrabevo	Cultural tourism and cultural-historical tourism
Museum of Natural History	Cherni Osam	Cultural tourism and cultural-historical tourism
Church school	Gumushnic	Cultural tourism and cultural-historical tourism
Markova house	Troyan	Cultural tourism and cultural-historical tourism

Roman fortress "Sostra"	Lomec	Cultural tourism and cultural-historical tourism
Roman road "Via Trayana"		Cultural tourism and cultural-historical tourism
Troyan Monastery	Oreshak	Religious tourism
Zelenikov Monastery	Zelenikovets	Religious tourism
Church "Vaznesenie Gospodne"	Shipkovo	Religious tourism
Church "St. Nikolay Letni"	Gumoshtnik	Religious tourism
Church "Svyah Svetih"	Goliana Jelyazna	Religious tourism
Church "Saint Petka"	Debnevo	Religious tourism
Church "St. Arhangel Mihail"	Dalbok Dol	Religious tourism
Church "Vaznesenie Gospodne"	Shiplovo	Religious tourism
Church "Uspenie Bogorodichno"	Troyan	Religious tourism
Church "Vaznesenie Gospodne"	Kaleica	Religious tourism
Church "Arhangel Mihail"	Vrabevo	Religious tourism
Church "St. Dimitar"	Dobrodan	Religious tourism
Church "St. Dimitar"	Lomec	Religious tourism
Church "St. Dimitar"	Beli Osam	Religious tourism
Church "St. Petka"	Borima	Religious tourism
Church "St. Duh"	Belish	Religious tourism
Church "St. Petka"	Chiflik	Religious tourism
Church "St. Ivan Rilski"	Balkanets	Religious tourism
Chapel "St. Bogoroditsa"	Oreshak	Religious tourism
Chapel "St. Velikomachenik Mina"	Gorno Trape	Religious tourism
Chapel "Rozdestvo Bogorodichno"	Belish	Religious tourism
National Park "Central Balkan"		Mountain, hiking, eco and green tourism
Eco – trail Vidimsko Praskalo		Mountain, hiking, eco and green tourism
Vidimsko Praskalo Waterfall		Mountain, hiking, eco and green tourism
Summer tourist route: 1. Sopot - hut. Nezabravka - hut Dobrila - Topalitsa - hut Levski		Mountain, hiking, eco and green tourism
Summer tourist route: 2. Iganovo village - hut. Dermenka - part through the Steneto reserve (Pevtsite locality - Kelkaya		Mountain, hiking, eco and green tourism
Summer tourist route: 3. village of Karnare - the town of Troyan (Troyan Pass) - second class republican road		Mountain, hiking, eco and green tourism
Summer tourist route: 4. Karnare village - hut. Dermenka - part through the Steneto reserve (Kasia Chamlak locality - Peshova muka)		Mountain, hiking, eco and green tourism
Summer tourist route: 5. The village of Cherni Osam - Neshkovtsi - Dermenka hut		Mountain, hiking, eco and green tourism
Summer tourist route: 6. The village of Cherni Osam - Smesite locality - Zoranov Rat - hut. Ambaritsa - h. Dobrila - part through the Steneto reserve		Mountain, hiking, eco and green tourism
Summer tourist route: 7. hut Echo - hut Vasilyov - part through the KoZIA		Mountain, hiking, eco and green tourism

Stena reserve		
Summer tourist route: 8. hut Pleven - Turtle Peak		Mountain, hiking, eco and green tourism
Summer tourist route: 9. h. Pleven hut Yavorova luka		Mountain, hiking, eco and green tourism
Summer tourist route: 10. Hut Haidushka pesen - peak Kucheto - hut. Goat Wall - part through the Goat Wall Reserve		Mountain, hiking, eco and green tourism
Summer tourist route: 11. h. Haidushka pesen - Ushite peak - hut. Echo - part through Kozia stena reserve (Kashka locality - Cherven Bryag locality - Ushite peak)		Mountain, hiking, eco and green tourism
Summer tourist route: 12. h. Hubavets - h. Ambaritsa (through Kyumyurdzhieva Polyana) - part of the Stara Reka Reserve		Mountain, hiking, eco and green tourism
Winter tourist route: 1. The village of Cherni Osam - Smesite locality - Zoranov Rat - hut. Ambaritsa - h. Dobrila - part through the Steneto reserve (winter road)		Mountain, hiking, eco and green tourism
Winter tourist route: 2. Chiflik village - Tumin Dyal locality - Kucheto peak - hut. Goat Wall (winter version) - part through the Goat Wall Reserve (Tumin section - Windy waterfall)		Mountain, hiking, eco and green tourism
Winter tourist route: 3. hut Echo - hut Vasilyov - part through Kozia Stena reserve (winter road)		Mountain, hiking, eco and green tourism
Route: The Edelweiss Road		Mountain, hiking, eco and green tourism
Route: Beklemeto - Kurthisar		Mountain, hiking, eco and green tourism
Route: Thracian-Roman road - Beklemeto (including Markova Kapiya locality, Krali Markov Karaul gate), Kurthisar		Mountain, hiking, eco and green tourism
Beklemeto complex ski resort "Beklemeto" /		Ski tourism
Mineral springs	Shipkovo	SPA and balneal tourism
Mineral springs	Chiflik	SPA and balneal tourism
Horse base "Alpha Daniel	Balkanets	Extreme tourism
Squirrel Rope Park	Beklemeto	Extreme tourism
The buggy track "Trojan"	Dalbok Dol	Extreme tourism
Paragliding	Oreshak	Extreme tourism
Sopot Dam	Goliama Geliazna	Alternative tourism

Tourist superstructure of Troyan municipality includes the following sites (Table 2)

*Table 2. Tourist superstructure of Troyan municipality*

<b>Object</b>	<b>Location</b>	<b>Type of Tourism</b>
Park Hotel Troyan	Troyan	SPA tourism
Hotel Chatau Montan	Troyan	SPA tourism
Hotel Mars	Troyan	SPA tourism
Family resort Alfaresort Chiflik	Chiflik	SPA and balneal tourism
Family hotel Shipkovo	Shipkovo	SPA and balneal tourism
Family hotel Ilinden	Shipkovo	SPA and balneal tourism
Family hotel Balkan	Chiflik	SPA and balneal tourism
Family hotel Panorama	Chiflik	SPA tourism
Hotel Diva	Chiflik	SPA tourism
Hotel Feya	Chiflik	SPA tourism
Family hotel Bile	Chiflik	SPA tourism
Family hotel Blyan	Chiflik	SPA tourism
Family hotel Chiflik Hills	Chiflik	SPA tourism
Hotel Galaxy	Chiflik	SPA tourism
Complex Chiflika	Chiflik	SPA tourism
Complex Izgrev	Chiflik	SPA tourism
Complex Antik	Balkanets	SPA tourism
Hotel Casa Art	Oreshak	SPA tourism
Coplex Terra Verde	Oreshak	SPA tourism
Family hotel Strannopriemnitsa	Oreshak	SPA tourism
Hotel Sveta gora	Oreshak	
Holiday village Ostrova	Beli Osam	SPA tourism
Hotel Via Trayana	Beklemeto	
Hotel Sima	Beklemeto	
Family hotel Panorama	Beklemeto	
Hotel complex By the river	Balkanets	
Family hotel Panorama	Baba Stana, Oreshak	
Hut Kozya Stena		Mountain, hiking, eco and green tourism;
Hut Koman		Mountain, hiking, eco and green

		tourism;
Hut Echo		Mountain, hiking, eco and green tourism;
Hut Haidushka pesen		Mountain, hiking, eco and green tourism;
Hut Ambaritsa		Mountain, hiking, eco and green tourism;
Hut Dermenka		Mountain, hiking, eco and green tourism;
Tourist Information Center	Troyan	Mountain, hiking, eco and green tourism;

Table 3. Number of places for meals and entertainment on the territory (Tourist superstructure) of Troyan municipality in 2011

Restaurants and entertainment	Number	Places
1. Restaurants	61	5005
2. Fast food restaurants	35	1601
3. Drinking establishments	64	2196
4. Coffee shops	16	519
5. Bars	21	1091
<b>Total:</b>	<b>197</b>	<b>10412</b>

Source: Program for sustainable development of tourism in the municipality of Troyan in the period 2012-2015, Available at <<https://www.troyan.bg/tourism/saobshteniya/viewdownload/218-saobshteniya-turizam/1910-otchet-na-programa-za-razvitiето-na-turizma-na-teritoriyata-na-obshtina-troyan-prez-2018-g.html>>, Accessed 15.02.2020

## CONCLUSIONS

The tourist infrastructure and superstructure of the Troyan municipality are extremely diverse. The most important is the natural and anthropogenic tourist attractions.

According to the different resources of the municipality of Troyan, the following types of tourism are developed: cultural and cultural-historical; religious; cognitive; mountainous; hiking, eco or green tourism; ski tourism; SPA and balneal tourism; extreme tourism and alternative tourism.

The most important for the development of the municipality of Troyan is religious tourism, followed by SPA and mountain tourism. Therefore, the relevance of the chosen topic is sought in the importance of tourist infrastructure for the development of tourism and the competitiveness of the destination, as well as the ability of GIS to meet the information needs of a wide range of users.

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# CHARTS AND MAPS FOR STATISTICAL YEARBOOKS OF FIRE AND RESCUE SERVICE OF THE CZECH REPUBLIC

**Pavel Špulák, Bohuslav Ježek and Zdeněk Červenka**

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## **Abstract**

*For many years, Fire and Rescue Service of the Czech Republic annually publishes its Statistical Yearbook. This publication provides an overview of the past year's activities of the Fire and Rescue Service. It serves as a valuable data source for the professionals and presents the Fire and Rescue Service to the common public.*

*Two types of data visualization are presented in the Yearbook, the charts of various types (line, bar, stacked bar, grouped bar and pie charts) and choropleth and kernel density map. To make the process of data visualizations less time demanding and error-proof, we decided to automatize it with the Python program, which reads data from the database and according to instructions in configuration files create desired outputs.*

*The process starts with the transfer of all required data to the local SQLite/Spatialite database. The data are copied from comma-separated files or the database of the Operational center of Fire and Rescue Service of the Czech Republic. The data are read from the local database to the Pandas DataFrame. The data processing is done during the data read operation from the database through the SQL query sent to the database. After that, the Matplotlib library is used for charts creation and the ArcPy library for maps creation. The outputs of the program are the maps or charts images of various formats according to the possibilities provided by the libraries mentioned above and application settings.*

**Keywords:** map, chart, automation, data mining, Python, ArcPy, Matplotlib, Pandas, statistical yearbook

## **INTRODUCTION**

For many years, Fire and Rescue Service of the Czech Republic annually publishes its Statistical Yearbook. This publication provides an overview of the past year's activities of the Fire and Rescue Service. It serves as a valuable data source for the professionals and presents the Fire and Rescue Service activity to the common public. The Yearbook is published each year as a supplement of the March issue of the magazine 112 [1, 2]. It is also available online as a pdf file in both Czech [3] and a shortened English version [4]. The Czech versions are available from the year 1991 to the present and the English version from the year 2004. The mutual comparison of the Yearbooks from various decades gives us an interesting overview of the development of technologies in the field of desktop publishing, data visualization, and cartography.

The Yearbook is divided into sections, which focuses on the activity of the professional and voluntary units, emergency calls, fires, fire prevention, international cooperation, psychological service, and economic and personal issues. Each section consists of various tables, charts, maps, and accompanying explanatory texts. The sections usually have the standard part, which is the same for many years and the part which focuses on current important topics, like, for example, wildfires in the times of droughts, escape games, or results of fire prevention controls in pubs.

The preparation of the Statistical Yearbook of Fire and Rescue Service of the Czech Republic is time and precision demanding. It requires careful processing of a large amount of data from various sources and various types. Because of that fact, it was decided to create a computer program for data processing and make the whole process as much as possible automatized, standardized, repeatable and less error-prone.

## THE USED DATA

The data used for Statistical Yearbook come from various sources. The primary source of the data is the database of the Operational and Information Center of Fire and Rescue Service of the Czech Republic, which contains necessary information about each event in which both voluntary and professional units are involved. Other data comes from internal statistics or information systems of the various departments of the Directorate General of Fire and Rescue Service of the Czech Republic, like from the system of human resource management and fire prevention. The reference data, like for example the borders of the regions and districts of the Czech Republic comes from Central Data Warehouse of Fire and Rescue Service of the Czech Republic [5] in which they are transferred from Registry of Territorial Identification, Addresses and Real Estate (RÚIAN) [6].

The pdf file containing the previous issue of the Statistical Yearbook has a considerable size (more than 100 MB), which caused severe problems with its printing and transfer. The origin of these problems was the precise boundaries of administrative units of the Czech Republic (regions and districts) used for the creation of the choropleth map. The accurate boundaries caused a large size of the files containing these maps and the subsequent enormous size of the whole Yearbook. To minimize the size of the files with choropleth maps, the boundaries were generalized with the tools of QGIS. The figure 1 shows how the size of resulting pdf file containing the borders of administrative units decreases with the increasing maximum tolerance value of used Douglas generalisation method.

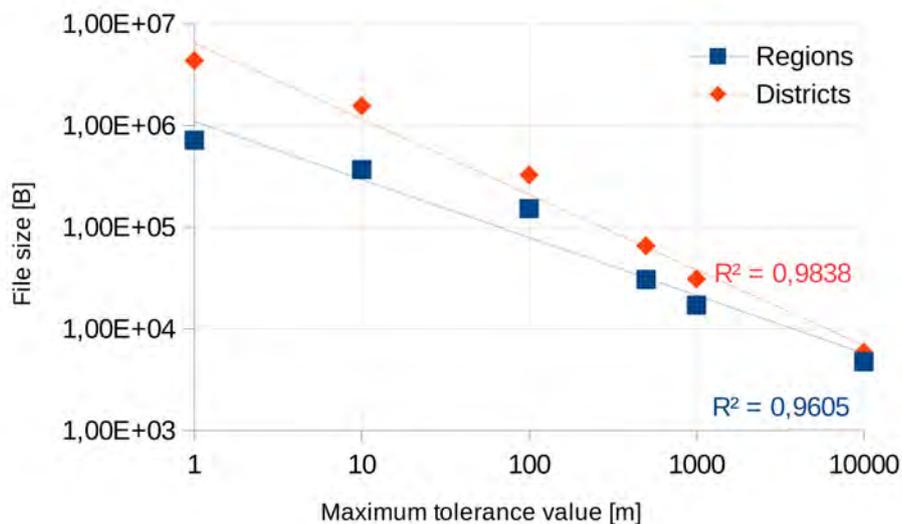


Figure 1. Generalization of the administrative units borders. The size of the pdf file, which contains only the generalized border of the administrative units depicted against the parameter of the generalization.

The generalization of the adjacent polygon is a little bit complicated task [7]. The adjacent boundaries must be generalized in the same way to prevent the creation of the overlaps and void spaces between them. With respect to the discussion on the question and answer forum [7] we used the following algorithm for generalization:

1. The polygon layer was converted to the line layer.
2. From the line layer, the topology information was removed.

3. The line layer was generalized using the Douglas algorithm.
4. The generalized line layer was polygonized.
5. The parasite polygons originated during polygonization were removed, and the borderlines were repaired. The parasite polygons were identified owing to the fact that its size is many times smaller than the area of administrative units.

As the generalization increases, the amount of the data representing the borderlines of the regions substantially decreases. On the other hand, the increasing generalization also causes the deformation of the borderlines and loss of its precision. Because of these facts, the final decision about the usage of the degree of generalization of borderlines is the compromise between the amount of the data representing the borderlines and acceptable measure of its deformation. After careful consideration of these contradictory criteria, the borderlines generalized with maximum tolerance value 500 m of the Douglas algorithm were chosen for further processing and generation of choropleth maps.

The primary source of the data used for charts and maps in the Statistical yearbook is the aforementioned database of the Operational and Information Center of Fire and Rescue Service of the Czech Republic. It is a living database used for support of ongoing emergencies and containing information about it. Because of that fact, great attention must be paid to the communication and usage of this database. It is necessary to avoid the slowdown of the database performance because of its use for another less critical task, as is the creation of the charts and maps for the Statistical Yearbook.

To cope with this problem, the two mechanisms were used. First, the one large special view containing all necessary information for Statistical Yearbook was created. It amalgamates the information from various database tables into one virtual table. It leads to the minimization of the number of queries to the different database tables. Second, the full view is only once transferred to the local SQLite/SpatiaLite database [8, 9] and is refreshed only when substantial changes of the view occur or if the final generation of the charts and maps is taking place. The transfer is done with a small tailor-made Python 3.X program. This program connects to the Oracle database on the Operational and Information Center of Fire and Rescue Service of the Czech Republic, reads the previously mentioned view into Pandas [10] DataFrame [11, 12], and saves the DataFrame to the already prepared SQLite database, which also has spatial capabilities through the SpatiaLite extension.

Whenever the program for generation of the charts and maps of Statistical Yearbook starts, it makes a copy of the previously mentioned SQLite database. Also, it transfers to the database the other data. Such data comes from different departments of the General Directorate of Fire and Rescue Service of the Czech Republic and contains information other than directly connected to the operational management of emergencies. These data are stored in the folder for source data in the form of a csv file. The files are read into Pandas DataFrame and saved to the SQLite database.

## **TAYLOR MADE APPLICATION**

### **Motivation**

Each year it is necessary to prepare about 60 charts and maps for Statistical Yearbook. Some of them are standard parts of the Yearbook and changes from year to year concerns only to the range of the years for which they are generated. Other charts and maps are usually focused on the important current topics in the field of emergencies in the area of the Czech Republic. The charts and maps must be prepared in time to catch the deadline of the magazine 112 March issue. Unfortunately, the various and large datasets used for its preparation changes as come final data from regional offices of Fire and Rescue Service of the Czech Republic. Because of that, it was decided to create a tailor-made application for data processing and subsequent creation of the charts and maps. The reasons for creating the application were the following:

1. To eliminate repeated, monotonous works on charts and maps preparation.
2. To make the whole process less error-prone.
3. To standardize the workflow and make it repeatable and reproducible.
4. To enable the production of the charts and maps depicting actual state according to the current needs.

### **Application Start**

The application starts with a few initial steps, which prepare the application environment for its run. The application begins with reading its settings and logging settings from json files. After that, the user is asked for the year for which

the maps and charts will be generated. The year gives the upper bound of the interval for which the values will be depicted. The lower limit of the interval is provided in the particular task settings. The range of the interval is usually 5 or 10 years.

The next step is the settings of the application paths. The year given by the user also sets the name of the folder from which the input data and templates will be read. The output subfolder is freshly created for each application run in the folders where application outputs resides. The subfolder name is given by the timestamp derived from the time of application start. When the subfolder for the outputs is set, the two SQLite databases are copied in it. The first is assigned for input data and the second for output data produced by the application from input data. The setting of the output folder also enables the start of the logging facility, which uses two handlers, one for screen and one for the file. The screen handler is more detailed and informs the user about the progress of the application tasks. The file handler is less detailed and writes only important information concerning to the application run. It documents mainly the facts necessary for control and comparison of the outputs.

The logging starts with the writing of control records of various logging levels, application header, and description of the python application environment and versions of used libraries.

In the database, containing input data is the table with data already downloaded from the view in the database of Operational Management of Operation and Information Center. After the logging is established, the other data used for the preparation of the maps and charts are copied into input database tables from csv files.

Now the settings of particular application tasks are read and processed. They are read from json files and transformed into a form of a tree of objects. During the transformation, the predefined values are overwritten by the more specific settings if they are provided. The tasks contain the data for creating one or more maps or charts.

The knowledge of the particular task settings enables the display of the available tasks to the user, which can select the tasks for further processing. The predefined choice is the processing of all jobs. The selection of a particular task is usually used in the final fine-tuning phase of the maps and charts preparation. If all settings are ready, the all set of the maps and charts can be created by two pressing of "enter" key. First pressing confirms the selected years for which the outputs are generated, and the second confirms the selection of all tasks. The selected task are further processed independently one by one in the order given by the menu displayed to the users. For better orientation, the tasks are grouped into the groups according to the chapters of the Statistical Yearbooks in which they maps and charts belong.

## **Execution of the tasks**

The execution of a particular task differs according to the nature of the produced output. If the job produces maps, the template in the form of the ArcGIS Pro project is used, the ArcPy library is used for its manipulation, and the data are stored into a layer depicted in the map object of the project. The final representation of the map object is done through the layout object, which can be exported to the picture of various formats according to the possibilities of the ArcPy library and demands of the user.

The job of producing a chart is processed differently. It uses the Matplotlib library for the creation of the chart from the beginning without using any template. The created charts are exported to images of the various formats according to the possibilities of the Matplotlib library and the demands of the user.

The processing of the data is done during the loading of the data to the pandas DataFrame from the database containing input data. It is realized through the SQL query sent to the database. The processed data used for the creation of the chart or stored to the layer used for the creation of the map are saved to the database containing output data for further processing and sharing.

## **PYTHON ENVIRONMENT**

One of the main reasons for creating a tailor-made application for the generation of the charts and maps for Statistical Yearbook was to ensure a repeatable and well-documented process of its creation. To support these goals, we decided to use Conda [13] package, dependency, and environment management for the Python environment, in which the application was running. Conda use prevents unpredictable behavior of python environment and python program results owing to package incompatibility or actualization. Use of Conda ensures a stable Python environment with predictable behavior. It also provides tools that made the installation of the missing packages and its dependencies easy.



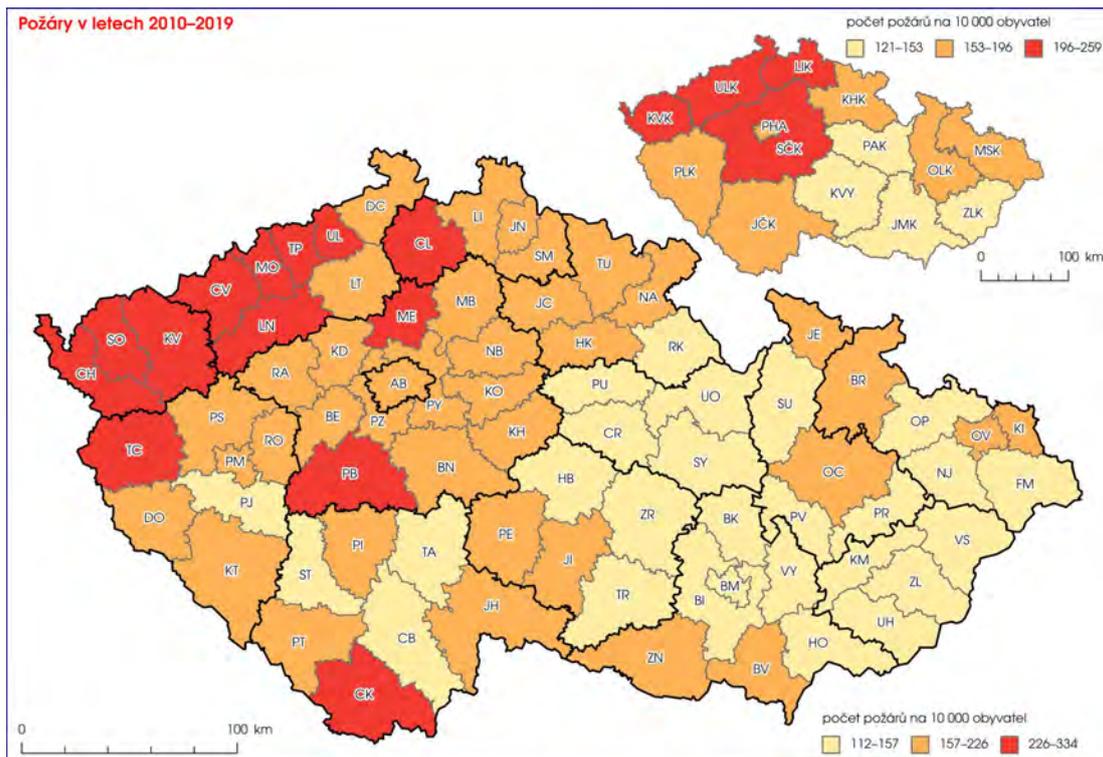


Figure 3. The maps display the number of fires per 10 000 inhabitants in the years 2010 – 2019 in regions (small map) and districts (large map) of the Czech Republic.

The prepared charts types span from simple bar charts to complex charts using various kinds of data representation in one chart (figure 4).

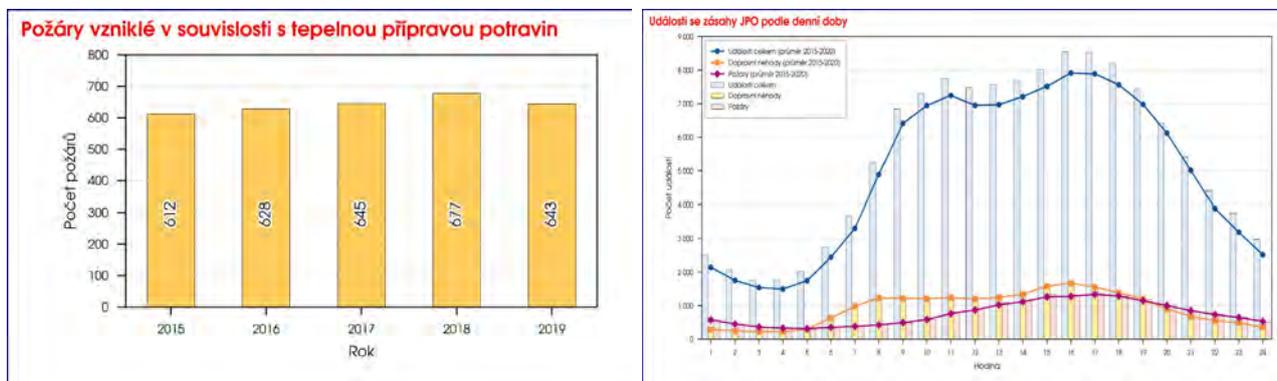


Figure 4. Examples of the simple and complex chart. The left simple bar chart shows the number of fires connected with the meal preparation in the various years. The right complex chat shows the daily course of different emergency types. The values for the year 2019 are shown together with the long time averages.

In some cases, the depiction of absolute and relative values can provide valuable information about the trends (figure 5). In the case of the representation of various variable categories in different years, the stacked bar chart is used (figure 6). The logarithmic scale on the dependent variable axis is used if it is necessary to show the values of a different order (figure 7).

The Statistical Yearbook deals not only with emergencies but also with the Fire and Rescue Service of the Czech republic. Because of that fact, personal information is also mentioned in the Yearbook (figure 8).

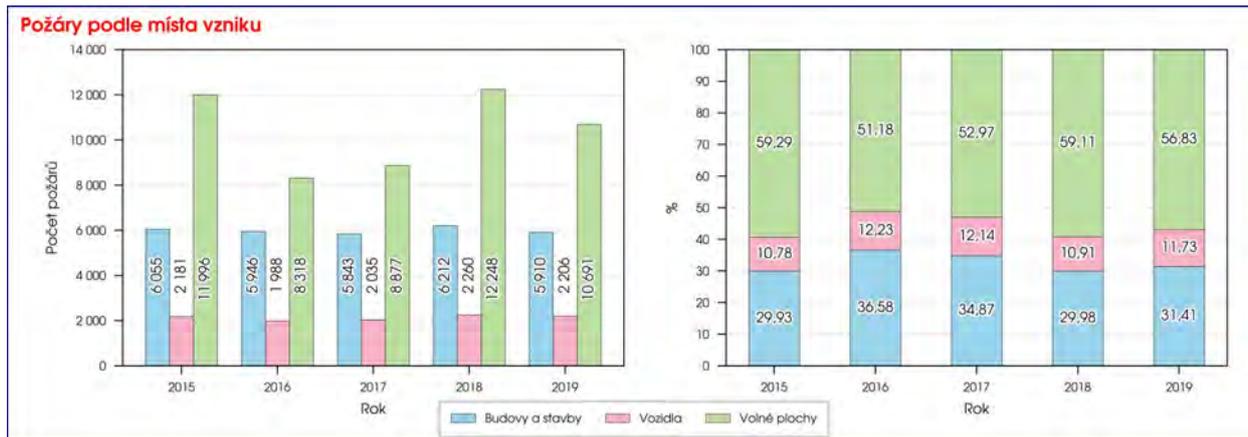


Figure 5. The absolute and relative number of fires according to its place of origin (buildings, cars, free spaces) in different years.

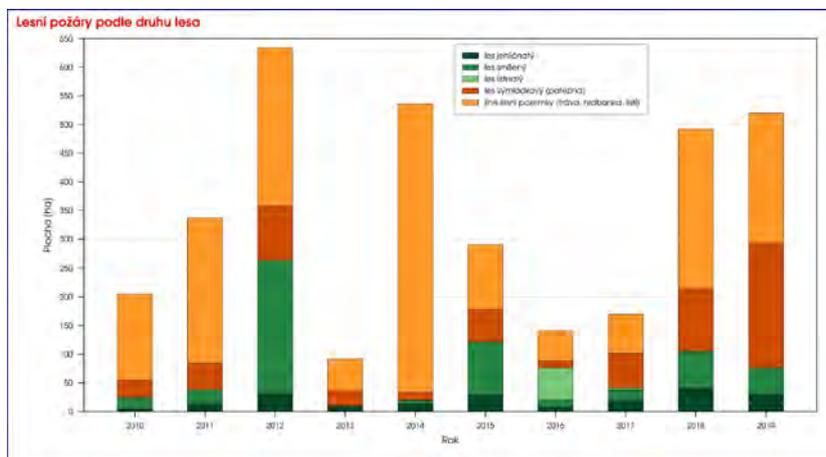


Figure 6. The forest fires in different years. The categories represent various types of forest (coniferous, deciduous, mixed, ...).

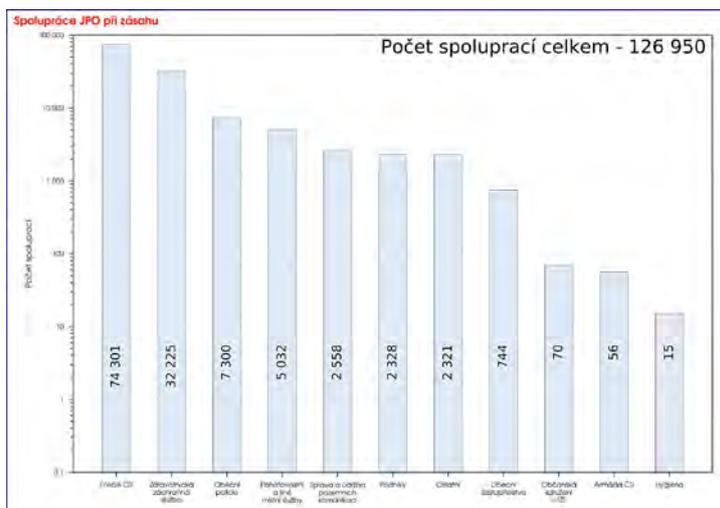


Figure 7. The number of the collaboration of Fire and Rescue Service of the Czech Republic with various subjects during emergencies in a given year.

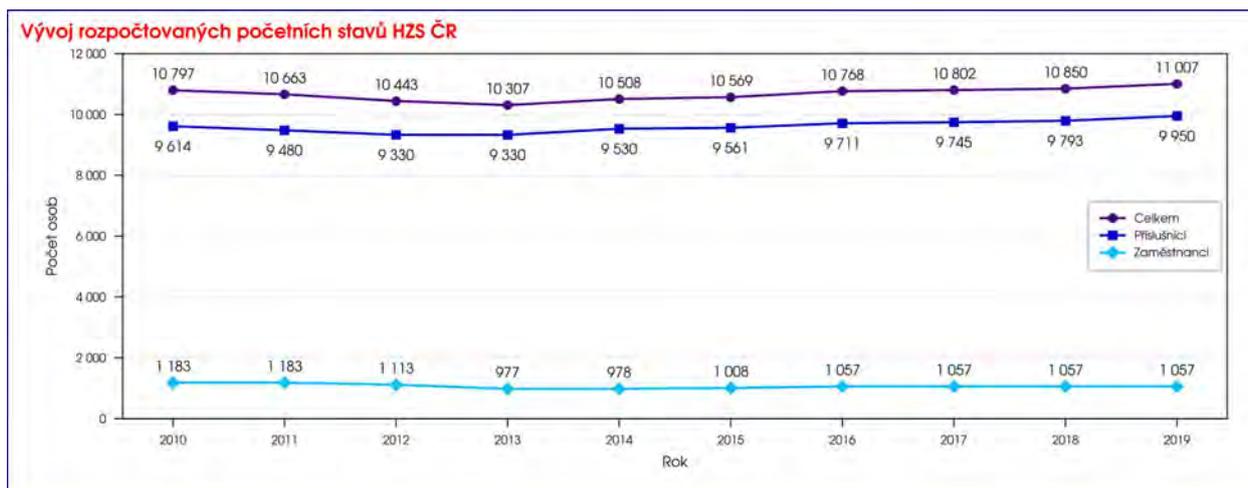


Figure 8. The personal information concerning to the Fire and Rescue Service of the Czech Republic. The number of firefighters (dark blue line) and civil employees (light blue line), together with the total number (violet line) in various years, are shown.

## CONCLUSIONS

The Statistical Yearbook 2019 of Fire and Rescue Service of the Czech Republic [3] contains 11 maps and 42 charts. All charts were created automatically with a tailor-made application. From 42 charts, the 39 charts were simple charts three were double charts depicting relative and absolute values of the dependent variable. Some charts depict one dependent variable against an independent variable; some are more complicated, depicting more variables. From 11 maps, the nine maps were created by the application, and two, kernel density map and bivariate choropleth map were created by hand. From the nine maps created by the application, the five maps were a simple map, and the rest, four maps were double maps containing choropleth maps depicting the variable with respect to the regions and districts of the Czech Republic.

According to the numbers mentioned above, it is possible to say that the tailor-made application for the generation of the maps and charts for the Statistical Yearbook has provided substantial help with its creation. It not only spare the tedious, monotonous work, it also prevented errors by its production and recreation if the data was actualized. The application can be run according to the actual needs. It can provide quarterly reports for high levels of commands of Fire and Rescue Service. It also simplifies the creation of the other language version of the maps and charts. In the near future, in the new version of the application, it is planned to make the generation of other language versions of the charts and maps even more straightforward. It is also necessary to mention that the application made the whole process of production of maps and charts well documented, repeatable, and less error-prone.

The application development also started the further improvement of the data visualization in Statistical Yearbook and discussion about the usage of the statistical methods, data treatment, and data visualization techniques in Fire and Rescue Service in general. It also gives the background for further broader deployment of statistical methods. The application can serve as a starting point for the development of analytical tools for the particular needs of the Fire and Rescue Service of the Czech Republic, which will lead to the improvement of the public service and following of the data, information, knowledge, and wisdom hierarchy [22] in general.

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## BIOGRAPHY



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# MAPPING OF URBAN MASKS IN EUROPEAN CITIES BASED ON OPEN GEODATA AND CONCEPTUAL APPLICATIONS TAKING INFRASTRUCTURE EFFICIENCY AS AN EXAMPLE

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## **Abstract**

*In the light of sustainability transformation, buildings and infrastructures play a central role as elements of the settlement structure. Therefore it is essential to understand settlement structures with their characteristics. In this context geodata provide a wide range of support. At European level Urban Atlas data are of particular interest. However, the delineation of urban areas in which the settlement elements are concentrated is not considered although such areas represent important reference geometries for planning. In Germany, a corresponding layer of urban mask, denoted with "Ortslage", is provided by official topographic geodata. In this paper we present a method of defining corresponding "urban mask" units using the Urban Atlas database. The processing steps are defined based on objective criteria. The results comprise 30 European cities with contrasting urban structures. Taking the infrastructure efficiency as an example we demonstrate and discuss a possible application of urban masks.*

**Keywords:** Urban Atlas, urban mask, generalization, infrastructure efficiency, sustainable transition indicators

## **1 INTRODUCTION**

In the light of sustainability transformation, buildings and infrastructures play a central role as elements of the settlement structure. They induce up to 30 % of waste and 40 % of greenhouse gas (GHG) emissions associated with material production across the EU (International Resource Panel 2020). They are also encompass around 50 % of material consumption in industrialized countries (Leising et al. 2017). About 2 % of the total global land area was covered by settlement areas and infrastructures, a doubling of these shares is expected until 2050 (Kemp-Benedict et al. 2002; Electricis et al. 2009). Therefore it is essential to describe and understand settlement structures in their physical and spatial characteristics. In this context geodata provide a wide range of support. Of particular interest are open geodata, such as those from the Urban Atlas as part of the Copernicus Land Monitoring Service. This service offers open geodata on land use for almost 700 European city regions in detailed scale 1:10,000. Land use is differentiated into 27 classes (EU 2016). However, the delineation of coherent settlement areas in which the settlement elements are concentrated is not considered although such areas represent an important reference geometry for the definition and application of planning-relevant performance indicators (Deilmann et al. 2017).

In Germany, a corresponding layer of urban mask, denoted with "Ortslage", is provided by official topographic geodata ATKIS (AdV 2015, 215). In this paper we present a method of defining "urban mask" territorial units using the freely accessible Urban Atlas database that is available at European level. The data processing steps are defined based on objective criteria and thus basically can be carried out automatically.

The infrastructure efficiency represents an essential efficiency parameter in urban and regional planning (Schiller et al. 2020) and has at the same time very close links to environment-related sustainability indicators such as resource consumption (Miatto et al. 2017) and land use (Community research connections 2020). Using this example, we demonstrate and discuss a possible application of such defined "urban mask".

## 2 DATA AND METHODS

### 2.1 Urban Atlas

The Urban Atlas as part of the Copernicus Land Monitoring Service provides detailed vector data on land cover and land use for numerous city-regions in Europe. Such data is available with a largely standard nomenclature of 28 classes at scale 1:10,000 for the reference years 2006 and 2012. The completion of data for the year 2018 is currently in progress. For the year 2012, the Urban Atlas has been available for almost 700 European city-regions (“Functional urban areas” or FUA) as open geodata (Copernicus Land Monitoring Service 2018). These include all EU cities with more than 100,000 inhabitants as well as their commuting zones. A mapping guide contains the product description, mapping guidance and class description for the Urban Atlas (EU 2016). This data is used for spatial analysis within the framework of the European Union’s Urban Audit (Montero et al. 2014). With the assistance of the Urban Atlas data, generalized patterns of urbanization can be identified by deriving various metrics on settlement structure, as shown in a methodological study that compared Greek cities (Prastacos et al. 2017).

### 2.2 Delineation of an urban mask

First it is necessary to define what we mean by an “urban mask”. For our analysis this term is used in analogy with the term “Ortslage” from official German spatial surveys. The following definition is given in the documentation of the ATKIS Basic Landscape Model: “An ‘Ortslage’ is a contiguous built-up area. It encompasses ‘residential areas’, ‘industrial and commercial areas’, ‘mixed-use areas’ and ‘areas of special functional character’ as well as areas which have a close spatial and functional relationship to these dedicated to transportation, watercourses, areas occupied by ‘buildings and other facilities’, for recreation, sport and leisure, as well as ‘vegetation areas’ ”(AdV 2015, 215). An “Ortslage” represents a settlement polygon, which is geometrically bounded by a continuous line. In contrast to “Ortslage” in urban masks defined in this paper directly adjacent polygons are merged into one polygon in order to reduce the number of settlement polygons. Only spatially separated polygons should be preserved geometrically as such.

As described in the introduction section, the Urban Atlas geodata contains no specific layer of an urban mask. Therefore we developed a GIS method to delineate the urban mask using Copernicus data at medium scale. In this regard, we follow up on investigations described by Schumacher & Deilmann 2019, 37 ff. in the context of studies on comparison of urban fragmentation in selected European cities. In this research the authors used an approach to define urban masks based in automatic steps and manual editing of polygons in orientation to defined criteria of delineation. These criteria offered a scope for subjective decisions for the delineation, which allows the consideration of specific local peculiarities, but requires extensive mapping work by experienced cartographers. In this paper, the method is further designed in such a way that it is based exclusively on objective criteria and therefore in principle can be carried out without manual editing of polygons.

According to the philosophy which guides the definition of “Ortslage” ten relevant land use classes were selected from the nomenclature of the Urban Atlas (EU 2016) as components for the urban mask. These classes represent both built-up and green urban areas:

- Continuous and discontinuous urban fabric (built-up area and associated land, residential structures predominant) [5 classes – the differentiation is indicated in figure 1],
- Industrial, commercial, public, military or private units [1 class],
- Construction sites and land without current use [2 classes - the differentiation is indicated in figure 1],
- Green urban areas (public green areas for predominantly recreational use such as gardens, zoos, parks, castle parks and cemeteries) [1 class],
- Sports and leisure facilities [1 class].

In general, the Urban Atlas contains polygon geometries, not line geometries. In contrast to ATKIS, this also concerns the road and rail networks. The Urban Atlas includes only two classes of road transport (“Fast transit roads and associated land”, “Other roads and associated land”) and one class of railway transport (“Railways and associated land”). The polygonal geo-objects of these transport classes are not distinguished, whether they are within the settlement or in open space. However, the streets and squares in the settlement area are part of the “Ortslage” (see above definition in the ATKIS model). Therefore, these transport areas from the Urban Atlas cannot be simply included to complete the urban mask, because they would spread out like a spider’s web from the settlement into the open space. It should be noted that shipping and air traffic are not considered because both types of traffic are not in such a close functional connection with the built-up areas.

The delineation of an urban mask is achieved by using methods of cartographic generalization. In this study we applied a procedure from the ESRI ArcGIS toolbox: Delineate Built-Up Areas (ESRI 2019). This method was originally developed to define polygons for the mapping of built-up areas, whereby densely clustered arrangements of buildings are visualized as generalized polygons in the process of downscaling. The procedure is thus concerned with the spatial grouping of building footprints – for example for the quantification and monitoring of the urban sprawl (Harig et al. 2016).

In this study, however, the procedure "Delineate Built-Up Areas" shall be transferred to another application. The input data differ. To define urban masks we use polygons of built-up areas and urban green spaces as input data but not building footprints. Accordingly the applied GIS processing results in different kind of generalized output data, which approximates to the definition "Ortslage" mentioned above. The main difference between the objects in the 10 land use classes considered and the areas resulting from the definition of "Ortslage" is that roads and other gaps in the settlement area (e.g. small water bodies) are not taken into account.

In order to bridge these gaps, criteria were developed based on the following considerations (ESRI 2019):

- Input polygons that are closer than the *grouping distance* are considered together as candidates for representation by one output polygon in the urban mask. Common traffic areas have a maximum width that corresponds to the definition of "grouping distance".
- The *minimum detail size* defines the relative degree of detail in the output polygon of the urban mask. This is approximately the minimum permitted diameter of a hole in the input polygon. The real size and shape of holes are also determined by the input polygon placement and grouping distance.
- The *minimum building count* corresponds to the minimum number of input polygons that have to be considered together for the representation by an output polygon in the urban mask.

Assumptions for quantifying these generalization parameters were made on the basis of expert assessments. In addition to the authors of this paper, four experts with long-standing practical experience in the field of GIS-based settlement structure analysis and mapping of settlements and open spaces were involved. In the result the following parameters of this procedure were set:

- *Grouping distance*: 50 m,
- *Minimum detail size*: 50 m,
- *Minimum building count*: 1.

An area of 0.25 ha (50 x 50 m) corresponds to the minimum mapping unit of artificial surfaces in the Urban Atlas (EU 2016, 8). The option "Minimum building count = 1" means that all relevant settlement polygons are included in the algorithm. Furthermore, so-called "sliver polygons" smaller than 1 ha were deleted from the preliminary settlement mask in the open space. This value corresponds to the minimum mapping unit of agricultural areas, (semi-) natural areas, wetlands and water in the Urban Atlas (EU 2016, 8).

After applying the ArcGIS procedure "Delineate Built-Up Areas", there are usually still gaps in the urban mask which are not defined as "urban mask areas". Therefore, after discussion with experts, further holes smaller than 3 ha within the preliminary settlement mask were filled in and merged into the final settlement mask in the interests of the cartographic generalization of polygon geometry.

Figure 1 illustrates the application of the procedure for objective delineation of the urban mask using the example of the city of Plovdiv, Bulgaria. Two levels of abstraction are presented: Figure 1 a (above) shows the polygons of the ten selected land use categories which can be distinguished with the data of the Urban Atlas. Figure 1 b (below) shows the result of the generalization process of the urban mask.

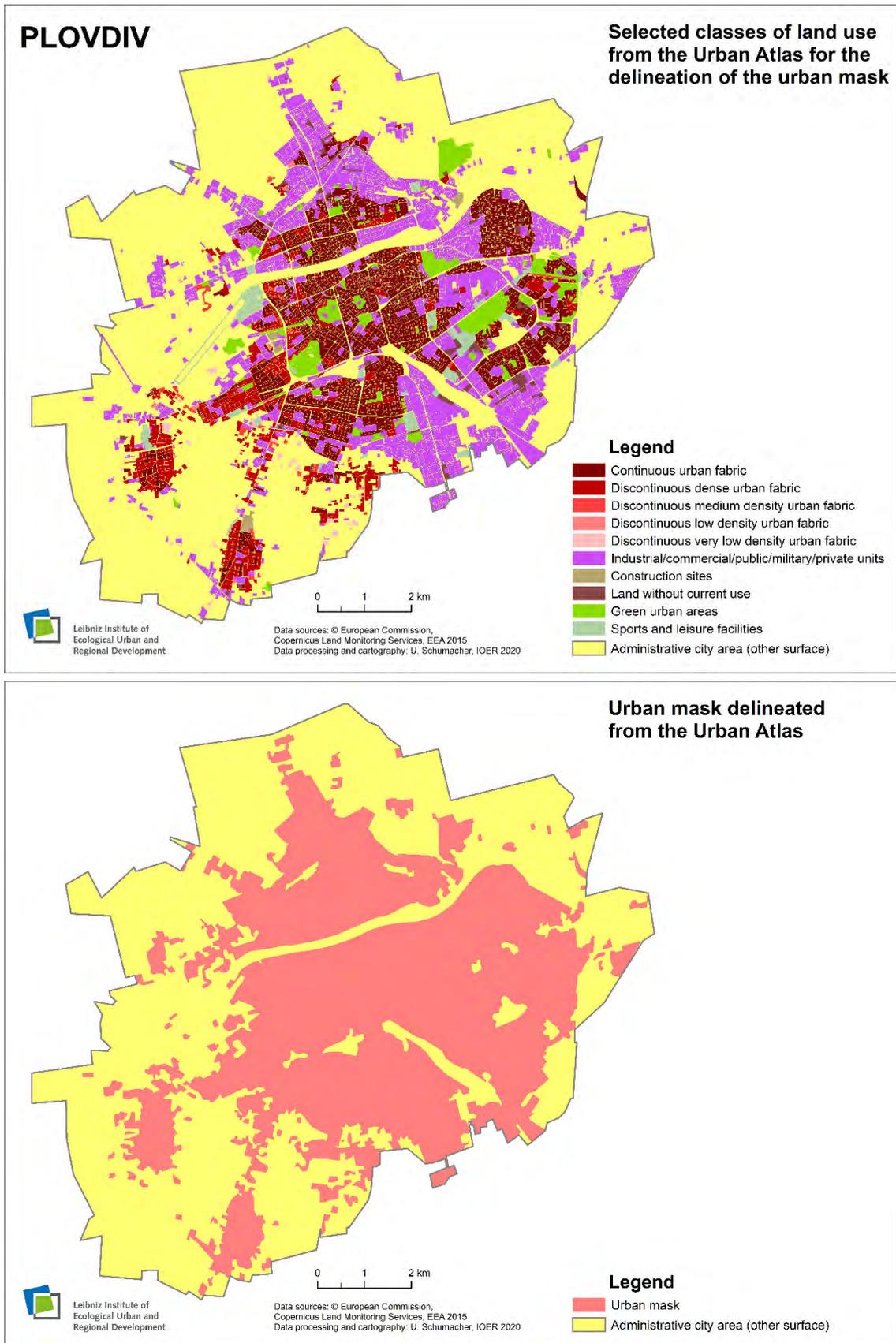


Figure 1. Selected classes of land use from the Urban Atlas 2012 (above) and delineation of the urban mask (below), mapped for the city of Plovdiv, Bulgaria

## 2.3 Analysis of the road network

From the perspective of urban morphology, the streets system (road network) of a city in principle has a strong stability over long period of time. *“In morphological terms, and in a temporal perspective, streets are the most stable element of urban form. While the physical process of city building is something that ‘takes time’ involving permanent transformation – it has a past, a present and a future – the streets system of a city is the one that offers greater resistance to this process of urban transformation, attaining a great temporal stability.”* (Oliveira 2016, 15) This applies especially to the area within the urban mask of a city. With regard to the overall urban infrastructural efficiency, the measure "Road length in urban mask per capita of population" is therefore of great importance for the spatial analysis.

In the Urban Atlas, all geodata objects – including the road network – are represented as areas. However, line data are required to derive road section lengths. Therefore, geodata of the road network from Open Street Map (OSM) is used (Ramm 2019). As exemplary tests have shown, the geometrical fit of the OSM data to the Urban Atlas data is rather good. In addition, OSM data is also even used in the production of the Urban Atlas. Now the question arises, which OSM road categories are relevant for the infrastructural efficiency of a city? The following twelve road categories of motor vehicle traffic in public urban areas were selected from a total of 26 road and path categories – after reviewing the description in the wiki (Wiki OSM 2019):

- motorway,
- trunk (important road, typically divided),
- primary road (typically national), secondary road (typically regional), tertiary road (typically local),
- unclassified road (smaller local road),
- residential road (road in residential area),
- living street (street where pedestrians have priority),
- motorway link, trunk link, primary link, secondary link.

Mostly non-public service roads to buildings and facilities such as car parks or sports facilities were not taken into account. Furthermore, pedestrian only streets, roadways in agriculture and forestry were not considered. Spatially separated lanes of road sections are recorded as separate vectors in the OSM geodata. Thus, motorways and expressways receive a double weighting when calculating the total length of a city's road network, which is basically in line with the infrastructural efficiency. Before the total is calculated, the selected street network was clipped to the urban mask of the respective city.

## 2.4 Case study cities

For the case studies, the aim was to achieve the broadest possible geographical distribution of selected cities with contrasting urban structures in Europe, i.e. from the member states of the European Environment Agency (EEA) where Urban Atlas data 2012 is available. Finally, 30 large cities with more than 100,000 inhabitants and contrasting urban structures from 20 countries were selected. For each city a spatially contiguous administrative area is considered - without exclaves or islands. The urban mask of a city should be easily distinguishable from the neighbouring communities. Therefore, megacities or large urban agglomerations are not considered here.

One third of the selected reference cities are coastal cities, which is an adequate representation of Europe's pronounced and well developed coastal areas. Nine cities are located in countries east of the former "Iron Curtain", in which strong social, economic as well as urban morphological transformations took place after 1989/90. Unfortunately, Urban Atlas data is not available for cities from some Eastern European countries (Russia, Ukraine, Belarus and Moldova), so that no comparable analyses are possible in these cases.

## 3 RESULTS AND DISCUSSION

### 3.1 Measures of the case study cities with reference to infrastructure efficiency

The diagram in figure 2 (left) shows an exponential relationship between the road length in urban mask per capita of population (measure of infrastructure efficiency) as a function of settlement density in the selected European cities. This hyperbolic curve can be regarded as rather typical for such a relation (Burchell et al. 2002; Siedentop et al. 2006; Bettencourt et al. 2007; Kurvinen & Saari 2020). In the diagram the cities of the former Eastern Bloc are highlighted in red. These nine cities with medium settlement densities are in the lower range of the measure “Road length in urban

mask per capita of population". It might be interesting to take a closer look at a corresponding thesis: Do cities of the former Eastern Bloc still have comparatively more efficient infrastructure systems than Western cities in Europe, although socio-economic conditions have converged significantly since 1989/90? In any case, this confirms the already proven persistence of road networks in view of the enormous dynamics in the construction and socio-economic environment within these cities.

The diagram in figure 2 (right) shows the relationship between the road length in urban mask per capita of population as a function of population density (related to administrative area) in the selected European cities. The values scatter relatively widely, so that a hyperbolic curve is not visually apparent. Cities from the former Eastern Bloc and Western cities are mixed in the point cloud. This shows that the urban mask is much better suitable for the spatial analysis of cities than the administrative municipal area.

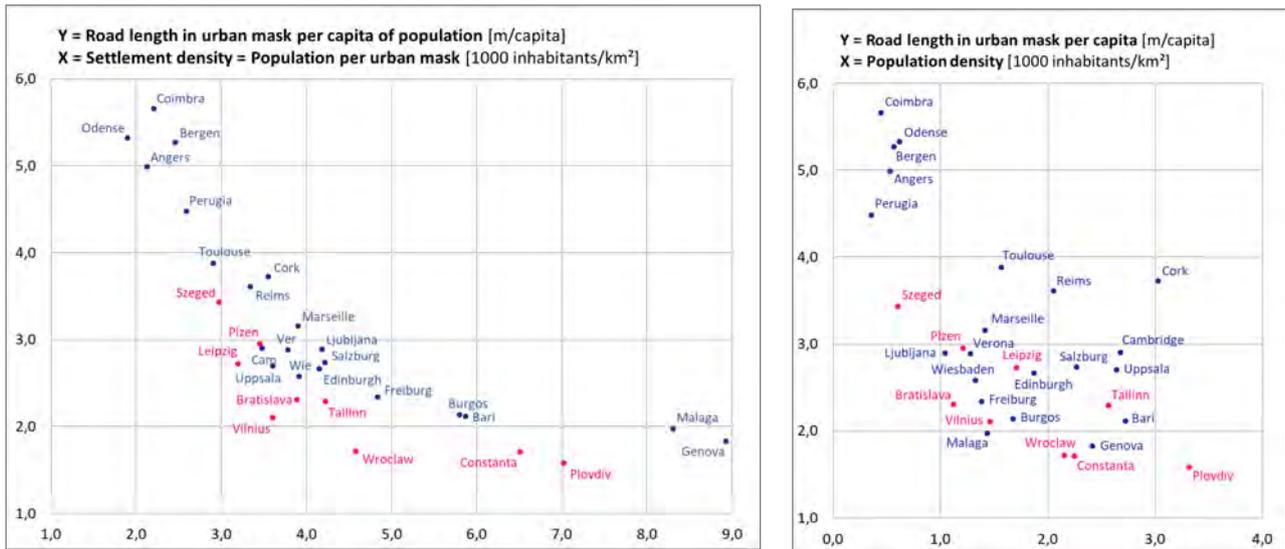


Figure 2. Diagram of the road length in the urban mask per capita of population as a function of settlement density (left) and population density (right) in selected European cities

As figure 3 shows the correlation between the road density in the urban mask and the settlement density is only moderate ( $r = 0.53$ ). Nevertheless, possible city clusters become visible in the diagram. Most noticeable are the two Mediterranean coastal cities of Malaga and Genova, whose characteristic values clearly differ from the other cities (both highest settlement density and highest road density in the urban mask). For both cities the local topography, especially the pronounced relief and the location on a narrow coastal strip, plays an important morphological role. Another cluster could be formed by the four cities Vilnius, Wrocław, Leipzig and Bratislava with the lowest values of road network density in urban mask but medium settlement densities. These cities are all located in the lowlands with no significant relief influence (except for some districts of Bratislava) and were part of the Eastern Bloc until 1989/90. Otherwise, the diagram shows a large point cloud of cities with medium road density in the urban mask and low to medium settlement density, where most of the reference cities are located. Only the city pair Constanta - Plovdiv deviates slightly with higher settlement density.

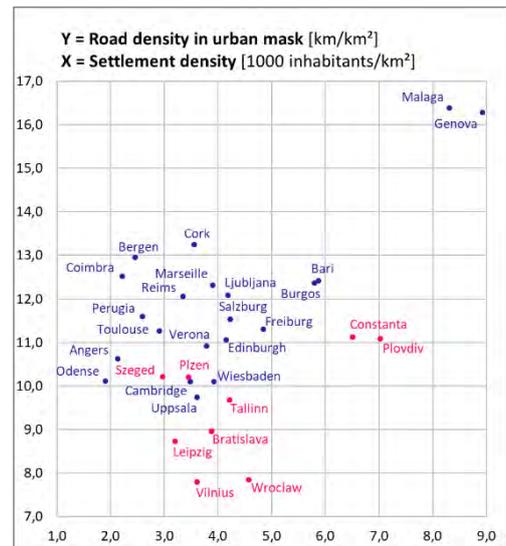


Figure 3. Diagram of the road density in the urban mask as a function of settlement density in selected European cities

The main results of the study for all reference cities are presented in an overview map (figure 4). The map shows the values of the road length in the urban mask per capita of the population as a measure of infrastructure efficiency in the

selected European cities. The point symbols vary in colour according to this measure and in size according to the urban mask area. At first view, the map does not indicate any spatial relationship of the value distribution.

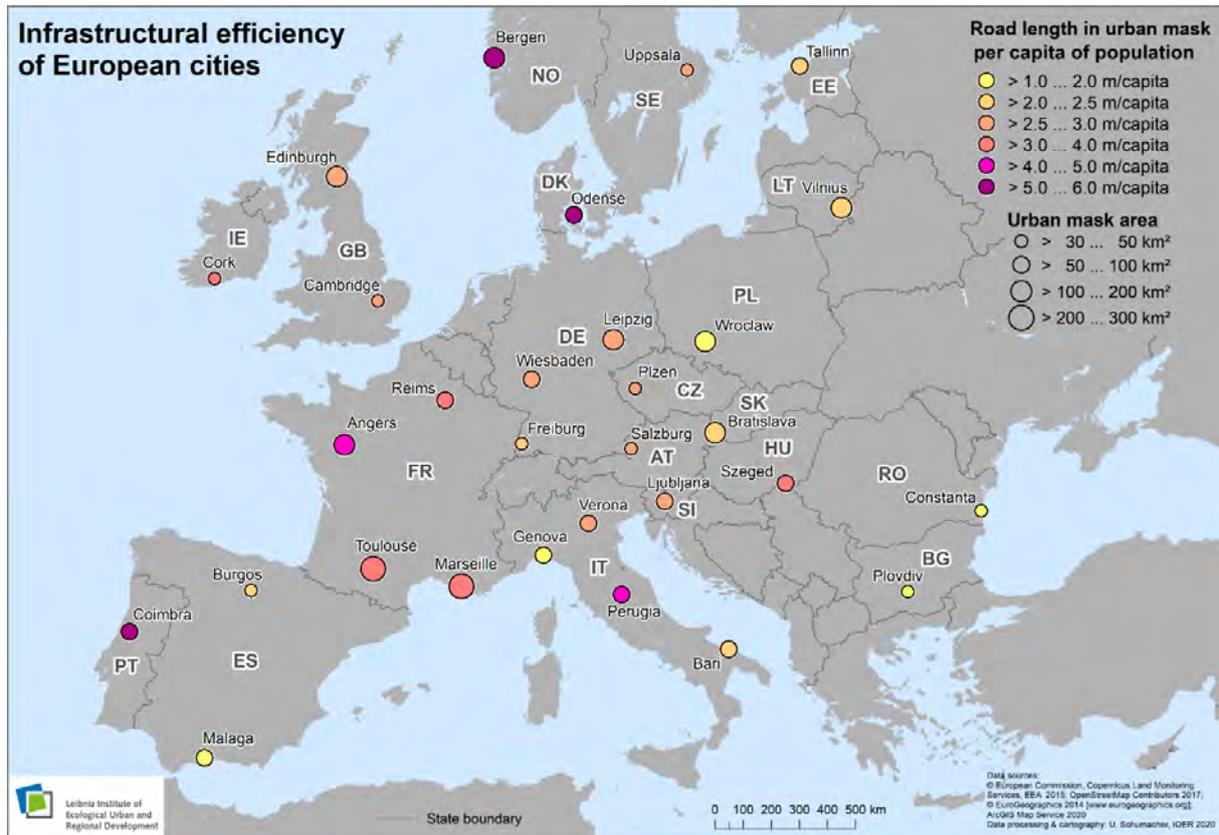


Figure 4. Overview map of infrastructural efficiency in selected European cities (2012)

The two maps in figure 5 show the case study cities with maximum and minimum road network density per capita of population (Coimbra in Portugal and Plovdiv in Bulgaria). If all public roads are included, their network density within the urban mask is almost identical in both cities. Because of the much higher settlement density, a resident of Plovdiv claims only 1.6 m of road, while a resident of Coimbra uses three and a half times as much with 5.7 m of road. This does not include the whole road length in the open space of the administrative city area, which is much greater in Coimbra (260 separate polygons of urban mask) than in Plovdiv (57 polygons) due to urban sprawl.

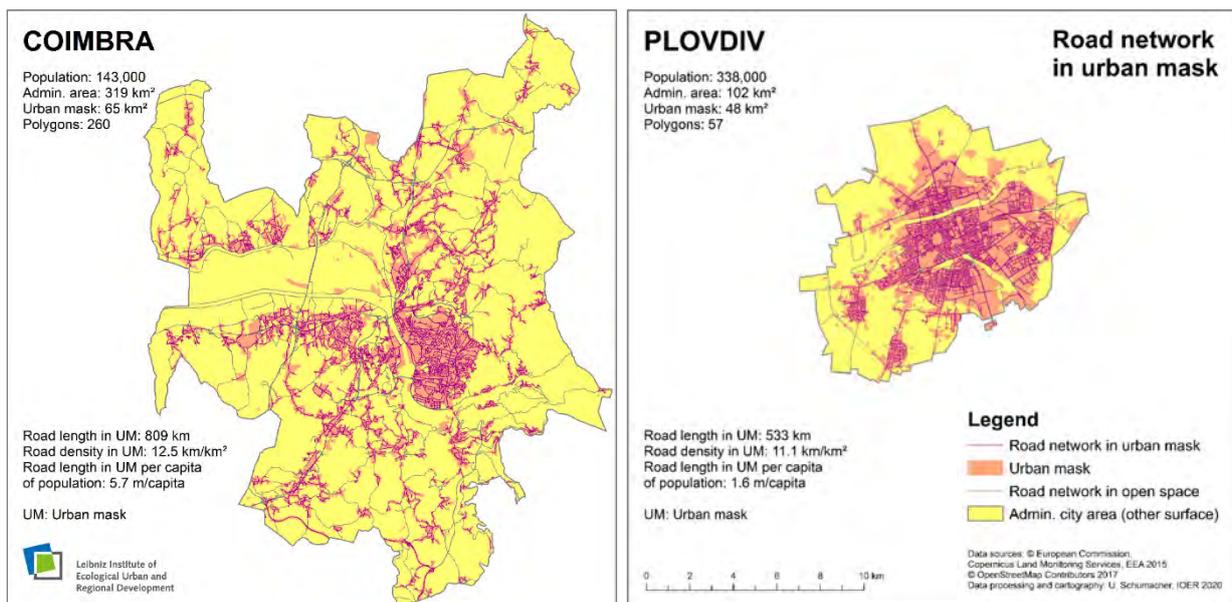


Figure 5. City maps with extreme values for infrastructural efficiency (Coimbra and Plovdiv)

Figure 6 summarizes the parameters respectively measured variables shown above in an overview chart. The values are standardized with  $n(\max) = 1$ . For each variable the maximum value ( $n_{\max}$ ) is determined. All other values ( $n_i$ ) of the variable  $n$  are divided by this value. The x-axis shows the cities, arranged in descending order of the values of the measure "Road length in urban mask per capita of population". As a result, the normalized value of this measure follows a descending line. It is evident that the settlement density (population per urban mask area) follows an opposite (ascending) course. This path follows a rather stable trend, which is clearly interrupted only in the cities of Malaga and Genova. The special features of these cities have already been discussed above (see comments on figure 3). This trend is not apparent in the values of the population density. Its values fluctuate strongly between very high and very low values. The observations on the value curve of the measure "Road density in urban mask" (road length per urban mask area, in figure 6 normalized as described above) are also of interest. The majority of the values are in a corridor between 0.6 and 0.8, with only a few exceptions deviating significantly from this interval. These are the six cities that were already highlighted as emerging clusters in the explanations of figure 3.

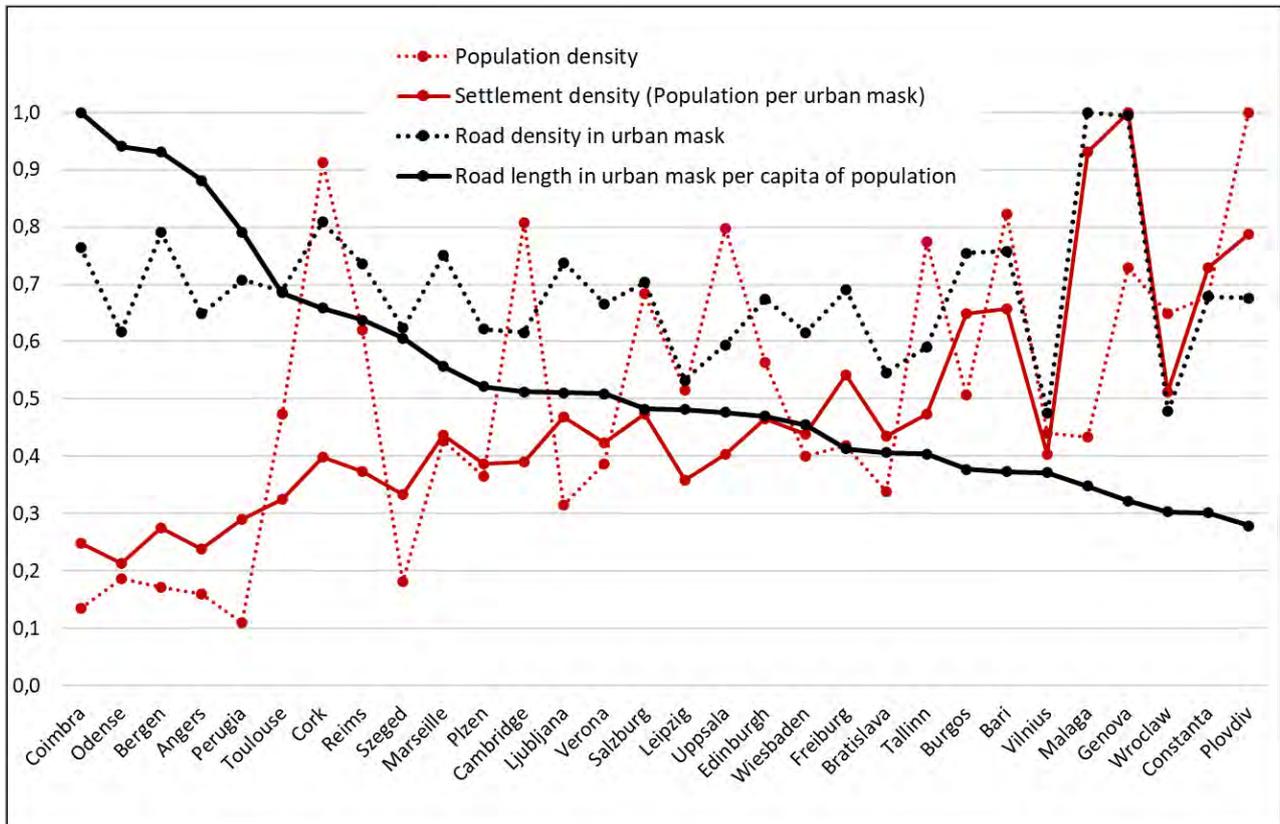


Figure 6. Selected parameters of the case study cities with reference to infrastructure efficiency (2012), normalized with  $n(\max)=1$  and arranged according to "Road length in urban mask per capita of population" in descending order

### 3.2 Urban mask as suitable reference geometry?

The correlations of the selected measures make it clear that in the context of the discussion about infrastructure efficiency, urban mask is a suitable reference geometry to describe efficiency parameters which allows significant interpretations and supports to find settlement related influencing factors. This is due to the simple fact that the physical connection between the urban built environment and the settlement area is directly given, which is not the case for the administrative area. In this respect, urban masks are applicable for all questions and associated analysis and planning tasks in which the described physical relationship is relevant. Urban metabolism research, e.g., is only one more example among others.

### 3.3 Automated delineation of an urban mask – limits and possible solutions

The GIS method for generating an urban mask that is introduced in this paper is reproducible, whereby the quantitative parameters of the algorithm were derived from objective criteria. Thus the method is basically suitable for medium-scale mapping applications and analyses. In the resulting geometries of various cities it is noticeable – in the context of topographic maps or aerial photographs – that larger railway station complexes are not part of the urban masks. In

relation to the total area of an urban mask this gap is not significant. Nevertheless, it would make sense from a cartographic point of view to find solutions on this issue. The affiliation of inner-city railway stations to the urban mask can be discussed controversially. It is difficult to extend the vector-based algorithm with the available Urban Atlas data adequately, because there are no structural features that can be generalised. In such exceptional cases it can make sense to switch to manual editing taking aerial photographs or city maps into account.

### 3.4 Features beyond built-up areas

In this paper we discussed urban masks as a reference geometry to analyse settlement structure features. However, settlement structures do not only consist of built-up areas, they also include other structural elements, especially green spaces and other open spaces. Such elements are considered in Urban Atlas data and part of urban masks, namely gardens, zoos, parks, castle parks and cemeteries. *“Forests or green areas extending from the surroundings into urban areas are mapped as green urban areas when at least two sides are bordered by urban areas and structures, and traces of recreational use are visible.”* (EU 2016, 21) In such cases, the urban mask may extend quite far into the non-urban open space, where the question of demarcation can arise. When assessing the Urban Atlas as a geodata source for the delineation of the urban mask, it is important to consider how these source data were generated. Thus, automatic algorithms as well as interactive editing were used for the preparation of the original remote sensing data.

## 4 CONCLUSIONS

The delineation of coherent settlement areas in which the artificial elements are concentrated as so-called “urban mask” is a necessary precondition for numerous analyses in urban space. The procedure for the cartographic generalization of open geodata presented here can be applied wherever European Urban Atlas data is available. Using the example of measures of infrastructure efficiency, it could be demonstrated that the urban mask area is better suited as an overall urban reference value than the administrative area of a city. The urban mask represents an important reference geometry for the definition and application of planning-relevant performance indicators.

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# ANALYSIS OF THE DYNAMICS OF BUILT-UP AREAS AND ARTIFICIAL IMPERVIOUS SURFACES OF THE BULGARIAN COASTAL MUNICIPALITIES USING GHSL AND GAIA DATA

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## Abstract

*Socio-economic development and intensive urbanisation in coastal areas in many parts of the world in recent decades have led to a rapid increase in built-up areas. These activities have negatively affected the environment and upset the balance in the vulnerable coastal ecosystems. The Global Artificial Impervious Areas (GAIA) data analysis indicates an Artificial Impervious Surfaces (AIS) increase of 1.5 times since 1990. Since the 1960s, AIS has been dynamically expanded along the Bulgarian coastal zone. The main factors contributing to increasing AIS are urbanisation, industrialisation and tourism development processes. This study aims to assess the dynamics of impervious surface Bulgarian coastal region in the period 1975-2018, the not studied in detail so far. The analysis is carried out for the Black Sea coastal municipalities using Google Earth Engine platform of the Global Man-made Impervious Surface (GMIS), GHSL (JRC-EC) and GAIA data. Some inferences about the temporal trend of growing and spreading of AIS for four-decadal changes are made. Furthermore, recommendations for national spatial planning for responsible national authorities are provided.*

**Keywords:** *Impervious surface, Built-up, GHSL, GAIA, Copernicus Program, Landsat, Bulgarian Black Sea coast*

## INTRODUCTION

The impact of increased built-up areas on several socio-economical fields has been established in many places along the European and world coastal regions in the last decades. The urbanisation leads to significant changes in landscapes and ecosystems, and poses many problems, creating risks for environmental and coastal activities. Among them, the most affected are the water cycle, water retention, risk of coastal flooding, overexploitation of the natural resources, disruption of the natural and protected habitats and the agricultural areas, increasing the soil and water pollution. There is need of timely, accurate and frequent information to artificially impervious areas for tracking and controlling the process of urbanisation and changes in Land Cover/Land Use Change (LC/LUC), as well as their impact on the environment and biodiversity (Gong et al., 2020).

The process of soil sealing in coastal area refers to soils used and permanently built for settlement construction, industrial and infrastructural construction, commercial and transport sections, road and railway networks. In the coming years, the process will be even more pronounced due to the continuing growth rates of some settlement structures and the development of ancillary infrastructure.

A study of the European environmental agency based on Copernicus Land monitoring High-Resolution Layer 'Imperviousness' shows that only for the period 2006–2009, the AIS increased with 4.9% for selected European countries and Bulgaria, it is about 4% (Zaucha and Świątek, 2013; EEA, 2018). In March 2020, the European Environmental Agency published maps of the imperviousness and imperviousness changes in all EEA-39 countries for

the period 2006–2015 (<https://www.eea.europa.eu/data-and-maps/indicators/imperviousness-change-2/assessment>). The average annual increase in soil sealing relative to the country area varied from 0% to 0.088% with an annual average increase of 429 km<sup>2</sup>. For Bulgaria, the calculated percentages of country sealed in 2009 are 1.89% and in 2012 is 1.94%; the annual sealing increases for the period with 0.34% and annual change relative to the country area is 0.006%. This fact poses it among the countries with the low sealed area as a percentage of total area (i.e. <1.0%) for that period. The EU policy objective is to measure the extent and dynamics (change) of soil sealing, resulting from the development of urban and other artificial land uses. The intentions are to publish maps of soil sealing/imperviousness on an annual basis for the upcoming 2015–2018 products at 20m spatial resolution using Earth observation data (moving to 10m from the 2018 reference year onwards).

The preparation of thematic maps for AIS on an annual basis with the necessary accuracy for practical applications requires extensive computer resources and efficient mapping algorithms for processing big data sets from different sources. The accuracy of mapping the urbanisation and AIS worldwide significantly improve in the last two decades with the freely available satellite data. Starting initially from 1000m resolution at a global scale, going through 250–500m from MODIS satellite data, to 30m resolution based on Landsat data, at present AIS can be mapped with 10m resolution using Sentinel-2 data. The Global Artificial Impervious Areas (GAIA) data analysis indicates an increase in Artificial Impervious Surface (AIS) 1.5 times since 1990. AIS is an essential cover type to characterise the built-up area and urban expansion (Liu et al., 2014; Gong et al., 2020).

The main environmental problems and trends in the Black Sea coastal zone are mainly related to soil sealing, erosion, landslides, local pollution and acidification and salinisation (MOEW, 2016). The negative impact is expected to increase the anthropogenic pressure from the construction of new coastal hydro-technical facilities related to tourism, port activities, coastal development and urbanisation. The decrease in the habitat area of shallow sublittoral rocks compared to the original reference state as a result of sealing and backfilling by human-made structures is significant in the coastal zone. In the region of Kaliakra - Galata it is > 50%, moderate in the region of Emine - Sozopol (7%) and insignificantly (<1%) in the other regions. Urbanisation in the coastal municipalities along the Bulgarian coast is one of the most visible processes since the 1960s. This process is due to industrialisation, the baby boom and the development of international tourism, which have not been comprehensively studied so far. The municipalities in the coastal area are among the leading regions in Bulgaria regarding urban development. They are experiencing urbanisation along with pressure from local migration, as people are looking for a better lifestyle and basic life necessities, such as education, health, and employment.

The study aims to present an overview of the available databases of the impervious surfaces for Europe and an attempt to evaluate their AIS / built-up area dynamics for the Bulgarian coastal zone in the period 1975–2018. The specific goal is to analyse the spatial and temporal characteristics of the AIS expansion in 14 municipalities in Eastern Bulgaria, bordering the Black Sea. The analysis is carried out using satellite data using the full archive of 30m resolution Landsat images on the Google Earth Engine platform of the Global Human Settlement Layers (GHSL) produced by JRC-EC. With ancillary ‘imperviousness’ datasets from the Sentinel-2 of the Copernicus Program optical data with 20m resolution and national datasets, we verified the delineated artificial impervious surfaces on a municipal level using annual maps of the GAIA developed by Tsinghua University, China. Some inferences about the temporal trend of growing and spreading of AIS for four-decadal changes are made, and some recommendations for national spatial planning for responsible national authorities are provided.

## **IMPERVIOUS SURFACES AND BUILT-UP AREAS MAPPING BY EARTH OBSERVATION**

### ***Impervious surfaces, soil sealing and built-up areas definitions***

Impervious surfaces are generally human-made land surfaces such as pavements (roads, sidewalks, driveways and parking lots) that are covered by impenetrable materials such as asphalt, concrete, brick, and stone and rooftops that repel rainwater and do not permit it to infiltrate (soak into) the ground. These areas include representing materials that do not absorb water or moisture, including rooftops, walkways, patios, driveways, parking lots, storage areas, concrete or asphalt paving, gravel roads, packed earthen materials, macadam or other surfaces that similarly impede the natural infiltration of the runoff. Some natural surfaces can be relatively impervious, for example, compacted clay in some desert environments. Soils compacted by urban development or agriculture practices are also highly impervious. Impervious surfaces cause the water to flow off the ground in the form of urban runoff or stormwater. On such areas, the rainfall can cause the rapid overland flow to drainage inlets and causing unnaturally large and sudden flows that contribute to stream erosion. Also, the high velocity and high volume of water flowing off impervious surfaces cause more significant and more frequent flooding. AISs are considered a critical indicator of the urbanisation growth rate in terms of the quality of urban development. The built-up indicator (often used interchangeably to the AIS although built-up areas are part of the total imperviousness) is used for the first time in EU coastal areas within the project DEDUCE (Marti

et al., 2007), and for the Bulgarian coastal zone in (Vatseva, 2015). AIS is calculated as a percentage of the total area covered by impermeable material.

The term 'sealing' is internationally used in soil science for describing the effect of soil crusting (FAO/ISRIC 2000). The degree of sealing is defined as the percentage of area that is covered by an impermeable material that is very close to the definition of AIS. In European land-use planning, the term 'soil sealing' is also used to indicate the separation of soils from the atmosphere and the above-ground biosphere by constructions (Burghardt, 2006). The Task Group on Soil Sealing, Soils in Urban Areas, Land Use and Land Use Planning of the European Commission identified three different ways of defining sealing following different approaches:

- A systems approach: Soil sealing is the separation of soils by layers and other bodies (consisting of totally or partly impermeable material) from other compartments of the ecosystem, such as the biosphere, atmosphere, hydrosphere, anthroposphere and other parts of the pedosphere.
- A purpose-related approach: Soil sealing is the covering of the soil surface with impervious material, or the changing of its nature so that the soil becomes impermeable so that the soil is no longer able to perform the range of functions associated with it.
- Soil sealing, including natural characteristics: Changing the nature of the soil so that it behaves as an impermeable medium. Compaction of soils or subsoils may affect larger areas than the sealing as defined in this definition.

Built-up and related land, in land use and agriculture statistics, comprises residential land, industrial land, quarries, pits and mines, commercial land, land used by public services, land of mixed-use, land used for transport and communications, for technical infrastructure, recreational and another open land. Separate farm buildings, yards and annexes are excluded ([https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Built-up\\_land](https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Built-up_land)). There are some differences between Closed-block built-up areas and Open-block built-up area and block the built-up border area according to the urban land-use area. In some cities, the first could be 8-100%, and the second one can comprise 7-90%, respectively, from the sealed area (Burghardt, 2006). The European Commission applied a universal definition of settlements across all countries (<https://ourworldindata.org/urbanization>): 1) Urban centre: must have a minimum of 50 000 inhabitants plus a population density of at least 1 500 people per square kilometre (km<sup>2</sup>) or density of build-up area higher than 50%; 2) Urban cluster: must have a minimum of 5 000 inhabitants plus a population density of at least 300 people per square kilometre (km<sup>2</sup>); 3) Rural: fewer than 5 000 inhabitants. However, these include demographics (census) data which is not always available when studying soil sealing.

Furthermore, the AIS represents a land cover class rather than a land-use class which the definitions of the urbanisation provide. Therefore, both terms cannot be used interchangeably, although the human settlements are one of the leading 'culprits' for soil sealing. In this study, we will not develop on the CORINE Land Cover classes and definitions and EAGLE classification which cover the AIS because 'Imperviousness' is already developed as separate products by JRC-EC and Copernicus program. In the following sub-sections will be given a brief overview of the freely available AIS RS/EO products used in this study.

### ***'Imperviousness' HRL (Copernicus)***

The Copernicus 'Imperviousness' maps are 'Status' and 'Change' maps (Imperviousness, Copernicus 2020). The 'imperviousness' products capture the percentage and change of soil sealing. Built-up areas are characterised by the substitution of the original (semi-) natural land cover or water surface with an artificial, often impervious cover. The imperviousness High-Resolution Layer (HRL) depicts the spatial distribution of artificially sealed areas, including the level of soil sealing per area unit. The level of sealed soil ('imperviousness' degree 1–100%) is produced using a semi-automated classification, based on calibrated NDVI imagery from satellite data (Langanke, T., 2018). Imperviousness data is available for the reference years 2006, 2009, 2012 and 2015, and contains two types of products: 1). "Status layers" which is the percentage of sealed area for each status layer for any of the four reference years (e.g. degree of Imperviousness 2012). The status layers are available in the original 20m spatial resolution and as aggregated 100m products. 2). Change layers which are two types of change products for each of the 3-year periods between the four reference years (2006–2009, 2009–2012, 2012–2015), and also, for the period 2006–2012 (that is in line with the 6 years between two Corine Land Cover products). Data for 2006 and 2009 were produced initially in the frame of GMES precursor activities and Geoland2 project (Imperviousness, Copernicus 2020).

### ***Global Human Settlement Layers, GHSL (DG JRC-EC)***

The GHSL (Built-Up Grid 1975–1990–2000–2015), produced and released by JRC-EC, relies on the design and implementation of new spatial data mining technologies over heterogeneous data including global, fine-scale satellite image data streams, census data, and crowdsources or volunteered geographic information sources. These data contain a multitemporal information layer on "built-up" presence as derived from the Landsat Global Land Survey (GLS) image

collections (GLS1975, GLS1990, GLS2000, and ad-hoc Landsat 8 collection 2013/2014). The data have been produced by utilising Global Human Settlement Layer methodology in 2015 (Pesaresi et al. 2015).

### **FROM-GLC, GAIA (Tsinghua University)**

The FROM-GLC (GAIA) dataset by Tsinghua University contains annual change information of global impervious surface area from 1985 to 2018 at a 30m spatial resolution. Change from “pervious” to “impervious”, or “built-up” used interchangeably in this study, was determined using a combined approach of supervised classification and temporal consistency checking. Impervious pixels are defined as above 50% impervious, which is the main difference with GHS Layers provided by JRC-EC. The year of the transition (from ‘pervious’ to ‘impervious’) can be identified from the pixel value, ranging from 34 (year: 1985) to 1 (year: 2018). The dataset is temporally consistent, following the conversion from ‘pervious’ (e.g., non-urban) to ‘impervious’ (e.g., urban) monotonically (Gong et al. 2020).

### **STUDY AREA**

In this study, we analyse the AIS for the territory of 14 municipalities from north to south, including *Shabla, Kavarna, Balchik, Aksakovo, Varna, Avren, Dolni Chiflik, Byala, Nessebar, Pomorie, Burgas, Sozopol, Primorsko* and *Tsarevo*, located in three administrative districts *Dobrich, Varna* and *Burgas*. The study area covers the Black Sea coastal zone with geographical coordinates 41°.9725N – 43°.7389N and 27°.2111E – 28°.6078E. The entire territory of the municipalities under investigation is 5737.3 km<sup>2</sup> with a length of the coastal line 378 km (NSI, 2020).

Based on the morphographic relief features and following the zoning of the Black Sea coast (Popov and Mishev, 1974), the region is divided into North and South Black Sea coasts. For structure and geomorphology, the coastal zone is divided into four subzones (from North to South): the Moesian, Balkan, *Burgas*, and Medni rid–Strandja subzones. The study area is characterised by significant natural and geographical diversity. In the northern part, there is a lowland-plain, plateau-hilly and mountainous terrain; the dry valleys are typical. The southern Black Sea coast is characterised by lowland and hilly terrain, with a very weakly and very strongly indented coastline, with a high steep (cliff) shore and low accumulation shore with wide or small sandy strips, with lagoons, estuaries, lakes, various natural forest and grass vegetation. The Bulgarian coastal zone is exposed to a wide variety of natural hazards such as soil compaction, erosion, landslides, local pollution and acidification and salinisation. Their complex impact may cause negative social and economic consequences and environmental changes.

### **MATERIALS AND METHODS**

In the presented study, the following datasets were used: GHSL (JRC-EC) built-up product for the period 1975–2014 and FROM-GLC, GAIA (Tsinghua University) for the period 1985–2018. Both products were produced with the longest stable and time consistent civilian satellite data record of the Landsat programme. The datasets were extracted from Google Earth Engine using a shapefile of the Bulgarian Black Sea municipalities which have a coastline. Descriptive statistics of the pixel count for each of the available classes were extracted and recomputed in km<sup>2</sup>. The results were consecutively analysed and plot to get an insight into the driving processes and to reveal the general trends. Correlation analysis between different epochs was also employed to analyse the consistency of the observed trends.

### **RESULTS AND DISCUSSIONS**

Spatial structure of the urbanised territories of the Black Sea coastal zone for the period 1977–2011 was studied previously by Vateva (2015). According to her estimates, the territorial distribution of the urbanised territories during this period shows a steady increase in the total area of urban areas from 30 439.54 ha (1977) to 33 607.42 ha (2011), and in 2011 it represented 5.83% of the area of the Black Sea coastal zone. The highest relative share of the urbanised territories for 2011 have the municipalities of *Varna* (33.59%), *Burgas* (10.75%), *Balchik* (6.39%), *Aksakovo* (5.56%) and *Nessebar* (5.19%), and the lowest - *Primorsko* (1.81%) and *Tsarevo* (1.66%). The data on the relative share of the types of urbanised territories show that the settlements dominate (52.56%), followed by the places for sports and recreation (26.07%) and the industrial and commercial sites (15.05%). These types of territories are continually increasing their area during the period 1977–2011, while there is a decrease in green areas in settlements. There is an apparent concentration of changes mainly after 2000 in four municipalities: *Nessebar, Kavarna, Balchik* and *Sozopol*. Another feature is the concentration of changes (after 2000) near the coastline.

In contrast, the changes in the first period of 1977–1990 are located mainly in the interior of the coastal zone and are located primarily in the area of major cities - *Varna* and *Burgas*. The analysed data show that throughout the study period, urban areas increased growing by 999.68 ha in 1977–1990 and 1 819.13ha in 2006–2011. In general, for almost all municipalities, the changes remained minimal in the first decade of the period of socio-economic and political

transformation (1990–2000), and are maximum in 2000–2006. As an essential feature, it should be noted that the total changes in the southern part of the Black Sea coastal zone are significantly more than those in the north. This built-up area is very pronounced in the period after 2000. The dynamics of the changes of the urbanised territories with a maximum area of the changes is in the municipalities *Nessebar*, *Kavarna*, *Balchik* and *Sozopol*. There is a sharp expansion of the urbanised territories in these municipalities for the period 2000–2006, and in 2006–2011 the growth rates remain high only for *Kavarna*. The structure of the changes shows that the changes in the places for sports and recreation have the most significant area. In 1975–1990 they covered 215.19ha, and in 2006–2011 they had almost seven times larger area. The study of the structure of the changes reveals that in 2006–2011 the significant increase in the area of places for sports and recreation (new hotels, resorts, holiday villages) is mainly due to the transformation of construction sites that have a maximum area of the changes in 2000–2006. In connection with the increase of the area of the industrial and commercial sites for the period 2006–2011, it can be noted that this is mainly related to the development of Kaliakra Wind Farm in *Kavarna* municipality.

The results from the analysis of the GHS layers and FROM-GLC (GAIA) datasets carried out in our study are presented in Table 1.

Table 1. Impervious (FROM-GLC, GAIA layers; Tsinghua University) and built-up area changes (GHSL; DG JRC-EC) in the Bulgarian Black Sea municipalities [Units are in km<sup>2</sup>]

Data sets	Built-up epoch	Shabla	Kavarna	Balchik	Aksakovo	Varna	Avren	Dolni Chiflik	Byala	Nesebar	Pomorie	Burgas	Sozopol	Primorsko	Tsarevo
GHSL	1975–1990	1.03	1.34	3.11	2.84	7.65	1.96	1.54	0.69	1.66	3.07	11.55	1.61	0.62	0.65
	1990–2000	0.29	0.64	1.03	0.62	2.94	0.89	1.26	0.38	2.02	0.71	1.11	0.21	0.24	0.19
	2000–2014	0.94	3.20	5.11	2.24	11.65	4.37	4.67	2.12	0.26	1.67	3.22	1.34	0.38	0.51
GAIA	1985–1990	0.42	0.93	2.04	0.49	13.30	0.41	0.38	0.40	2.45	1.48	7.16	0.66	0.24	0.36
	1990–2000	0.40	0.54	1.62	0.41	8.88	0.36	0.46	0.44	2.03	1.01	6.25	0.44	0.23	0.19
	2000–2014	1.76	2.67	6.17	2.16	21.15	0.97	4.32	1.92	0.01	3.63	6.24	0.87	0.45	0.60

a)

b)

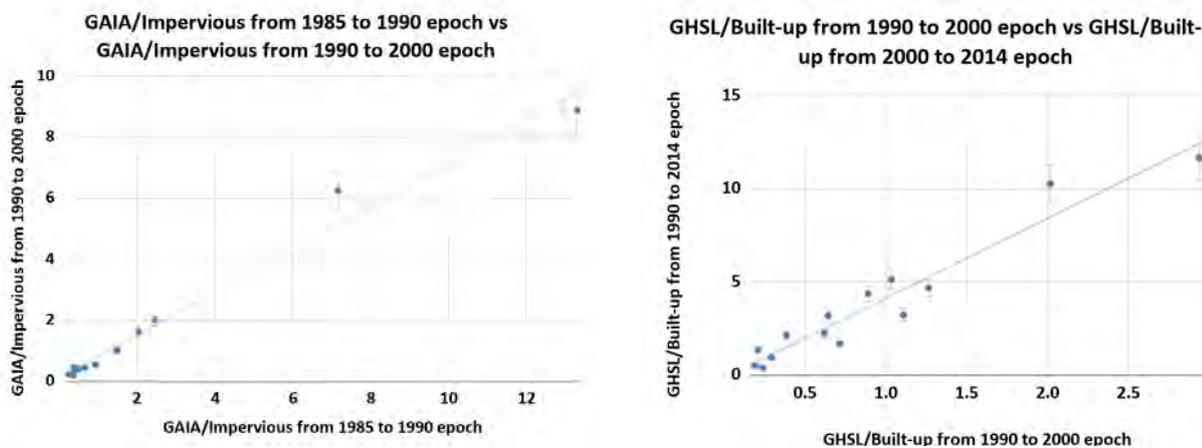


Figure 1. Comparison of built-up trends for GHS layers and impervious areas changes for GAIA for different epochs: a) trend line for the impervious surface from 1980 to 2000 epoch,  $R^2=0.980$ ; b) trend line for the built-up area from 1980 to 2000 epoch,  $R^2=0.934$

From Table 1, the analysis reveals a strong correlation, i.e.  $R^2 = 0.934$  (GHS) and  $R^2 = 0.980$  (GAIA), between the built-up area estimates from 1990 to 2000 epoch vs built-up area from 2000 to 2014 epoch (GHS) and impervious area estimates from 1985 to 1990 epoch vs impervious area from 1990 to 2000 (GAIA). This result reconfirms the trend of increasing built-up areas due to the economic development of Bulgaria after its change from plan to a market-oriented economy.

### ***Built-up and impervious area changes in 1985–1990 epoch***

The top three lowest built-up rates according to GHSL data in the 1975 to 1990 epoch are the Black Sea municipalities of *Primorsko* (0.62 km<sup>2</sup>) followed by *Tsarevo* (0.65 km<sup>2</sup>) and *Byala* (0.69 km<sup>2</sup>). These lowest impervious area rates three municipalities for the 1985 to 1990 epoch are almost twice as low according to GAIA dataset, i.e. *Primorsko* (0.24 km<sup>2</sup>) followed after *Tsarevo* (0.36 km<sup>2</sup>) and *Dolni Chiflik* (0.38 km<sup>2</sup>), which can be attributed with the different time-span of both datasets and the methodology for extracting the impervious services.

According to GHSL data, the highest built-up rates from 1975 to 1990 epoch are in the Black Sea municipalities *Burgas* (11.55 km<sup>2</sup>) followed by *Varna* (7.65 km<sup>2</sup>) and *Balchik* (3.11 km<sup>2</sup>). These highest impervious area change rates for top three municipalities for 1985–1990 are different according to GAIA, i.e. *Varna* (13.30 km<sup>2</sup>) followed by *Burgas* (7.16 km<sup>2</sup>) and *Nesebar* (2.45 km<sup>2</sup>). Interestingly, the first two most built-up municipalities of *Varna* and *Burgas* are very different from one another in both datasets. This fact can be explained with the different periods for the GHS and GAIA products which for GHS spans ten years more. It can also be inferred that both main Bulgarian Black Sea towns have exchanged their places in the construction rates in the ten years (1975–1985). However, it is also worth noting that *Varna* is reported with lower values of new built-up areas for a more extended period in the case of GHS compared to the product from the shorter period of GAIA. It can be inferred that the 1975 product of GHS might have some differences and inconsistencies with following products and layers from GAIA which can be attributed to the downscaling of the different spatial resolution of ERTS or later on Landsat to 20m spatial resolution which is the GHSL target resolution. It is well known that the 1975 epoch data of Landsat is not fully compatible with the 1985 epoch data due to different spatial and spectral resolution. Therefore, the GHS layer of 1975 might be worth a reprocessing to match the accuracy of newer Landsat products.

### ***Built-up and impervious area changes in 1990–2000 epoch***

According to GHSL data, the lowest built-up rates from 1990 to 2000 epoch are the Black Sea municipalities *Tsarevo* (0.19 km<sup>2</sup>) followed by *Sozopol* (0.21 km<sup>2</sup>) and *Primorsko* (0.24 km<sup>2</sup>). These lowest impervious areas change rates three municipalities are slightly different according to GAIA, i.e. *Tsarevo* (0.19 km<sup>2</sup>) followed by *Primorsko* (0.23 km<sup>2</sup>) and *Avren* (0.36 km<sup>2</sup>). As the period of this epoch is equal to the differences observed in the first period under scrutiny are closing in.

The top three highest built-up rates according to GHSL data in the 1990 to 2000 epoch are the Black Sea municipalities of *Varna* (2.94 km<sup>2</sup>) followed by *Nesebar* (2.02 km<sup>2</sup>) and *Dolni Chiflik* (1.26 km<sup>2</sup>). These lowest built-up rates three municipalities are different according to GAIA dataset, i.e. *Varna* (8.88 km<sup>2</sup>), followed by *Burgas* (6.25 km<sup>2</sup>), *Nesebar* (2.02 km<sup>2</sup>). The obtained result is observed as both datasets appear to be consistent in the lower estimates while at higher, they tend to deviate more.

### ***Built-up and impervious area changes in 2000–2014 epoch***

According to GHS data, the lowest built-up rates from 2000 to 2014 epoch are the Black Sea municipalities *Primorsko* (0.38 km<sup>2</sup>), followed by *Tsarevo* (0.51 km<sup>2</sup>) and *Shabla* (0.94 km<sup>2</sup>). These lowest impervious area rates in three municipalities are slightly different according to GAIA, i.e. *Primorsko* (0.45 km<sup>2</sup>), followed by *Tsarevo* (0.60 km<sup>2</sup>) and *Sozopol* (0.87 km<sup>2</sup>). Both datasets, although slightly disagree, reveal the same trend expressed in the previous epoch 1990–2000 for these municipalities.

The highest built-up rates according to GHS data in the 2000 to 2014 epoch are the Black Sea municipalities of *Varna* (11.65 km<sup>2</sup>), followed by *Nesebar* (10.26 km<sup>2</sup>) and *Balchik* (5.11 km<sup>2</sup>). These lowest impervious area rates three municipalities are again deviated from GHSL almost twice according to GAIA dataset but continue the trend from the 1990 to 2000 epoch, i.e. *Varna* (21.15 km<sup>2</sup>), *Nesebar* (10.01 km<sup>2</sup>), and *Burgas* (6.24 km<sup>2</sup>). Interestingly, the GAIA's estimate for *Nesebar* is close to the GHSL estimate, which is not the case for the third candidate.

The annual trend of the built-up areas and imperviousness is also interesting to be analysed. It can be traced back with the GAIA product, which allows analysis from 1985 until 2018, i.e. four years more in comparison to GHSL of JRC-EC, see Fig. 4. However, because 1985 is the base year of the impervious areas, the analysis of changes is possible from 1986 onwards. The analysis of the figure reveals a more detailed look at the trends which are hindered in the decadal assessments. Here one can see the ups and downs of the construction and try to link it to the social and economic

processes. For instance, it is interesting to observe the social and economic stagnation and crisis in the late 1980s followed by a short construction revival in the early 1990s of the 20th century, i.e. 1988 and 1991 which is then followed by a long ‘hiatus’ of construction until 1998. This period is well documented in Bulgarian socio-economic history as a ‘transition’ period for the economy from planning to the market economy. A steady increase in the economic activities in construction is followed after the early years after 2000 until the EU accession of Bulgaria, i.e. 2007. The sudden decline in construction after the accession of Bulgaria in the EU can be explained by the economic uncertainty and the introduction of new EU standards for the sector.

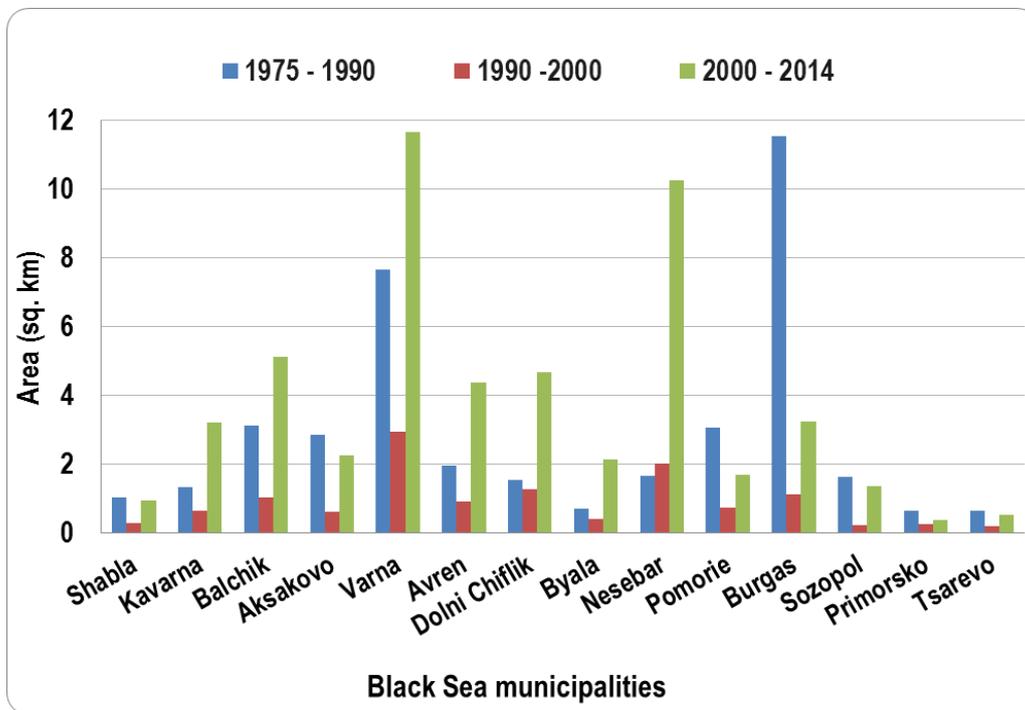


Figure 2. Built-up area changes for Bulgarian Black Sea municipalities in 1975-2014 according to GHS layers (DG JRC, EC)

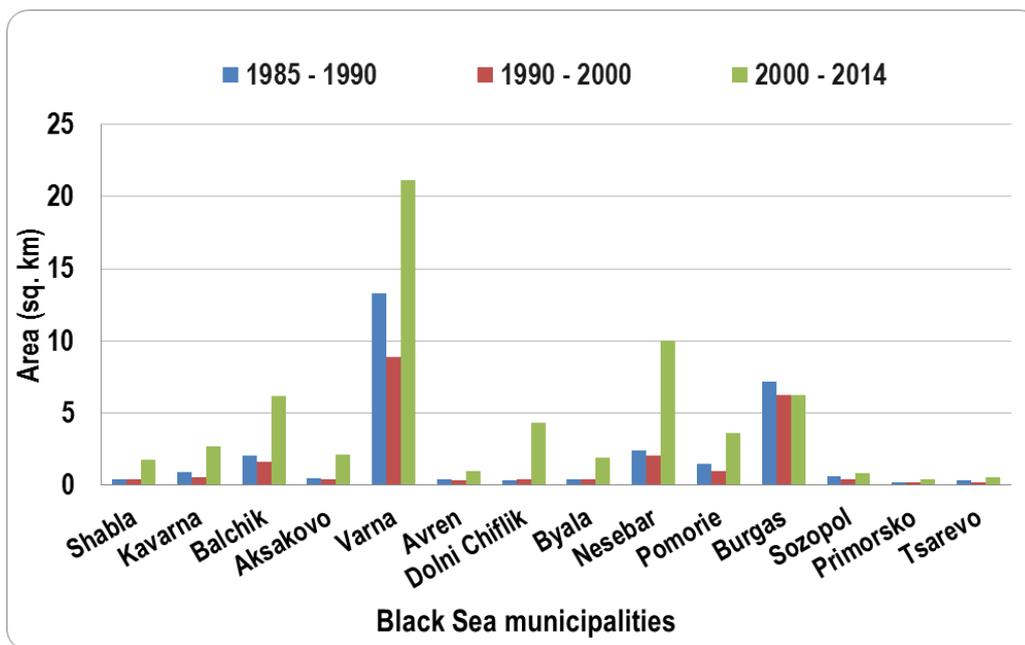


Figure 3. Impervious area changes for Bulgarian Black Sea municipalities in 1985-2014 according to GAIA layers (Tsinghua University)

This process continued from the Global Economic Crisis in 2008 until 2011, when the trend was reversed following the economic recovery. It is apparent from the figure that the highest rates in construction were 2014 and 2015 after the economic recovery which short trend is again diverted to a significant drop in new construction activities leading to almost a full hiatus in some municipalities such as *Primorsko*, *Sozopol* and *Tsarevo*. After the COVID-19 crisis, the sector is expected to recover even more slowly than after the crisis in 2008, as many tourist facilities will be closed due to lack of tourists or strict new regulations to which existing facilities would not be able to respond. However, this trend can be resumed anytime if the public investments are diverted toward the construction of the Black Sea highway which is seen as a significant factor to facilitate the economic regrowth in the Bulgarian Black Sea region. It is expected to act as a vital link between the Black Sea resorts and municipalities, thus boosting the economic relations and exchanges of goods in the meridional direction. The expected completion of Hemus highway in 2023–2024 will link the North Black Sea municipalities with the capital city of Sofia, which is also seen as a stimulus for economic regrowth linked with new construction in this region.

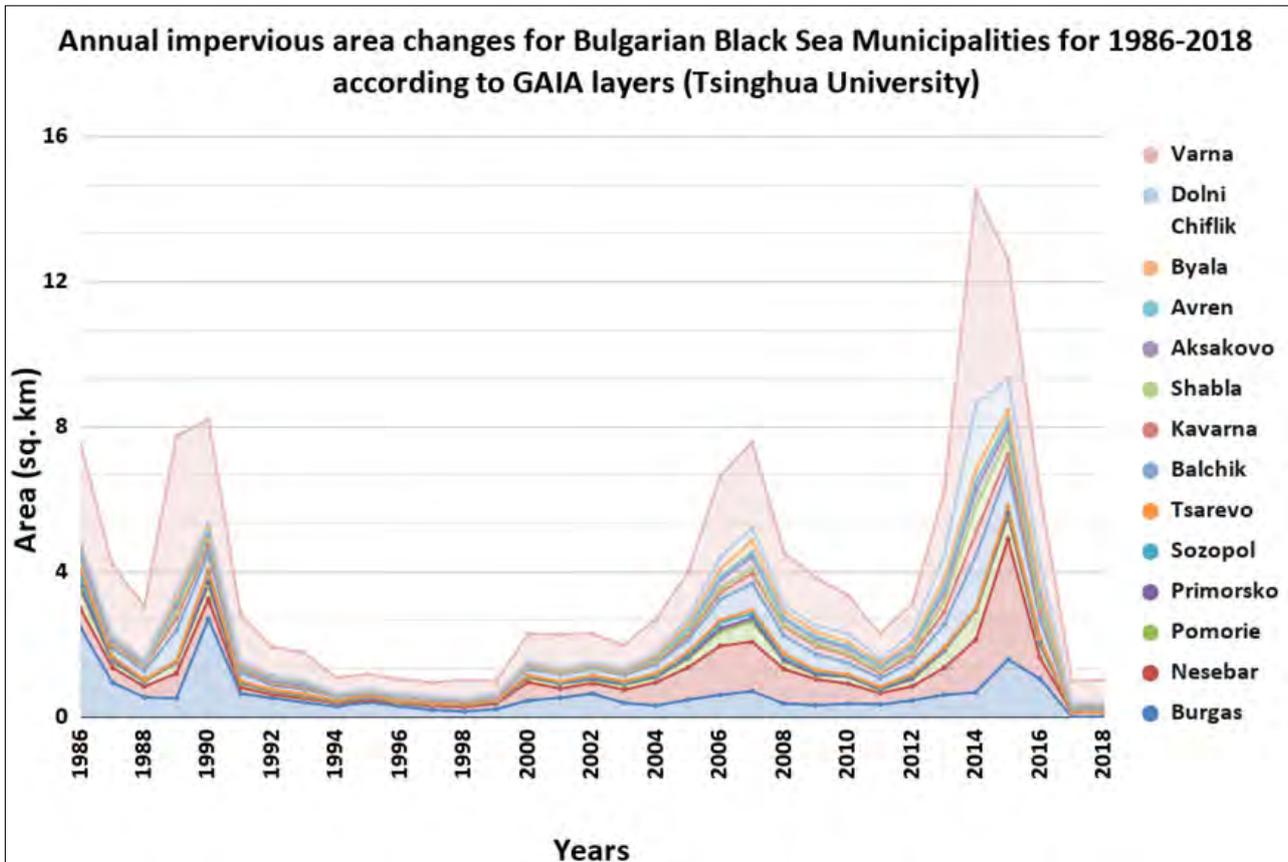


Figure 4. Annual impervious area changes in the Bulgarian Black Sea municipalities in 1986–2018 according to GAIA layers (Tsinghua University)

## CONCLUSIONS

The analysis of AIS and built-up areas as a mapping of results is performed mainly through various methods, definitions and satellite data used. It is sometimes difficult to assess the global products available and to provide a reasonable range of differences by comparing these products in terms of size as well as time trend. Many impervious areas in small towns and villages were not detected from coarse-resolution satellite observations (see, e.g. Gong et al., 2020). Also, there are significant uncertainties in the early years (e.g., 1985) comparing to those in more recent years (e.g., after 2000) because of the low availability of Landsat data. Besides, there are more impervious areas in Europe of GHSL in GAIA products than other products. There are some uncertainties in mixing the pixels on the mapping performance coming from two sources. The first is the mixed spectral signatures in 30m Landsat pixels due to the complex surface ground in the urban environment. The second is the change of training samples over time due to possible issues like the urban renewal process.

Some of the revealed trends in this preliminary investigation of AIS can be summarised as follows: the municipality of *Varna*, according to GHSL, has the highest values for “Built-up from 1990 to 2000 epochs” (2.94 km<sup>2</sup>) and “Built-up from 2000 to 2014 epochs” (11.65 km<sup>2</sup>) and the second-highest value for “Built-up from 1975 to 1990 epochs” (7.65 km<sup>2</sup>) providing an insight that the construction in the Municipality of *Varna* increased almost twice for the period after 2000 compared to the communist times. However, according to the GAIA database, *Varna* has the highest values for “Imperviousness from 1985 to 1990 epochs” (13.30 km<sup>2</sup>), “Imperviousness from 1990 to 2000 epochs” (8.88 km<sup>2</sup>) and “Imperviousness from 2000 to 2014 epochs” (21.15 km<sup>2</sup>), see Fig. 3. Outlying values at *Burgas* according to GHSL: “Built-up from 1990 to 2000 epochs” peaks at 1.11 km<sup>2</sup> and “Built-up from 2000 to 2014 epochs” peaks at 3.22 km<sup>2</sup> showing that the construction rates in the municipality of *Burgas* slowed down three times and even more after the socialist economy collapse; the built-up area from 1975 to 1990 is 11.55 km<sup>2</sup>. In general, for every increase of 10 km<sup>2</sup> in “Built-up from 1985 to 1990 epochs” (socialist economy), “Built-up from 1990 to 2000 epochs” increases by about 7.58 km<sup>2</sup> (economy in transition) and matches more than two times increase of 20.51 km<sup>2</sup> in the “Built-up from 2000 to 2014 epochs” (market economy).

This study presents valuable information for the development of regional urban planning strategies to mitigate the effects of AIS during rapid urbanisation. The options for reducing impervious surfaces range from large-scale planning of new developments to simple back yard modifications. New developments can be “clustered” to reduce the area of impervious surfaces required. By doing so, it is often possible to create or preserve publicly-accessible green space, which may include a natural stream corridor or wetland. “Smart Growth” is an example of this type of planning. Based on the obtained results, we revealed different trends of AIS between the two major Bulgarian Black Sea cities *Varna* and *Burgas*. The developments under different economic principles, though apparent for the observer, are possible to be quantified with the aid of satellite data and imperviousness products. The benefits of using new products and services of the Copernicus program, as well as other global databases, provide excellent opportunities at a national level to map AIS and receive more detailed information in high spatial and temporal resolution. New tools are needed due to growing pressures and requirements for land use and the legislative framework, which is often outdated and not well adapted to the real situation. Government bodies are now mainly involved in spatial planning as a long-term process, which also refer to indicative recommendations from a wide range of interested parties in discussions about the society of the future. All AIS products enable local and national authorities to make informed decisions in the spatial planning process, with political awareness of the need for strategic tools for sustainable development in coastal areas.

## ACKNOWLEDGEMENTS

The authors acknowledged the freely provided data from GHSL (DG JRC-EC) and GAIA (Tsinghua University) through the Google Earth Engine platform, which was also used for the pre-processing of the data. The Global Human Settlement Layer (GHSL) project is supported by the European Commission, Joint Research Center, and Directorate-General for Regional and Urban Policy. The GHSL produces new global spatial information, evidence-based analytics, and knowledge describing the human presence on the planet. The study is implemented within the SatWebMare project (Project ID No.4000124110/18/NL/SC) of ESA-PECS for Bulgaria. The authors declare no conflict of interests.

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# TACTILE MAPPING IN KURDISTAN REGIONS, IRAQ: UNDERSTANDING THE RULES OF DEVELOPING ON TACTILE CARTOGRAPHY DESIGN

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## **Abstract**

*This article presents the basic guidelines of adapting traditional maps into modern methods according to the major guidelines of tactile maps. The bullet point of the analysis for the development of the problem associated with geographical names and labels on the coloured tactile maps is to examine the shapes and the key elements of mapping. The lack of tactile maps in the educational system in Kurdistan regions especially and Iraq, in general, should have been mentioned: blind and low vision students should learn according to the same system that normal students use to learn with maps at school. The examples are chosen from the educational curriculum, which proves this study is based on a graphic and technological solution in order to develop the current educational system of the school. The obtained results are very useful for blind and low sighted students to communicate information through the key and abbreviations on the map due to finding the geographical location easily. All the described elements on maps have a notorious impact on raising the practical value of tactile maps in Kurdistan regions in Iraq.*

**Keywords:** Tactile maps, Tactile Graphic, Sightless, Education

## **INTRODUCTION**

Maps have been a significant part of human history for a long time. Paper maps were used and printed as guides for geography, geopolitical, historical, social knowledge and sciences, which all resulted in mankind navigating and viewing on the world easily. Additionally, maps are the best tools that can aid people to build a better theory of changes and the level of their education as well as cartography allows people to achieve knowledge effectively due to leading them into the important step towards independence and examine the way to participate more fully in the regular geography and social studies curriculum. Commonly, school is the first step to develop map knowledge that reaches people from early school life, then they start gathering locational information in different sources. For those reasons, schools should offer professional maps for those students who enjoy their science subjects and more information about the location, resulting in students have a better idea about maps and can explain their opinions more obviously and the results will be rich in map materials. In the Iraqi Kurdistan region sight students have full access to study all map facilities including the library maps for students, to be familiar and achieve map information easily. However, blind and low vision students must have access to this type of information, and it cannot be apart from it. Unfortunately, the lack of tactile maps is mainly obvious in Kurdistan Iraq educational system. It should be noted that all students with low sight and blind people have to learn according to the same program that is accessible on the public and private schools in Kurdistan Iraq. The educational programs in Iraqi Kurdistan have a full range of educational sources they can use during their classes. On the other hand, both vision and especially blind children, to learn not only to need a teacher with a special knowledge, who can carry out the program using oral teaching methods but also with the help of teaching aids. One such source is a tactile map. The source of blind and visually impaired in tactile map works in Kurdistan Iraq is insignificant or it can be said that the supplementary of the tactile map in Kurdistan Iraq does not exist: this research allows to have hope that the new tactile maps for Iraq generally and Kurdistan particularly will be appearing soon as well as the research becomes the part of the school curriculum for developing map skills for blind and low vision students. Tactile maps aims at investigating the need for detailed rules and standards on how maps should be made available or how to provide a valuable source for assistive functionalities about the geographic data for all people with disabilities. The kernel of this investigation is to provide equal access to information. Regarding the terms of the tactile map is to have the specific target for the act of understanding the locational information which can be presented on a map.

## METHODOLOGY

Significantly, the maps for the blind and visually impaired must be similar to the maps for the healthy sighted, so the researcher has taken the sample maps, which are identical to those in school atlases or textbooks. Also, maps have to be clear enough for sighted people because parents or teachers would work with blind and low vision students and they might have habits to learn the differences between reading maps with healthy sight and sightless. Figure 1 shows an example of „map” used in blind and visually impaired schools in Kurdistan Iraq. Geography teachers confirmed that for low vision and blind students, maps were created using plastic, sugar, rice, seeds, beans, nuts and cereals, which brings the view or concepts that need to memorize map information for users (Kareem.A, 2019). Figure 2 shows another technique that was used to produce maps for blind and low sight people: the art of embroidering. This was a very creative way to highlight all locational features and then used as an aid for disabled memories.



*Figure 1. The old method of maps used by schools in Kurdistan*



*Figure 2. Embroidery of the map displayed by schools in Kurdistan*

The result from comparing both maps was that teachers used it, but they found that these were not useful for learning at school. They rejected both old methods made by hand, because teachers found that students were not satisfied and maps were not qualified with the newly available technology that is available in other private schools for learning and using maps. As previously mentioned, this research is becoming the first hope to develop a map in Iraqi Kurdistan for people who are blind and low vision, so the map should be felt rather than be seen. In most blind people the tactile consciousness is highlighted to reward for the loss of sight and this research aims to experiment with these solutions in the autonomous region of Kurdistan in Iraq, beginning the study of the options on the use of the most modern techniques and solutions in the Kurdish special education. The research investigated that maps have been developing more accurately such as using software and drawing on a special paper for blind or using contrast color gels for low

vision users. Human civilizations have never been able to stop technology, so mankind starts the processes for producing printing maps by different types of plastic, shaping carton or metal (Virga, Vincent, et al., 2007). These days they can produce not very complicated tactile maps but also, they can deliver 3D printing and dot maps for blind people. Interestingly, some of the manufacturing can produce maps by using screen printing known as serigraphy. This method is creating an image on paper, fabric or some other object by pressing ink through a screen with areas blocked off by a design map. Additionally, the most popular printing for the Braille is called swell paper and it is also known as the microcapsule, puff or fuser paper. This technology is the heat-sensitive paper and contains chemical ingredients that swell up to form a raised texture (Thinkable products for visually impaired people, 2015). Figure 3 shows one of the samples that the researcher was able to quickly create, in total 47 different and distinct maps that could be exported from ArcGIS for blind and visually impaired users. However, printing and publishing all tactile maps can be one of the requirements that should be considered in future studies. The result of developing the tactile sample maps is to assure learning for tactile readers through the standardization of braille and tactile graphics so the map follows all rules which provide opinions concerning braille in all existing techniques. The effects of its decisions on additional existing Braille codes and formats will be the ease of production by various methods and suitability to all readers and students. The below briefly explains some rules, which have been used on the map:

1. adding the Braille writing system onto maps can be one of the requirements that should be considered for studies. It deals with rules now in existence or to be developed in the future, in collaboration with using English Braille.
2. The research facilitates the use, teaching, and production of -Braille. For that reason, the design map should follow the standard tactile graphic, for example, developed the abbreviation letter is the only way to achieve the main goal, which is facilitating map reading for the blind and completely developed the graphic of the map due to having more spaces to write both texts and shown more graphically rather than words (Table 1).
3. Graphic shapes like points, areas, and lines have a particular significance for the map. In some types of maps, they represent how information changes from map to another. Typically, shapes illustrate the content of the map.
4. It is very important to describe the tactile maps correctly and the choice of fonts must be familiar with Braille standard because the font is important elements in the world of the blind, which can hinder the process of reading with touch. For that reason, the RNIB font is used. RNIB was created by the Royal National Institute of Blind People (RNIB).

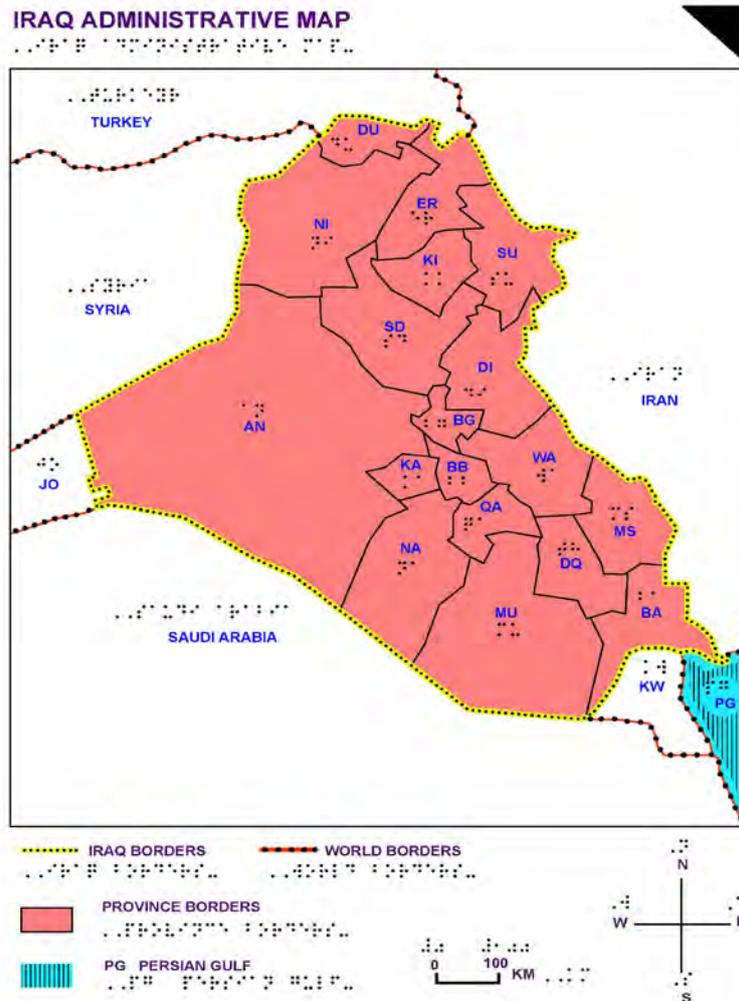


Figure 3. Sample map produced by adapting the traditional method to the new modern ways

## CONCLUSION

Considering the recent achievements and development, there is a reason to hope the development of more projects that would provide schools with new educational supplements similar to colored tactile maps. In this research, a sample map was presented for blind and visually impaired students successfully. The study showed that this technology is used by all people widely. Low vision and blind people will access the knowledge that used to be challenging to attain. In addition, tactile maps can help them by giving them a chance to learn about geographical information. The aim is to use, maintain or improve physical ability and skills while providing enjoyment and in some cases, entertainment for observers. The graphic of tactile maps set out an approach to tactile map design and production that will enable anyone to prepare raised graphics that can be understood by, and meet the needs of, blind and visually impaired people. The research serves them maps to be independent in the future and familiar with county names and regions in the world. The results of this research represent that scholars are trying harder to familiarize low vision and blind people with this technology. Also, studying maps is a part of the school curriculum that requires skills and technology needs that have not been accessible to low vision and blind people until now so shortly students can have fully accessible to study maps at school as the same sight students in Kurdistan regions of Iraq. For future studies would be better for researchers in the area to examine on publishing atlas and perform the study in a 3D map for blind and vision students.

*Table 1. List of 'keys' used in front of abbreviated proper names on the map for blind pupils*

DU	DUHOK
ER	ERBIL
NI	NINAWA
KI	KIRKUK
SU	SULAYMANIYAH
SD	SALA AL DIN
BG	BAGDAD
AN	ANBAR
DI	DIYALA
KA	KARBALA
BB	BABYLON
WA	WASSIT
QA	QADISSAYA
NA	NAJAF
MU	MUTHANNA
DQ	DHI QAR
MS	MISSAN
BA	BASRA
JO	JORDAN
KW	KUWAIT

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## BIOGRAPHY

Ashna Zada moved to Portsmouth in the United Kingdom for a fate scholarship program, which allowed her to join the University and study a master's degree in Geographical Information System (GIS). She spent an enjoyable 2 years in Learning GIS, Remote Sensing, IT course, stimulated my continuing interest in the maps and graphic images. After graduation, she returned to her home country and started working at one of the Iraqi universities. The first job, she joins the Information System Engineering Department from 2014 to 2017 as an Assistant lecturer. She was responsible for supporting the teaching of GIS in the department at undergraduate levels. After that, she got another scholarship to study Ph.D. in a European country, so now she is doing a third-year Ph.D. student at Eötvös Loránd University in Hungary. She obtained experience in various domains like using the newest technology for creating maps for blind and visually impaired people. During the period of her studies, she has obtained some other publications that are available on the internet.

## SOME REFLECTIONS ON SCHOOL CARTOGRAPHY

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### **Abstract**

*School cartography is a specific research field, but at the same time a very important area considering its role in the cartographic education of young generations as future map users. This paper begins with a brief historical overview of school cartography: first concepts related to maps taught in schools, publication of the first school atlases and other topics. Next, the most relevant moments and specialists working in this theme during the 20th century are presented, explaining how school cartography became a scientific research field. Other addressed topic is the role developed in research activities by world-wide organizations like the International Cartographic Association or the International Geographical Union. Finally, the influence of computer-based solutions is also presented, trying to find answers to questions such as: Can the use of GIS in the classrooms be considered successful and widespread? Can GIS be substituted with other web-based solutions? How will school cartography develop in the future?*

**Keywords:** *school cartography, cartography for children, school atlas, web map services, GIS*

### **BRIEF HISTORICAL INTRODUCTION (18<sup>TH</sup> AND 19<sup>TH</sup> CENTURIES)**

The use of maps in schools is an activity that dates back to a distance of around 300 years and that involves the use of different map-based educational materials such as earth globes, wall maps and perhaps the most symbolic and complex of them all, the school atlas. The 18th century can be considered the period when the use of atlases specifically published for schools began to expand to several countries. Two of the first school atlases are works related to the German mapmaker Johann Baptist Homann (1664–1724). The first atlas saw public light in 1710 under the title of “Kleiner Atlas Scholasticus”, with 26 coloured maps (Figure 1).



Figure 1. World map from the “Kleiner Atlas Scholasticus” (1710)

The second atlas was published in Nuremberg in 1719 and its Latin title is "Atlas Methodicus" with the subtitle "Explorandis Juvenum Profectibus in Studio Geographico ...". Fourteen maps represented the countries of Europe, Asia, Africa and America, and at the same time it included four representations of the Solar System according to the ideas of Ptolemy, Tycho Brahe, Copernicus, and Descartes. An interesting detail in this atlas is that California was drawn as an island on the map of America, and appeared in the list of the names of islands too.

In 1774 in Lyon (France), Jean-Marie Bruyset published his "Atlas des enfans, ou nouvelle méthode pour apprendre la géographie ...", with 24 maps characterized by simplified content and it was even translated into English. At the end of that same century, in 1792 the first Spanish-language school atlas was published in the city of Madrid. It was entitled "Modern Elemental Atlas or collection of maps to teach children Geography with an idea of the Sphere". Its author was Don Tomás López, who was a named Spanish geographer and cartographer. The atlas counted with an introductory text of 24 pages followed by 27 maps. A main characteristic of this atlas (apart from the degree of detail of the maps) was that it enriched the example of the Homann Methodical Atlas, since the Introduction explained basic concepts of Astronomical Geography and there were two pages dedicated to the graphic representations of this topic (Figure 2).

The first school atlas in the American continent was published by Mathew Carey in the United States three years later, in 1795: "The General Atlas for Carey's Edition of Guthrie's Geography Improved". However, Carey had already published the maps of this atlas previously in his others atlases for adults according to Patton (1999).

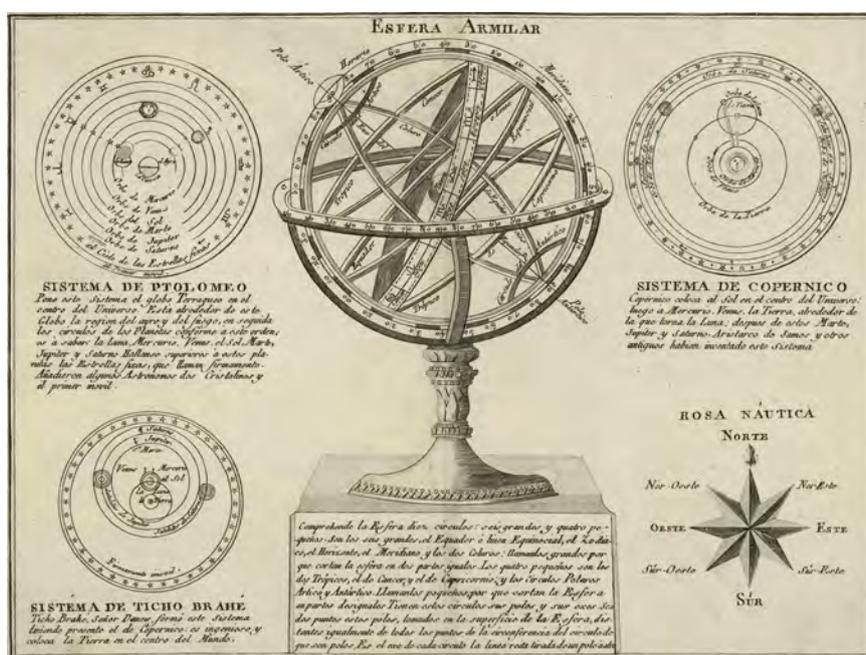


Figure 2. Fragment of one of the two pages dedicated to Astronomical Geography in the "Modern Elemental Atlas" of Don Tomás López (1792)

Textbooks on Geography cannot be forgotten when researchers write about the beginnings of school cartography. For centuries, these books were mainly textual descriptions complemented by data related to the given topic. Different types of illustrations increasingly accompany the texts during the 18th century; the first diagrams or charts began to be included only in the last decade of this century. The most influential changes occurred already in the 19th century, when authors began to illustrate or complete the text using thematic maps. Reliable examples are the textbooks on Geography written by the French professor, economist and historian Pierre Émile Levasseur, who was later named honorary president of the French Geographical Society. In his books, the pupils found maps that were made using the most innovative methods of representation at that time, even including solutions that would be the starting point for new representations to be developed in the future, such as cartograms.

Levasseur not only wrote textbooks, but also created school atlases that included an introduction containing a very detailed graphic and textual presentation of elementary concepts related to astronomy, maps and geography, in addition to combining the maps of his atlases with detailed texts. At the same time as France, other European countries also paid special interest to the edition and publication of school atlases, highlighting names as Stieler or Sydow in the current Germany or Hölzel and Freytag & Berndt in Austria.



point of creating atlases for children? What, really, is a „children’s atlas”? How does it / should it differ from an „adult atlas”? Who decides what information goes in atlases? Are there fundamentally different kinds of „children’s atlases”? How does atlas content relate to the total school curriculum? How do maps as a form of information relate to all other forms in which information is presented to and obtained by children? Is it possible to establish any meaningful, specific standards in comparison to which atlases can be evaluated, or which would allow one atlas to be judged „better” than another? Are there any widely acceptable „first principles” which apply to atlas development in the following domains, for example: perceptual, cognitive, affective, geographic/spatial, societal, utilitarian, aesthetic, political, commercial? What about the future? Are technological/societal changes now underway going to render this current discussion obsolete? (Petchenik, 1987)

Remembering those colleagues who developed significant research activity related to maps for children I could not omit the name of Simon Catling, Professor Emeritus of Primary Education at Oxford Brookes University, United Kingdom. He is currently retired, however already involved in active professional life participating in events, where presents his valuable ideas related to children’s geographical knowledge, the primary geography curriculum and how children can use maps in the classroom and out-of-school activities in a more effective way. Catling began his research activities in the second half of the 1970s, focusing on topics as children and cognitive mapping as well as children’s spatial conception in the geographic education. In his articles and books, he always defended that “the use and study of maps is central to geographical learning and understanding”, as he wrote in an educational guidance material expressly written for teachers after 2005 (Catling, n.d.). One of his latest works is the “Understanding and Teaching Primary Geography” book, which wrote with Tessa Willy (Kingston University) and published in a second edition in 2018.

Other of the most recognized specialists in the decade of 1980s was the geographer David Boardman, who taught at the University of Birmingham. His main research theme was children’s understanding of maps, on which he published numerous scientific articles studying diverse themes as how young children can identify features on vertical aerial photographs and large-scale maps of areas known by them (Boardman, 1989). His book entitled “Graphicacy and Geography Teaching” (published in 1983) constituted one of the obligatory reference works for specialists interested in this topic.

In this period, the list of colleagues working on themes related to school cartography in different countries became very extensive and it is practically impossible to mention all of them. Articles written by Mark Blades, James M. Blaut, Rodney Gerber, Herbert A. Sandford, Christopher Spencer and others can be found in the scientific journals published in those years. Other numerous colleagues (less known internationally by different reasons) also developed an important scientific career in their countries, as Prof. Livia de Oliveira from the Sao Paulo State University, who is author of pioneer works related to school cartography in Brazil, beginning with her MSc thesis entitled “Methodological and Cognitive Study of the Map” from 1977 (Oliveira, 1977).

However, the works developed by individuals are always determinant for a strong scientific base of a research area; colleagues cannot forget the role played by international organizations. The research related to the role of maps in the children’s geographical education is also present in the development of scientific activities encouraged by these organizations. First, I should mention the International Geographical Union (IGU), which was officially founded in Brussels, Belgium in 1952. In this year was founded the Commission on the Teaching of Geography, which membership was formed by geographers interested in the geographical education in general, but more specifically in primary and secondary education. During the decade of 1960s the commission worked together with UNESCO to draft a Source Book for Geography Teaching, which included also themes related to map use by pupils. The book was published in 1965 and was translated into eleven languages in the following years (Graves and Stoltman, 2016). From the IGU Congress held in Montreal in 1972, the name of the commission was changed to the current “Commission on Geographical Education” and it follows organizing periodically scientific events that include also themes related to school cartography.

Already in the late 1950s, a group of internationally recognized cartographers took the first steps to create an international organization specifically dedicated to cartography. Despite some initial contacts with the IGU in 1957 to discuss the possible inclusion of a cartographic section in this organization, representatives of thirteen countries founded the International Cartographic Association (ICA) in Bern, Switzerland in 1959 (Ormeling, 1985). For a relatively long time, colleagues working in school cartography did not count with a commission dedicated to this research area in this association. After the great success of the first International Children’s Map Competition and Exhibition held in Cologne (Germany) in 1993, colleagues developing research on cartography for children in general and in school cartography in specific considered that the conditions were given for the foundation of a commission representing this area. In 1994, a joint Canadian-Brazilian survey was developed to investigate the international level of interest and support to a formal working group concerned with children’s graphic literacy and children’s relationships with maps in this period of changing technology (Anderson and Vasconcellos, 1995). As a direct consequence of this study, the Cartography and Children Working Group was founded at the ICA 10th General Assembly in Barcelona in

1995. Four years later, recognizing the valuable activities developed by the working group to encourage and publicize research related to this topic as well as the growing international interest towards the Barbara Pechenik Competition, the ICA 11th General Assembly approved the group to become the Cartography and Children Commission (Anderson, 2006). Names of researchers as Jacqueline Anderson (Canada), Regina Araujo de Almeida (Brazil), Henry Castner (USA) and Patrick Wiegand (United Kingdom) should be highlighted because of their role in the organization and posterior development of the commission among their scientific contributions to school cartography:

- Jacqueline Anderson (Concordia University, Canada), who developed research on themes related to the use of maps by younger children and the teaching of map skills at early ages. She was first the promoter of the foundation of the working group and later first Chair-person of the Commission.
- Regina (Vasconcellos) Araujo de Almeida (University of São Paulo, Brazil), who participated with Jacqueline Anderson in the organization of the working group and the commission. In her most notorious research projects, she devoted herself to studying the role of cartography in the education of blind and partially sighted children, as well as the cartographic education of Amazonian indigenous peoples in Brazil.
- Professor Henry W. Castner (USA), who in his articles addressed cartography for children in the broader framework offered by the geographic education, developing research on themes related to space perception by children, cartographic and geographic questions in the development of school curriculum, use of map projections in the classroom and the educational taxonomy for maps.
- Patrick Wiegand (University of Leeds, United Kingdom), who conducted research related to the use of maps by children in schools, studying the development of cartographic skills of pupils from their earliest ages. Author of a work already considered anthological on this research area ("Learning and Teaching with Maps", 2006), he applied the results of his research in practice as the advisor-editor of numerous school atlases published by the Oxford University Press in recent years. He served as Chair-person of the ICA Commission on Cartography and Children from 2003 to 2007.

IGU and ICA commissions supported the research activities with the organization of meetings and international events, which constitute an opportunity to meet personally colleagues from different countries, to present results of current research projects and to exchange ideas about ongoing or planned research activities. Many of the works presented at these events have been the basis for the publication of scientific books related to school cartography in different languages and countries.

## **CURRENT RESEARCH ON CARTOGRAPHY FOR CHILDREN AND SCHOOL CARTOGRAPHY**

Readers found two essential terms used in this article to distinguish our research themes from other cartographic topics: cartography for children and school cartography. Figure 4 intends to reflect on the relation between them: cartography for children can be considered a wider term, ranging from studying the first experiences acquired by children about their surrounding space and their individual orientation within this space to the use of maps at the secondary level of education. School cartography overlaps cartography for children: it begins when a child became pupil in the kindergarten or elementary school and includes the learning of spatial orientation without and with maps, the teaching of concepts related to maps, as well as map use in schools and in out-of-school life, together with orientation and experience on creating map-based educational products.

Colleagues continue to develop their research activities, very often in themes that overlap both terms. If we try to classify the general research themes or areas, five main categories could be obtained:

- Theoretical bases related to children's map knowledge: spatial thinking, spatial representation, etc; in general, theoretical knowledge related to map reading and understanding
- Teaching methodologies and materials (maps, atlases and other materials used in schools)
- Technologies used in school cartography (traditional and digital technologies)
- Teacher training and curriculum development
- Study of out-of-school activities related to children's cartographic knowledge in its broadest meaning

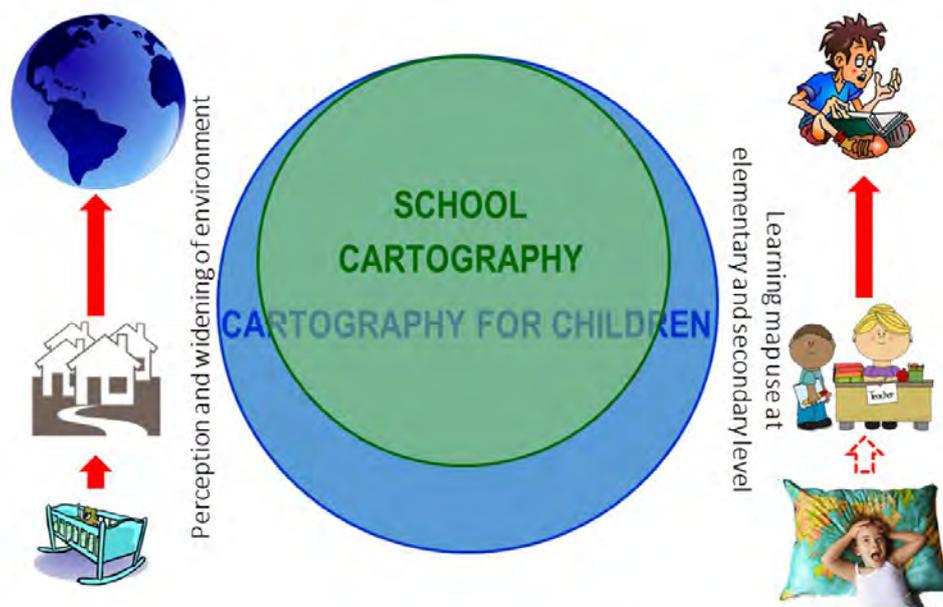


Figure 4. Relation between cartography for children and school cartography

We cannot ignore that very often school cartography overlaps other research areas within cartography (e.g. geovisualization, GIS, web cartography, etc) and other related scientific areas (e.g. data visualization, pedagogy, etc). Other important field overlapped by school cartography is the cartography for blind and partially sighted people, which in our specific case means all the studies related to the edition of atlases, maps and other cartographic products to be used by disabled children in the schools and their daily life. Colleagues can periodically find this research theme in events and publications, because it counts with a rich tradition not only within the ICA, but also in other international organizations too.

At same time, other less researched themes should not be forgotten either, e.g. the teaching of map use for pupils in special schools, which includes the need of children with learning disabilities, communication disorders, emotional and behavioural disorders, physical disabilities, and developmental disabilities among others. Due to the few research done worldwide, colleagues should encourage the development of projects on this topic e.g. by MSc and PhD students.

It is also very important to carry out new international projects, which allow specialists to better understand the differences and similarities of school cartography in different countries, trying to adapt the obtained results or continue developing them together. There have been developed international projects such as the Hungarian-Argentine research entitled “Use and interpretation of maps by school-age children” (2004–2005). One of the suggestions made in this project was the study of new cartographic solutions for their use in maps for children. A result derived from this idea was the Hungarian-Argentine project entitled “Possible uses of the Chernoff faces for data visualization in school cartography” (2008–2009) followed by the Hungarian-Austrian project “Use of Chernoff faces in school maps” developed in 2010 and 2011.

The impact of technological development experienced in the last 30 years is also present in research topics. Already in the decade of the 1990s, works began to be published whose subject was focused on the use of computational techniques in school cartography, studying and predicting the influence that those techniques exerted in subsequent years. It is reflected in the research projects developed by members of the ICA Commission on Cartography and Children, as well as works carried out in the IGU Commission on Geographical Education. In national, regional and international events became habitual the presentation and discussion of papers on topics such as:

- The publication of digital materials for schools, e.g. the publication of school atlases on compact discs and other media, often as annexes or extensions of paper-printed atlases. In the 21<sup>st</sup> century these atlases continued to develop, becoming more complex educational materials, which included not only interactive maps combined with multimedia representations, but also exercises and games based on the guidelines of the national curricula and therefore of the textbooks. In recent years, these materials have been developed for their use in combination with digital whiteboards and tablets.

- The use of GIS in the teaching of Geography and other subjects, its possible use as an effective tool to complete the traditional teaching methods and as a tool used by pupils to answer questions and solve tasks given by the teachers
- Internet and especially the web as an innovative tool in the transmission of information. Among its many roles and purposes, it has been used to teach and popularize basic cartographic knowledge for the new generations. Already in the 21<sup>st</sup> century, school cartography is also influenced by the appearance of Google Maps and Google Earth on the market and the role of web map services in teaching activities constitute the subject of many research projects today.
- Mobile-based solutions in school cartography: a relatively younger research theme, studying how teachers and pupils could take advantage of the mobile technologies in activities inside and outside the classroom

I would like to make a few short reflections on the last three topics that are closely related to each other. The research projects related to GIS in schools have been developing since the 1990s. Despite this, we cannot affirm that we have witnessed the general and successful widespread of the use and teaching of this technology in (mainly secondary) schools in the last 30 years. There were/are different reasons for this situation:

- High costs of GIS software: it was a typical problem in the last decade of the past century and beginnings of the 21<sup>st</sup> century, but the offer of free and open source software (e.g. QGIS) made GIS accessible for those educational institutions with low budget in less developed countries too.
- Difficulties with the GIS formation of teachers: International research projects confirmed that teachers recognized the importance of using GIS in educational activities, but also faced problems to incorporate GIS to these activities. Research developed by Baker et al. (2009), Wheeler et al. (2010), Höhnle et al. (2011) and Singh et al. (2012) considered the lack of time to develop lessons and the lack of practice of the teachers using GIS as crucial factors discouraging the use of GIS in the classrooms, followed by other factors that can be characteristic of a specific country as irrelevance to syllabus (Singh et al., 2012), lack of knowledge about concrete integration of GIS in teaching and lack of interest of other subjects for an interdisciplinary GI(S) cooperation (Höhnle et al., 2011), difficulties in booking the necessary computer labs for GIS lessons (Wheeler et al., 2010) or variable skill levels among students (Baker et al., 2009).
- Decrease in the number of hours dedicated to Geography teaching: However, GIS can be used as a powerful tool in different subjects (e.g. History and Biology), teaching activities about or supported by GIS can be mainly developed in subjects related to Geography. Unfortunately, in the last years we can see a continued decline in the number of hours planned to teach Geography in the majority of European countries. This fact also exerted negative influence in the efforts trying to incorporate GIS into the teaching activities for pupils in the schools. Despite this, some projects try to find solutions to compensate for the decrease in the number of teaching hours. One of them can be the teaching of GIS in activities programmed outside the prescribed class time, e.g. as an optional course (Dékány, 2020).

The factors given in the second and third points are still valid in a vast majority of countries. By this reason, those colleagues interested in developing the teaching and use of GIS in school activities, should find answer to an important question: Did teachers and pupils take advantage of all the options offered by GIS software in those few schools where it has been implemented? Or asking the same question in another way: is it really needed to use GIS in secondary schools to innovate and strengthen teaching activities, to make teaching more interesting and to further involve students in these activities? The results of projects developed in this topic in the last two decades included different types of maps made by pupils using GIS solutions. If we analyse the themes of those maps and the solutions used to represent data on the maps, we can conclude that in a high percentage of cases they are univariate thematic maps that could be made using other less complex software. Taking into account the lack of time and practice of teachers to learn GIS, we should consider the implementation of other GIS- and web-based solutions, which are easier for teachers and pupils to learn and use in the classes or in out-of-school activities. Other factor to be considered when deciding which specific solution can be used in classrooms (and outside of them), is to give preference to services and applications with which they are familiar and are also used in daily life. By these reasons, specialists began to seek new research topics and many results and examples corroborate that one of the most popular solutions is the use of Google Maps as web mapping service and Google My Maps as application to create simple maps. Surfing the web, colleagues can find different projects offering from more general solutions as mapping directions or adding images and videos to a map (Elliot, 2009) to more specific solutions on how to use Google My Maps to illustrate and complete knowledge acquired in the classroom, e.g. working out topics related to the Geography subject (Reyes and Kiss, 2018) (Figure 5).

Teachers can also use online GIS and cartographic applications if they wish to enrich their pupils' abilities. One of the most significant obstacles to solve GIS-based exercises in the classroom is the lack of free and trustworthy databases and base maps. I can suggest two possible solutions depending on the type of maps that teachers wish their students to make:

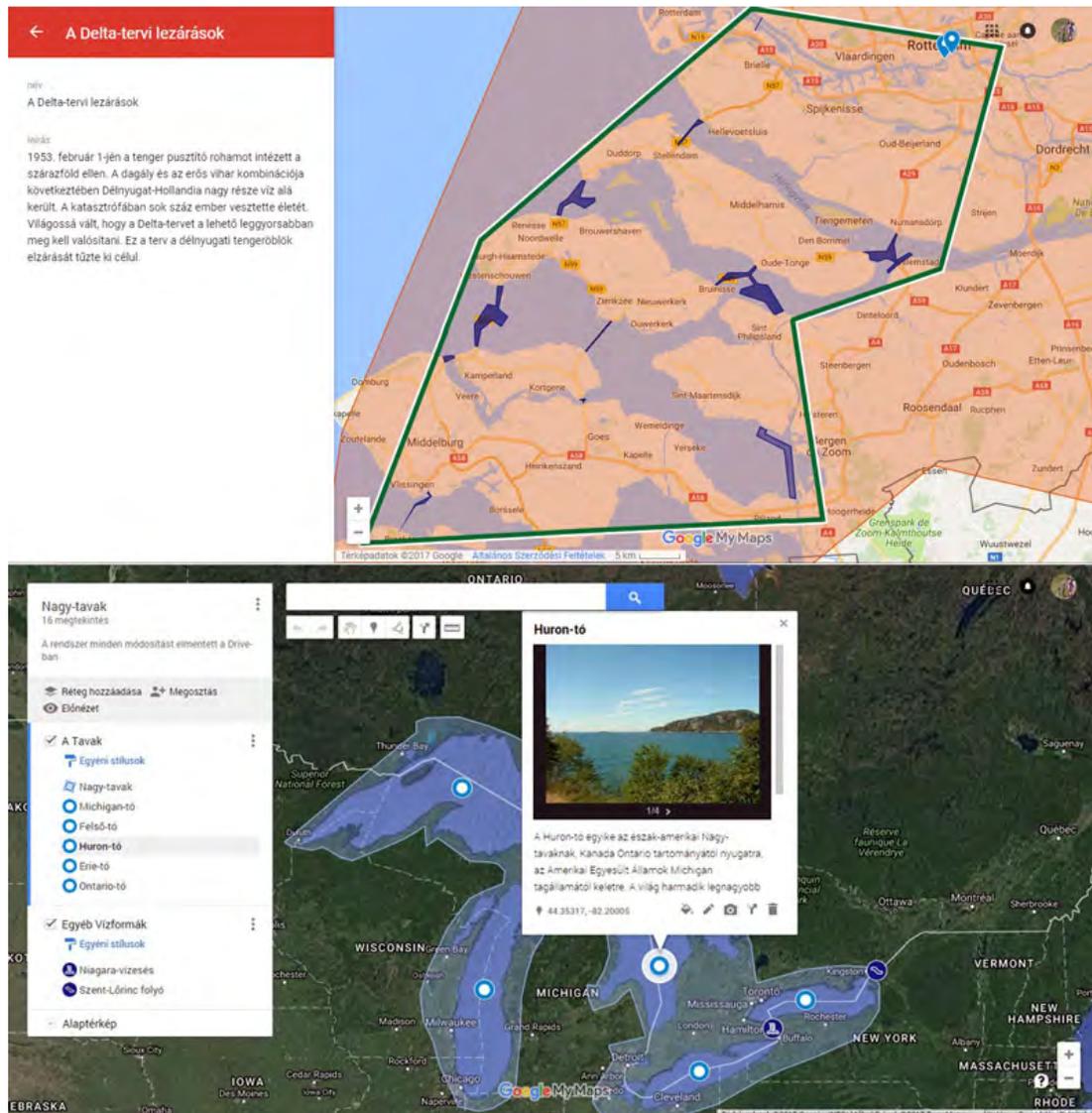


Figure 5. Two maps made by 15-year-old pupils of 9<sup>th</sup> grade in a Hungarian secondary school. The topic to represent was related to the Geography of Water: above, representing the areas taken from the sea and the dams in the Netherlands, below a map of the Great Lakes region in North America. Both maps were made using Google My Maps (Reyes and Kiss, 2018).

- If the main aim is to teach or to use the options offered by GIS at a basic level, then ArcGIS Online ([www.arcgis.com](http://www.arcgis.com)) can be the appropriated choice. Any interested person can open a free account on this website and will have access not only to simple, but smart map editors that are easy to learn. Furthermore, the user can have access to layers and data created and made public by their authors, as well as to a Living Atlas, a free collection of thematic maps. Finally, you also will have an option to create your own presentations and specially story maps, which are interactive multimedia materials to make your maps more dynamic and to combine them with texts, images, videos, etc. Story maps became a very popular solution to present maps and educational materials for the public in general in the last years. Using story maps specialists can even create an online school atlas, as demonstrated by a research project developed by Spanish universities entitled “School Digital Atlas: Learn Geography in Secondary Education with ArcGIS Online” and whose general idea can be accessed at the following address (Miguel González et al., 2016):  
<http://atlas-escolar.maps.arcgis.com/apps/MapJournal/index.html?appid=77ae3efc94174a2fb216abda32b564f4>
- If the teacher is only interested in having pupils create their own thematic maps, then a GIS-based, but simpler online map editor can constitute a good solution. One example is the Datawrapper website, created by Gregor Aisch („visualization architect, interactive news developer”) in 2017 (<https://www.datawrapper.de/>). Using it you can create a chart, a thematic or a locator map, but you should have your own data in text or Excel format.

The limitation for a free account is that you cannot export your map, however you can use a link to visualize it on the web or can get a HTML code to embed it into a homepage.

## FUTURE OPTIONS?

Another challenge to be faced by the school cartography is the adaptation to teaching activities of solutions conceived for mobile devices. Visiting webshops users can find numerous LBS (Location-Based Systems) applications that have been developed e.g. for tourists. In contrast, the number of educational map-based applications created not specifically for teaching activities (e.g. atlases for the public in general) is relatively low, and there are practically no applications created for the school cartography (e.g. school atlases). At the same time, the majority of atlases developed for mobile devices can be classified as view-only atlases (those with some advantages such as fast random access to maps and a minimal interactivity) according to the definition given by Kraak and Ormeling (1996). It means that those products do not make use of the advantages offered by mobile-based solutions that have been described in articles related to ubiquitous cartography, Location Based Systems and others.

A school atlas developed for mobile devices could be considered a combination of diverse existing solutions that can include view-only maps combined with the *flexible cartographic models* defined by Safiza (2007), after its adaptation to the didactical aims of school cartography and for a particular group of users formed by scholars and teachers. These dynamic maps are visualized as the result of an adaptive representation made after positioning the user in space and time, and collecting data related to the user's environment. School atlases can be developed to more complex educational materials taking advantage of LBS options offered by mobile devices, including adaptive geo-exercises related to the pupil's place, that is, combining pre-stored and LBS data to word the questions (Reyes, 2013).

3D solutions are also developed for mobile devices, even though currently the use of 3D mobile devices is very limited due to the insufficient technological development. Different devices (e.g. glasses-free, autostereoscopic parallax barrier displays) have been tested and put out for sale, but without real success and they did not make their presence felt in the market. Despite this situation, specialists are testing different mobile applications designed for the future, using the options offered by the Augmented Reality (AR). Only two examples: in 2019 was founded the Elsa 3D MAP Hungarian startup, which is making 3D maps in Augmented Reality specifically designed for education (Zsoldi, 2020). In the startup's website you can find examples of physical and thematic maps developed specially to be used in teaching activities. During the 29<sup>th</sup> International Cartographic Conference celebrated in Tokyo in July 2019 participants had the opportunity to listen to the ideas presented by a young Bulgarian researcher, Nikolai Yonov, about how Augmented Reality could be used to complement the visualization of a school atlas with thematic information (data, images, 3D models) collected and updated in real time (Yonov, 2019). Could these technologies be applied in schools in the near future? All of us should be confident that a positive answer can be given to this question in the coming years.

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# EXPLORING MINECRAFT AS A TOOL FOR GEOSPATIAL EDUCATION

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## **Abstract**

*The advanced technology of video games is considered to promote motivation, excitement and participation of users, and this kind of interactive engagement is proved to improve learners’ understanding and outcomes. As Minecraft is a world-famous game widely known as an educational platform, the aim of this paper is to investigate what is unique about it and how it can be utilized by geospatial education. Thus, it is made a general overview of the game, its specific features and versions, and the place it takes in the world of video games. This research is followed by a solution developed for the environment of Minecraft, and the main steps, benefits and challenges are presented. It is extended with an questionnaire on audience approval of game-based learning, gamification and Minecraft in particular.*

**Keywords:** geospatial education, Minecraft, game-based learning

## **INTRODUCTION**

While traditional learning is based on teacher-student interaction, this focus changed during the last decades. The contemporary technologies, including internet, virtual reality (VR)/augmented reality (AR), and video games, are gaining growing popularity. Their applicability in the classroom has been a subject of studies for a variety of academic researches since 1970s, when educational researchers felt there’s a need to have a different instructional design in the classroom [18]. The traditional teaching methodologies have failed to invoke learning interest, especially in hard disciplines like mathematics and sciences. On the other hand, regarding to modern education perspective, video games seem to be the needed tool to advance cognitive development, creativity, innovativeness and organization.

## **MINECRAFT**

The current paper focuses on the use of Minecraft as an educational tool, which is not a new idea. Created and published by Mojang in 2009, and bought by Microsoft in 2014, it becomes one of the most popular sandbox games in the world. The term ‘sandbox’ refers literally to sandbox, emphasizing the great degree of creativity within this kind of video games.

Its applicability for education are studied and presented in [4], discussing its capability ‘to benefit the learning process in scientific or social way’, containing ‘amazing opportunities for development in field of scientific education’, and concludes that ‘despite the game limitations, possibility of usage in educational field education is limitless’. Today, 7 years after this paper was published, not only Minecraft’s popularity has grown but its opportunities for the purposes of education.

Regarding to [15], by September 2019, 112 monthly users play Minecraft, and its versions, on games consoles, computers, mobile devices. The average age of a Minecraft player is 24 years old. At first sight it might be difficult to propose what makes Minecraft such a hit, but the given explanation by [14] sounds reasonable at last: ‘It’s a system for fitting pieces together to create something — sometimes amazing somethings — from nothing. "Minecraft" provides endless building blocks and a blank canvas; it’s up to you to create something incredible, or silly, or referential, or whatever else using the tools it provides. The tools are blessedly user-friendly, as are the systems for employing those tools.’

The choice of Minecraft as an educational platform, opens the door to a large community on which one can rely. The access to it is available through its official website [13], containing four main sections:

- Games – links to Minecraft, Minecraft Dungeons, Minecraft Earth and Minecraft: Education Edition;

- Community – including news, streams, official Youtube channel, community creations and discussion and help;
- Merch – the official store of Minecraft;
- Support – the help center.

### **Some Applications of Minecraft in Education and (Geo)spatial**

Regarding to [10], gamified learning tools, like Minecraft, give students 21st century skills (creative thinking, reading and writing skills, computational thinking), job preparedness and STEM, and social-emotional development, as well. 98% of teachers who use Minecraft in their classroom mark problem solving as the main skill their students learn from Minecraft, and 71% of teachers using digital games reported improvement in computational thinking and numeracy skills.

In [2] is described a study on the effect of video games on the development of generic skills like problem solving, communications, resourcefulness and adaptability in higher education students. The games used in this pilot project were selected with the assistance of professionals from industry and academia and included 8 titles, one of which was Minecraft. Regarding the conclusion ‘playing video games can have a positive effect on communication ability, adaptability and resourcefulness in adult learners’ and ‘also suggests that graduate skills may be improved in a relatively short amount of time [...] over a period of eight weeks and representing just 14 h of game play’.

Minecraft is also a game that promotes creativity in players. Considered as ‘digital LEGO’ [17], in [8] a participant in the study shares his opinion ‘I enjoy molding it [Minecraft], so adding things that weren’t in there originally. And I am fascinated by automation systems, so I’ll have mods that allow me to instead of building my own stuff, I’ll start a factory that will build the stuff for me.’

The study presented in [11] is focused on how VR can assist architects at the early stages of ideation and design. Compared to conventional CAD systems, which offer many design functionalities, but require long time to master and seems not so suitable to support initial architectural design concepts, Minecraft allows players to creatively build virtual objects with textured cubes in worlds made from voxels, and this inspires a designing system based on a simple set of operations.

In [1] LiDAR technologies are used to measure the 3D urban greenspace which data was being a subject of experiment on new methods for mapping by Geographic Information Systems (GIS), Minecraft, 3D printing and Computer Numerical Control (CNC) milling processes. Minecraft was applied for visualization of GeoTIFF images on Raspberry Pi. Being presented on several exhibitions it raised discussion on both the data and the visualization itself as a tool to ‘be in’ the model allowing to see it and understand it in a new way.

### **Spin-off games**

There are four different versions of Minecraft. Here is what each of them represents:

- Minecraft – described as “an adventure of limitless possibilities to build, mine, battle mobs, and explore the ever-changing Minecraft landscape”. It can be played in two different modes: “Creative Mode” to build a dream world based on personal imagination and the limitless resources of the games; “Survival Model” to explore the landscape, construct shelter and fight night creatures. It can be played single or multiplayer. It is available for computer (Windows, Mac, Linux), mobile (Android, iOS), console (Xbox One, Xbox 360, Nintendo Switch, PS4, PS3, PSVita, Wii U, Nintendo 3DS) and other platforms (Fire, Fire TV, Gear VR, Oculus). The single license price is affordable low (about 30 dollars but could be found for less on sale).
- Minecraft Dungeons – a brand-new dungeon crawler game coming in spring 2020. It is available for up to 4 people playing together. Supported platforms include Windows, Xbox One, Nintendo Switch and PS4. It is currently available on pre-order at the price of about 20 dollars.
- Minecraft Earth – another brand-new game announced in 2019. Based on augmented reality (AR) technology it offers experience to create, explore and survive on the overworld map. Allows collaborations between players. The supported platforms include Android 8+ and iOS 10+. It is free to play.
- Minecraft: Education Edition – regarding to [13], it is ‘a game-based learning platform that promotes creativity, collaboration, and problem-solving in an immersive digital environment’. The supported platforms include both Windows and Mac. It is available via early subscription of 5 dollars. Without a license, M:EE is

still available for use but for a limited number of logins – 25 for educators and 10 for students. In order to login and purchase it, an Office 365 Education account is required.

Among this variety Minecraft: Education Edition stands out as a platform for learning. Therefore, a special overview of it will be made in the following lines.

## **MINECRAFT: EDUCATION EDITION (M:EE)**

Regarding to [15] the number of Minecraft: Education Edition users is more than 2 million (by 14 November 2017). The number of countries of M: EE users is 115 users (by 14 November 2017).

In the section of M:EE on the official website of Minecraft there are several subsections:

- How It Works – description, key features and impact on classrooms;
- Class Resources – educator resources, starter kits, world library, coding lessons and challenges;
- Community – global Minecraft educators community represented via forum, blog and social media (Facebook, Twitter, Youtube, Pinterest);
- Support – help center, contact and download;
- My Classroom – sign-in to personal account.

Though some of them remind of the main section mentioned above, these are specifically dedicated to this particular edition of Minecraft. All of them are useful for their purpose but for new users it is advisable to take the available ‘My Minecraft Journey course’ in Class Resources – an introductory course for educators who want to integrate M:EE in their classroom. The learning topics starts from ‘Why M:EE?’, followed by others including building community, basic Minecraft mechanics, designing learning experience, etc. with complete duration of 8.5 hours.

### **Class Resources**

There is a number of starter worlds available for download through the website and use in classroom. The list of featured worlds can be viewed or searched by keyword, type and game mode.

There is also a large amount of lessons available both on the app and on the website. They can be filtered by age – 3-5, 6-7, 8-10, 11-13, 14-18, 18+ and all ages. Another criterion is taught subject. Categories include math, science, languages, government, visual art, tech, geography, language arts, animals, business, environment, digital, theater, gaming, history, music, health, religion, safe schools, social good, security in e-learning, computer sciences, careers, special education and leadership.

In terms of current report of greatest interest are the available lessons for 18+ / all ages students in math, science, tech and geography. The currently available lessons relevant to a search by these criteria include topics like ‘Moon Craft 2.0 Lunar Learning’ about ethics of the Moon use, NASA’s Lunar Orbital Platform Gateway, Lunar living, mining the Moon and Lunar transport; ‘History Blocks’ aiming to guide teachers through an activity in which students reconstruct UNESCO world heritage sites; ‘Renewable Energy Sources’; ‘Map the Journey’ for practice in finding locations on a map of United States; ‘Building a refugee Camp’ for planning and creating a refugee settlement, etc.

An interesting example is the ‘Coordinate System Tutorial’ (Fig.1, a)) dedicated to users of all ages who want to get familiar with 3D coordinate system. The guiding ideas of this lesson raise questions on what a 3d coordinate system is, what coordinates mean, map use and navigation. The lesson consists of three activities including exploring and learning about 3d coordinate systems, practice on finding coordinates and practice teleporting. More on it can be found in [3].

‘The City of Florence (Italy)’ (Fig.1, b)) is another example of a lesson for all ages in subjects including art and design, geography and history [19]. The amazing thing about it is that it gives the chance to explore real-life historical and cultural sites from Florence represented in the world of M: EE.

‘Pipe Dreams’ (Fig.1, c)) is about an engineering task on building an oil pipeline from one village to another considering safety, lifestyles, cost and landscape beauty [12]. Learning objectives include students pipeline route planning as a team, engineer a safe, non-intrusive and cost-effective pipeline from the oil source to the processing town, employing critical thought when adding extra safety aspects near rivers and mountains.

‘The Island’ (Fig.1, d)) is another interesting lesson in the field of science, technology and geography [21]. It is about mining from the island and building innovative islands in a world that offers ocean side villages and plenty of coastal

space. Performance expectations include students' collaborations as village teams to mine materials needed for island development, designing an innovative pattern for the islands, focusing on safety, beauty and maximizing land space and determination a purpose for the islands and build of appropriate structures.

'The Eiffel Tower' (Fig.1, e)) is a challenge for students to read a comprehensive description of the Eiffel tower and built it according to the provided specifications [20]. Presuming one Minecraft block equals 1 meter cubed, they have to use a range of mathematical skills to reproduce it according to the provided information.

Most of the mentioned lessons are considered to develop critical thinking, and collaboration as they involve not single students but whole teams. Other mentioned skills include creativity, communication and citizenship.



Figure 1. Examples of M: EE lessons dedicated for students of all ages in the fields of mathematics, science, technology and geography

## Registration

The process of registration as a Microsoft educator includes a few simple steps. Being a registered educator is a joint a community of fellow educators and earn badges, as well. The second is a sign of being an active supporter of Minecraft and game-based learning. Each level is unlocked after completing different task, including the My Minecraft Journey course. The final step is application for Minecraft Mentor.

## SOLUTION

### Choice Software

While ME:E seems a logical choice when it comes to teaching, its usage is limited to educational institutions. As the basic Minecraft remains the most popular, and accessible one for everybody, as well, it was chosen for core solution of the current case study. In order to create own worlds Java edition is required.

Then came the question of how geospatial education could benefit from it. There have already been released tools like GeoBoxers [6] and Geocraft [7] dedicated to geospatial education in the environment of Minecraft and integration of real-world data, modelling, GIS, for dealing with issues in water management, land use, urban planning, etc. As key features for the choice of solution outlined versatility, as well as ease-of-use and affordability which eventually led to Safe Software's FME.

FME's key capabilities include data integration, transformation, conversion and validation, as well as application integration. The supported data types include 3D, big data, BIM, CAD, GIS, LiDAR, markup languages, raster and imagery, satellite images, sensor data, web services, database and data warehouse integration solutions, and business intelligence. Google, Microsoft, Esri ArcGIS and Autodesk are among the technologies of over 450 integration options. Minecraft is the first gaming format added to this list allowing users to bring real-world data from vector layers, rasters, point clouds and 3D models into the world of Minecraft.

Its official website [5] contains extensive information on the following topics:

- FME products – FME Desktop (a subject of the current study), FME Server and FME Cloud; release notes, downloads, licensing.
- Why FME – industry and data type solutions, customer stories, data management.
- Community – forums, ideas exchange, blog, etc.
- Support – training materials, technical support, etc.

FME pricing is divided to subscriptions for organizations, and individual license purchase. However, a few free-license opportunities are also available including: 30-day trial for anyone, 1-year home use, 4-month student license, 1-year license for recent graduates, as well as free ongoing licenses for instruction and unfunded research.

FME Desktop is supported on Windows, Linux and Mac operating systems. Recommended hardware requirements include Pentium 4, AMD Opteron or newer with 8 GB or more of RAM and 20 GB available disk space.

There are some examples of how FME works for creation of Minecraft world, available for download on the FME Community section. The list include the Easter Island (Fig. 2 a)), LAS of a Norway landscape (Fig. 2 b)), vector/raster of Bowen Island (Fig. 2 c)), BIM of Arboleda (Fig. 2 d)), a Vancouver railway (Fig. 2 e)), and even game withing the game represented by a maze (Fig. 2 f)). In addition to them are available extensive explanations on their creation [9].

### Workflow

Blocks are the basic units of structure in Minecraft and can be directly placed in the game world [16]. They are arranged in a three-dimensional grid, typically of 1 m size. The textures on their faces are 16x16 pixels, but both of them can be changed using resource packs (APIs which makes it possible to customize textures, models, music, fonts, etc. without code modification).

FME can both read and write Minecraft worlds. In the environment of FME this data exists as a point cloud with 3D coordinates complemented with blockID and blockData. Basic workflow in FME (Fig. 3) include the following steps:

1. Data import – drag and drop data from file browser to an empty FME canvas
2. Data visualization – run workspace to view data

3. Transforming data + modify transformer parameters – a data transformer is added by simply typing on the canvas; double clicking on it allows change of its parameters
4. Data output – a writer is added in order to write data in a chosen output format; running the workspace writes it to disk

To create a Minecraft world from LiDAR measurements it is enough to read the available point cloud information, and write it in the relevant format (Fig. 4). Tested with a simple XYZ file, columns' content is defined through a component map at the data import. Other import parameters like lines to skip, maximum lines to scan, etc. can be also specified, as well as to choose the coordinate system.

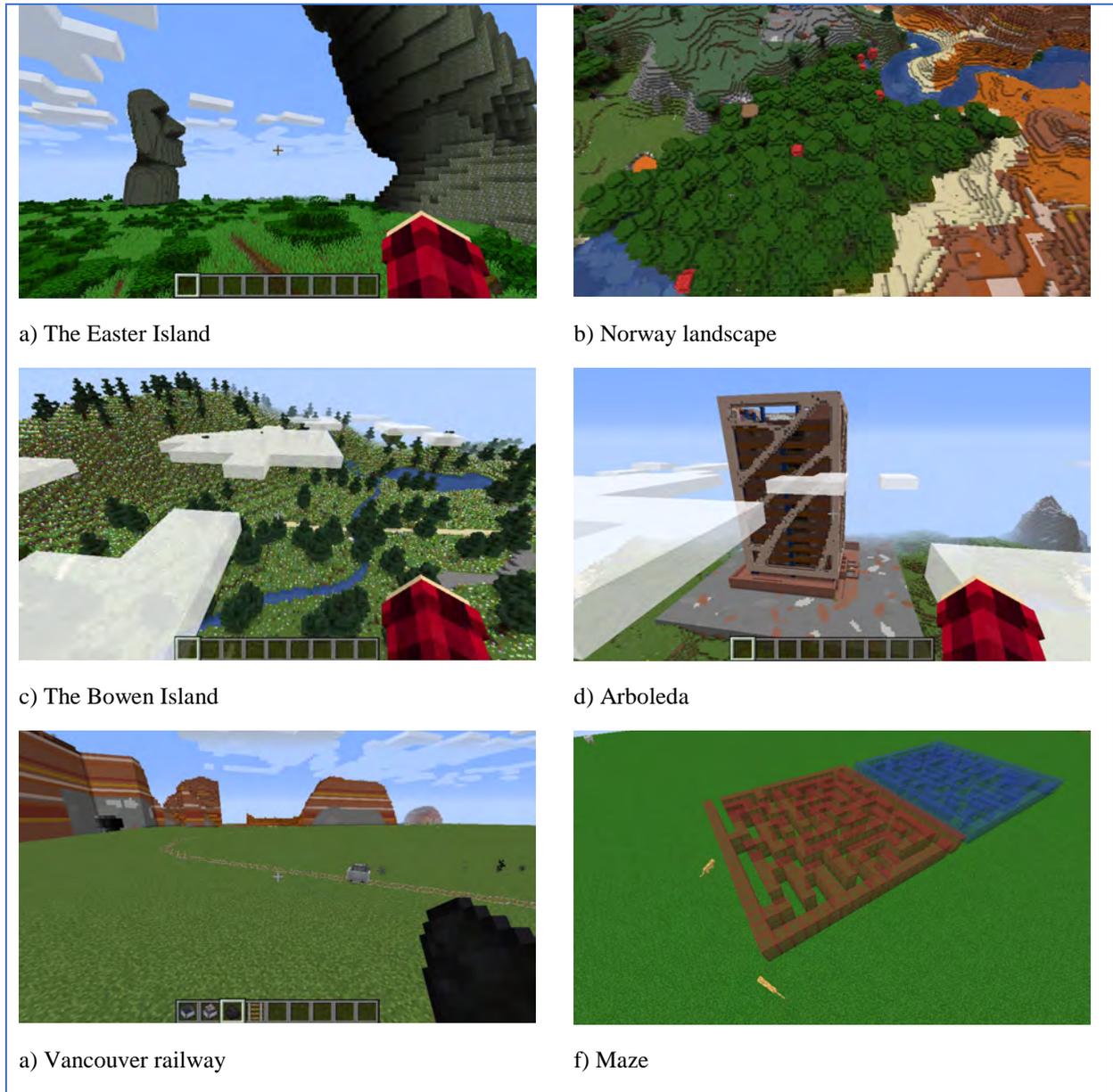


Figure 2. Real-world sceneries in Minecraft



Figure 3. Basic workflow in FME

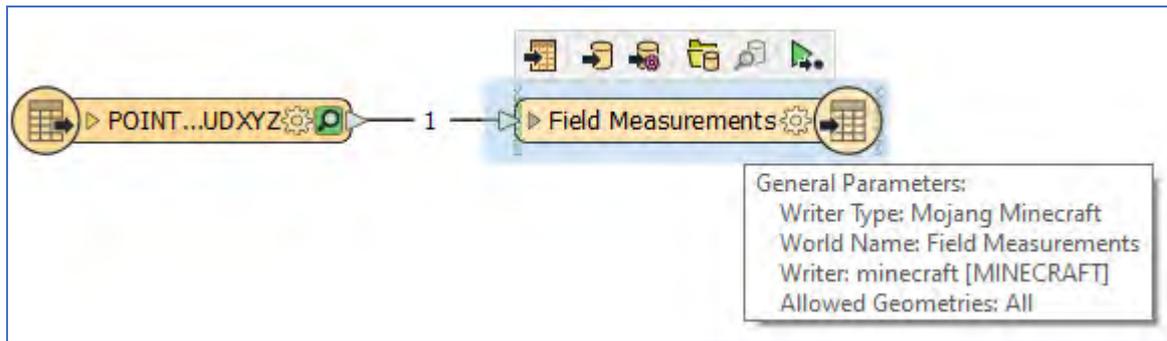


Figure 4. Simple read&write workflow to transform field measurements into a Minecraft readable format

Once the data is transferred into the format of Minecraft, it must be put in the folder of Minecraft's worlds. ".minecraft", or "minecraft" in macOS, is the folder which Minecraft creates to run from. Its location on Windows is "%APPDATA%\minecraft", on macOS is "~/Library/Application Support/Minecraft", and "~/minecraft" on Linux. The newly generated data must be copied into the "saves" folder there. If there are any other worlds created previously on Minecraft, they can be seen there stored in their own folders.

Regarding to [9] a few essential things to bear in mind when making a Minecraft world are:

- Size: the scale must be considered so it won't take too much time (as if in the real world) to walk the Minecraft world. Also, the heights are limited to values between 0 and 256, and the sea level is at 63, so the altitudes and bathymetry must be scaled to these.
- Blocks: blocks are defined by their blockID and blockData which plays a role in building realistic world both in terms of visual appearance and logic. But for some cases, i.e. creation of a physical map, these components are not important.
- Irregularly spaced input data: direct writing of such data to Minecraft will lead to holes in the world.

## AUDIENCE APPROVAL

A questionnaire was held among students in Mine Surveying and Geodesy in the University of Mining and Geology 'St. Ivan Rilski' (Sofia, Bulgaria). The aim was to study the application and approval of gamification and game-based learning, and Minecraft in particular. The number of people who took part is 16, 12 women and 4 men, at the age of 20. Their answers are presented in Fig. 5.

Regarding to the given answers, most of them play video games, although not as an educational tool. Just a few have ever played Minecraft but it is a popular name among them. Most of them think that game-based learning could improve educational process, and it is followed by gamification – the introduction of game elements (passing levels, earning badges. etc.) into the learning process; one student suppose that neither game-based learning nor gamification could enhance education.

In one last, optional question, students were asked to propose a game which they found close to their specialty. Six of them gave their proposal, and half of them gave Minecraft as an answer.

## SUMMARY AND CONCLUSIONS

Game-based learning is a contemporary way of gaining learners' attention and enhancing their results, and Minecraft is a worldwide popular video game known for his creativity features, educational capabilities and large community support you can rely on. Both basic Minecraft and Minecraft:Education Edition are affordable and applicable in geospatial. But while the use of M:EE is limited to educational institutions, Minecraft is accessible for anyone.

Creation of Minecraft worlds is much similar to geospatial tasks. With the presented software solution for bringing real data into Minecraft, it turns into simple and yet spectacular modelling tool.

Students also see game-based learning and gamification as methods which could enhance their education, and recognize Minecraft as an appropriate tool. Regarding to previous studies on these topics, as well as the solution and attitude presented above, it is reasonable to integrate it in geospatial education.

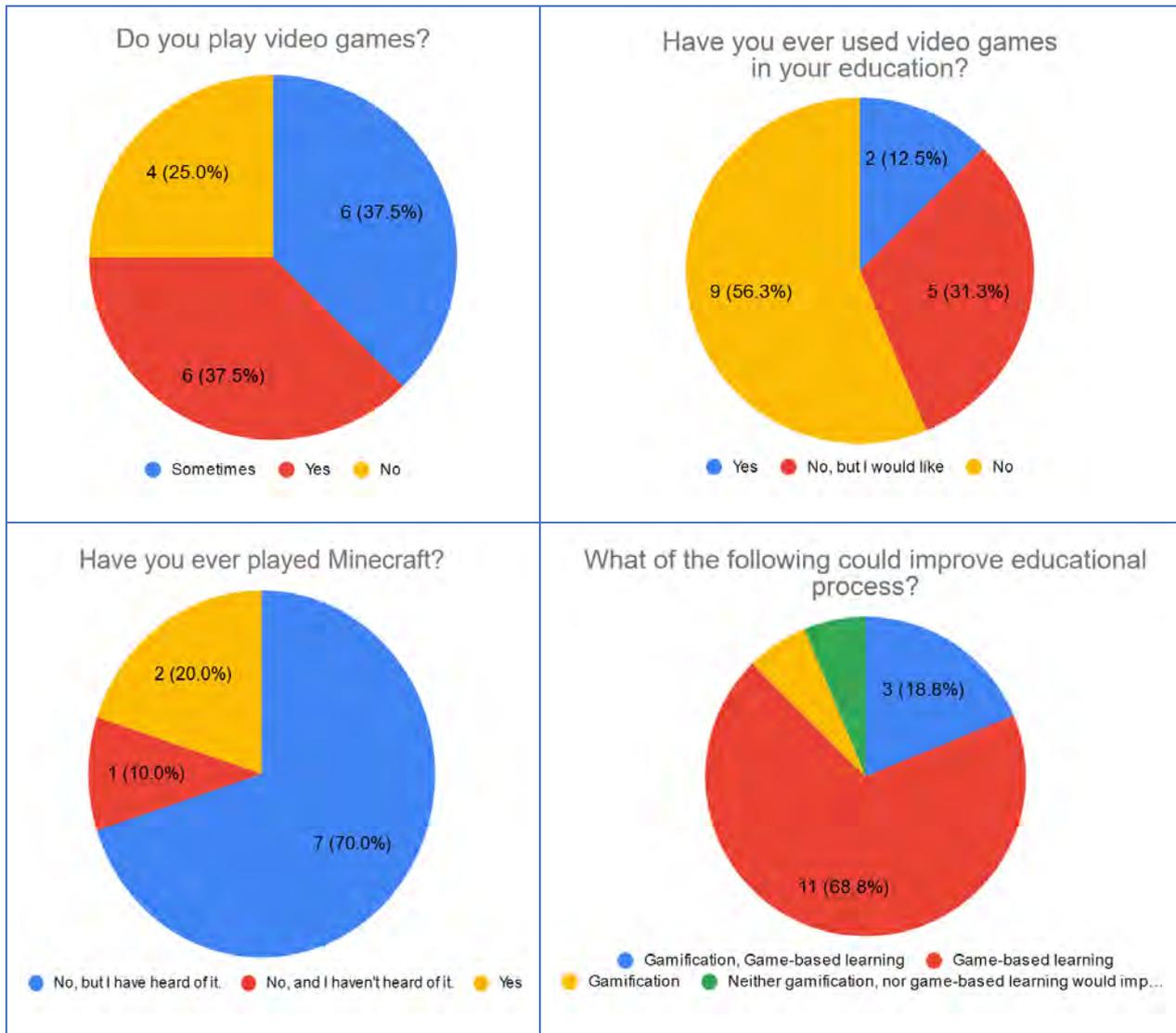


Figure 5. Audience approval

## ACKNOWLEDGEMENTS

The author of this paper would like to express her gratitude to Safe Software and their grant on FME software.

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# APPLICATION OF GIS METHODS FOR THE STUDY OF RIVER ECOSYSTEMS IN THE TEACHING PROCESS OF THE UNIVERSITY OF FORESTRY

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## **Abstract**

*Water is a major natural resource that ensures the creation of all life forms. At the same time water has an economic, social, political and other impacts, while influencing both all other human activities and lives, and the efficiency of ecosystems. In this case, with all the questions, connected to the research and analysis of the regularity of the division and movement of water, as well as their interaction with the earth's surface, which is influential in a large part of their quantities and qualities, and are of fundamental interest for researchers and specialists working in different sectors of the economy, the administration itself at all levels and non-government organizations. It is knowledge of these processes in the context of rivers and rivers systems that is particularly important in the preparation of specialists in fields such as: ecology, forestry, agronomy, landscape architecture, administration and management and tourism. This is an area in which the University of Forestry is dedicated to proving itself as an established and leading educational and research institution. The current article reviews the acquired experience and good teaching practices in teaching students the application of GIS tools and methods, in models, research and analysis of rivers and river systems, related to aspects such as the watershed determination, longitudinal profiles of rivers and others. Research of methods and accumulation of experience can be done in the context of the existing expertise and activities at the University of Forestry, but it can be offered by specialists and researchers in other fields of study.*

**Keywords:** GIS, DEM, water resources, education

## **INTRODUCTION**

The existence and course of every process on Earth is directly or indirectly determined by water as a major resource. From purely physical survival, through its use as an environment or resource for economic activities, to its application and as a remedy, water is present in the daily lives of all living beings. Regardless of how it is used - directly or indirectly, it is a key factor in any activity. The inevitable climate change is leading to changes in the functioning of aquatic ecosystems. In order to survive and be used effectively, it is increasingly necessary to use methods for their modeling other than those based on economic considerations regarding their distribution. Traditional cost-benefit analyzes do not take into account ethical, political, social, historical or environmental issues that cannot be easily quantified [1]. Wider decision-making frameworks are required, such as multi-criteria analysis, which include other factors, such as environmental support systems, to support aquatic ecosystems. The long-term use of GIS in many areas related to the prediction and prevention of disasters and accidents is crucial for their recognition and rapid development. The functional capabilities they provide make them particularly suitable for solving problems related to the study and analysis of patterns in the distribution and movement of water, as well as their interaction with the earth's surface, which reflects on their quantitative and qualitative changes. On the other hand, GIS has long been part of the process of active use of information and communication technologies in the field of creating, managing and providing access to scientific resources and activities. This is largely due to the accumulated useful practical experience and know-how of scientific organizations and the development of the normative base in the Republic of Bulgaria, regulating the use of various tools to accelerate the process of digitization of accumulated resources in scientific data base. Any activity,

project and initiative leading to the creation of digital content, with the help of innovative means to improve access to high-tech solutions that lead to higher quality in science and education are a key goal of development policies and priorities under the national development program "Bulgaria 2020". The application of GIS tools and methods in the modeling, study and analysis of rivers and river systems related to aspects such as watershed determination, longitudinal river profiles and others is part of the training of students and PhD students. Knowledge of these processes in the context of rivers and river systems is especially important in the training of specialists in areas such as ecology, forestry, agronomy, landscape architecture, administration and management and tourism. These are areas in which the University of Forestry has long proven itself to be an established and leading educational and research institution.

## **SECTORS FOR USE OF GIS IN THE FIELD OF RIVER ECOSYSTEMS**

Water has significant economic, social, political and other impacts, affecting both the daily activities and lives of people and the functioning of various ecosystems. For this reason, all issues related to the study and analysis of patterns in the distribution and movement of water are of major interest to researchers and professionals working in various sectors of the economy, public administration at all levels and non-governmental organizations. Existing global estimates in monetary terms provide guidance on the importance of the various eco-services, including the use of river ecosystem resources, but they need to be complemented by other methods and means to identify changes resulting from different scenarios and policies [2]. With the variety of information processing tools related to water modeling and management, GIS provide the opportunity to perform various analyzes related to river ecosystems. In watersheds characterized by land fragmentation and terrain cleared of primary vegetation, GIS can be used to identify and delineate the river channel network in reservoirs, to map slope and direction of outflow, and to assess human impact on the land cover of river ecosystems [3]. Sustainable management of aquatic ecosystems can be greatly aided by the use of GIS as a means of assessing and tracking spatial information on the availability of water in water bodies over time and within a predetermined unit of space [4]. This is based on the combined use of rainfall and temperature data, elevation, slope and soil type data, and land use. Water resources management based on a hydrological model based on geomorphology (GBHM) is another aspect of the use of GIS in this direction. The creation of a series of land use classifications, using the controlled classification method, based on digital elevation and model data, allows for the analysis of river basins, using the geomorphological properties for each hydrological process of a catchment area [5]. Spatially distributed hydrological models enabling the combined study of climate, topography, vegetation and soils are the basis of the integrated GIS tools for watershed assessment. In order to increase the profitability of their use, they must provide a framework that combines all the spatial data used to prepare input files for the models and based on widely available specialized sets [6]. GIS can be used in the processes of effective catchment of river ecosystems in the direction of modeling the drainage areas of rivers, which provide a natural boundary for management and mitigation of interactions between people and the environment. This can be used to address water scarcity and quality problems, floods and erosion [7]. The benefits of using GIS and remote monitoring methods can also be sought in the opportunities they provide for modeling and controlling sedimentation in river basins and associated ecosystems. They can be used in informed decision-making processes related to plans for the construction of recharging structures, planned afforestation or other actions aimed at limiting soil erosion [8]. Performing morphometric analysis for the management of watersheds and ecosystems can be supported by GIS, which proves to be an effective tool for outlining the model of drainage and management of water resources and their planning [9]. Remote monitoring and GIS tools have been successfully applied to understand morphometric characteristics in different morphoclimatic conditions. Drainage morphometric parameters are an important indicator for understanding the hydrological and morphological characteristics of each region. In this regard, the mentioned methods and technologies are used as effective tools for delineating and understanding any morphometry of river drainage basins and their catchments [10]. GIS can also play a synchronizing role in the processes of cooperation and communication between state institutions and individual stakeholders related to water management, balancing biophysical and socio-economic problems. This is due to the fact that the general public is increasingly involved in initiatives related to environmental solutions, which leads to an increasing need for technology transfer from public agencies to stakeholders [11]. In some cases, in order to get the maximum benefit from the application of GIS in modeling processes, both in river basins and ecosystems, it is appropriate to combine them with traditional mathematical models [12]. A major problem here is the development of systems that manage spatial processes based on interactions between spatial units. In summary, GIS are an important and invariable part of the processes related to solving a number of complex tasks and for this reason the education of trained staff to apply them is of particular importance. The experience gained in the development and implementation of GIS and databases for experimental sample areas can be applied in the study of protected areas, environmental monitoring and ensuring the sustainable development of biological resources [13].

## **GIS AND THE TEACHING PROCESS**

In science and education, as in many other areas, there is a need for innovative digital solutions to support core activities, driven by the increasingly common corporate approach to information management, with an emphasis on data

sharing and reuse. This highlights a number of challenges related to their effective and coherent use, such as: designing, developing and implementing the next generation of critical digital solutions; modernization of the existing base; models allowing flexible, innovative and shared use. Essential here are actions in terms of governance, resources and digital skills, without which it is impossible to achieve the desired transformation.

The traditional organization of the educational process related to the theory and practice in the field of use and application of geographic information systems in the system of higher education is usually composed of two parts. The first part of the training covers the theoretical aspects of GIS and includes issues in the field of information systems and technologies, definitions and scope of related concepts, corresponding mathematical models, coordinate systems, projections, features of raster, vector and attribute data, levels of detail, sources for gathering georeferenced information, means and methods for digitalization and visualization and others. The second part emphasizes the features of GIS, as part of the family of modern information technology, with the aim to acquaint students with the main features of the environment, graphical user interface, organization and access to available tools, data storage methods, basic and auxiliary data formats supported by the system, methods of installing and configuring the software application. Despite the general principles underlying modern GIS software applications, these aspects are largely strictly specific to the respective software product, which creates difficulties in adapting learners to other environments and transferring the accumulated applied and practical experience to other software products. On the other hand, the training is closely related to the time component, most often within 15 weeks, which adds an additional element of difficulty in mastering the subject of GIS and requires a search for more effective approaches to obtaining time-sustainable knowledge, skills and the necessary practical experience for the successful future realization of students on the labor market.



Figure 1. Advantages of GIS training in a university environment

Unfortunately, the time component is a factor that largely determines the complexity of the practical examples and the tasks considered. Figure 1 shows the main advantages of GIS training in a university environment compared to specialized courses for working with GIS. Combined, they provide an opportunity to systematize knowledge and skills according to a specific professional field or specific scientific field.

In recent years, users can also benefit from GIS training courses. This includes training of employees from different levels of government, business or private users of these services. Due to a number of factors, they are strongly oriented towards the second part of the training, namely the practical use of the environment. As they are usually very limited in time and / or duration, this affects the accumulation of time-stable knowledge and skills. Even for users with closely specialized skills in the given professional field, the lack of a systematic approach and the gradual establishment of causal relationships significantly reduces the effectiveness of such training.

From this review of the components of the learning process in the field of GIS, the importance of the developed problems and tasks for the complete and sustainable acquisition of the necessary set of theoretical knowledge and practical skills in the context of a subject area or professional field is determined. As can be seen from the main directions of the practical use of GIS, at this stage it is necessary to consider strategies for maximum approximation of labor market requirements to the training of students in the relevant specialties.

## GIS IN THE TEACHING PROCESS AT UNIVERSITY OF FORESTRY

The University of Forestry complies with the established trends and practices in this area at national and global level, constantly adjusting the technical and technological support of scientific and educational processes. The use of the opportunities provided by GIS is embedded in the process of training students in the specialties "Ecology and Environmental Protection", "Forestry", "Plant Protection" and "Business Management". Applications of technologies and related methods for modeling, research and visualization, as well as the means and approaches for their application to solve specific tasks related to the study of river basins and related ecosystems, significantly expand the opportunities for students, teachers and young scientists.

Hydrology, and in particular the analysis of hydrological systems, provides a wide range of problems that allow to consolidate the theoretical knowledge and practical skills in the field of GIS in the context of systematization of knowledge and building the necessary causal links in the field. The analysis of river systems is an example of a complex task applicable in the education of students majoring in "Ecology", "Forestry", "Landscape Architecture", "Business Management" and "Alternative Tourism", trained in different educational and qualification levels of University of Forestry.

In the process of GIS training, the theory and practice of vector and raster data is a major problem. Theoretically, students are usually introduced to the advantages and disadvantages of the respective data types, the main file formats, and the methods for forming these types of data. The practical aspect is usually related to the commands for generating georeferenced data in vector and raster format, incl. commands for creating and editing features (points, lines and polygons), operations on raster and vector layers. Very often for the purposes of the exercise or practical demonstration of a lecture, ready-made data are used, which are "lightened" in terms of volume due to the time component.

In the context of the considered problem for analysis of river systems in the environment of QGIS [14], the student is stimulated to focus on the real sources of raster and vector data indicated in the lecture material, including: public data under the INSPIRE directive, such as is governed by LAU (Local Administrative Units) Codes; available satellite images for the territory, taking into account their accuracy and the need to select images that take into account the DEM. The process allows to improve the work with public resources available online and their provision of typed content, understanding of the main file formats for providing raster and vector information, the advantages and disadvantages of relevant online platforms, organization and structuring of information provided. In this case we are working on an analysis of a river system falling within five lands (codes under LAU 04234, 14831, 29150, 37914, 55419), and it is possible to perform an alternative task for a larger area. Special attention is paid to the problems of digital data encoding, especially when using Cyrillic. Fig. 2a shows the input volume of data required to perform the analysis. The problems to be developed by the students are selected in such a way as to allow the execution of commands for combining information from vector, raster or a combination of vector and raster layers. Students must choose a suitable map pad, taking into account the available online sources, in this case using Open Street Map, and the layer with DEM information must be obtained after registration and ordering from the USGS website (<https://earthexplorer.usgs.gov/>), based on the lecture material, the correct source of raster information and the appropriate level of accuracy to be applied at the next stage of the analysis must be selected.



Figure 2a. Input data in Raw format required to perform the analysis.

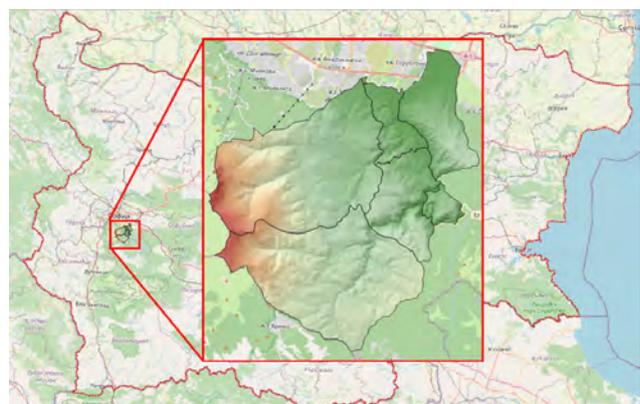
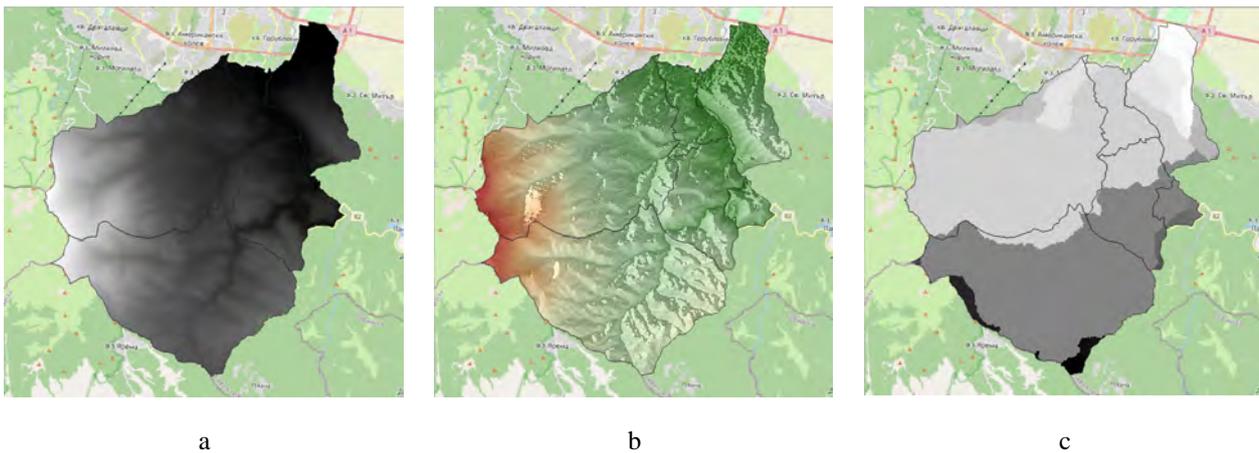


Figure 2b. Processed input data taking into account the projection and the real area of interest (detail area of interest).

The next step is to analyze the information related to the model used and the need for subsequent change of the projection before performing the operations of processing raster and vector images to define the boundaries of the digital model. In this situation, the student must link the acquired theoretical knowledge in the field of coordinate systems and projections with their significance and practical application in a GIS environment for the processed data. Answers to questions related to the used models and projections from the main sources of online georeferenced information and the necessary transformations in the GIS environment are sought, in order to achieve the correct initial conditions for the analysis and the subsequent visualization of the analysis results. The peculiarities and transformations related to the use of data in GeoJSON and KML / KMZ formats are considered. This is a prerequisite for learning good practices and establishing data integrity. In addition, emphasis is placed on the influence of the accuracy of input raster data, which will affect the subsequent settings of the parameters in the analysis of river systems, in the context of the considered theoretical statements linking pixel size to the actual size of the object on the earth's surface. The results of this pre-analysis step are shown in Fig. 2b.



*Figure. 3. First step results (Filled DEM (a), Flow Directions (b) and Watershed Basins(c)), according to application of SAGA-GIS Module Fill Sinks (Wang & Liu).*

Finding the right analysis from the rich set of tools provided by GIS software is also related to understanding the algorithms behind their operation. For example, in a QGIS environment, catchment analysis can be obtained using the SAGA or GRASS toolkit. Students must evaluate the advantages and disadvantages of the documentation offered and the availability of information available through search engines. Special attention is paid to the input-output data and the parameters for setting the analysis process. Ultimately, the goal is to compare the results obtained by the two alternative methods and to improve the work in the Processing Toolbox environment. During the analysis, students have the opportunity to consolidate knowledge related to the classification of raster data, methods for their visual presentation, as well as procedures for converting raster to vector data, as part of the analysis process. Fig. 3 shows a series of results that students must analyze and discuss with the teacher as a result of the first step of the analysis. In this case, the results were obtained using the SAGA-GIS Module Fill Sinks (Wang & Liu) [15], based on the study.

The next stage of the analysis is related to the application of a procedure for calculation the Strahler stream order on basis of a DEM and steepest descent (D8) algorithm, based on [16]. Students should make a connection with the study of the disciplines of Hydrology, Erosion, as well as the courses in higher mathematics, which are the basis of this part of the analysis. The results are shown in Fig.4. Different values for stream order are tested, as well as combining layers with the introduction of transparency, in this case relief and watersheds.

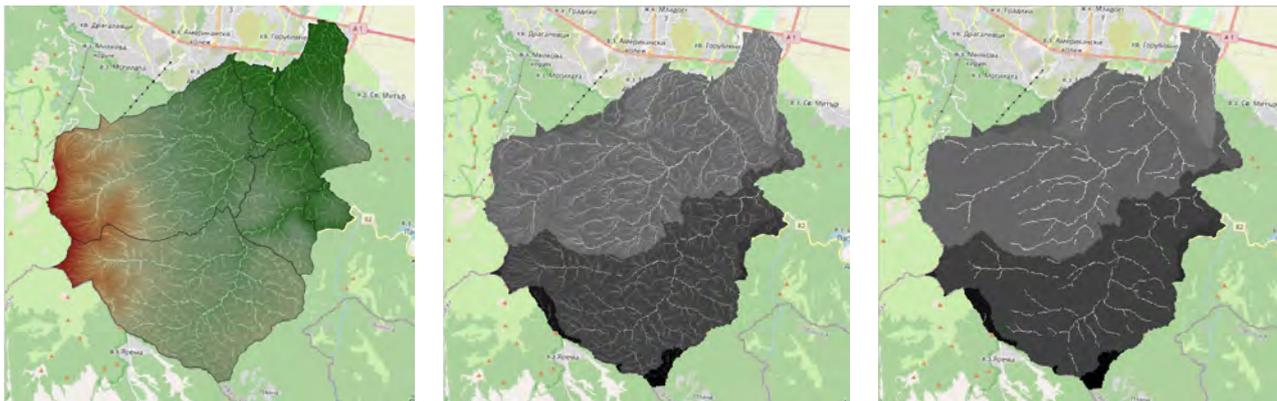


Figure 4. Results obtained from the analysis of the second step and techniques for combining the results in the visualization.

The obtained results from the analysis are compared not only by the two methods of implementation but also by the data publicly available in the system of the Ministry of Environment and Water [18], as shown in Fig. 5 (marked with an oval are the areas of coincidence of the data calculated by the students and publicly available data).

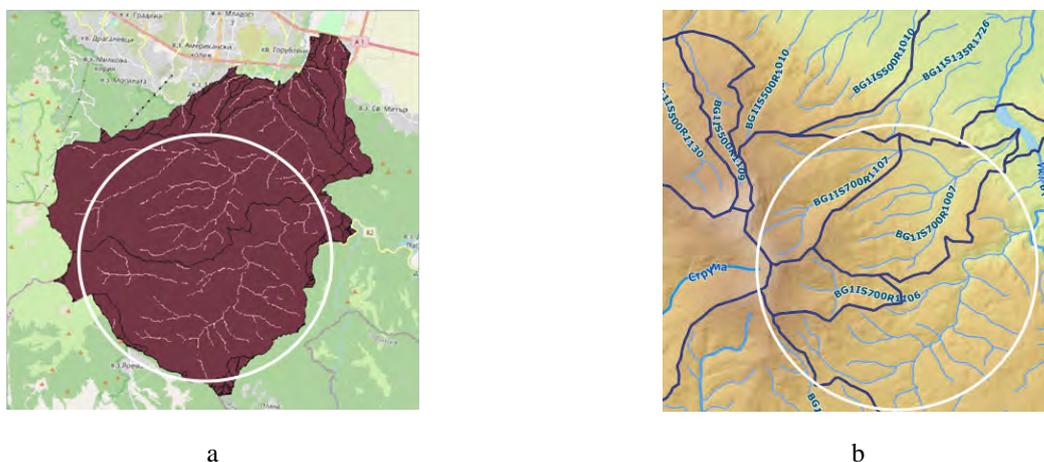


Figure 5. Comparison between the results obtained (a) and the publicly available data (b) based on [17].

Depending on the level students have the opportunity to perform other modules, independently or under the guidance of the teacher, related to the preparation of terrain profiles (according to use of Profile Tool plug-in [19]) of the river system (Fig. 6), slope and aspect analysis and etc.

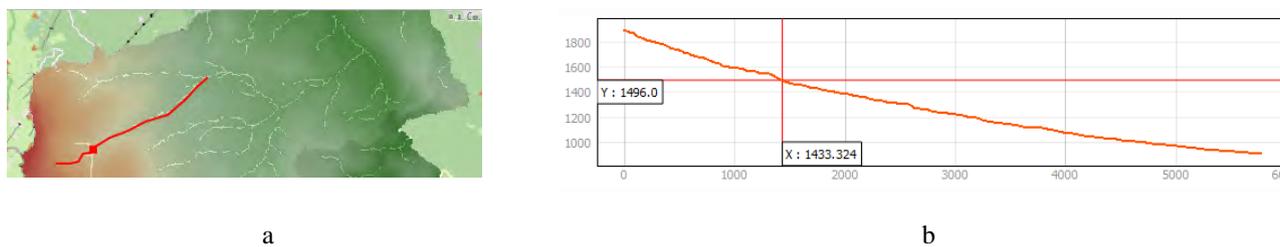


Figure 6. Terrain profile at the top area of BG115700R1107.

The integration of GIS in the training process allows solving complex tasks related to the creation of high quality static realistic images, animations and simulations of single objects and complete solutions, using two-dimensional or three-dimensional models generated in the design process. The obtained results and the acquired good practices provide significant potential for knowledge transfer and applicability in the main professional fields of the university, which in turn allows for a comparative analysis of the models and the degree of applicability of different interactive technologies in different specialties

## CONCLUSION

Although students are well acquainted with the individual operations, it is usually difficult to combine them as a part of an algorithm for solving a larger practical task. This determines the importance of defining complex problems close to practical tasks, which combine the solution of many cases. It is important to correctly determine the scope of the tasks and the amount of data about them. The maximum approximation of the tasks to real problems of practice must be strongly linked to an accurate assessment of the time needed to solve the problem. Otherwise, a negative effect can occur, including demotivation of the student. There is a need for a gradual gradation of the problems and a strict analysis of the feedback from the students, as this happens in the context of their overall presentation in the educational process, not only in the specific discipline, but in general. This would help to better define problem-solving tasks designed by students in order to acquire sustainable knowledge and skills. Flexibility and modularity of problem tasks and cases are needed to allow adjustment to an individual student, group or flow of students within the learning process. The experience of the lecturers and the educational institution are a key factor in this regard.

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## **BIOGRAPHY**

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## **ACKNOWLEDGMENTS**

This document has been implemented with the support of the project “Development of sustainable information infrastructure for application of GIS technologies within the professional areas of the University of Forestry”, Contract No. НИС-Б-1005 / 27.03.2019

and

the Bulgarian National Science Fund as a part of “Competition for financial support of basic research projects on societal challenges – 2018”, within the project “Assessment of the water ecosystem service provided by forest areas with water protection functions in Bulgaria”, Contract No. КП-06-ОИП 03/7.

# VR GEOLAB: BRINGING FIELD EXPERIENCE IN THE CLASSROOM

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## **Abstract**

*The paper starts with some basic definitions related to virtual reality (VR) and continues with an overview on the market size and diversification of VR applications. This is extended with a research on the role of computer simulations and gamification in modern education, how these improve teaching results, what are the strengths and the problems. In addition, it is studied how this technology is currently implemented in engineering and geospatial sciences and workflows in particular and how this could be developed in future.*

*A newly established VR geospatial laboratory (VR geolab) is presented. It is tracked the whole process from field measurements through data processing to visualization in virtual environment. As the VR geolab has already been presented on several events, it is made also an overview on different audiences’ adoption of VR technologies and the shared VR experience in particular.*

**Keywords:** virtual reality, geospatial, engineering, education, 3D modelling

## **INTRODUCTION**

Virtual Reality (VR) is a term traditionally associated with video games. These days however it is gaining wider popularity regarding to its potential for application in a variety of different fields. As this kind of technologies claims to bring real-life experience indoors, they seem suitable for educational purposes. There are examples of teaching with VR in many different disciplines, including medicine, physics, astronomy, chemistry, archaeology, etc., and geosciences are not an exception.

During the last decade in academic researches is visible a clear interest on virtual education, and a large part of them focus on the pedagogical aspect of this approach. Some of the benefits are obvious, but there are also disadvantages to bear in mind. While an overview like this is mandatory when considering such implementation, this paper focuses on the technological integration of VR in the classroom.

It is presented a virtual reality geoscience laboratory - VR Geolab, established in University of Mining and Geology “St. Ivan Rilski” (UMG), Sofia, Bulgaria in 2019 for educational and scientific purposes. It is made a brief overview on the currently available solutions, its first products and the audience feedback.

## BASIC DEFINITIONS

Nowadays, the term “reality” is not limited to the world we live in. The real environment is just the tiny point to the left on the reality-virtuality (RV) continuum (Fig. 1) which spills into the augmented reality (AR), transforming into the augmented virtuality (AV), and eventually immerse into the virtual environment, or VR, to the right [13]. Between the real environment and VR stand the wide field of applications provided by the mixed reality.

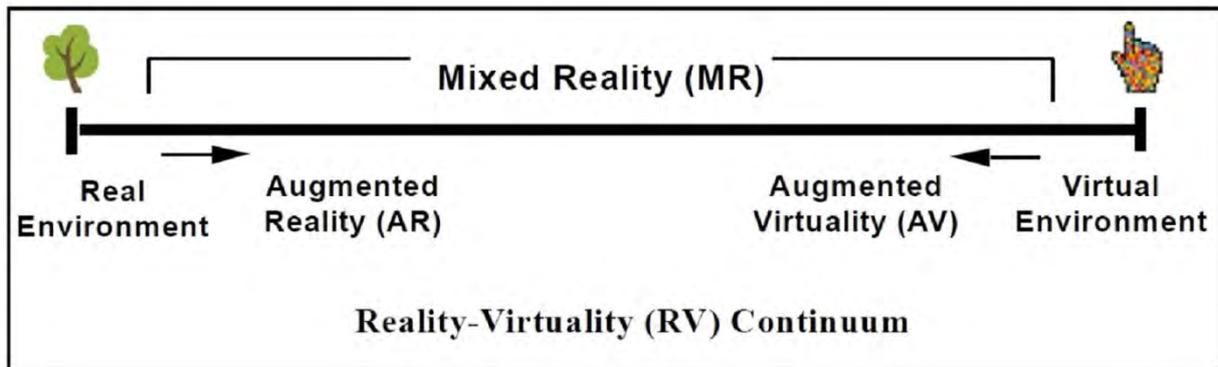


Figure 1. RV continuum

Regarding to some basic definitions by different authors, given in Boton’s study [2], VR represents: “computers, head-mounted displays, headphones, and motion-sensing gloves” and “electronic simulations of environments experienced via head-mounted eye goggles and wired clothing enabling the end user to interact in realistic three-dimensional situations”. Neither of these device-oriented definitions however seems acceptable to convey the complexity of the concept.

Others try to avoid any “reference to a particular hardware system”. Regarding to some authors, the key features of VR are the so-called “3 Is”: immersion, interaction and imagination [6], and for the others there are four basic elements: the virtual world, immersion, sensory feedback, and interactivity [2]. While they slightly differ, both of them include “immersion” and “interactivity” which are the essential features of a VR system.

Both gained wide popularity in the past years, VR and AR are often mentioned together. They however bring different opportunities. AR is technology that gives great advantage when used in the field to “augment” the visible environment with additional information. The strength of VR is to fully immerse the user in the virtual world, and of interest for the current paper is exactly the fully immersive environment that could “bring” the real-world experience inside the classroom.

## VR IN GEOSPATIAL EDUCATION

### Global Trends in VR Applications

Currently, videogames take the largest part on the market of VR/AR technologies. In the next five years this trend will keep [12]. In top 10 of applications are also fields like healthcare, real estate, retail, military, but of greatest importance is the presence of both engineering (3rd place) and education (9th place) which have relations to the current topic (Fig. 2).

### Educational Aspects

Regarding [13] two main division outlined in the usage of modern technologies for teaching – virtual and remote laboratories. The first group refers to computer simulation with typically high visualization and interaction capabilities, whereas the second one represents computer programs that provide a graphical user interface to interact with real hardware performing the experiment [3]. They can be developed solely or together, but in terms of this paper focus falls only on virtual laboratories (VL).

The term “virtual laboratory” first appeared in the early 1990s [13], but the large interest on it among universities and educational institutions raised later, in the 2000s, and especially in the 2010s. Studies evaluates the high potential of

virtual learning tools, but don't miss to mention some disadvantages, too. Regarding a number of studies ([7], [8], [9], [110]), summarized in [13], the pros and cons are represented in Table 1.

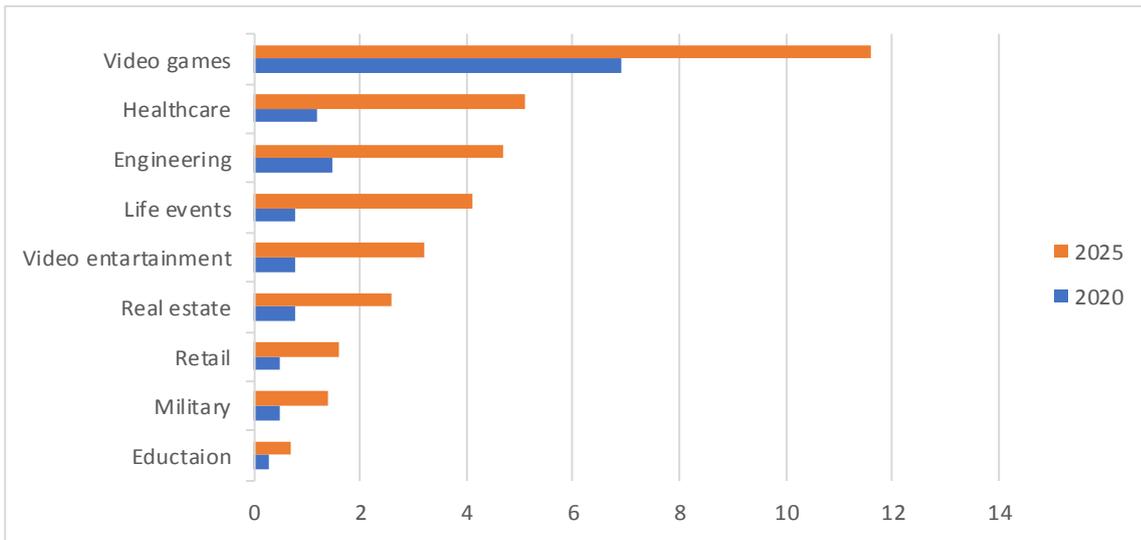


Figure 2. Forecast global market size of VR/AR (in billions of dollars) by segments [5]

Table 1. Advantages and Disadvantages of VR Education

Advantages	Disadvantages
Safe environment	Extensive planning and time for preparation
Adding experience in the classroom	Dependence on computer tools
Control of the experience	Possible lack of seriousness
Making the “unseen” seen	Possible need of final stage of training through actual hands-on experience
Custom design regarding to individual learners	
Easily reproduced experiments	
Damage resistance	
Setting a greater variety of simulations than practical experiments	
Providing experimental situations not observable in reality	
Not so complex and/or expensive as actual experiments	
Cost effectiveness	
Better understanding of the covered topics	
Learning is not dependent on specific time and place	
Learning materials adapted in the learning environment to the learner’s needs	

Game design principles and gamification theories can be found underlying in the development of VR [10]. Regarding different studies conducted in the past decade and summarized in [4], game-based learning environments have significant potential to challenge and involve students in an active learning process, and it is proven that this interactive engagement improves students' understanding, motivation and learning outcomes [3].

## **Spatial Applications**

According to Berg and Vance's study [1] on the industry use of VR, the technology is usable in industries such as architecture, engineering and construction. In comparison with traditional CAD tools, giving an outside-in view, VR visualizations allows user to explore information from the inside-out.

The use of computer games and game engines in environmental applications and planning is increasing due to their advanced performance and interactivity capabilities [11]. The concept of VRGIS – a combination of VR and GIS, initially appeared the beginning of 1990s, but it took some time to mature and eventually turned into a hot topic at the end of the 2010s. Regarding [13] VRGIS represents VR technology as a front-end interface with users and support of spatial GIS data in areas related to modern cities and urban management, such as transport and traffic, e-business and e-government, ocean and island management, scenic area management, virtual community and geography education. It is also a good tool to involve audience in the process of spatial decision-making relying on their experience of viewing and occupying space. Roaming in virtual cities has become a substitute for traditional maps, and utilizing GIS data in an immersive environment allows decision-makers, designers, engineers and public to easily see the effect of different scenarios.

## **VR GEOLAB**

VR laboratories are convenient and cost-effective way of improving education which usually doesn't require additional payments after the initial investment [13]. The main difficulties are related to the hardware and especially software expertise on building VR environment and planning learning scenarios.

The following lines refer to a VR Geoscience Laboratory – VR Geolab, established in the UMG. The chosen equipment is presented, as well as the first products as a results of the lab's activity and how they were produced.

## **Equipment**

The research and choice of equipment were extensively presented in [13]. The main factors to bear in mind included pricing, functionality, robustness and processing power requirements. These eventually led to the purchase of two systems – HTC Vive, which is a PC-based solution, and Oculus Go, which is an autonomous one. The essential part which serves immersive VR experience for the user is the head-mounted display (HMD) complemented by two hand controllers in each of them.

The necessary funding of 1750 € was provided through a dedicated university project, funded by the Ministry of Education and Science of Bulgaria though the "Ordinance #3 on the terms and procedure for evaluation, planning, distribution and spending of the state budget to finance scientific or artistic activity in state higher schools."

## **Products**

### ***Mining and Construction Sites***

Virtual reality lab requires both the necessary hardware and software components set in an appropriate room and also the acquisition of specific content to be presented through them.

In this regard, the possibilities of visualization of virtual environments representing real construction and mining sites both on the surface and underground are presented. They were selected to be interesting, diverse and accessible, and in that case more likely to be useful in educational programs for different students, professors and professionals from the university. The list of sites includes a section of a new metro line during its construction, a road tunnel, a mine gallery, a stockpile and an open pit.

Modern technologies like laser scanning and digital photogrammetry are the most suitable methods for making the measurements to generate geometrically accurate and realistic models of the desired objects. They provide good precision to solve various engineering problems and achieve high level of realism of the virtual environment, thus bringing it closer to the far right end of the reality-virtual continuum. The nature of the two types of technology is different, distinguishing their strengths and weaknesses, thus allowing them to complement each other. Both

technological methods require additional measurements of ground control points to ensure the necessary relative and absolute accuracy of the captured objects. These measurements were made with conventional instruments and technologies - GNSS and total station. All the measurements were made so that they do not interfere with the day-to-day activities of the sites.

The selected technologies for acquisition geospatial information are characterized by a common parameter - the presence of a digital camera, which provides the ability to generate photorealistic color of the final models.

The laser scanner - STONEX X300 was used. It is characterized by high precision and range, as well as the presence of two integrated digital cameras, each with 5MPx resolution. The major advantages of this type of technology are the relatively fast scanning performance and its easy operation - via a smartphone. In order to perform maximum full scanning of a particular site, sequential placement of separate scanning stations is required, which in turn requires time and a specific predetermined execution layout. The purpose is to minimize the undistributed sections of the site. This statement and the limited sensor resolution of the scanner's cameras lead to the presence of negative features of the technology due to static measurement, which affects the color quality of the points. In this case terrestrial and airborne photogrammetry with a digital camera was used. An unmanned aircraft - a DJI Phantom 4 Advanced drone, features a 20MPx resolution of the camera sensor and about 25 minutes of useful flight took the measurements for the open and some of the inaccessible parts of the sites. The underground shots were made via handheld digital camera with a 24MPx sensor.

VR visualization of the mining and construction sites mentioned above, was made using Unreal Engine and HTC VIVE glasses. The first stage was visualization of the point clouds via specific plug-in. This enables a light and easy to implement virtual environment of the raw data measurements. The second stage was the creation and visualization of surface meshes merging the two types of measurements - laser scanning and digital photogrammetry. This was done with the RealityCapture software product. In this way, the highest quality of spatial accuracy was achieved due to laser scanning measurements and the most realistic view was gained due to the better quality of digital photogrammetry images.

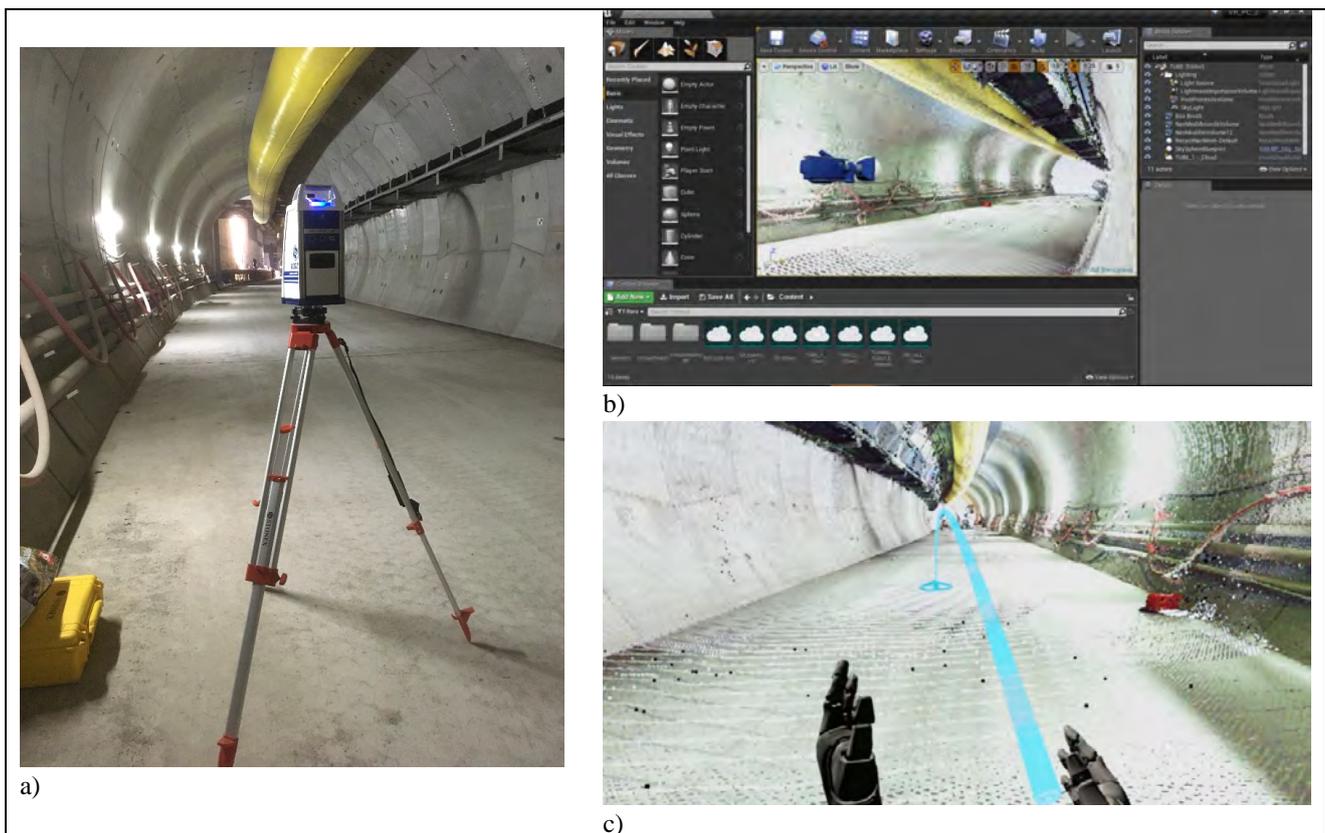


Figure 3. The process of laser scanning (a), VR modelling (b) and experience (c)

## Antarctic Chapel

The chapel “St. Ivan Rilski” lies within the premises of the Bulgarian Antarctic Station on Livingston Island, and is one of the first orthodox buildings established there. Its interior is elaborately painted with icons, created in situ by the painter Ganka Pavlova. Due to the remote location of this chapel, except scientist and station logistics crew outsiders rarely visit it. This was the main driver for a 3D building digitalization project, organized during the 25th Bulgarian Antarctic Expedition. A team from the University of Mining and Geology “St. Ivan Rilski” (Bulgaria) and Istanbul Technical University (ITU) performed the required field operations. All data is collected via terrestrial 3D laser scanning. A Stonex x300 instrument is used at maximum resolution (16000 hor. x 4000 vert. points per scan) with photo capturing plus external dual-frequency GNSS for georeferencing. The chapel’s interior and exterior is composed of 10 colored point clouds, co-registered and meshed together using the Stonex 3D Reconstructor software. Noise filtering and edge smoothing techniques was applied. All point clouds are decimated at 30% for optimal meshing and virtualization.

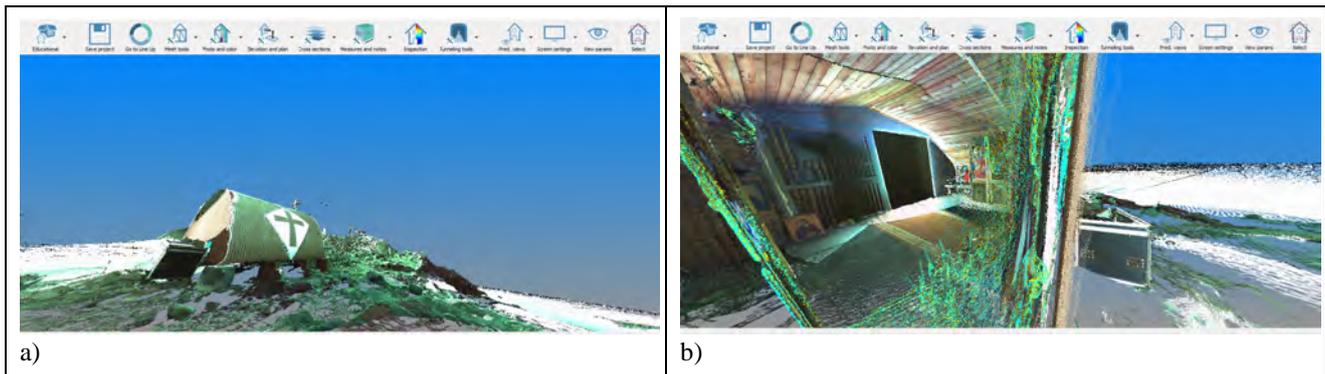


Figure 4. Outside view of the chapels exterior and surrounding environment (a) and point cloud view of the chapel’s interior from the outside environment (b)

The meshing was performed by using interpolative technique, with size of each triangle at 16 pixels plus vertex coloring. If the approximation error was too high, the triangle was subdivided in smaller pieces. The 3D model is created by minimization of the sum of squared distances between the interpolated surface and the data points. A weighting strategy is applied by using less triangles on planar regions, satisfying an approximation error threshold. The 10 mesh models are subsequently exported separately in Virtual Reality Modeling Language format (.wrl) for further processing.

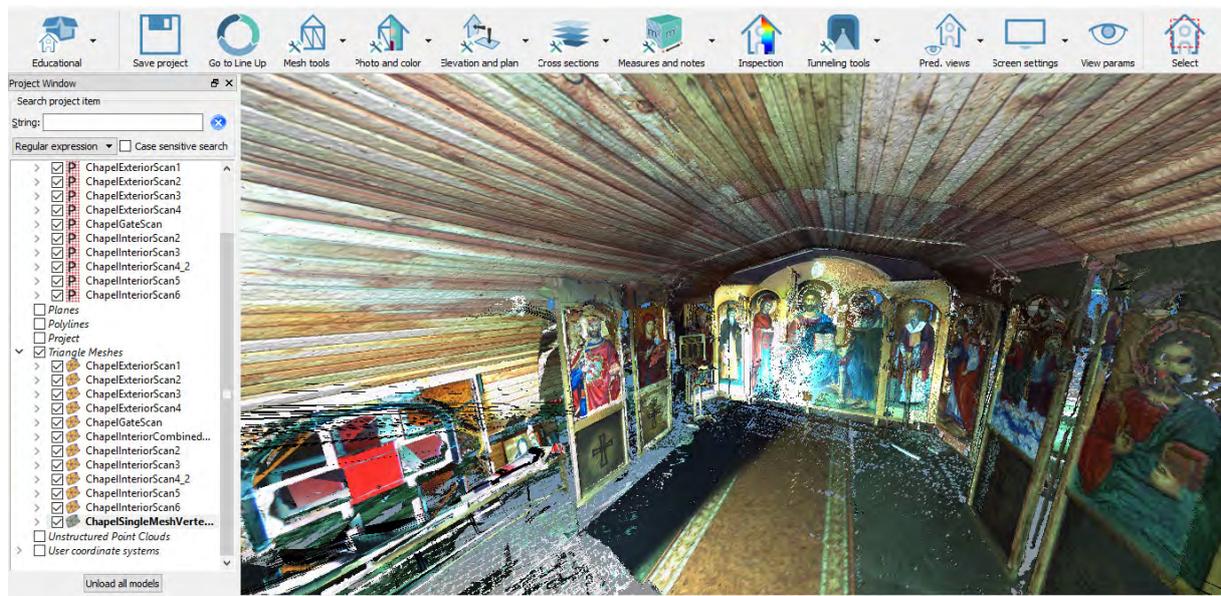


Figure 5. Mesh model view from the chapel door. Ceiling, floor, icon color and other textures are well preserved

The mesh models, transformed in vector graphics appropriate for VR modelling, are first imported inside the AutoDesk 3DS Max software. Further cleaning, hole filling and triangle editing is performed. The models are then combined and exported as a single model in Filmbox (.fbx) format. This model, containing faces (triangle) and coloured vertices is then imported in the 3DS Max Interactive application for final VR visualization. This platform allows connection to a number of external VR devices. For the project a Vive Pro headset, equipped with wireless adapter was utilized. Lights, cameras, materials, ambient music and other required elements are incorporated in to the VR model for optimal experience. The model is available for demonstration within the university VR lab.

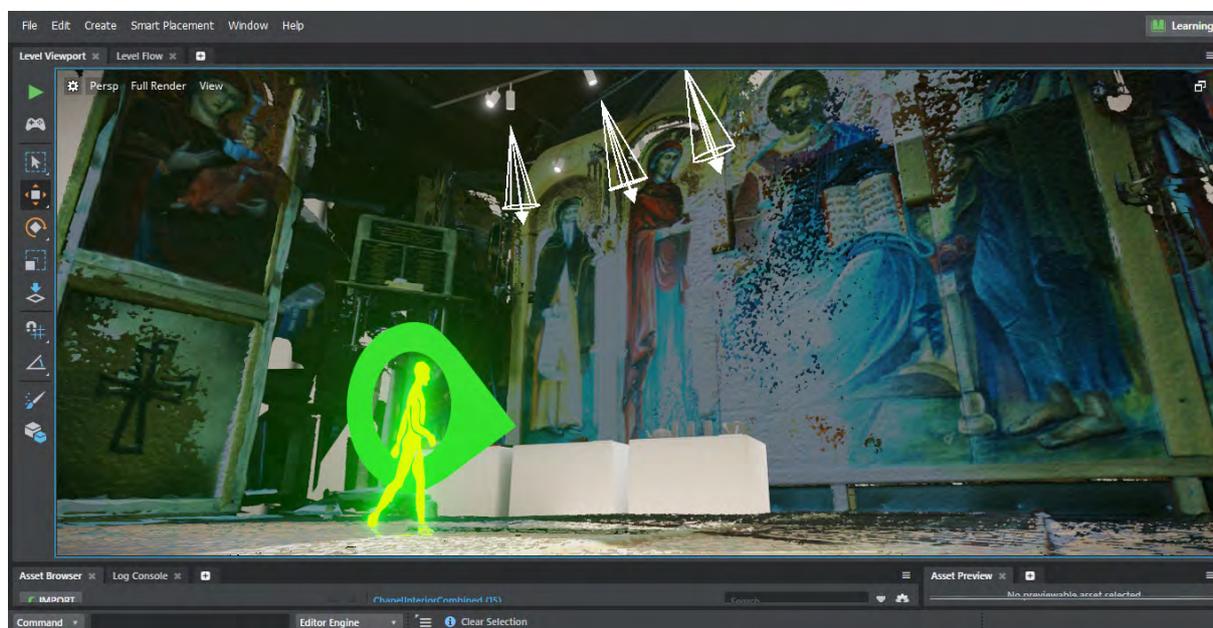


Figure 6. VR view – start point, cameras and lights, directed at the main altar

## Audience Approval

Since the beginning of the project dedicated to the VR Geolab in March 2019, it was demonstrated on many events (Fig. 7), most of which held in Sofia, Bulgaria:

- The Doors Open Day of UMG (April 2019) – an event dedicated to students
- The European Researchers' Night (September 2019) – a scientific event dedicated to non-scientists
- XXIX International Symposium on “Modern Technologies, Education and Professional Practice in Geodesy and Related Fields” (November 2019, Istanbul, Turkey) – an academic event dedicated to academics in geodesy
- Global GIS Day (November 2019) – both business and academic event dedicated to geospatial professionals
- November Talks of VR Lab BG (November 2019) – a monthly VR event dedicated to VR enthusiasts
- Entrepreneurs in Science (December 2019) – a pitching contest dedicated to scientists.

These events were not only a stage to present the VR Geolab but also a chance to study the audience approval. The overall positive feedback was more precisely studied through two questionnaires. The number of participants in the first questionnaire is 43 people, and in the second – 20, and the results are respectively presented in Fig. 8 and Fig. 9. They confirmed the overall impression of positive attitude to VR technologies and the VR Geolab in particular. The small number of negative answers could be given to older participants, technophobes or people who eventually dislike VR technology. A relatively small number stated their opinion as “neutral” or “may be”. They could be given to lack of information on the VR technology and have the chance to turn into positive in the future.

## CONCLUDING REMARKS

During the past decade the application of VR technology in education became a hot topic. Its benefits for the learning process and geosciences in particular laid as a base of a new VR laboratory dedicated to education and researches geosciences – the so-called VR Geolab, of the University of Mining and Geology. Its establishment in 2019 were

marked with the purchase of appropriate equipment, and since then were taken the first steps in the modelling VR environment.

The achieved results were demonstrated to different audiences, including both professionals and non-professionals in geosciences, VR enthusiasts, business and academics, and children, as well. The overall feedback is very positive -

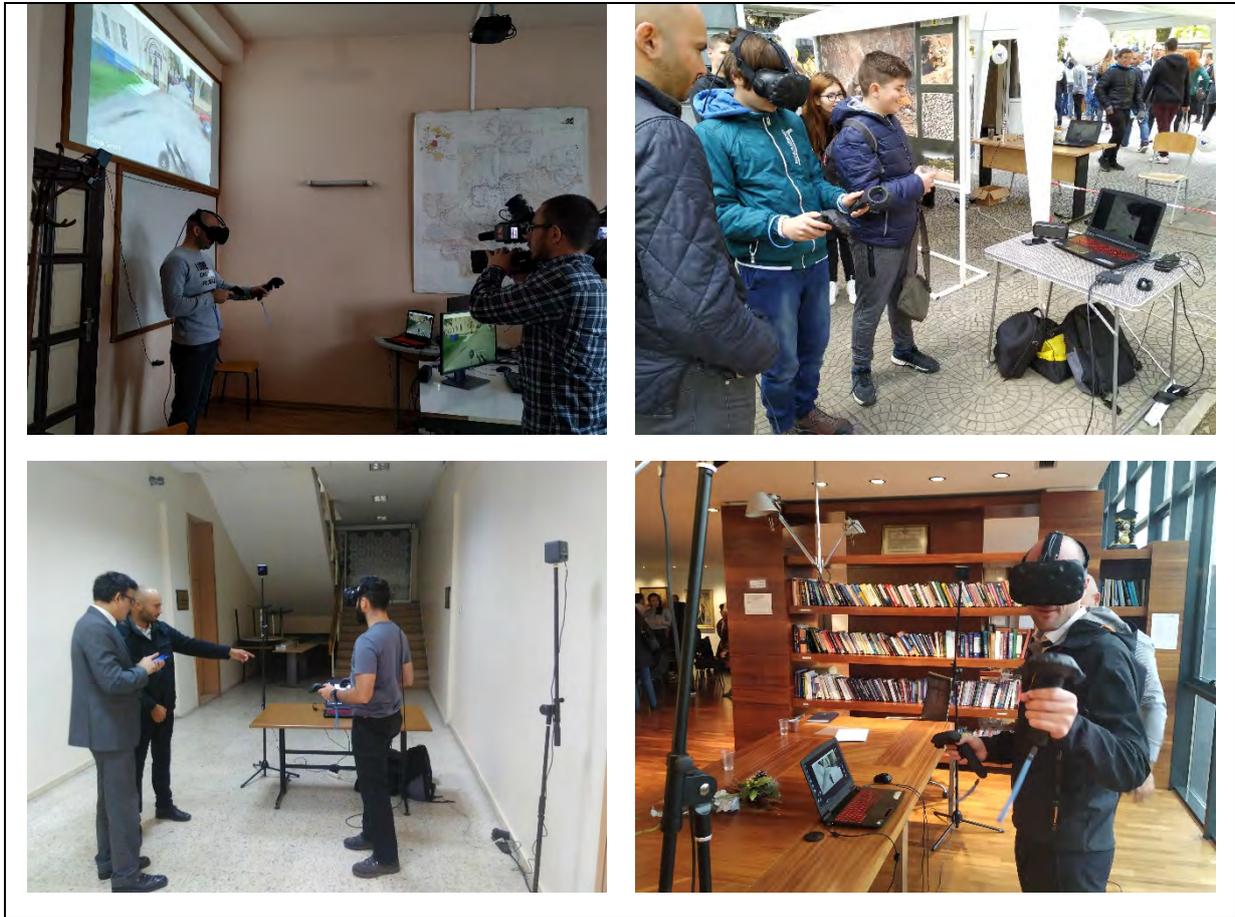
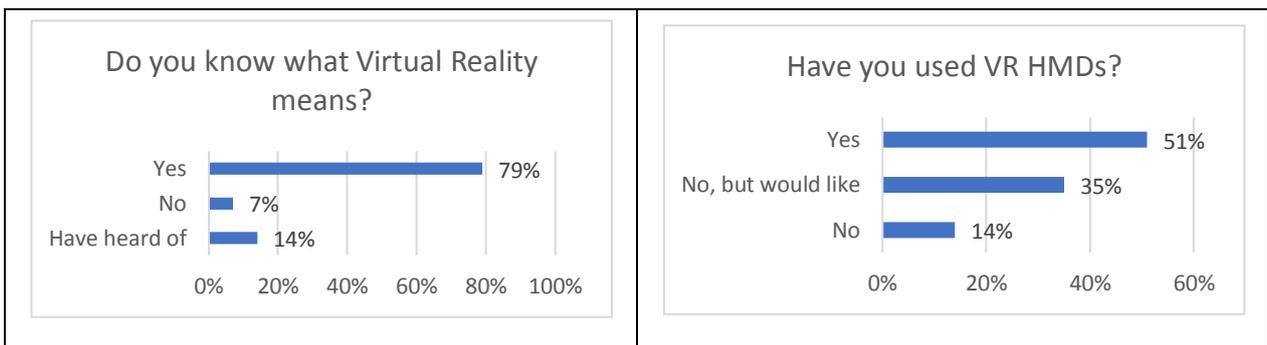


Figure 7. The VR Geolab is of interested for a variety of audiences – from students (upper right) and academic society (lower left) to media (upper left) and investors (lower right).



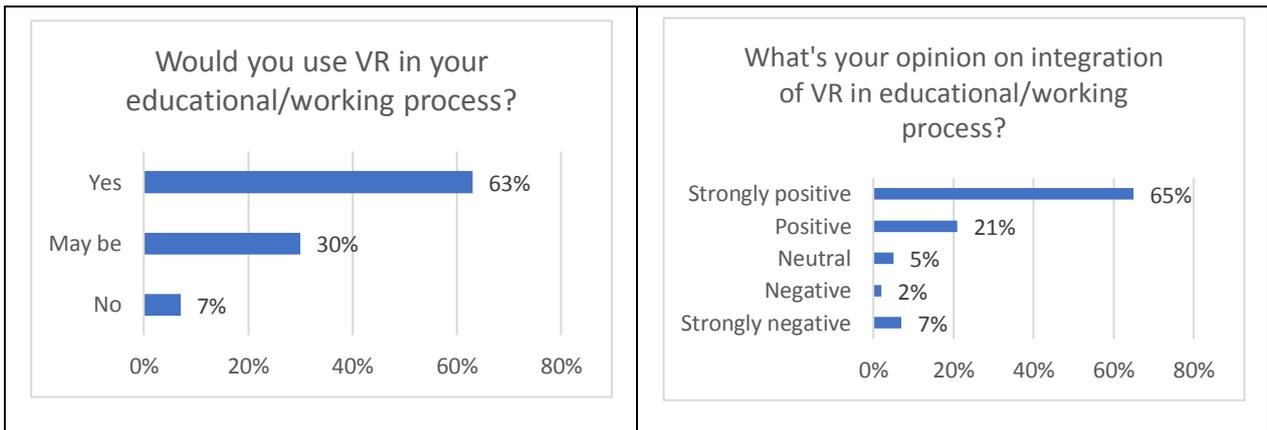


Figure 8. Results of the questionnaire on the European Researchers' Night 2019 in Sofia, Bulgaria

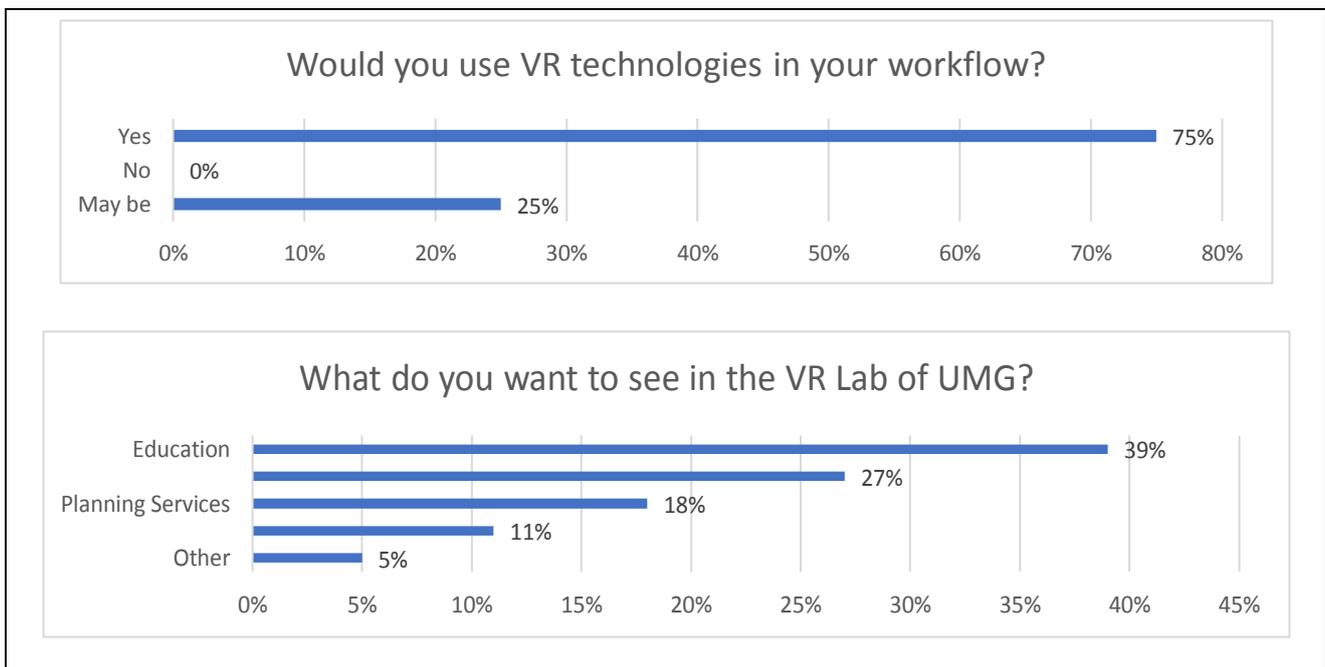


Figure 9. Results from the questionnaire during the presentation of the VR Geolab on the Global GIS Day 2019 in Sofia, Bulgaria

people enjoy using VR technology and would like to have it implemented in the educational/working process. It is exactly the education they want to see in the future development in the VR Geolab, but are also interested in the application of VR for analytical and planning purposes.

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Deyan Sosserov was born in 1988 in Sofia. He graduated PGCAG “Lubor Bayer” in Stara Zagora in 2007 with a geodesy specialization and received an engineering master’s degree in mine surveying and geodesy in UMG “St. Ivan Rilski”, Sofia in 2013. His professional path passes through some of the leading companies in the field of geodesy and cadaster, construction and mining. At the end of 2018 he founded “Geospatial” Ltd, a company specialized in geospatial solutions in the field of geodesy and construction and their digital visualization. His professional interests include laser scanning, digital photogrammetry, 3D modeling, as well as various augmented, mixed and virtual reality systems. He is a PhD student at the Department of “Mine surveying and Geodesy” of the UMG “St. Ivan Rilski” since 2015 with a theme of dissertation – “Potentiality integration of mine surveying technologies with virtual reality applications”.



Asparuh Kamburov works as an Associate Professor at the University of Mining and Geology "St. Ivan Rilski". He has a Ph.D. in GNSS. His professional interests include geodesy, satellite navigation systems, terrestrial laser scanning, science communication and GIS.

# THE METICULOUS WORK DONE BY THE SECOND-YEAR KINDERGARTEN PUPILS. WHERE EVERYTHING BEGINS: OPENING A CITIZEN'S EYE

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## Abstract

*The Cartographic-Workshops are permanently shared with pupils to whom I'm asked to explain my job as a cartographer, explaining them WHAT A MAP IS. It all begins with using the cartographic exercises created during my training at the National School of Geographic Sciences (ENSG/France)<sup>2</sup>. The pupils manipulate the layers of the thematic plots. They appropriate the landscape construction thus decomposed on these extracts of maps and observe them according to what a map evokes for each of them. This presentation proposes to describe how the work of constructing the link between the reality of space and its modes of representation, from the volume to the plan, can be carried out. From this practice of observation, we'll see how the space lived and shared is interpreted differently by each look, and how each one becomes aware that the gaze of the other is indispensable for him to build his own.*

**Keywords:** *Geodesy, Topography, Civilian Cartography, Map, Base map, Hydrography, Orography, Planimetry, Thematic layers, Sensitive Cartographies, Body of knowledge, Mapping-Workshop, Orienteering-activities.*

## INTRODUCTION

Mapping involves several disciplines, many techniques and skills to express what needs to be represented in a place through its intertwining, where each detail must be measured, defined, analysed and prioritized in order to be represented layer by layer superimposed making the map. Any mapping begins with a research work, a survey, where each plot must be staged as it exists in reality, carefully studied in order to meticulously report its elicited values. Each of the plots in the map is considered in its design as it is observed in the landscape, according to its exact location and orientation in its own environment. Each information in the map must be spontaneously identifiable and memorisable by the reading eye. To map means to think about the construction of a structured visual language accessible at a first glance, offering a coherent and memorisable interpretation of reality.

*I am told there are people who do not care for maps, and find it hard to believe. »*

*Stevenson continues: « The map was the chief of my plot. [...] the map itself with its infinite, eloquent suggestion, made up the whole of my materials. It is perhaps not often that a map figures so largely in a tale; yet it is always important. The author must know his countryside whether real or imaginary, like his hand; the distances, the points of the compass, the place of the sun's rising, the behaviour of the moon, should all be beyond cavil. [...] (I) adopted a precaution that I recommend to other men—I never write now without an almanac. With an almanac, and the map of the country and the plan of every house, either actually plotted on paper or clearly and immediately apprehended in the mind, a man may hope to avoid some of the grossest possible blunders. With the map before him, he will scarce allow the sun to set in the east [...] even with the imaginary places, he will do well in the beginning to provide a map. As he studies it, relations will appear that he had not thought upon. He will discover obvious though unsuspected short cuts and footpaths for his messengers; and even when a map is not all the plot, as it was in *Treasure Island*, it will be found to be a mine of suggestion.*

**Robert Louis Stevenson**, spring 1893. My first book, *Treasure Island* (Tusitala Edition, vol. II, page XXV)

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<sup>1</sup> *les Cafés-cartographiques*, association ruled under the 1901 Law, created in Paris in March 2013. Founded in October 1999 by J. D. Salachas, 'les Cafés-cartographiques' offer to meet around the riches of cartography Facebook pages presenting our activities are available and usage free [https://www.facebook.com/CafesCartographiques/info/?tab=page\\_info](https://www.facebook.com/CafesCartographiques/info/?tab=page_info)

<sup>2</sup> *École Nationale des Sciences Géographiques*, <https://www.ensg.eu>

## OBJECTIVES, APPROACH AND METHODOLOGIES

Regardless of the scales considered to reproduce it, mapping is not reinventing reality but proposing different modes of representation to account for it. There are strict rules for operating this persevering tedious work, rules that must be constantly and reasonably transgressed according to the scale, the projection, the characteristics of the field studied... whether it is a city centre, a mountain range, a vast plain, a coastal edge torn off by erosion or long sandy beaches. When mapping, each detail is thought of in its specificity in order to find the best way to reproduce it.

### The map must account for the real to “honestly” inform its users

Mapping is “The art of believable resourcefulness” where any information must remain as accurate as possible in order to reflect reality, so that the citizen stays properly informed.

### A cartographer never maps for her/himself, but to keep informed the users of the maps created

To achieve the best objectives of a map, a cartographer must know its readers and the conditions of its consultation and uses. It is the users themselves and what characterizes their use of maps that determine the elements that need to be built into the map to inform them. Which scale of reproduction and what type of projection are adapted to allow the readability of a data? Which level of details the map has to propose? How to find the best “visual language” through the best “graphic semiology” research to complete the final map to publish?

Throughout the process of making a map, it is necessary to be able to define which information should remain a priority, which information should be discarded, reduced or deleted. Adapting the 1:1 reality to a specific scale following a layout, a page size requires to abstract or remove excessively reduced information, to avoid the risk of illegibility. In reducing its scale, each information must be “generalised” in the map. Each data must be expressed in the most accurate cartographic language, the most suitable for its subject and the conditions of its reading. A map must make sense at first glance.



Figure 1. Mapping from a small-scale to a larger-scale requires several sets of transformations, essential steps to keep the schematic data into coherence. Generalizing an information means increasing its level of abstraction. (©ENSG)

### Generalisation: cartographic ethics to avoid map abuse

Points, lines, surfaces... The map is a modelling of a geographical space thought and calculated at a certain level of abstraction, defined by the scale of its representation: the lower the level of detail, the higher the level of abstraction. Mapping from a small-scale to a larger-scale requires several stages of transformation, essential steps to maintain the consistency of schematic data (Fig. 1). Generalising information means to increase its level of abstraction. Generalisation is necessary in any mapping adaptation from a small-scale to a larger-scale. The criteria of choice for any generalisation must remain accurate in any case. Cartographic tools and new technologies have gradually changed, But the principles for achieving the objectives remain the same : it is necessary to describe a consistent set of information so that the subject can be properly conveyed to, and interpreted unambiguously by the reader. To accomplish this tedious adaptation of information, it is imperative to master precise methods of execution, which always refer to the rules related to visual acuity and graphic semiology. Measuring, tracing, informing to understand to transmit facts related to the organization of our territories and our societies. Looking at the map as a guiding thread for our use of the world. The map offers an accurate approach to phenomena that combine through multifaceted applications. From the organization of the different layers of our territories and our environment to the flow of our exchanges, the subjects and the methods to express them are declined throughout multidimensional fields of thematics. The cartographer's choices are always bound by the rigour of the information that the map must transmit to its users.

## Teaching children the precision of the eye: the map is built as the landscape was built

For more than 30 years, the Cartographic-Workshops are shared with classes and pupils to whom it's asked to explain the job: **WHAT DOES IT MEAN TO BE A CARTOGRAPHER?** By always adapting to the age of the pupils, to explain to them what a map is, all begins in principle with using the cartographic documents realized during years of training at the National School of Geographic Sciences (ENSG/France), showing step by step the various elements of a map.

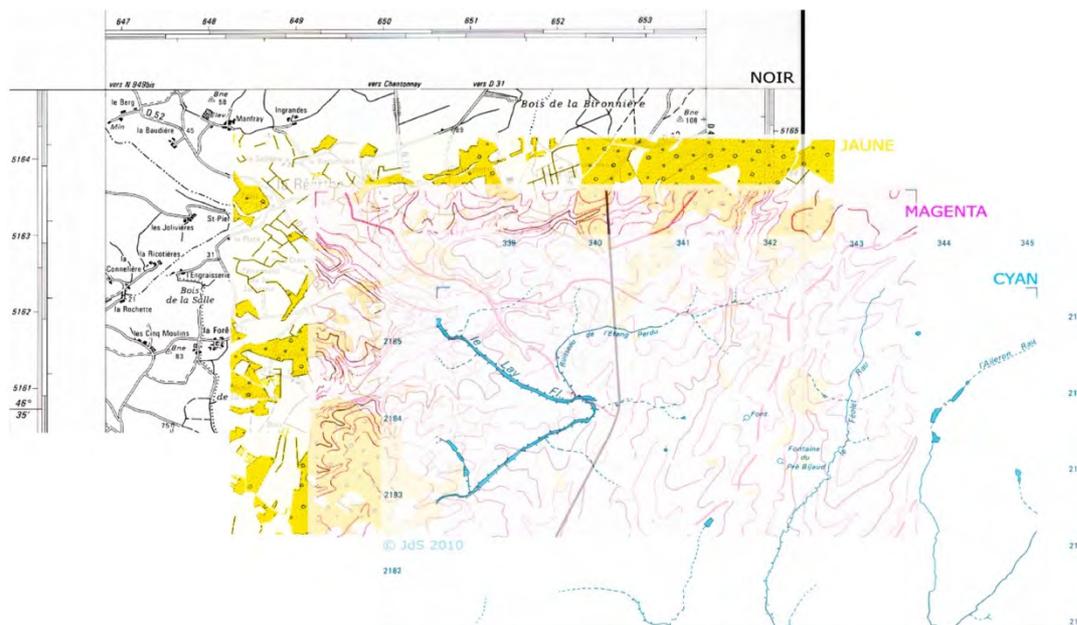


Figure 2. Fontenay-Le-Comte, School training: What does it mean to be a cartographer?  
How do we create a map? ©JdS

The pupils manipulate the layers of the mapped thematic plots, by colour sheet, as we realized them in traditional cartography (the process that we managed nowadays through our digital tools): first the plot of hydrography, those of orography, planimetry, the thematic layers representing accurately the environment, those with the texts by separated colour too (Fig.2). The pupils appropriate the landscape construction thus decomposed on these extracts of maps and they observe them, reflecting on the known places according to what the map evokes for each of them. For the youngest pupils — from the second part of the second year of kindergarten — after a moment of approach through the exchange of ideas and recognition of words, it is a matter of letting them draw their shared common space that they perfectly know, their classroom through the drawing of each wall.

### To observe in order to draw what is seen: the pupils start to direct themselves with awareness of the spatial identity

Each pupil represents in his own way what she/or he sees, wall by wall, on four strips of prepared paper at their disposal. One by one, when the pupils agree that their model of representation is finished, after their drawing of the four walls, without any comment, it is just a matter of taping the four strips, wall after wall gathered to set the classroom in volume. The pupils then look at their drawings, each one differently. They are inside their modelling reduction, moving quickly from the observation of their familiar space in volume to its planar map representation. So they discuss among themselves about the position of the door as well as the windows, each object in the room, whether they are well or not well located. They identify together the directions leading here to the staircase by example, leading to new directions... the courtyard of their school, then to the street, the street that bears such a name and leads to other specific places, etc. This gradually makes it easier to approach the idea of the plan, the map through the representation of their space seen from above. The pupils talk about orientation and envision each other together in their territory. **Their eyes are open.** The reflection can start with pupils at the age of 4 and consists in using these principles of observation to represent the immediate landscape around them by imagining its thematic 'layer'. At first, the inside of the class, the shared and familiar place, then, the exterior of the class for the older children. This invitation to draw and chart the environment for transmitting its representation, may lead to a walk in the neighbourhoods and to orientation activities in the vicinity. To complete this invitation to understand the structure of a map, we interrogate how the work of constructing the link between the reality of space and its modelling can be carried out. The youngest draw what they see, the oldest can

measure it to report more accuracy.

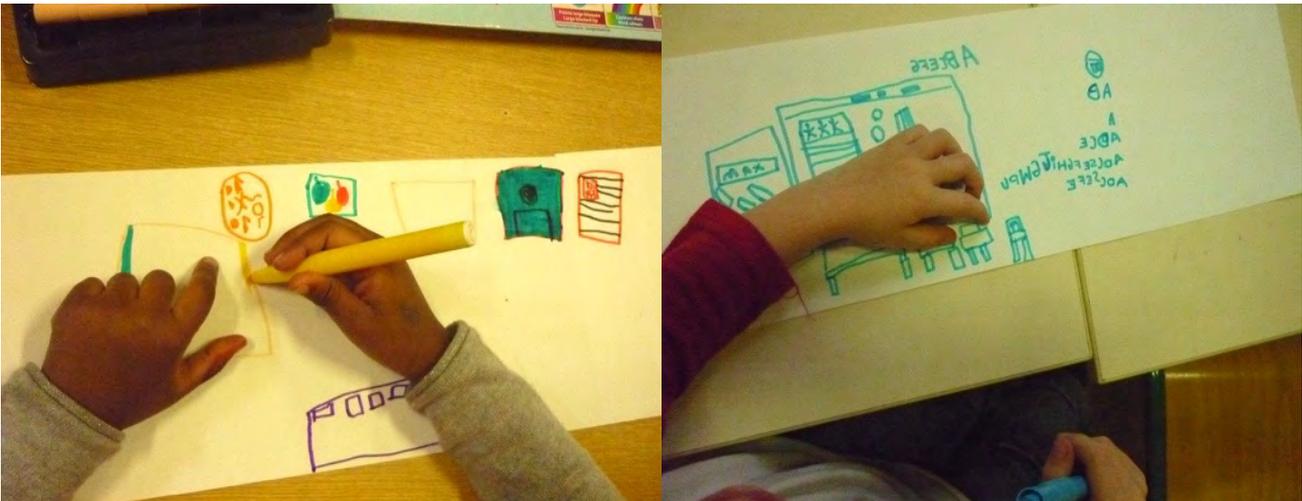
### Going from the construction of the gaze to the structure of a map

More broadly, from this practice of observation from the earliest age, we can see how the space lived and shared is interpreted differently by each look. **Each individual expresses one's view and listen to the view of others around. Each one becomes aware that the gaze of the other is indispensable for her/him to build his/her own.** Consciousness realizes that a map is made from several separated and superimposed layers representing each component of a landscape, from its curves until each of its object. By handling its layers, it becomes clearer how mapping requires measuring the forms of the territory and each detail of the landscape, to render each representation consistent with reality. It becomes clearer how cartography convenes different disciplines to process each step of a mapping construction. We cannot miss an opportunity to explain our scientific disciplines, often too much confidential, working together and collegially, sometimes for years, in order to create this iceberg that is a map, guaranteeing the quality of its argument.

### MAPPING: A SCHOOL OF OBSERVATION, ANALYSIS AND RIGOUR IN CREATIVITY - THE CARTOGRAPHY TO MAGNIFY THE UNDERSTANDING

Visions of a short or distant world, place of memory or space of anticipation, the map graphically depicts the representation of measurements carried over from reality. The map is a tool of apprehension and understanding of the world that we transmit to each other also in order to better understand each other. Mapping induces to choose the rigour of the transcription of the information that the legend of the map decrypts. At first, watching around us, observing each curve in a surrounding landscape, each of its object, each position, to define each orientation: it is here an invitation to draw what each can see, what is felt, in which shape and in which color. This is an invitation to understand how we do create the plan from the 3D environment we are living in together.

### Living mapping experiments: for an immersion in the heart of the real worlds. Demonstration in a classroom: The scrupulous work of the pupils in second year of nursery school



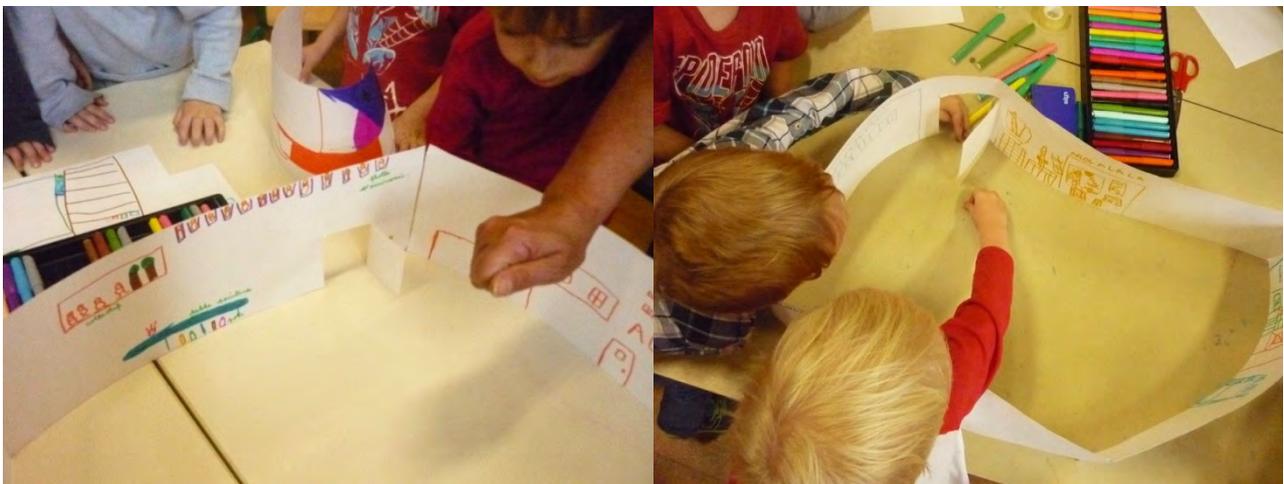
*Figures 3 & 4. Workshop in a classroom: from the observation to the drawing  
(second year of pre-school. Éc. Bretonneau, Paris, June 2011)*

The proposal consists to represent the common space of the classroom - in volume - then to take place over this volume to seize the space out off any specific directive, to observe how this space is inhabited, in an intuitive approach to find the best personal representation of what has to be seized (Fig.3, 4, 5, 6). The preparation for these mapping-workshop 'les Ateliers-cartographiques' takes place in a scolar program driven all along the year by the primary school teachers.

From the drawing of the walls and their adjustment to reproduce the space in volume, each pupil look over the familiar classroom and can easily identify and locate the informations supposed to 'inhabitate' the plan. Opening the door together invite each one to get out and start a discussion about orienteering oneself in this space, to move out even beyond the school itself (Fig.7, 8, 9,10,11,12).



*Figures 5 & 6. Workshop in a classroom: from the observation to the drawing  
(second year of pre-school. Éc. Bretonneau, Paris, June 2016)*



*Figures 7 & 8. Workshop in a classroom: from the drawing to the common uses of the space  
(second year of pre-school. Éc. Bretonneau, Paris, June 2016)*



*Figures 9 & 10. Workshop in a classroom: Each individual expresses one's view and listen to the view of others around.  
Each one becomes aware that the gaze of the other is indispensable for her/him to build his/her own  
(second year of pre-school. Éc. Bretonneau, Paris, June 2016)*



Figures 11 & 12. Workshop in a classroom: from the observation to the map (second year of pre-school. *Éc. Bretonneau, Paris, June 2016*)

**Mapping at college [1]**

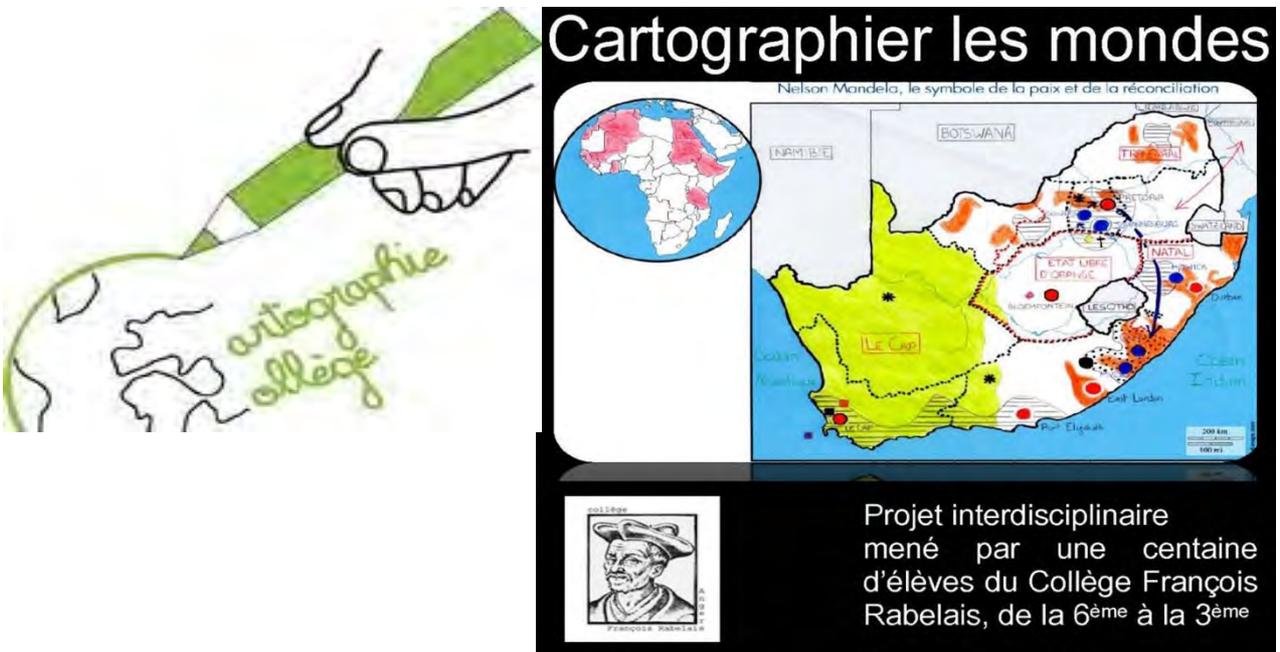


Figure 13. Mapping at Collège / “Mapping the Worlds”

"Mapping the Worlds" is a project offered to pupils at the Collège François Rabelais (in Angers/France) merging the opportunity to reflect on the complex universe that surrounds them and explore, through structured cartographic creations, the multiplicity of the territories (Fig.13, 14,15).

"Mapping the Worlds" is a multidisciplinary project that brought together a hundred pupils, from the 6th to the 3rd level, with the ambition to cross a reflection on time and space and a questioning on each different point of view. A multidisciplinary team of teachers manages the work.

The map is also a tool for exploring the imagination: for invitation revisiting the strength of imaginary worlds

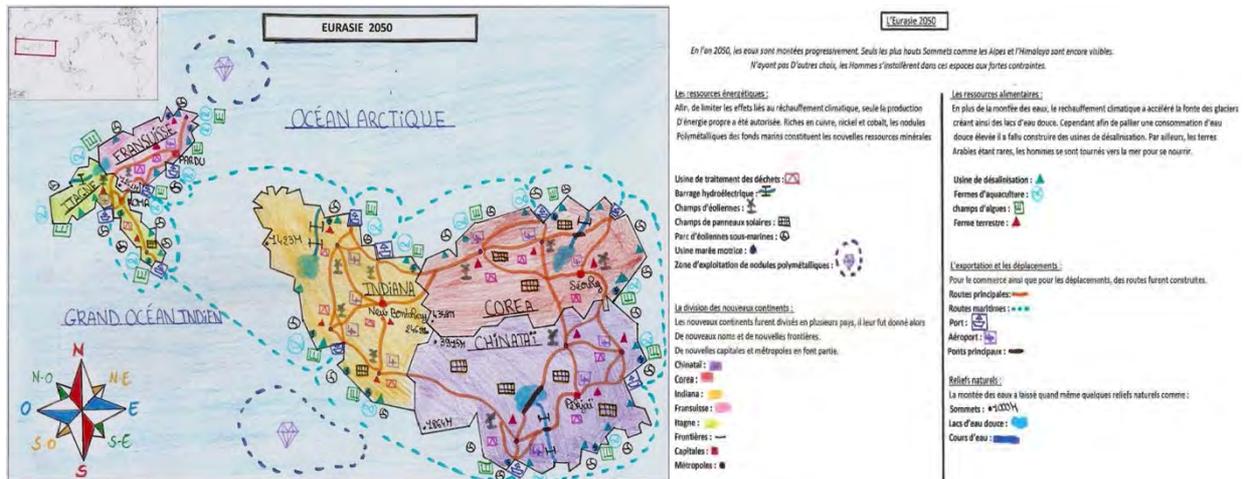


Figure 14. Laureate map MAPPING AT COLLEGE CONTEST. <https://www.concourscarto.com> (EURASIE 2050 by Ilayna Saa, College Pilâtre de Rozier, Paris 13e, France. June 2015)

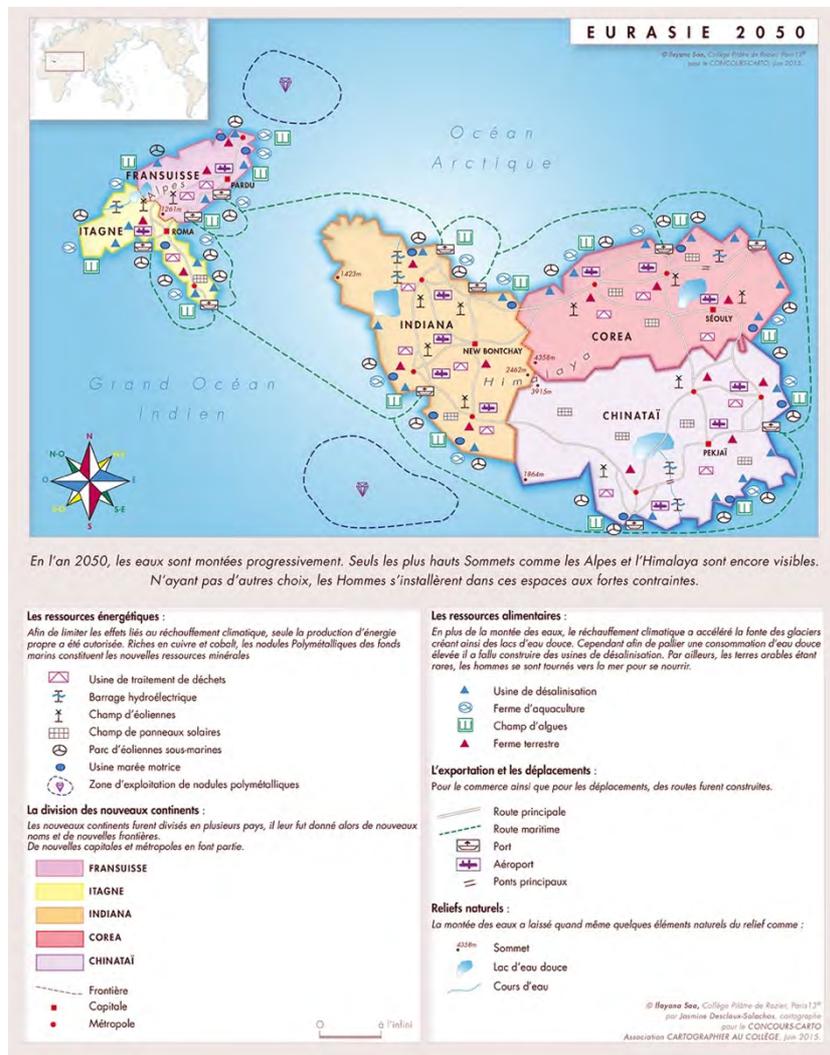


Figure 15. Laureate map MAPPING AT COLLEGE CONTEST, professionally mapped in order to teach the process of our mapping preparation (JdS). <https://www.concourscarto.com> (EURASIE 2050 by Ilayna Saa, College Pilâtre de Rozier, Paris 13e, France. June 2015)

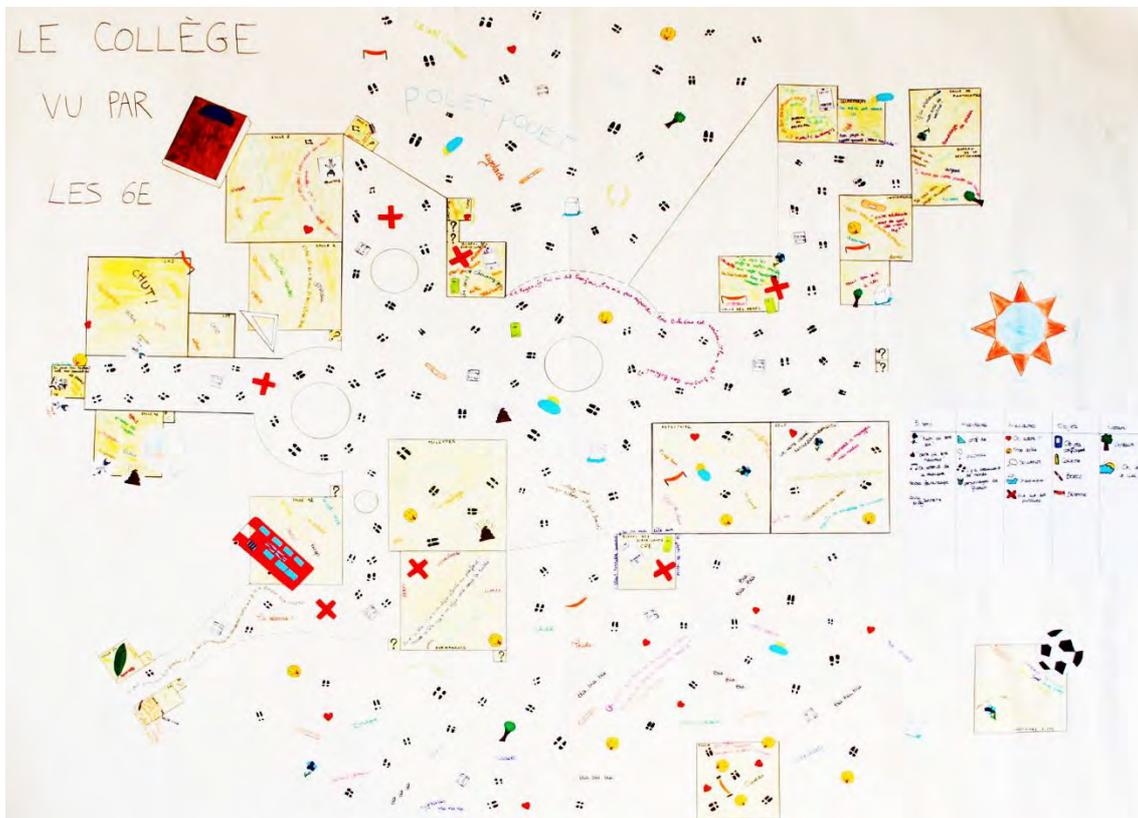


Figure 16. MAPPING AT COLLEGE, 2014. MAKE A SUBJECTIVE PLAN OF THE MILDDLE SCHOOL.  
An interdisciplinary project <https://www.concourscarto.com>



Figure 17. MAPPING AT COLLEGE, 2014. MAKE A SUBJECTIVE PLAN OF THE MILDDLE SCHOOL.  
An interdisciplinary project <https://www.concourscarto.com>  
[https://www.facebook.com/jasmine.desclauxsalachas/media\\_set?set=a.352185911586239&type=3](https://www.facebook.com/jasmine.desclauxsalachas/media_set?set=a.352185911586239&type=3)

« This work is freely inspired by the work of Mrs Catherine Jourdan made in Nantes and in other cities with the children of the social-cultural centers. **What the subjective Geography?** <http://www.geographiesubjective.org> A 'subjective' said plan represents the vision which a person or a group of its territory has, its city in a given time. We shall have understand, it does not base itself on real data (as the distance, the arrangement and the social function of places...) but on the impressions of the inhabitants. Subjective it is by it is objective! Thus we find the memories, the stories places or not, the hasty ideas, the belief there. This card points as well the dreamed spaces as those of the everyday life. It is fictif of much as it says. Freeze frame of the city, it is a facts to tell the others, about its district, its territory, its paths. Speaking about one and about the other : it tells and imagines a way of life and a territory.

Extract of **Catherine Jourdan's** site, subjective geography [2], 2014. » (Fig.16, 17)

## Demonstration outside, through a topographic survey and its available spatial data

Mapping-workshops and orienteering activities are experimented in 'The Gardens of Paradise', Battir (State of Palestine), where a young scientific team of urban-architects, later joined by a Battirian civil-engineer, experimented the complex operations from land surveying (over 12.5 Km<sup>2</sup>), to map editing. Finally, their immeasurable works aiming to offer the world an unprecedented cartographic spatial system characterizing a denied legacy, calling for their land and culture recognition and worldwide protection. As soon as 2007 on site, without any cartographic professional background, and outside of any professional cartographic framework, this visionary team initiated an universal collaborative mapping-masterpiece, overflowing all usual standards in cartography, opening with no warning to an unpublished topographic adventure which started for us in May 2012.

This aforementioned team produced its [Institutional cartography], opening to any possible experiment aiming to express, to superimpose or modelise through spatial data any [Sensitive cartography]. In a common will to share the meaning of 'a data' (that is not an image); in order to disinhibit anyone about any mapping representation of its own territory, as any social approach linking the people to their space; as for any kind of demonstration that anyone could wish to reproduce, workshops, publications, exhibitions, etc. remained available to share an unprecedented living mapping pedagogy. From very young childhood until any age, how maps can support the sharing of knowledge and skills, in order to express the link between each one of us, child or adult, our space and territories? (Fig.18, 19) How maps can reinforce our citizenship? The virtue of this 'Laboratory of Ideas' created in Battir [3, 4], remains to offer to anyone a complete travel through data, at any scale (until 1:1), for any civic experiment we are able to share.



Figure 18. Pupils of Hassan Mustafa School, Mapping-Workshop: « How to Think the Legend of the Map ? » with Mariam Mammam (Battir Public Library, May 2014)



Figure 19. Pupils of Hassan Mustafa School, Mapping-Workshop: « How to Think the Legend of the Map ? » with Mariam Mammam (Battir Public Library, May 2014)

Getting around the field with Battir's topographic maps. Spotting yourself to understand the representations of a landscape, find each of its objects — and rethink each representation to adapt themes chosen by the children, in order to create the keybox of your map.

## CONCLUSION

*Maps are travel companions, keeping us linked to the space as we stroll through the world out of necessity or desire. They measure, trace, and show the world for us, enabling us to better understand the societies and the world in which we live—they function as a golden thread leading us through the maze of life. Anyone curious about our world can, through maps, find out detailed information and its origin, from a local to a global recognition, or can even listen to dreams. Mapping is a complicated process. An accurate map always requires tons of work and efforts. It means data collection and documentation of their sources, in order to produce a set of information, which is then graphically drawn, allowing spontaneous interpretation by readers. **From this perspective, a map is a communication tool.** An honest work must begin with a serious survey, which should investigate the situation of the target territory, like the measurement of the field and analysis of its objects at a 1:1 scale, which specifically characterizes civil mapping.* (Desclaux-Salachas, 2016) [5]

**This body of knowledge is seriously endangered by the illusion of getting available maps with a simple keyboard click.** But so, only pictures are seen, often without any accurate references, or sources. Data behind the map stays protected by international copyright and intellectual property laws <https://www.copyright.gov/title17/>

**An empty polygone is not a map.** Behind our collective efforts to manage and synchronize our tedious professional processes, the common objective remains to offer any citizen, whoever and wherever located inside the perimeter of the mapped territory, the same quality of detailed information essential to build the level of citizenship required.

**A map is not a merely approximative illustration,** designed-on-the-go without any ethical requirements, and cannot be unclear to achieve its purpose. Security is at stake when citizenship is misinformed. Cartography remains multi-inter-trans-disciplinary' following the constant progress of its time, generation after generation, about every topic. Cartography offers common languages created to talk to each other. The more beautiful the maps are, the more their audience grow,-opening curiosities, discoveries, learning. Maps connect people to people through creativity. Citizenship begins with existence.

*Identity is localized. As I say, it has an origin, a local origin. Native soil. And it's indispensable to being enrolled in any citizenry whatever. In any society whatever, within any nationality.*

**Paul Virilio**, 2008. Terre Natale, Ailleurs Commence Ici [https://youtu.be/4OPyARv5P\\_E](https://youtu.be/4OPyARv5P_E)

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## BIOGRAPHY

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# CIVILIAN CARTOGRAPHY, BETWEEN GEODESY AND ART: BATTIR, AN UNPRECEDENTED CARTOGRAPHIC CITIZEN PATRIMONY, A VALUABLE COMMON GOOD ENDLESSLY RESTORED (THE CARTOGRAPHIC CITIZEN UNIVERSITY)

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## Abstract

*Geo-spatial technologies provides data resources, positioning landmarks, basic frameworks for key informations in any cultural application spreading the knowledge about the surveyed territory and its inhabitants. Small-scaled mapping aims at collectively unify the understanding of a space to accurately inform citizens, to solve a misleading lack of perception or location and with benchmark bond helps to prevent problems and avoid, why not, disasters. This contribution focused the ongoing process shared since May 2012, from the genuine framework and issues carried out through the Battir Landscape Management Plan [1] after 2003, in the village Battir, State of Palestine. Recognized as one of the most relevant contemporary digital mapping projects, this citizen-based experience offers an unexpected frame between geodesy and art to understand HOW WE DO MAP FROM A TO Z. From licenced and open source applications, more pedagogy remains available about the meaning of civilian cartography, institutional mapping and working processes, in principle confidential.*

**Keywords:** *Civilian Cartography, Institutional cartography, Geodesy, Topography, Survey, Map, Battir, Battir Landscape Management Plan, Battir Landscape Ecomuseum, Body of knowledge.*

## INTRODUCTION

After 8 years of collective professional works aiming first of all at geolocating the citizen-based battirian mapping experience, mainly through the free contribution of skills in geodesy, in topography, in institutional cartography, it is time to consider how this unbelievable amount of spatial data and mapping files, the very first Palestinian topo map, 12.5 Km<sup>2</sup> available in so many different cartographic systems since 2012, can be handled by its owners: this village community (fig. 1). No one should ignore that a map is not an image, nor an empty polygon, nor a miracle sent by satellites from a keyboard click. **Our body of knowledge shifts dangerously as we all note it: the quality of our citizen information is at stake. It means that our common security is at stake. The audience must know what a map is.** Here, the inhabitants of Battir must keep a chance not to lose their exceptional cartographic patrimony, or their rights on their data, or the copyrights of their maps. Their institutional model is an exclusive cartographic system allowing us to explain it publicly. As mentionned, Crafting a topographic map is like producing an iceberg (J. Desclaux-Salachas, 2019) [2] Maps users usually observe, enjoy and understand a map, as the result of a tedious work which is the submerged part of the iceberg. The variety of skills, the amount of work and the time consuming steps, as well as the commitment of the cartographers to produce the best possible map, lie under the waterline and thus are most often ignored. This collective work is a complex one. Here, each of its steps has been taken and, today constitutes an iceberg which brightly enlightens 12.5 Km<sup>2</sup> of a territory invisible everywhere around (fig. 2, 3). From heterogeneous topographic data handled on the spot at the end of April 2012, an unexpected universal topo-cartographic adventure followed up, spreading ever more the complexity of the meaning 'to be a cartographer', offering a visible definition of what is 'a topographic map', 'a base map', made of huge, complete and expensive procedures usually confidential. Battir, through its unpublished cartographic patrimony, that we have been restoring since 2012, provides an exceptional efficient range of tools that demonstrate this.

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<sup>1</sup> *les Cafés-cartographiques*, association ruled under the 1901 Law, created in Paris in March 2013. Founded in October 1999 by J. D. Salachas, 'les Cafés-cartographiques' offer to meet around the riches of cartography Facebook pages presenting our activities are available and usage free [https://www.facebook.com/CafesCartographiques/info/?tab=page\\_info](https://www.facebook.com/CafesCartographiques/info/?tab=page_info)

**BATTIR INITIAL MAPPING in AutoCAD®** —Software application for 2D and 3D Computer—Aided-Design/CAD  
**Battir Landscape Ecomuseum/BLE, 2007—November2011**

Map of Hydrographic System

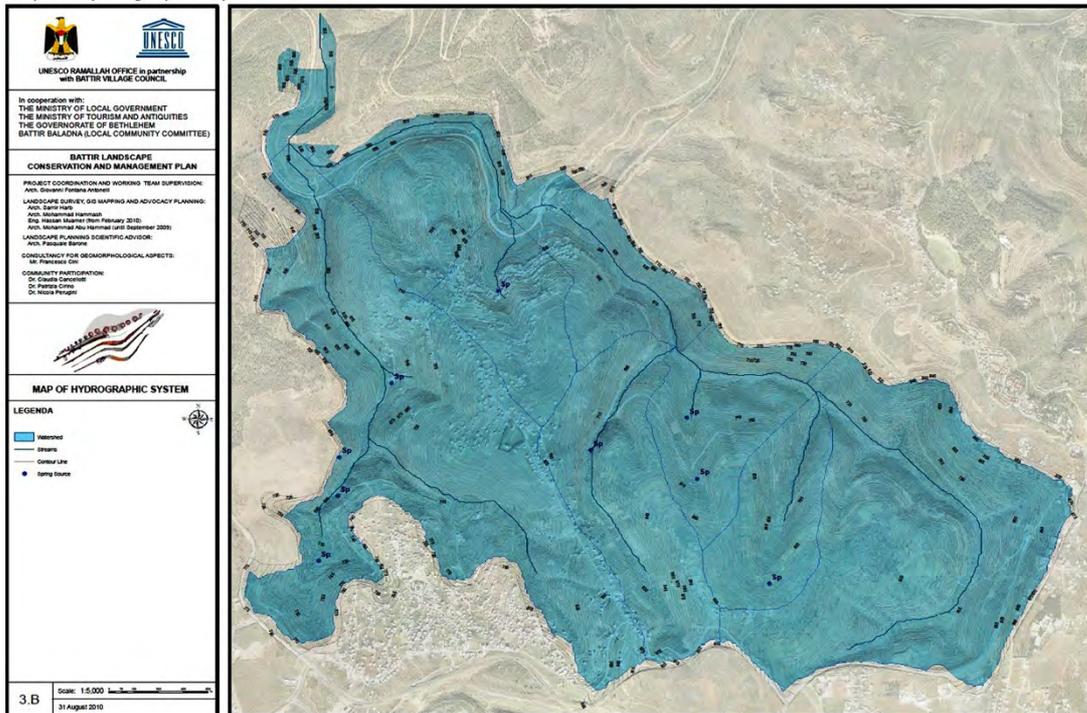


Figure 1. Map of Hydrographic System. Battir, 12.5 Km<sup>2</sup> surveyed after 2003, offers since the very first available palestinian spatial data and collections of topographical maps of Palestine (Battir Landscape Ecomuseum, 2003/2007-2011)



Figure 2. To map: an invisible collective tremendous work unfolding under the waterline. A map is an iceberg [2]  
Here 12.5 Km<sup>2</sup> were mapped: Battir, village of Palestine, has been surveyed, studied and mapped as part of a local anthropological study after 2003, until November 2011 - Battir Landscape Ecomuseum Management Plan [3]

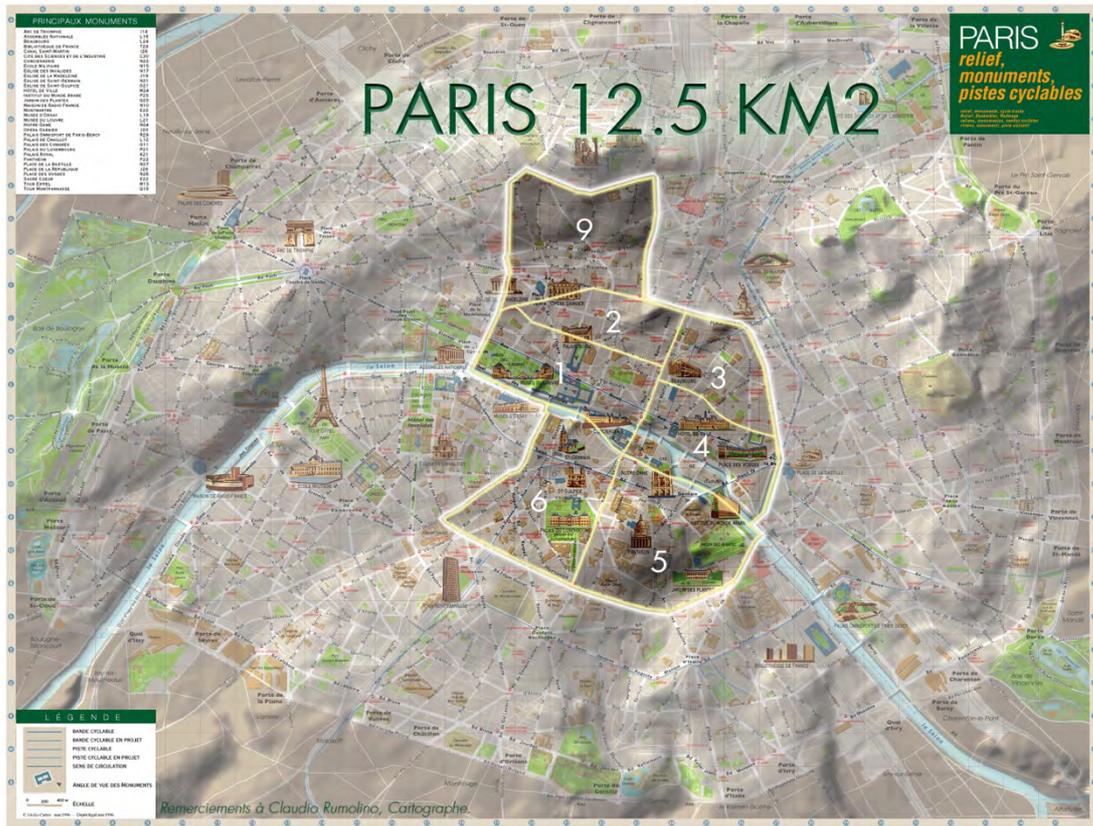


Figure 3. 12.5 Km<sup>2</sup> in Paris: to map involves series of professional skills in order to inform the citizens with maximum accuracy. Here is an image to reach a collective conscience about the quantity of work implemented in this palestinian village, 17 years ago (BLE, 2003/2007-2011)

### LIVING ONE'S TERRITORY: BATTIR, BETWEEN GEODESY AND ART

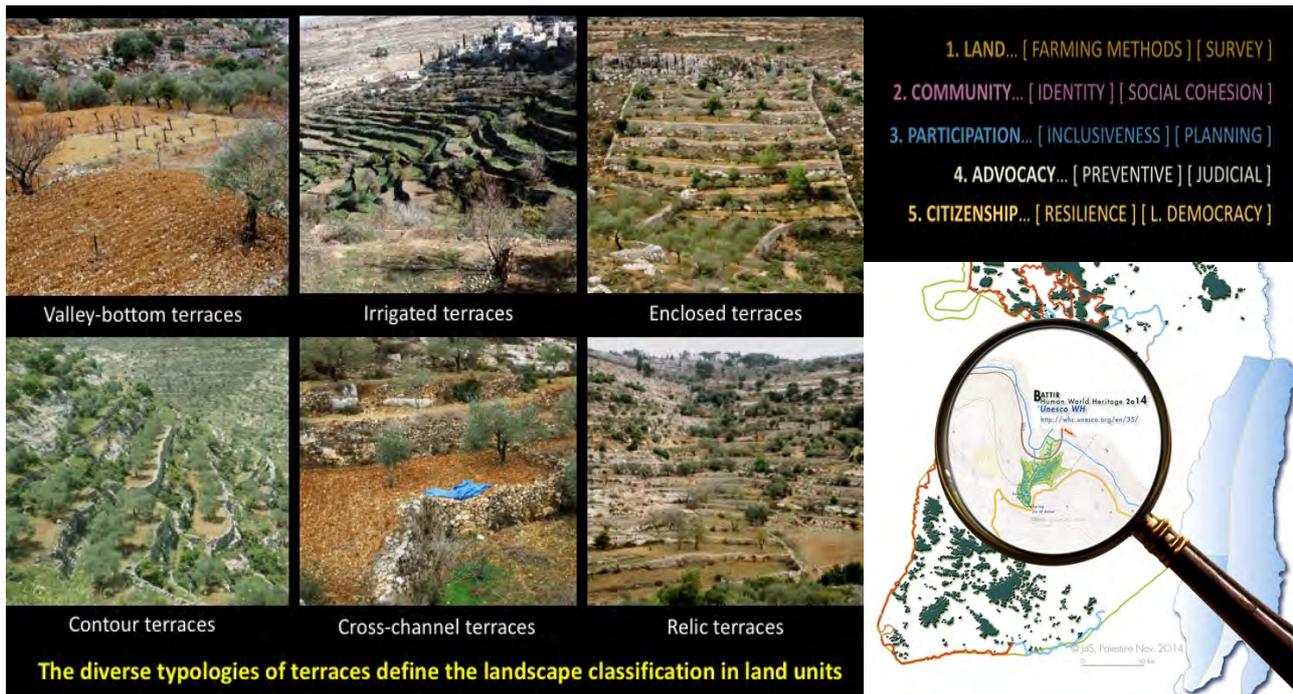


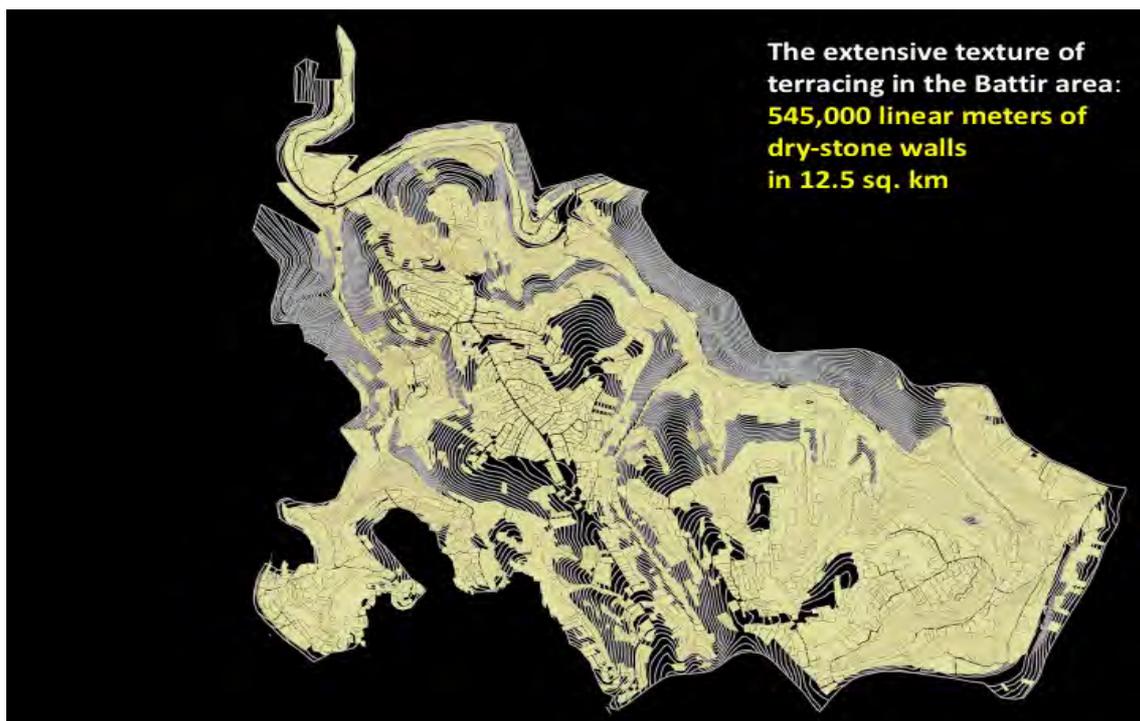
Figure 4. Battir Landscape Project. « Battir —a Laboratory of Ideas for the Safeguarding of the Nature and the Landscape »: 'Battir Cultural Landscape Conservation and Management Plan' by G. Fontana Antonelli (BLE, 2003/2007-2011)

Here, (fig. 4,5,6) after 2003 and 4 years of reflexion, from 2007 until November 2011, 12.5 Km<sup>2</sup> of the terroir were surveyed by a scientific team of young urban-architects later joined by a battirian civil-engineer (in February 2010) [4]



*Figure 5. Battir Landscape Project became the strategic tool to preserve both places and human rights by G. Fontana Antonelli (BLE, 2003/2007-2011)*

[https://www.slideshare.net/DESCLAUX\\_SALACHAS/traductionfontanaantonellienglish1mai2o14/?fbclid=IwAR39HkuI992uRP5H  
azpgF1z4cUxxGPEZAsE-oXHi-Rh7DRPbL5A0ofi0V8](https://www.slideshare.net/DESCLAUX_SALACHAS/traductionfontanaantonellienglish1mai2o14/?fbclid=IwAR39HkuI992uRP5HazpgF1z4cUxxGPEZAsE-oXHi-Rh7DRPbL5A0ofi0V8)



*Figure 6. Battir Landscape Project, irrigated terraces (BLE, 2003/2007-2011)*

Under the sign of exchanges, a spectacular collective experience of teaching local techniques and know-how emerged after the Second Intifada in this village, in occupied Palestine, a scientific citizen framework provided to enhance the country. It is, at the beginning, an anthropological study completed by the creation of an Ecomuseum and a local survey.

### The praise of progress

Battir, village in the West Bank, southwest of Jerusalem (fig. 7, 8), owns its institutional cartographic model, reflecting all the processes, usually confidential, of the creation of a topographical map. On an unprecedented local citizen initiative, fieldwork was carried out between 2007 and 2011, through the Ecomuseum created in the village to ensure its expansion and archiving. These topographical works offer the keys of the civil cartography that we explain and publicly share ever since their topographic data were entrusted to us (end of April 2012) to ensure its geolocation from Paris through the orthophotography, technical operations requiring tools then inaccessible to the village. From the data to the image, here, the measurement of reality makes visible what, everywhere else, remains invisible.

Managed from the local aerial photography, @AutoCad primarily and @ArcGis files, *data* was at first opened in @Illustrator, then harmonized through art mapping in order to render accessible training tools in cartography. The students of the National School of Geographic Sciences (Marne-la-Vallée, Cité Descartes, France) cleaned the *initial* databases and rectified the data through the orthophotography of the region, in order to produce a coherent *spatial* geographic dataset [5].

### A LABORATORY OF IDEAS BUILDING A DAILY PEACE

For 8 years, as part of our universal desire to restore these spatial data that do not belong to us, this Laboratory of Ideas, Battir's topo-cartographic work, is the result of a citizen approach that has never been seen in the history of cartography.

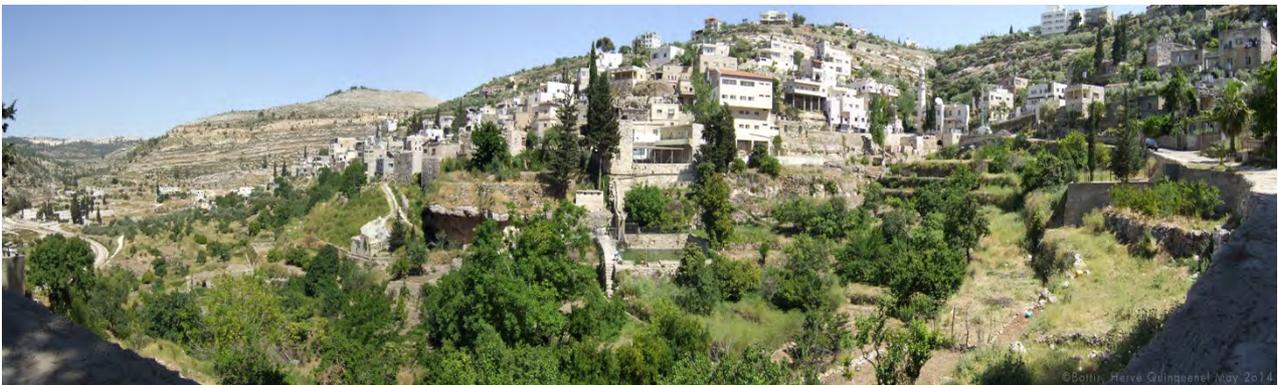


Figure 7. Battir, 5 Km west Bethlehem, 7 Km south-west Jerusalem: World Heritage Patrimony since June 20, 2014  
(Photo: H. Quinquenel, 2014)



Figure 8. Battir, Makhrou Valley. "Here, each curve, each perspective makes sense... Terraced orchards, olive tree fields, slopes and meanders irrigated by canal systems coming from the hydraulic engineering designed in the Antiquity. Human intelligence emanates from each stratum that convey all the perfumes while trail hiking." J.Desclaux-Salachas, *The Cultural Exception*.  
<http://extrazoom.com/image-105107.html> (Photo: H. Quinquenel, 2014)

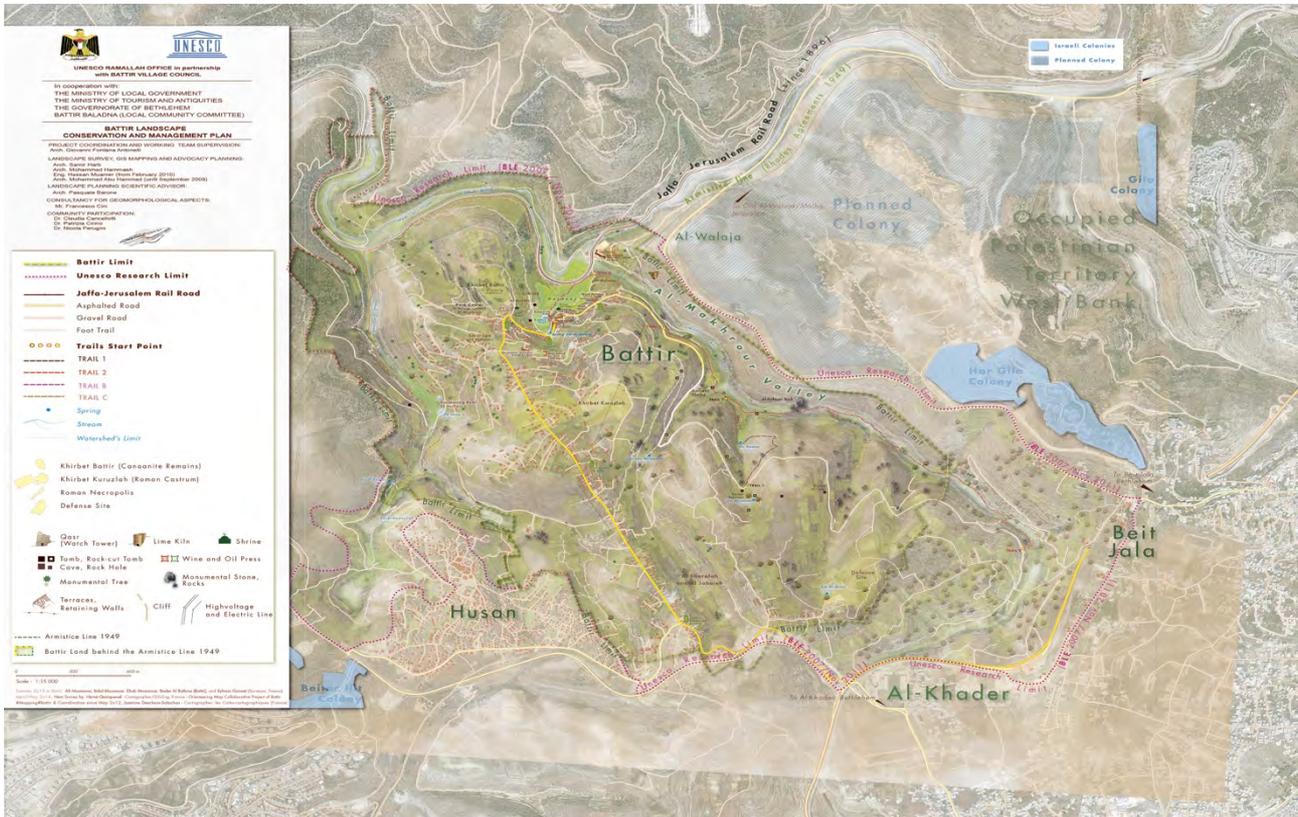


Figure 9. Battir in @Illustrator (J. Desclaux-Salachas, cartographer, 2014)

The inhabitants of this village in the West Bank tell us about themselves and their history by the exhaustive representation of their topography, measured by surveying, and the scientific description of their own territory (fig. 9). All its human dimensions resound through series of large-scale maps, whose data, the integral property of the inhabitants, is available to them for any editorial project, whatever it may be. Their topographical maps, known as the base map, teach both the preparatory works for the production of maps, step by step, through our professions of geodesy, topography, cartography, geography, the uses of space rooting in the minds the intimate ties of the past combined in a present thought for projects accessible to all, for all.

## A SCIENTIFIC BODY OF KNOWLEDGE

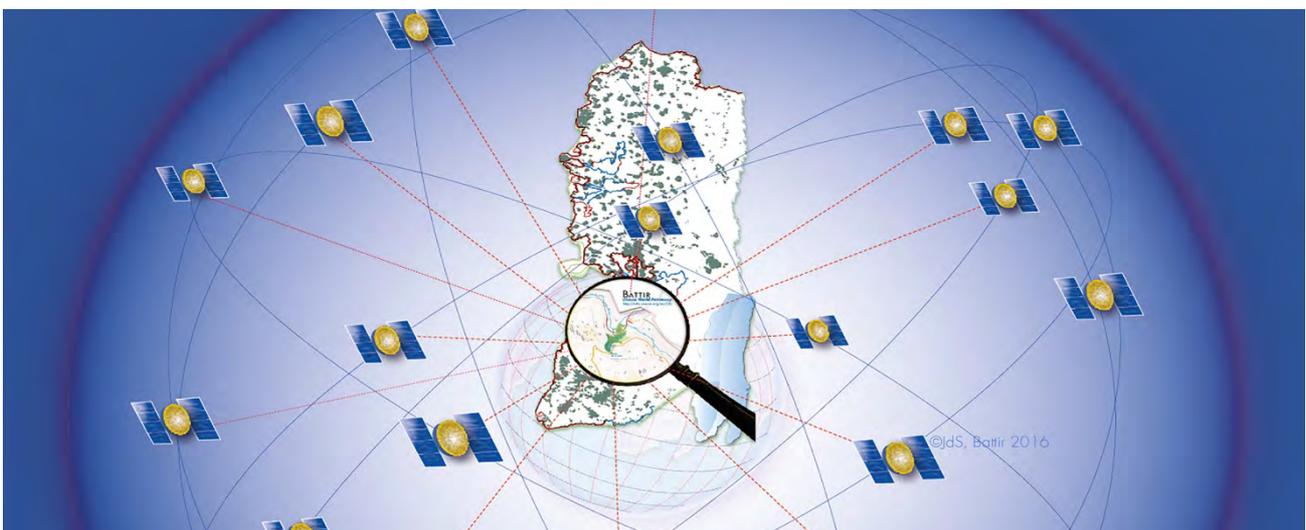


Figure 10. Battir offers the first spatial data produced by citizens, cultural goods belonging to them: a travel inside the map.  
 (Available Extrazoom Gallery: <http://extrazoom.com/gallery/JasmineDesclauxSalachas.html>)

For 8 years, this Laboratory of ideas multiplies its teachings in the world from the pedagogical model developed from Paris, as part of the activities of *les Cafés-cartographiques*.

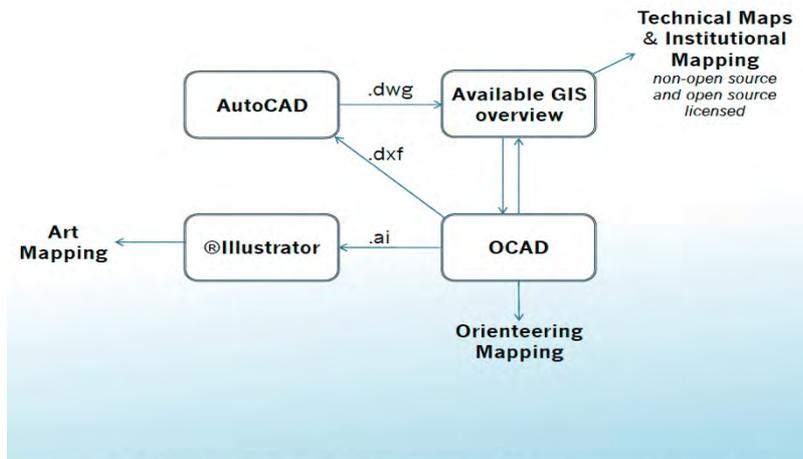


Fig. 28: Battir, the revealed citizen cartography between geodesy and art (*les Cafés-cartographiques* & *ENSG* since May 2012).

Figure 11. The Cartographic Citizen University from the unprecedented civic topo-cartographic model made in Palestine (Battir from Paris 2012-2019) *GeoSee*, ISSN: 1857-9000, EISSN: 1857-9019

[https://www.academia.edu/39505401/THE\\_CARTOGRAPHIC\\_CITIZEN\\_UNIVERSITY\\_FROM\\_THE\\_UNPRECEDENTED\\_CIVIC\\_TOPO-CARTOGRAPHIC\\_MODEL\\_MADE\\_IN\\_PALESTINE\\_BATTIR\\_FROM\\_PARIS\\_2012-2019?email\\_work\\_card=title](https://www.academia.edu/39505401/THE_CARTOGRAPHIC_CITIZEN_UNIVERSITY_FROM_THE_UNPRECEDENTED_CIVIC_TOPO-CARTOGRAPHIC_MODEL_MADE_IN_PALESTINE_BATTIR_FROM_PARIS_2012-2019?email_work_card=title)

Collecting and analysing to reproduce reality, our mapping activities explore protected sensitive data. Here, the geolocated data of Battir, a spatialised cultural citizen heritage of unparalleled value, is a common good to protect. Registered, since 2012, in our licenced and open source systems of the representation of space and territory, the Battir cartography offers to all the keys of the construction of the graphic language from the scale of the 1:1 to all its possible generalisations from one scale to another (fig. 10, 11).

### MAKING VISIBLE THE INVISIBLE

It has become a routine to call a map an empty image. Here, the image is supposed to be ‘an interactive map’: but the more you zoom in, the more you find the void (fig. 12, 13, 14, 15, 16).

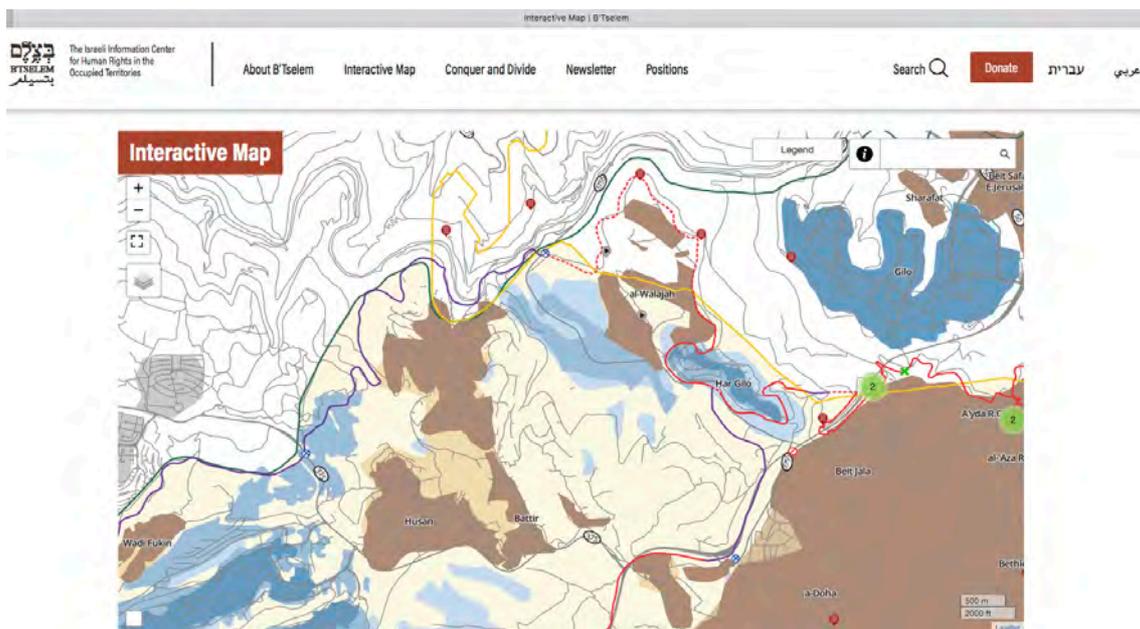


Figure 12. ‘Interactive map’ keeping the reality invisible <https://www.btselem.org/map>

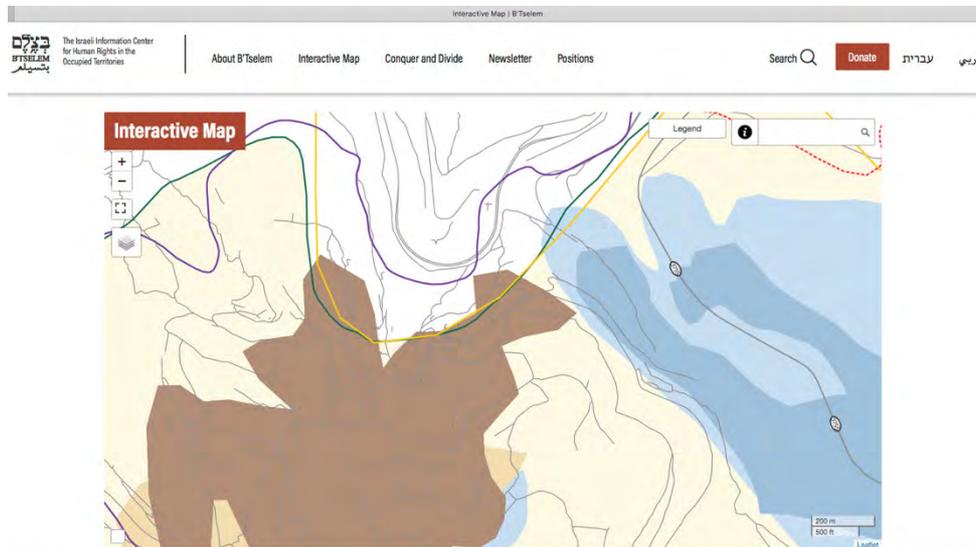


Figure 13. Zoom in : 'Interactive map' keeping the reality invisible <https://www.btselem.org/map>

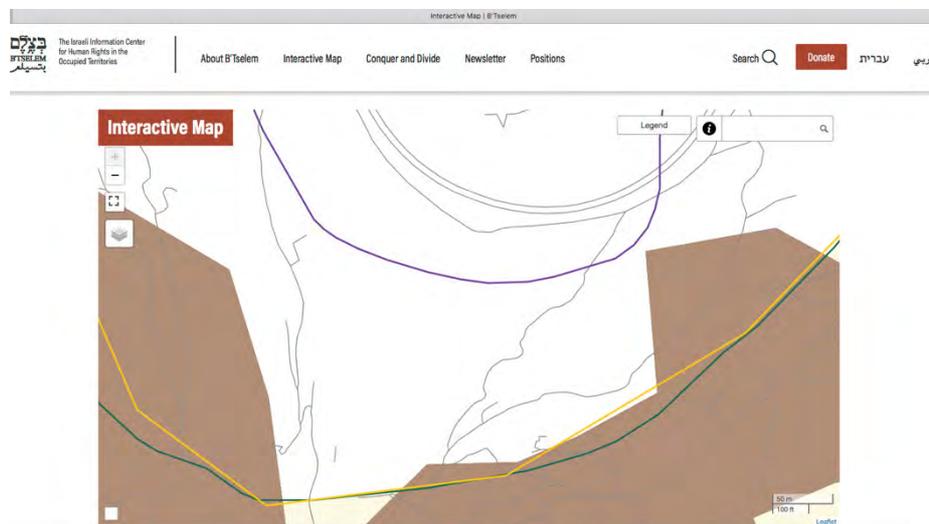


Figure 14. Zoom in : 'Interactive map' keeping the reality invisible <https://www.btselem.org/map>

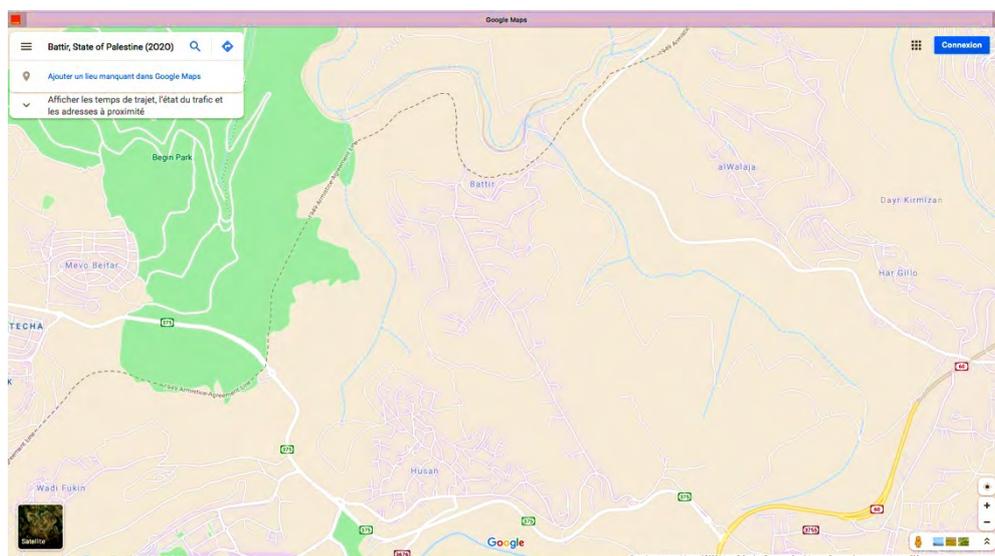


Figure 15. Zoom in: Battir in Google, May 2020.



Figure 16. Battir in its reality through its survey, @Illustrator file abstract, JdS 2014. (BLE, 2003/2007-2011, Paris 2012-2020)

**Misperception, misinformation, misunderstanding: everywhere citizens are living inside the void, invisible, at the risk of their life. Measures must be taken to fight the disinformation that erases the reality that maps are supposed to render.**

A map is a mathematic system combining collected data reinterpreted through graphic semiology. Mapping at small-scales demands a range of specific skills. At first, each data must be geometrically corrected — ‘ortho-rectified’—, planimetric rectifications have to be applied to remove lens distortions and optics, camera angle, differences in elevation of the topographic relief through a rigorous process. Each data must be characterized, analyzed, prioritized in order to be mapped. A survey is necessary to collect series of data needed then to represent the territory through its thematic realities, to offer the best accurate visual tools citizens may wait for. These huge collective works are usually managed by governmental institutions and implemented through national and international conventions, through amounts of rational investments to give to each citizen of a Nation the quality of information he deserves. One also forgets too often that GIS are not topographic tools nor tools made to produce maps, but are just tools we need to combine output data. Then, if a data is correctly characterized and geolocated, it can be register in any cartographic system.

**The Topography of the territory, object of the institutional mapping, falls within the military domain almost everywhere and remains, by principle, the state’s business.**

In France, it is a civil matter, thanks to the will of the National Council of the Resistance which created in 1945, the National Geographic Institute and its school, the National School of Geographic Sciences. De facto, Battir offers the only spatial topographical data available through a civic cartographic act with objectives of education in the culture of peace. We transmit this topographical adventure as it was conceived by the Palestinian scientific team that designed it. We explain it as it was entrusted to us 8 years ago to be developed and shared in these terms

**TO MEASURE AND REPORT IN ORDER TO BUILD THE MAP IN ITS TRUEST SENSE. THE AWARENESS OF THE PLACE WE ‘LIVE IN ‘**

**Battir is an invitation to envision how our skills can allow us to think about the space to create-its various modes of representation, together.**

Battir's children ask lots of questions about their topographic maps. Among all the questions, this one often comes up: « —I recognize my village very well. Every time I look at these maps, I know it's Battir. I recognize the place. But the map is never the same. There are so many... How that is possible? » (fig. 17).



Figure 17. Mapping-Workshops remain open to everyone, everywhere, especially in Battir (Battir Public Library)

## CONCLUSION

In complete respect of its intellectual property, in order to give account of its multifaceted scientific and human dimensions, this experiment remains a continuous peaceful call to understand our living environment, the structure of our society from past to future, and to travel inside data, inside the map which outlines its challenges. We face an unusual travel that must remain accessible to everyone, widely, to protect everyone from misinformation.

Since 2016, to protect the intellectual property of the initial authors, to protect the collective property of the community of Battir on its copyrights; to make known throughout the world the value of these collective cartographic works, we are submitting to the vote of the Norwegian Nobel Committee their collective nomination to the Nobel Peace Prize. This is an ongoing process shared to sustain their practices and their impact in the longer run, as to preserve their memory.

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[https://www.academia.edu/39505401/THE\\_CARTOGRAPHIC\\_CITIZEN\\_UNIVERSITY\\_FROM\\_THE\\_UNPRECEDENTED\\_CIVIC\\_TOPO-CARTOGRAPHIC\\_MODEL\\_MADE\\_IN\\_PALESTINE\\_BATTIR\\_FROM\\_Paris\\_2012-2019?email\\_work\\_card=title](https://www.academia.edu/39505401/THE_CARTOGRAPHIC_CITIZEN_UNIVERSITY_FROM_THE_UNPRECEDENTED_CIVIC_TOPO-CARTOGRAPHIC_MODEL_MADE_IN_PALESTINE_BATTIR_FROM_Paris_2012-2019?email_work_card=title)
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# POSSIBILITIES OF QUANTITATIVE ANALYSIS OF HYPSOGRAPHY EDUCATION PROCESS IN COLLABORATIVE IMMERSIVE VIRTUAL REALITY

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## **Abstract**

*In 2019, a transdisciplinary team at Masaryk University, Brno, CZ, developed a solution for collaborative education of hypsography in immersive virtual reality (collaborative immersive virtual environment, or CIVE). Its primary purpose was to help its users understand and apply the acquired knowledge of the principle of contour lines, which was achieved by solving map-based tasks together in pairs. Pilot use of the environment had been a subject of qualitative analysis, which allowed in depth insight into the users' experience, means of collaboration and communication, and cognitive processing. (Šašinka et al., 2019) After we examined thoroughly what the participants were going through, another research challenge has occurred: to identify and measure relevant objective variables on a quantitative level.*

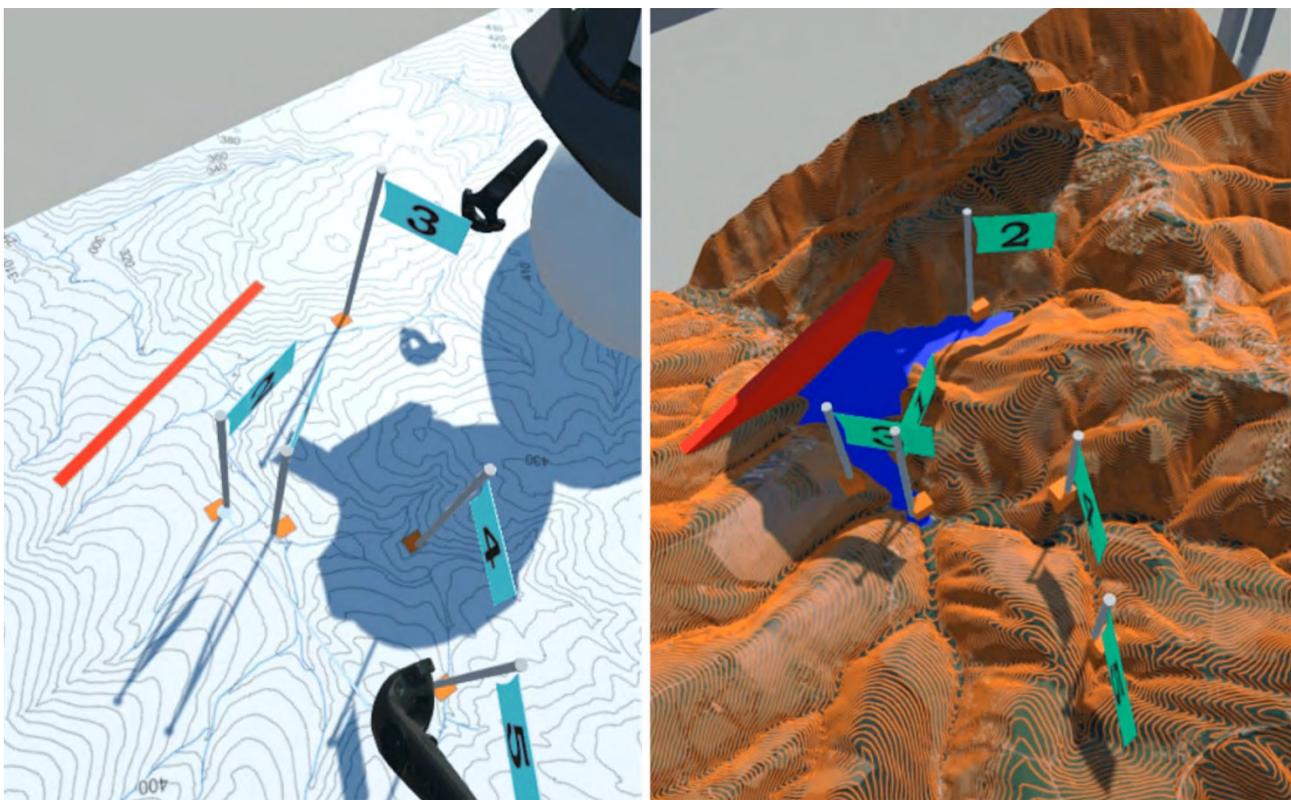
*Complex behaviour is difficult to crumble into well observable and well measurable variables that may be later analysed, especially in the setting pair (or group) collaboration in virtual space, where both interactions with other users and with the elements of the environment may be significant. The aim of this paper is to present a conception for quantitative analysis of the educational process in immersive virtual environment in the context of hypsographic task solving. That includes identification of relevant phenomena to focus on, definition of criteria according to which these phenomena will be assessed, and suggestion of means of statistical analysis of these data. Variables to be observed are for instance proximity between avatars (or users' virtual personas), avatars' locomotion, users' oculomotor behaviour, speech production, and more. This conception may serve for further analysis of social interaction and provides basis for our current research of cross-cultural differences.*

## **1 INTRODUCTION**

The development of virtual educational platforms has been running for many years now, however, recent survey (AR/VR Innovation Report, 2019) has shown that 30 percent of developers working in virtual, augmented or mixed reality consider education their priority for the following years. That is to no surprise of researchers working in the field. Sadly, it does not result in much deeper insight into the educational process run in virtual environments as the educational applications' development seems to run in two slightly different paths: One is commercial, result oriented, focusing on creative, innovative and entertaining use of the technology. The other, scientific branch is slower in developing and publishing the findings and working applications as research demands rigorous, methodologically pure procedures, and going public with any results is weighted by the lengthy review and publication process. (For

comparison see for example an overview of interesting virtual reality (VR) commercial educational apps of 2019 by Bambury (2020), and research-focused educational apps by Halabi et al. (2017), Solomon et al. (2011) or Šašinka et al. (2018)). In result, there are many interesting VR educational platforms with no or very little research behind them, while the general understanding of how the educational process, learners' experience, or learning outcomes differ from real world lessons or courses is still very shallow.

To overcome this knowledge abyss, Šašinka et al. (2019) published their conclusions about the subjective experience of virtual-reality-based collaborative educational intervention participants: The application included a virtual classroom with a table in the middle where a 2D contour map was presented which could eventually be switched to a 3D model of the corresponding terrain (see Fig. 1). Pairs of participants were required to fulfil to different tasks based on these visualizations. Firstly, they were supposed to find a way to connect two spots (A and B) on the maps with "light signals" (i.e. to mark spots that were visible from one to another and that could link a direct signal paths between point A and B). S, secondly they were to decide in what order selected points on a map would be flooded if a highlighted dam is going to be filled in. By various methods, Šašinka and his colleagues (2019) examined the subjective sensations and the participants' feedback on how they felt and what and how they learned. According to the results, the applications are currently being elaborated and refined and the direction of further research is clear: to examine the objective measures of virtual-reality-based collaborative education.



*Figure 1 The contour lines 2D map (left) and a 3D model (right) of the corresponding terrain presented during a map-based task. Switching between these two visualizations enabled better comprehension of the principle of contour lines. (Šašinka et al., 2018)*

## **2 FOR WHAT IT'S WORTH MEASURING?**

Traditionally, when researchers intend to measure anything about education, it is correctness and time spent on task solving (see examples in Issa et al., 2011; Parong & Mayer, 2018; Rawson et al., 2017; Bernacki et al., 2020, etc.), or how precisely and how fast they manage. These are the very basic metrics to evaluate efficiency of educational interventions and are, indeed, included in our research design. Delayed knowledge post-test is a part of the design in order to gain information about the long-term effect of our lessons, on which the scientific community so far lacks data (Merchant et al., 2014). Virtual environments, however, enable many more phenomena to be observed and measured on a level of hard data. Although it is quite possible to record speech production and track students' movements in real classrooms, virtual environments utilizing head-mounted displays (or "VR glasses") which already have a tracking device built-in, offer possibilities of such tracking without the necessity of special hardware, painful adjustments or participants getting tangled in wires. Simply put, VR enables decomposing human behaviour into little pieces and

studying these pieces of a puzzle, and bringing it back to the gestalt in its entirety would presumably offer an unprecedented insight into the ways people work and learn in context of hypsography education.

## **2.1 Pieces of a Puzzle**

### **2.1.1 Position and Direction Data**

The data that we can collect with very little effort or slight adjustment of the logging applications or the environment are those about the position and locomotion of avatars (i.e. the participants' virtual personas). It is rather simple to track for instance how willingly (i.e. how much and how fast) the participants move in the VR – we can track their position by tracking their camera placed in the head-mounted display (HMD). Raw data from this tracker contain 3D coordinates (X, Y, Z) with a time stamp. Thus we gain information about the students' trajectories as well as – and perhaps more importantly – about the proximity (or distance) from which they approach other avatars, various objects, the lecturer (if present), the edges of the virtual space, etc.

Another type of information we can collect from the HMD is those of head direction – we can easily find out what is the participant's field of view at each moment of the session. And should there be an eye-tracker inserted in the HMD (such as the one by Pupil Labs that we use in our experiments), we receive a log several times per second (depending on the features and setting of the eye-tracker) about the precise coordinates of the point where the student is looking. Lukáš Herman and his colleagues, for instance, have recently published a tool that simplifies collecting this sort of data. (Herman et al., 2018)

### **2.1.2 Gestures and Postures**

Recording and observing postures and gestures will come especially handy if we want to focus on the social aspect of collaboration in virtual reality. Unlike in real classes (Torres et al., 2017) where we hardly ever get a better option for judging nonverbal communication features than recording simple observation, virtual space gives us the possibility to track sensors in the controllers held in the participants' hands (which basically means tracking their hands or gestures). Just like tracking position of the HMD, we can track the controllers and analyse, how much the participants gesticulate. These data itself may feel uninteresting to some, but it is worth considering that certain similar gestures may in terms indicate for instance panic fear or elated joy (for examples of detailed analysis of gesture-emotion relationship see Dael et al., 2012), which are very valuable data. Similarly, we can make conclusions about the learners' frustration, level of engagement or joy expressed for a certain topic.

From raw data about the position of the controllers, we may rather easily elaborate the speed and range of gestures by calculating the distance between every two neighbouring positions of the controllers. Similar procedure works for the position of HMD as well. It is notable though, that it is a matter of time when expressions of this kind (gestures as well as facial expressions etc.) will be evaluated automatically (see e.g. Alabdulkarim, 2014) and the way towards the described data shall be much shorter and more simple.

Postures are a chapter of slightly higher demand. Since Durlach and Mavor published their monography on virtual reality (Durlach & Mavor, 1995), not that much has changed in the principle, that additional sensors need to be placed onto participants' bodies, although only few points or landmarks on limb segments need to be tracked to gain the complex image of one's body position. Huang and his colleagues (2019) brought a well-organized overview and a comprehensible comparison of up-to-date technological options of position and posture tracking and explain that there are generally two methods of posture detection: computer vision and acceleration sensor data analysis.

### **2.1.3 Interaction**

One of the aspects in which we as researchers are especially interested is interaction in virtual reality as interactivity is a key feature of these environments. And his interest is not limited to interaction between people (or avatars), but obviously includes interaction and manipulation with the environments itself, with objects placed in there. Thanks to the technological possibilities described above, we are currently able to record, visualize, and analyse when a person in VR gazes at an object or a person, touches an object or another person, grabs or change a position of an object, etc.

Collaborative education has been subjected to much research in the recent decades (Johnson et al., 1984; Cohen & Cohen, 1991; Webb, 1982; Slavin, 1980; etc) and results are more than promising – with Laal and Ghodsi (2012) we can divide the benefits of collaborative learning into 4 categories: social, psychological, academic and assessment-related benefits. Confirmation of similar effects in virtual collaborative educational interventions will be subjected to future research.

In the virtual environments, we will be able to analyse interaction in detail, however, in some ways it may be demanding and perhaps even too costly in terms of time and work. It is also important to note that the above-mentioned phenomena are all parts of interaction and should always be evaluated in that regard: for instance, proximity, its changes and continuous development is an important aspect of interaction both with objects and avatars.

In a narrower meaning, verbal production of the users can be assessed in terms of the time spent talking, engaged in a dialogue or silence.

### 3 Why Measure and Why Not?

Observing education process in virtual environment to such details as this paper suggests, brings several opportunities that motivate further research:

- Better design of educational virtual environments.
- Better suited application for various target groups – whether differentiated by age, ethnicity, and other characteristics.
- Better educational intervention design.

A considerable counterargument against a detailed observation of the described kind may lie in the field of research ethics. We suggest contemplating the borderline between reasonable scientific insight and undue violation of users' privacy.

Hypsography– and geography in general – provide an ideal material to present and teach via immersive virtual environment as its understanding depends on the visual and spatial aspects of the topic. And this paper intends to present the opportunities of collaborative virtual environments from a wide and detailed point of view. This conception may serve for further analysis of social interaction and provides basis for many domains.

### ACKNOWLEDGEMENT

This publication was supported by the Czech Science Foundation (GC19-09265J: The influence of socio-cultural factors and writing system on perception and cognition of complex visual stimuli).

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# FUN WITH MAPS-ROAD MAP TOWARDS IMPLEMENTING A LEARNER-CENTRED CARTOGRAPHIC TRAINING IN KENYA.

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## **Abstract**

*The importance of maps as tools providing location-related solutions, supporting spatial behavior, enabling spatial querying, or providing information about space cannot be overstated. In Kenya, cartography is taught at the tertiary education level where thorough instructions on cartographic tools are impacted. However, inculcating the cartographic skills at the earliest primary education level is known to create a greater impact on the learners' interests in mapping. This project aimed at formulating a framework to best aid in the successful incorporation of mapping activities into the country's Competency Based Curriculum education system. The various framework activities were formulated through interactions and discussions with learners and teachers from eight primary schools in Mweiga, Nyeri County, Kenya. The activities were later tested on the learners. From the results, commendable interest in maps in children aged 4 – 10 years was observed with some activities being more successful than others. Future works envisages to incorporate more schools into cartographic mapping activities.*

**Keywords:** *Competency Based Curriculum, Learner-centered Cartography, Model Maps, Cartographic tools.*

## **INTRODUCTION**

Allan & Barbara (1999) noted that most women do not delight in spatial activities nor pursue professions or hobbies that require them. Hence there is a need to create the spatial interest early in the childrens' lives to grow the love of spatial environment in the girls as well. Early interaction will nurture the right attitude towards maps. However, cartographic principles are often ignored resulting to visually unpleasing maps or misleading map communication. This raises concern about map use in regulatory applications. The government of Kenya, in 2017, introduced the Competency Based Curriculum (CBC) education system whose focus is on developing a learner's competencies (Kaviti 2018). This system of education was fully rolled out across the country by the year 2019. It focuses more on the learners' flexibilities on opportunities for specialization, offers balanced foundational and comprehensive assessment and values learners' different skills. A pilot programme by Njore *et al* (2019) to introduce mapping to children aged between 4-10 years was successfully implemented in three schools. The objective was to develop a framework of cartographic activities that could be implemented in the CBC. There has been continued interaction with learners on favorable activities. The government while launching the CBC, directed the community to provide supplementary resources to make its implementation a success. The current work with the children shared in this paper aims at augmenting map reading and interpretation skills taught at primary school level by introducing basic cartographic skills particularly creating model maps; a way of learning effective map communication. To make cartography more learner-centred, it is necessary to design activities for the different learning levels. The focus was to initially introduce

cartography through hand-drawn models so that each learner would be more engaged and as such own the final product and create an interest in maps. A team composed of academic staff as well as Survey of Kenya (the National Mapping Agency) staff, is currently developing a childrens' book on cartography and formulating cartographic activities at the Institute of Geomatics, GIS and Remote Sensing at Dedan Kimathi University of Technology.

In the Competency Based Curriculum (CBC), a learner is required to complete two years of pre-primary education, six years of primary education, six years in secondary education and 3 years of tertiary education hence the 2-6-6-3 system. This differs from the old system (8-4-4) which was content based and mostly targeted on classroom performance. CBC aims at developing the core competencies in communication and collaboration, critical thinking and problem solving, citizenship, digital literacy, learning to learn, creativity and imagination and self-efficacy, promoting application of acquired skills and children led activities where parents and the community participation is required (KICD 2017).

Maps are initially introduced to school pupils in Kenya at the third grade (learners aged 9 to 10years) of the primary education while only one type of atlas is available. Different grades from pre-school have different understanding on symbols and information contained therein. From the different map activities introduced earlier by Njore *et al* (2019) different atlases should be prepared for the different levels of learning in Kenya. Bulgaria has atlases on geography and history for children from 1st to 12th grade of Bulgarian schools. Given the different map cognitive skills and capabilities observed in children between the ages of 4-10, different atlases should be prepared for the different levels of learning Njore *et al* (2019). The main aim was to design activities that can be employed in the geography content under the social studies subject. Even though the map work starts at Grade 3 (9 years), the map activities were prepared for all the learners from pre primary (aged 4 to 6 years)

The proposed framework was guided by previous research by Njore *et al* (2019) that proposed grouping learners in ages of their respective classes since this made it possible to have the map sessions in their classes. The ages of the children ranged from 4 -10 years in three schools. In the first phase of this framework development it was observed that learners in the pre-primary level (aged 4 to 6 years), also comprehended basic maps of their immediate environment.

## **METHODOLOGY**

Eight schools in Mweiga, Nyeri County were selected. Three of the schools had been involved in the introduction to map use in 2018 – 2019. The working groups were initially created as described in Njore *et al* (2019), and were based on the ages of the learners. The groups were a) pre – school (ages 4-6), b) two lower primary groups (ages 7-8 for Grades 1 and 2, and ages 9-10 for Grades 3 and 4). The 11-12years; Std 7 and 8 were excluded as the existing primary school atlas in Kenya is most relevant to their level.

Identification of the eight schools to participate from the start was based on the proximity to each other to increase the number of visits and also proximity to the university where the authors work. The schools were a mix of public and private schools and within one community. The initial step involved setting up a consultative meeting with the relevant teachers to deliberate and brainstorm on the proposed learning concept. The concept agreed upon involved preparing an activity for each of the three working groups and executing it at least twice as most were interacting with map activities for the first time. Also, it was decided to have a common activity for all learners. Each group contained 15 learners. Total participants were 120. Three sessions of 45 minutes each were utilized.

The map activities introduced aimed at simplicity since there was no map use culture among the learners. Activities introduced also made reference to the content of the curriculum on the application of maps. The common activity was preparation of a map chart (figure 1) with all the countries of Africa. Learners using the similes method of identification that all are familiar with as they learn the alphabets and numbers at 4 years old would fill any shape or object they felt looked like the physical attribute of each of the African countries. The main aim of this activity was to familiarize with the Africa continent as a start.

SCHOOL						SCHOOL						SCHOOL					
No.	Country Name	Map	Where in Africa	Shape Similar to	Name of Child	No.	Country Name	Map	Where in Africa	Shape Similar to	Name of Child	No.	Country Name	Map	Where in Africa	Shape Similar to	Name of Child
1	Algeria		ALGERIA			20	Gambia					39	Republic of the Congo				
2	Angola		ANGOLA			21	Ghana					40	Rwanda				
3	Benin		BENIN			22	Guinea					41	Sao Tome and Principe				
4	Botswana		BOTSWANA			23	Guinea-Bissau					42	Senegal				
5	Burkina Faso		BURKINAFASO			24	Ivory Coast					43	Seychelles				
6	Burundi		BURUNDI			25	Kenya					44	Sierra Leone				
7	Cameroon		CAMEROON			26	Lesotho					45	Somalia				
8	Cape Verde		CAPE VERDE			27	Liberia					46	Somali-land				
9	Central Africa Republic		CENTRAL AFRICA REPUBLIC			28	Libya					47	South Africa				
10	Chad		CHAD			29	Madagascar					48	South Sudan				
11	Comoros		COMOROS			30	Malawi					49	Sudan				
12	Democratic Republic of Congo		DEMOCRATIC REPUBLIC OF CONGO			31	Mali					50	Tanzania				
13	Djibouti		DJIBOUTI			32	Mauritania					51	Togo				
14	Egypt		EGYPT			33	Mauritius					52	Tunisia				
15	Equatorial Guinea		EQUATORIAL GUINEA			34	Morocco					53	Uganda				
16	Eritrea		ERITREA			35	Mozambique					54	Western Sahara				
17	Eswatini (Swaziland)		ESWATINI (SWAZILAND)			36	Namibia					55	Zambia				
18	Ethiopia		ETHIOPIA			37	Niger					56	Zimbabwe				
19	Gabon		GABON			38	Nigeria										

Figure 1: List of countries of Africa where the children filled what they felt was similar to the various countries' outlines.

The identification of countries using their physical attributes was a fun way to engage the cognitive skills of the children, most of whom were interacting with the map of Africa for the first time. It would have been an oversight to assume that the learners had keenly looked or used the map of Africa since it was present in their libraries and classrooms or staffrooms.

The pre-school learners (4-6years) fun map activity involved drawing their classroom (figure 2a) out of which a simple treasure map was prepared (figure 2b). From previous interaction with the learners referring to previous map drawing activities by Njore *et al* (2019), the pre-school children aged 4-6 years had no understanding of scale hence the abstraction of their classroom for a map activity did not focus on scale. Also important was where a pictorial symbol was used inside the teaching map had be exactly the same as on the legend to avoid confusing the learners.

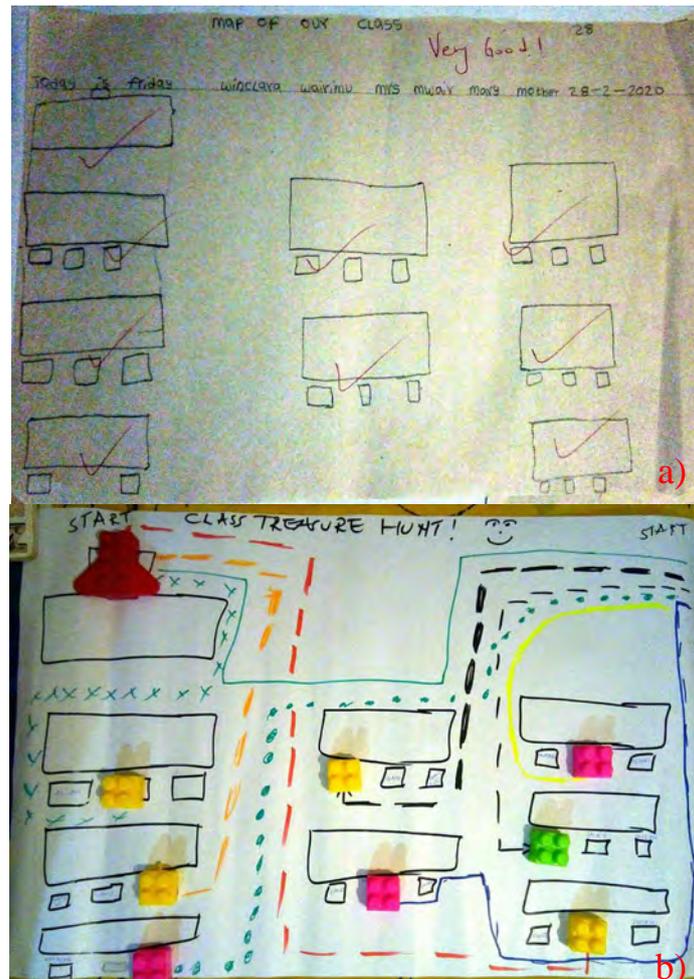


Figure 2. a) is the class room map drawn by a 6 year old child, and b) is the treasure hunt map prepared from a) and used for the treasure hunt activity.

The lower primary Grade 1 and 2 working group activity was suggested by one child and was adopted. In the child's words: "with our school map showing our classes, you ask me where to go and where to start from, I leave the map and try to follow that path from memory, if I get it right I win!" The learners' initial task was to prepare their school maps for the activity. Example task was how to get to the staffroom using the path by the parade ground, and avoid walking by the big black tank. This was successful with all that participated, as they were familiar with their school surroundings.

The lower primary Grade 3 and 4 working group activity was a suggestion from a child, which was to draw roads connecting all Africa countries on the map of Africa, having folded papers or a dice with the alphabets A to Z, the letter a learner (player) picked would be his/her country of destination. The starting point was home which was randomly picked by the player. As the learner used the road to get to the destination, he /she was tasked to name the countries on the way. If one failed to name them correctly, the player would go back to home till their next turn to play.

## RESULTS AND DISCUSSIONS

Table 1 shows responses to the identification of maps using their physical attribute was very enlightening, but the results showed no particular list of similes could be compiled for that specific activity. For example, South Africa and Djibouti were identified as rhino by different school children, also Burundi and Liberia were identified by a bat whereas in some responses were the same; for example Kenya was likened to a baby vest by all learners in all participating schools. To note is that most countries were not identified using the physical attribute. This activity was successful in that they had great recollection on the countries identified. The table content was compiled from all the filled charts by the learners in all the eight schools (figure 3)

During the treasure hunt exercise with the age 4-6 years old learners, two marked routes were not accessible and the children easily pointed out alternative routes. This showed their understanding of maps was advancing as they continued to be taught more on maps. At every marked treasure point, the learner were rewarded (figure 4).

*Table 1. Answers of countries identified using the simile style by the learners.*

Country	Shape similar to	Number of learners
Algeria	1. Flower vase	40
	2. Heart	70
Angola	1. dress	42
	2. girl cloth	60
Benin	1. Monkey wrench	70
	2. Tree	40
	3. Flower	10
Botswana	1. Castle tilted to the right	80
Burundi	1. Face of a puppy	30
	2. A bat	90
Benin	1. Monkey wrench	70
	2. Tree	40
	3. Flower	10
Cameroon	1. Bird with crown	60
	2. Duck / hen	60
Cape Verde	1. Blood plateletes	30
	2. Chocolate chips in a cookie	70
Djibouti	1. Toothless hippo with mouth open	70
	2. Stiletto shoe	40
Equatorial Guinea	1. Trapezium	70
	2. Van	50
Eritrea	1. Funnel	80
	2. Ear canal	10
	3. Vuvu zela	10
	4. Elephant trunk	20
Gambia	1. Earthworm	80

	2. Snake	40
Kenya	1. baby vest	120
Liberia	1. Flying bird	70
	2. Boat	30
Madagascar	1. Sweet potato	90
	2. Car without wheels	20
	3. Boat	10
Malawi	1. Sea horse	100
Mauritius	1. bowl	30
	2. Irish potato	20
Mozambique	1. Baby crawling towards South Africa	50
	2. puppy	30
Niger	1. Tied sack	50
	2. Fish	70
Senegal	1. Sperm whale head	100
Mozambique	1. Baby crawling towards South Africa	50
	2. puppy	30
Somalia	1. raised and fisted right hand from behind	100
	2. horn	20
South Africa	1. Rhino head	100
Uganda	1. male lion head	120
Zimbabwe	1. bird's head	40
	2. chick head	30

SCHOOL KAWANZAZA Primary school					SCHOOL KAWANZAZA Primary school					SCHOOL KAWANZAZA Primary school							
No.	Country Name	Map	Where in Africa	Shape Similar to	Name of Child	No.	Country Name	Map	Where in Africa	Shape Similar to	Name of Child	No.	Country Name	Map	Where in Africa	Shape Similar to	Name of Child
1	Algeria			House	Little Edwin	20	Cambodia			Snake	Winnie	38	Republic of the Congo				
2	Angola			Castle	Winnie	21	Ghana					41	Rwanda				
3	Benin			Box with T. all flowers	John Cynthia	22	Guinea					42	Sao Tome and Principe				
4	Botswana			Castle	Alfred	23	Guinea-Bissau			Frog	Shamma	43	Senegal			Whale	Clare
5	Burkina Faso			Seahorse	Alfred	24	Ivory Coast					44	Seychelles				
6	Burundi			Box of a dog	Clare	25	Kenya			vest	Shamma	45	Sierra Leone				
7	Cameroon			Box	Clare	26	Lesotho					46	Swaziland			High road	Clare
8	Cape Verde			Ducks	Cynthia	27	Liberia			boat	Cynthia	47	Tanzania			Boat	Mirry
9	Central Africa Republic			Platters	Winnie	28	Libya					48	South Africa				
10	Chad					29	Madagascar					49	South Sudan				
11	Comoros					30	Malawi					50	Sudan				
12	Democratic Republic of Congo					31	Mali					51	Tanzania				
13	Djibouti			Box with 100 in Salim and	Clare	32	Mauritania					52	Togo				
14	Egypt					33	Mauritius			Bowl	Winnie	53	Tunisia				
15	Equatorial Guinea			Tap	Shamma	34	Morocco					54	Uganda				
16	Eritrea			Tap	Cynthia	35	Mozambique			Puppy	Cynthia	55	Western Sahara				
17	Eswatini (Swaziland)			Jungles	Shamma	36	Namibia					56	Zambia				
18	Ethiopia					37	Niger			Snake	Clare		Zimbabwe			Box with Alfred	
19	Gabon					38	Nigeria										

Figure 3. Sample of a filled list of the identification of countries using physical attributes.



Figure 4. Learner during treasure hunt activity.

The Grade 1 and 2 activity was a ‘how to’ scenario and the learners understood what was required of them. The Grade 3 and 4 activity was prepared but never got executed as the Corona Virus Pandemic (COVID-19) led to abrupt closure of all schools. When we inquired about the choice of activity (for the Grade 3 and 4), learners reported that the previous activity of identifying countries using similes was fun but many countries were left out and they wished to memorize them too.

There were occasions of variation in symbol identification thus creating a challenge in an activity for example the treasure hunt game. Color differentiation was a challenge to some learners across all age groups and scale concept was

not applicable to the 4 – 6 year old learners. To note is that during these interactions the learners were also consulted on what they wished captured in the children map book being prepared. The book will be in form of a narration by a young boy about his adventures and use of maps. He meets with friends and animals that teach him more on maps. He is empowered with more information on maps and learns what a cartographer does. This shall demystify Cartography in the mind of the learners. It is hoped to be an interesting read for all ages who have had little or no interaction with maps.

The activities using maps were most successful with the first 3 schools which had been familiarized with maps for over a year. Clearly showing that the more a learner were exposed to maps the more they understood them.

## RECOMMENDATIONS

More time would have been required as it was literally introducing maps to the learners. Most had not yet interacted with maps more than once. Children maps of all administrative units of Kenya should be compiled for the learners as it will be a guide to the teachers to formulate relevant activities. For example, activity 9 in Grade 4 social studies recommended text book: in pairs children are supposed to identify the sub-county where their school is located, name their neighboring sub counties, name their county and draw and color their sub county. Lacking children themed atlases is an oversight that needs to be acted on.

Some decisions should be made initially before interacting with the learners; abstraction of the classroom when the pre – school learners draw their classroom map should not focus on scale as they have no understanding of scale. Also important is where a pictorial symbol is used inside the test maps it should be exactly the same on the key/ legend to avoid the problem of reification, Liben and Downs (1986). At every instant when a new map product is to be designed there is need to interact with the children to get guidance on how best to design their maps. Spatial thinking is vital from a tender age especially in this technological era where almost anyone in possession of a smart phone can make a simple map using the many available mapping applications.

This project advocates for incorporation of more schools into cartographic mapping activities and introduction of the map activities and children themed maps in the Social studies subject in the Competency Based Curriculum. This is projected to help Kenya advance in children use of maps and enable application of sophisticated activities such as those outlined by Juliasz and Castellar (2019) for children aged 4-6, which are the ages of Kenya pre –school classes. Further, for children with special need, activities and products by Zada (2019) would be pretty handy.

## CONCLUSION

All participants gained new knowledge on maps and more wished to participate. This project helped to demystify cartography and ignited a lot of interest on map use among school pupils. Introduction of relevant maps is evident that it shall aid in the current classwork and the map activities will bring about daily map use by the children. Only one activity failed to be executed with the abrupt national closure of schools but it shall be implemented when normalcy resumes.

Some learners got very interested and are hoping for more map activities. The pre-school learners shall have three more activities this year relating to the subject content of the environmental studies. Children themed maps will create interest to the learner to engage with the maps more often and their use in activities will make maps a part of their daily lives. There is need for continued studies on childrens' map use in Kenya.

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# UNDERSTANDING MAP PROJECTION DISTORTIONS: A COMPARISON BETWEEN HUNGARIAN AND KURDISH MAP READERS

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## **Abstract**

*The advancements of mankind led to significant improvements in map understanding and as a consequence two-dimensional maps were produced. However, the theory of map projections proved that when three-dimensional Earth is drawn into a plane surface, distortions occur inevitably. Understanding these distortions' properties is challenging for the map-users, especially and more effectively for the general people. This paper aims to make a comparison between the Kurdish and Hungarian map-users in terms of comprehension of various map distortions in case of small scale maps. The previous approach of Kerkovits & Szigeti (2018) was repeated among Kurdish people to understand the influence of the cultural background and education system on the interpretation of map distortions. For the purpose, surveys were performed which were filled in by a variety of people; and two diverse sets of maps with different projections were used. Furthermore, the examination of the survey's outcome applies sophisticated statistical methods.*

**Keywords:** *User study, Map projections, Map distortion, Understanding map projections, Map projection and culture, Map projection and education*

## **INTRODUCTION**

Maps can be briefly defined as a two-dimensional representation of the real world to a certain scale. From ancient times, people found maps handy and tried to visualize their understanding of a regional inhabited area or the world. The history of maps-making started with simple concepts using simple tools such as stone, wood, metal, parchment, cloth, paper, and film. The development of the civilizations, then, required more sophisticated concepts, high reliability and very-well defined maps. With these advancements, the maps were no longer regional cognitive map representations but the mapping of larger areas and the world in small-scale became necessary.

These desires and the improvement of mathematics science led to the concept of map projections, which is one of the most important principles of map-making along with scale, two-dimensional condition, and orientation. To convert the terrestrial features from the curved surface to a two-dimensional surface some mathematical formulas must be used. The advantage of having a 2D map is that the whole Earth can be shown on a map as two hemispheres cannot be seen at the same time on the globe. However, the disadvantage lies in the concept of map distortions. The theory of map projections has proved that distortions' occurrence is unavoidable. On the other hand, these alternations in the map properties such as distance, area, angle and shape can be controlled and various types of map projections have been developed. All these can be classified under the scientific view also known as mathematical cartography.

The other view of this classification, which the research focuses on, is the general cartography or the result of the map production for the users. The prolonged difficulty of map projections is reflected here more intensively. The problem arises when various projection types for different purposes are used since the daily users are not necessarily trained to be able to distinguish and understand the nature of map distortions. This act likely leads the map readers to misconceptions, for instance, the famous Mercator projection or the Web version of this projection is a conformal mapping, which causes large areal distortion in the regions far from the true scale latitude.

The previous study of Kerkovits & Szigeti (2018) under the name "Relationships between the Distortions in Map Projections and the Usability of Small-Scale Maps" was conducted within Hungary. The research paper points out two important facts, firstly, the frequency of maps readings with some specific properties forms more concrete preconception of the "right map". Meaning, choosing to use the right type of mapping is important knowing the fact that this affects the worldview of map users. Secondly, it concluded that projections are a major factor affecting small-scale

maps. Besides the aesthetic look that they give, feature parameters need to be considered as they can help to develop the map reading skills of the users.

A previous study (Ito & Sano, 2011) indicated that the understanding of maps depends heavily on the cultural background. This was confirmed by Albert et. al. (2017) on a larger sample size. But no study has been conducted to examine this influence on the understanding of map distortion. Therefore, the previous survey of Szigeti & Kerkovits (2018) was repeated using the same set of questions (translated from Hungarian to Kurdish) and the same methodology in a different culture. The purpose of this research is to compare the original results on the Hungarian sample and our new results about Kurdish readers, to explore how the culture influences the results.

Based on an online survey or test, data about map readers, which are divided into different demographic groups were taken. The surveying consists of two sets of seven questions, control and test groups, each with unique questions around the same kind of map distortions. For each question, there were 7 answer options, including an “I don’t know” option. During these tasks, the participants had to face various types of map distortions: areal distortion, meridian convergence, antimeridian cuts, discontinuities, curved graticule lines, pole-lines and the curvature of mapped geodesics. This helps to give an understanding which projections are more favoured by the different demographic groups and later by the different cultures, and also aids to determine the weaknesses in the map reading and understanding the nature of distortions and gives insight on how to help improve the map readers’ skills.

## **SURVEY & METHODOLOGY**

### **Data collection**

The process of data gathering followed an online surveying test through a website. After giving an introduction, instructions, and information, the questionnaire started with gathering data about the participants such as gender, age, education/qualification, and frequency of using various types of map. The next step performed an automated separation of the users into two groups: the test and control groups. An algorithm was applied in the grouping process in a way to maintain a balance of participation between the users under different demographic groups as most probably the same. The webpage questionnaire link was launched on 06th April 2019 and ended on 26th November 2019. The total number of participants was 151 and 96 persons were considered for the investigation (55 test and 41 control). The process of choosing these suitable participants followed some pre-set filtrations such as the conditions of the test completion within a limited logical time between 2 and 30 minutes. The time limitation was defined by the existing natural breaks in the dataset.

### **The participants’ groups**

The testers were classified by several demographic statistics as mentioned before. These were: gender (male, female), age (below 20 years, 21–25 years, 26–30 years, above 30 years), education (primary, secondary, and higher), qualification in the fields of geography or earth sciences, and map usage habits. The separation of the genders was unexpectedly unequal: we had 74 male and only 22 female participants. Age groups: 7 participants were under 20, 29 of them were aged between 21–25, 23 people were between 26–30, and 37 participants were older than 30. According to the level of education, only 1 of them had primary education, 28 of them with secondary school education, and 61 university student or graduates. Among all of them, only 6 persons indicated themselves as geographers. Regarding the map using habit, 46 of them were seldom, 28 occasional, and 22 frequent map-users.

## **STATISTICAL CALCULATIONS**

### **The General Approach**

The results were analysed using two approaches. The first approach works with the ratio of the correct answers and makes comparisons of the percentage of the correct answers among the different groups. The t-test was used to find out how much the variation was due to the uncertainty of sampling and how much was due to the choice of projection. To use the method, the data was needed to have a normal distribution, and since the answers were either correct or incorrect, it gives a discrete distribution. Nevertheless, due to the large number of samples and the central limit theorem, the distribution can be considered as normally distributed. In this case, the two-tailed (unpaired data) t-test is applicable. According to this test, if the probability is smaller than 5% the results are considered significant (Table 1).

The second approach refines the answers by highlighting or describing the goodness of the incorrect answers, presuming these wrong answers are not equally bad. To perform this, the answers were ranked between 1 (worst) and 6 (best), then the two-tailed Mann–Whitney test – hereafter U-test, which is appropriate for ordinal scales was used. The method used to estimate the probability of a better answer from the control group while selecting one random subject

from the test and one from the control group, i.e. the better map resulted in a better response. During processing, the correction of tied ranks – i.e. identical given answers – and the continuity correction were taken into account (Bergmann, Ludbrook & Spooren, 2000). On this basis, if the probability that the choice of projection did not affect the response was below 5%, the results were identified as significant according to the U-test (Table 2).

*Table 1. The proportion of correct answers per demographic groups. Highlighted results are significantly better according to the t-test at significance level 95%. The red highlighted numbers indicate significant response, and the blue highlighted number indicates an inverse significant response (better answer in case of the more distorted map).*

	Gender				Education						Geographer?			
	Men		Women		Elementary		Secondary		University		Not qualified		Qualified	
	test	control	test	control	test	control	test	control	test	control	test	control	test	control
<i>Areal distortion</i>	6.7	6.9	10.0	0.0	n. d.	0.0	5.9	0.0	7.9	7.7	7.7	2.6	0.0	33.3
<i>Meridian convergence</i>	40.0	69.0	30.0	75.0	n. d.	100.0	52.9	78.6	31.6	65.4	40.4	68.4	0.0	100.0
<i>Antimeridian</i>	33.3	20.7	40.0	58.3	n. d.	100.0	47.1	28.6	28.9	30.8	36.5	34.2	0.0	0.0
<i>Discontinuities</i>	17.8	6.9	20.0	8.3	n. d.	0.0	23.5	7.1	15.8	7.7	17.3	7.9	33.3	0.0
<i>Graticule</i>	73.3	58.6	90.0	75.0	n. d.	100.0	82.4	57.1	73.7	65.4	76.9	63.2	66.7	66.7
<i>Pole-lines</i>	6.7	34.5	40.0	50.0	n. d.	0.0	5.9	42.9	15.8	38.5	13.5	36.8	0.0	66.7
<i>Curve</i>	13.3	34.5	20.0	25.0	n. d.	0.0	35.3	42.9	5.3	26.9	13.5	31.6	33.3	33.3

	Age categorized								Map usage habit					
	under 20		21–25		26–30		Above 30		Rarely		Sometimes		Often	
	test	control	test	control	test	control	test	control	test	control	test	control	test	control
<i>Areal distortion</i>	25.0	0.0	5.0	0.0	7.7	0.0	5.6	10.5	11.1	5.3	0.0	0.0	8.3	10.0
<i>Meridian convergence</i>	75.0	100.0	35.0	77.8	46.2	80.0	27.8	57.9	33.3	73.7	37.5	75.0	50.0	60.0
<i>Antimeridian</i>	50.0	100.0	35.0	22.2	46.2	30.0	22.2	26.3	29.6	47.4	43.8	16.7	33.3	20.0
<i>Discontinuities</i>	0.0	0.0	20.0	11.1	15.4	0.0	22.2	10.5	7.4	0.0	18.8	0.0	41.7	30.0
<i>Graticule</i>	100.0	66.7	75.0	55.6	84.6	70.0	66.7	63.2	85.2	63.2	62.5	58.3	75.0	70.0
<i>Pole-lines</i>	0.0	33.3	20.0	55.6	7.7	30.0	11.1	36.8	11.1	42.1	18.8	25.0	8.3	50.0
<i>Curve</i>	25.0	0.0	15.0	22.2	7.7	40.0	16.7	36.8	11.1	21.1	18.8	58.3	16.7	20.0

Table 2. The results of the U-test. Sign + marks that a projection with more favourable distortion helped, sign – indicates that it resulted in worse answers at significance level 95%.

Q.	GENDER		EDUCATION			GEOGRAPHER		AGE				MAP USAGE HABIT		
	Men	Women	Primary	Secondary	Higher	Not qualified	Qualified	Under 20	21-25	26-30	Above 30	Rarely	Sometimes	Often
1														
2	+				+	+					+	+	+	
3														
4														
5														
6	+			+	+	+				+		+		
7									-					

## DETAILED ANALYSIS OF THE ANSWERS

### Areal Distortion

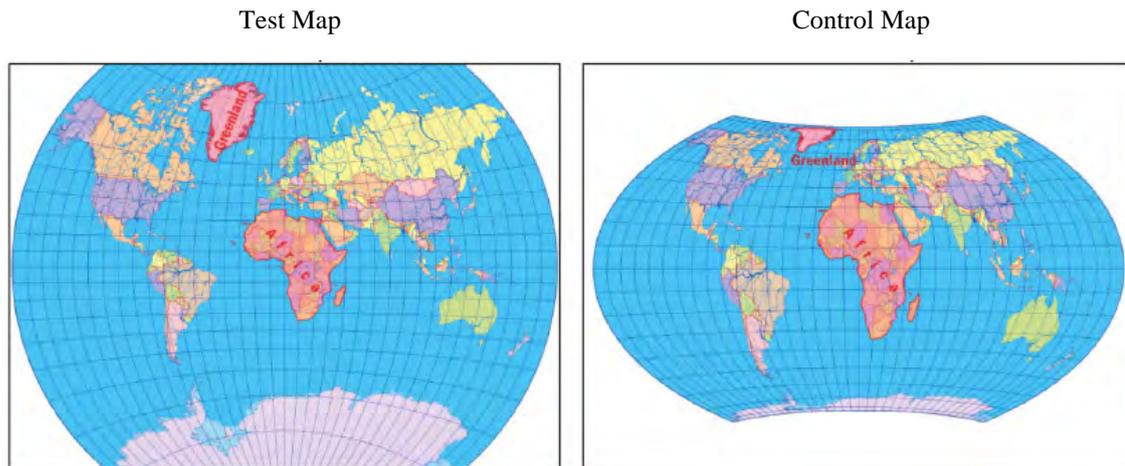
For the purpose of the questionnaire, Van der Grinten I projection, which is more common in world atlases, was used as a test map. The task of the control group was carried out on an equal-area map. To avoid large angular distortions and confusion of the readers, Wagner-transformed Hammer map was used, (Figure 1).

The results of the statistics for the Kurdish map readers show that there is a high underestimation about map distortion in case of the first question. Only 6 people out of all the participants (96) gave the right answer “Africa is fifteen times larger than Greenland” which is about 6.25% and there are no significant differences between the groups. This indicates that Kurdish participants had strong preconceptions, and did not trust the undistorted map. According to the t-test results, 7.3% and 4.9% of the test and control group answered correctly respectively. The most common incorrect answer was “1.5 times larger” with 40% by test group and 26.8% among the control group resulting in no significant difference.

On the other hand, results of the Hungarian map readers show that 28.7% of respondents answered correctly. The most common incorrect answer was “five times larger” with 26.5%. In contrast, 31.5% of the control group indicated the correct response, but 33.3% indicated the incorrect five times larger in size.

To compare, the Hungarian map readers performed better in general and this might be due to some reasons. One of the main reasons is the difference in education system. From the outcomes, one can notice that the choice of the map projection had no significant effect among those who only had elementary or secondary education. However, it can be noticed that considerable differences occurred among participants with higher education. Regarding this demographic group, the proportion of correct answers were 34.4% and 40% in case of test and control groups respectively for the Hungarian participants and 5.6% and 8% for the test and control groups respectively for the Kurdish participants.

The map using habit and the cultural background can be another reason. Regarding the people who often use maps, 22.9% of the Kurdish people are frequent map users, while 32% of the Hungarian people are the frequent map users. Together the education system and the map reading habit can affect the skills and experience in the map reading and understanding the different distortions. The results also demonstrate that there is similarity in the percentage of the right answers given by the geographers in both Hungary and Kurdistan Region (30% to 35%), unlike the large variations in the other groups. Further, the U-test showed no significant response for the Kurdish map readers, in contrast, in case of Hungarian participants the test showed that primary education, not geographers qualified and seldom map users could use the less distorted map better.



In reality, how many times is the area of Africa larger than the area of Greenland?  
A) Both have the same size (1)    B) 1.5 times larger (2)    C) 3 times larger (3)  
D) 5 times larger (4)    E) **15 times larger (6)**    F) 25 times larger (5)

Figure 1. Test question of the areal distortion. The correct answer is shown in bold, 1 is the worst, and 6 is the best answer.

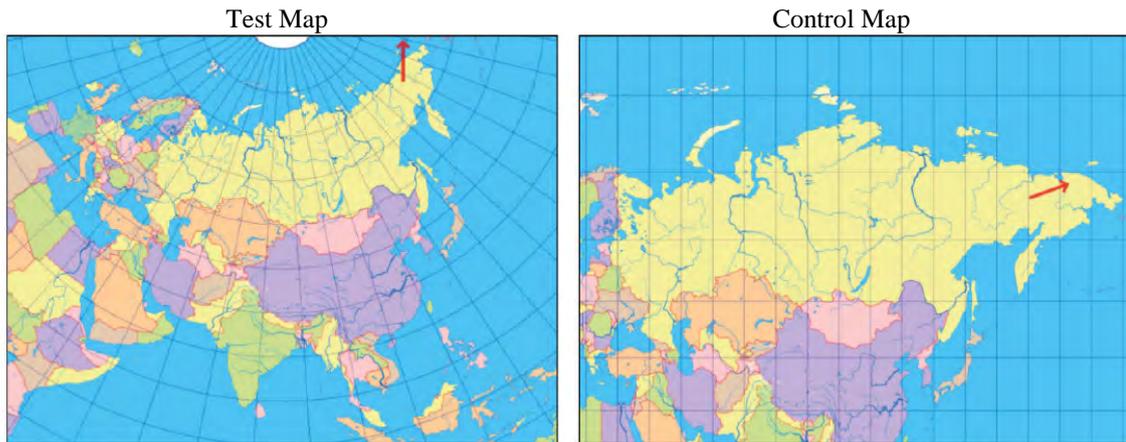
### Meridian convergence

The question examines the understanding of the meridian convergence on two different map projections, Gall's cylindrical stereographic projection, and Mercator projection. The maps are oriented to the north and the meridians are parallel to the north direction, thus, the user can estimate the azimuth from the angle between the meridian lines and the drawn line, (Figure 2).

Between the Kurdish test group participants, 38.2% correctly answered the question, however, 70.6% of the control group have chosen the correct answer, regardless of the level of education. This demonstrates a large difference between the two groups which is also indicated by the t-test. 29.1% of the test group answered North and 12.2% of the control group answered East. The results of the U-test show that men, higher education, non-geographers, age above 30, rare and occasional map users performed better on the control map.

Between the Hungarian participants, 83% of the test group answered correctly. A roughly equal number of participants marked each of the remaining answers. Conversely, 70.3% of the control group indicated the correct response and 13.5% of the group members incorrectly answered north. For each group, users of test maps with a familiar projection have achieved better results than those using unusual looking control maps. The U-test value approached the critical value in most groups, but it was only exceeded among people with higher education and without qualification in geosciences. These tendencies are the opposite of the Kurdish results: Kurdish participants tended to assume that North is always up, while a notable group of Hungarian participants were suspecting the meridian convergence even if it disappeared.

To compare, there is no significant difference in the case of the comparison between the control groups, however, for the test groups, the results show extremes by the weighted mean of 38.2% and 83% for the Kurdish and Hungarian testers respectively. This conveys that the known test map help the Hungarian map readers to perform better, thus, the familiarity of a projection leave a noticeable effect. Map projections with no meridian convergence on the map caused misconceptions only among the Kurdish map-readers. Despite, in reality, understanding the nature of this projection makes it easier to presume the azimuth.



- In which direction is the red arrow pointing in Chukotka?  
A) North (4)                      B) South-southwest (1)                      C) East (5)  
D) Northwest (3)                      E) South (2)                      **F) East-northeast (6)**

Figure 2. Test question of the meridian convergence.

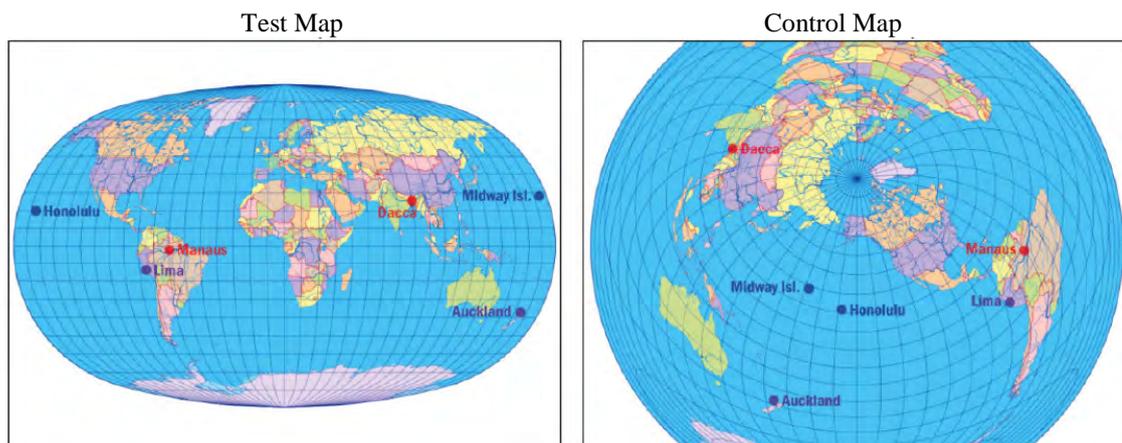
### Cut on antimeridian

Most projections display the antimeridian twice on the plane at the eastern and western edges of the map. For this reason, close points near the antimeridian are shown at the opposite parts of the map, spoiling the visualization of global relationships. In reality, these points can be connected with a short line but the projection forms a kind of discontinuity and likely causes misinterpretations.

During the test, Baranyi IV projection for the test group and Ginzburg projection for the control group are used. The map of the test group has the cut on antimeridian but the control map contains discontinuity at a single point. The Ginzburg projection was used in oblique aspect to avoid confusing amounts of distortion at the points examined. The participants had to put the distances of the point pairs in ascending order according to their true distances on the Earth. Three pairs of points were indicated on both of the maps and two pairs of them or two lines were affected by the discontinuity according to the test map, (Figure 3).

In the case of the Kurdish test-takers, 34.5% and 31.4% had chosen the correct answer in the test and control groups respectively and the statistics indicate no significances in both t-test and U-test. Almost the same proportion as of the correct choice answered for no guess in this question. However, previous results showed that Hungarian participants chosen the correct answer with the rate of 53.7% and 61.3% in the test and control groups respectively.

The comparison depicts that there are significant differences in almost all the various groups with both of the test and control maps except for women participants in the control group with the Kurdish women performing slightly better. Both of the maps have difficulties for the readers, nevertheless, familiarity with the concept of antimeridian and the used projections can improve the map-users. Studying and working with maps is more frequent in Hungary and this might have left effects on the interpretation and the results. This is concluded by the fact that the U-test showed significant differences between Kurdish and Hungarian participants rather among age over 30 and higher educated groups of the Kurdish participants.



Put the distances of the point pairs in ascending order (from shortest to longest) according to their real distance on the Earth.

- |  |   |
|--|---|
| A) Auckland–Lima; Dakka–Manaus;<br>(1)<br>Midway–Isl.–Honolulu (2)               | B) Dakka–Manaus; Auckland–Lima; Midway–Isl.–Honolulu        |
| C) Auckland–Lima; Midway–Isl.–Honolulu;<br><b>Manaus (6)</b><br>Dakka–Manaus (4) | <b>D) Midway–Isl.–Honolulu; Auckland–Lima; Dakka–</b>       |
| E) Dakka–Manaus; Midway–Isl.–Honolulu;<br>(5)                                    | F) Midway–Isl.–Honolulu; Dakka–Manaus; Auckland–Lima<br>(3) |

Figure 3. Test question of the cut on the antimeridian

### Discontinuities at the Centre of Maps

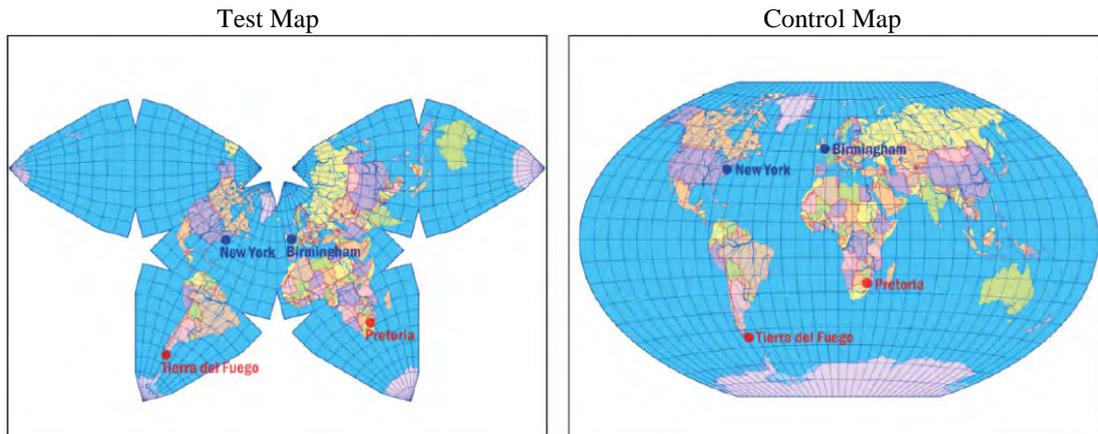
These are discontinuities or cuts in locations on the maps other than on the edges of the map such as in the antimeridian cut to minimise distortions. Depending on their derivation, these mappings are called interrupted or polyhedral projections. For the test group, Waterman’s butterfly projection was used with properties of favourable distortions. Here the participants had to evaluate the length of an interrupted section (Pretoria–Tierra del Fuego) taking an uninterrupted section (New York–Birmingham) as the unit. For the control group, Winkel III projection was used which has antimeridian cut but the two distances were not interrupted (Figure 4).

In case of Kurdish participants, the percentage of the correct answers were only 20.5% and 6.8% for the test and control groups respectively, the most popular answer was a slight overestimation in both groups (27.2% and 45.2% answered C, respectively). Both of the t-test and U-test show insignificance between the two groups. To make a comparison between the test and control groups, the Kurdish map readers gave better answers in case of the test map. Some demographic groups such as geographers in the test map and frequently map users recorded better answers on both maps. Interestingly, an almost equal amount of the test group participants read the distances directly from the map without any compensation for the distortion (20.5%) than who overcompensated the distortion (25%), so no clear tendencies are visible.

As for the Hungarian participants, 39% and 52.2% had chosen the correct answer for the test and control maps respectively. The most common misconception was that the distances are nearly the same and resulted in 31.6% and 27% of the answers for test and control groups. Regarding the demographic groups, the control group performed better in all cases. For those with secondary education, this shows a significant difference according to the t-test, while among men according to the U-test.

By comparing both Kurdish and Hungarian participants significant differences can be observed in almost all the cases, except for the women and frequent map-users in both maps. By comparing the participants individually and together some trends can be highlighted and studied. The secondary school students performed better than most of the other groups and probably this caused by geography, map, mathematics, and geometry studies at school. The theory lies in that those pupils are involved in a study environment which helps the improvement of interpretation and visualization. On the other hand, after their graduation, there will be less interaction with the mentioned subjects. Thus, the skills can be maintained in case of geographers, occasional and frequent map-users because of the more likelihood of reading

maps. There is no significant variation in the case of women but this might be the result of the low number of Kurdish women participants.



Which statement is true considering the shortest path on the surface of the Earth?

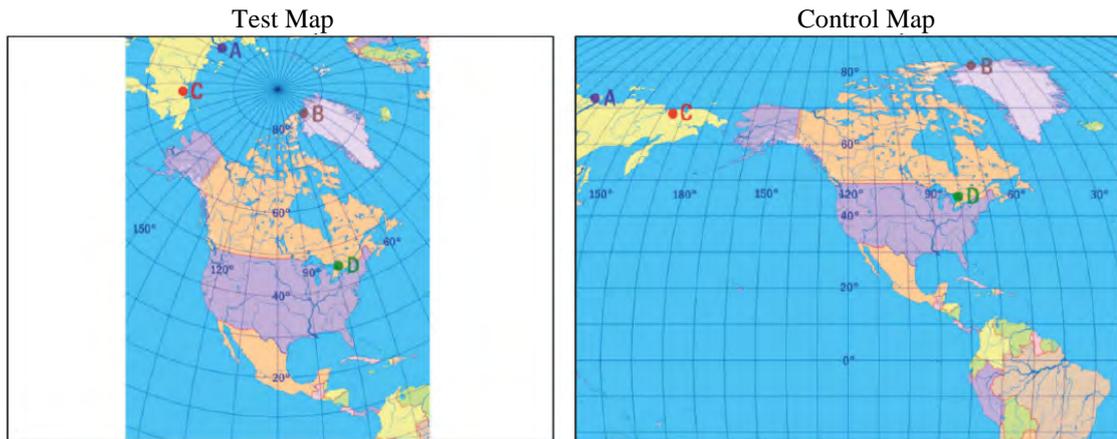
- A) The distance between New York and Birmingham is the same as the distance between Tierra del Fuego and Pretoria. (4)
- B) The distance between Tierra del Fuego and Pretoria is 1.5 times longer than the distance between New York and Birmingham.**
- C) The distance between Tierra del Fuego and Pretoria is 2 times longer than the distance between New York and Birmingham. (5)
- D) The distance between Tierra del Fuego and Pretoria is 3 times longer than the distance between New York and Birmingham. (2)
- E) The distance between Tierra del Fuego and Pretoria is 1.5 times shorter than the distance between New York and Birmingham. (3)
- F) The distance between Tierra del Fuego and Pretoria is 3 times shorter than the distance between New York and Birmingham. (1)

Figure 4. Test question of the discontinuities in the centre of maps.

### Understanding Curved Graticule Lines

The task asked the participants to order the indicated points on the maps by their closeness to the North Pole. For the purpose, oblique Lambert azimuthal projection was used as the test map. An important feature of this projection is that points beyond the North Pole can be shown since the parallels are closed arcs. The control group worked with the Kavrasky VII projection, which is one of the best pseudo-cylindrical projections. The advantage lies in the fact that the parallels are shown as straight lines, hence, the geographical zones are shown expressively, (Figure 5).

The Kurdish test-takers answered correctly (B-A-C-D) by the proportions of 76.4% and 63.2% for the test and control maps respectively and the statistical tests show no significant difference. As for the Hungarian test-takers, 95.6% of the experimental group indicated the correct answer, similarly, a high score was achieved in the control group since 92.8% indicated the correct response, without significances. The Hungarian participants performed better than those from the Kurdistan Region and the t-test shows significant variations except for the women in case of the test map. The variances in the scores again indicate the different experience and skills obtained in two different cultures. Moreover, part of the test-takers were probably misled by the pole-line in case of the Kavrasky VII projection besides of the fact that the straight parallels make it easy to decide the answer. This might be the reason the test groups performed better than the control.



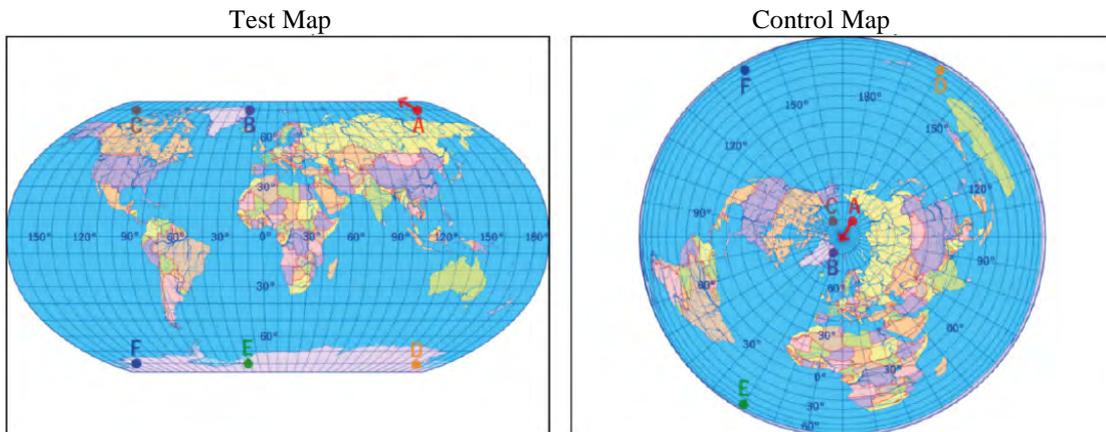
Put the points in order from the northernmost one to the southernmost one.

- |                |                |                       |
|----------------|----------------|-----------------------|
| A) A B C D (4) | B) A C B D (2) | C) <b>B A C D (6)</b> |
| D) B C A D (5) | E) C D A B (1) | F) C B A D (3)        |

Figure 5. Test question of the understanding of curved graticule lines.

### Pole-lines

For the experiment, six points were spread North and South on both of the maps and the user has to find out the first point reached from point A with the indicated direction. The test group worked on the Robinson projection, which was more challenging. The control group received the Lambert azimuthal projection, which illustrates the polar region better. (Figure 6).



Which point would you reach, if you followed the red arrow from point A along the meridian, and crossed the edge of the map?

- |                  |                 |          |
|------------------|-----------------|----------|
| A) Back to A (4) | <b>B) B (6)</b> | C) C (5) |
| D) D (2)         | E) E (3)        | F) F (1) |

Figure 6. Test question of the understanding of pole-lines.

The Kurdish participants scored low for the correct answers with the proportions of 12.7% and 39.2% for the test and control groups. The highest incorrect answer was D in case of test map with the ratio of around 23.6% (which means that the participants incorrectly connected the poles). In the control group, a considerable number (24.5%) of participants marked the point C, in spite that this option was clearly wrong on their map. It is easier to explain, why this answer (C) was popular also in the test group: the interpretation of the pole-line is not a straightforward task. The t-test showed there are significant variations in most of the cases, and the U-test shows that men, secondary and higher education, age between 21 and 25, and rarely map-users performed better on the control map.

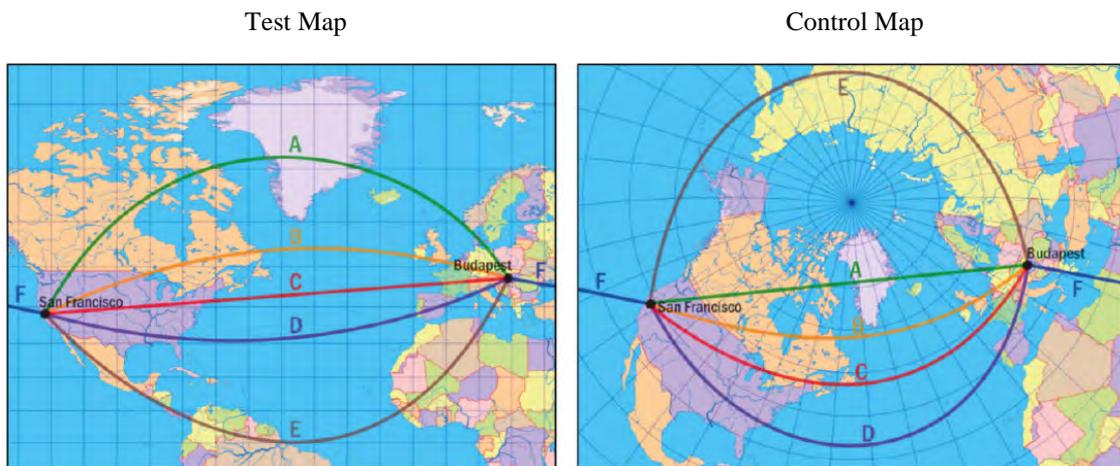
As for the Hungarian participants, the test group yielded similar results to the Kurdish survey: Although 32.4% indicated the correct answer, a similar proportion of participants marked the C and D responses (both 21.3%). The better results of the Hungarian participants were significant compared to their Kurdish fellows in some demographic groups. The influence of the gender is not observable on the Kurdish sample, while Hungarian men clearly

outperformed women on this task. Therefore, the difference between Kurdish and Hungarian participants was significant among men but not among women. The level of significance was also exceeded among younger participants and those with a secondary degree of education.

In the Hungarian control group, 76.6% of participants gave the correct answer. The control group results show that there is a similarity in the proportion of the correct answers given by the geographers in both cultures, this similarity in both cases indicates the abilities of map reading are almost the same.

### Curvature of mapped geodesic lines

The question is related to the curvature of the mapped geodesic lines and the test taker need to figure out which is the shortest route from Budapest to San Francisco by aeroplane. The mapped image of geodesic lines on world maps may be extremely complicated and varied based on the projection used: they can be straight lines, simple curves, or a twisted S-shape along the Equator. The knowledge of this concept is scarce not only among general people but also among the university researchers (Anderson & Leinhardt, 2002), therefore, it is a challenging question.



Which is the shortest route from Budapest to San Francisco by aeroplane?

- A) A (6)      B) B (5) C) C (4)  
 D) D (4)      E) E (3) F) F (1)

Figure 7. Test question of the second term of correction.

The percentages of the correct answers by the Kurdish participants were 14.5% and 31.9% for the test and control maps. T-test results depict there are significant variations in almost half of the demographic groups. Most notable exceptions are women and frequent map users. The most common incorrect answer among the test group users was C, which is the straight line between the two points, with a ratio of 52.7%. On the other hand, the ratio of the other answers in case of the control map was roughly close, even the obviously wrong answers (D, E, F) were popular in the control group. The U-test result indicates that the participants with age under 20 performed significantly better in the test map which is opposite the expected results.

The percentage of the correct answers by the Hungarian participants are 42.6% and 39.6% for the test and control maps. The most common incorrect answers were C in both test and control groups by the ratios of 25.7% and 36.9% respectively. Here the U-test showed that men and geographers performed better in the test map with significant differences.

In comparison, Hungarian participants performed better than the Kurdish fellows with significant differences for the test map with some remarkable exceptions: Among women, geographers and frequent map-users. Nevertheless, there are no significant variations between Kurdish and Hungarian participants in the case of the control map. By analysing the most common incorrect answer in both cultures one can observe both resulted in the option C. This is due to that the route between the two destinations expressed by a straight line with the Miller cylindrical projection, which is similar to the familiar Mercator projection. This might led Kurdish participants to trust the usual map blindly. This is the opposite preconception that was measured on the Hungarian sample. The overall analysis of the problem shows strong false preconceptions. As a conclusion, a specific type of map projection should be introduced to general map users for the purpose of navigation and mapping geodesic lines such as Mercator projection to avoid misinterpretation.

## SUMMARY

Maps have become an important part of life and it is used by many people of various ages and discipline. Many researches have been conducted to understand how map-users interpret small-scale maps. Due to the concept of map projection and its complexity, the importance of “right maps” emerge.

The research discusses the comparison between the results of two surveys which were performed in Hungary and Kurdistan Region. The statistical outcomes were analysed based on different demographic groups, study systems, and cultures. The t-test indicates significant variations in many cases, however, some interesting facts can be seen within exceptions. In the case of the test group, the women participants show no significant variations and in case of control group four questions resulted in significant differences. It can be also observed that no great differences for the age under 20 and there are similarities in case of participants with geoscience background and frequent map-users. This clearly indicates that the observed differences have roots in the education systems.

To conclude, it can be seen that different projections can play a significant role in the map reading and the current map reading skills need development through different approaches. The map projections need to be classified more explicitly into scientific view, general, and school system purposes with more sophisticated geography and cartography studies in the education system. For each class, a list of right maps needs to be determined and familiarized. The first step of improvement for the Kurdish map readers can take advantages from the Hungarian education system and the way of cultural usage, for example by pointing out pupils that maps should be interpreted with special caution for the possible distortions.

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# INTERNATIONAL EPSG CODING OF THE STATE COORDINATE REFERENCE SYSTEM OF THE REPUBLIC OF KOSOVA

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## **Abstract**

*As part of former Yugoslavia, from 30's of last century, the coordinate reference system locally known as FRYREF30 and internationally as MGI/Balkan zones 7 (EPSG 3906), was in official use until year 2001.*

*The state coordinate reference system (CRS) of the Republic of Kosova (KOSOVAREF01) as independent country was defined on year 2001. It is the legal and technical base for all official spatial data in Kosova.*

*Even though it was established on year 2001, until July 2019 it was not internationally coded as formal state CRS in EPSG. Upon initiative to register it as official state CRS in EPSG database (<http://www.epsg-registry.org/>), request EPSG 2019.042 was accepted, and Kosova's CRS was registered with nine EPSG codes: 9140 (geographic 2d), 9138 (geocentric), 9139 (geographic 3d), 9141 (projectedCRS), 9144 (coordinate transformation from Kosovaref01 to WGS84), 9143 (coordinate transformation from MGI 1901 to WGS84), 9142 (coordinate transformation from MGI 1901 to Kosovaref01), 4542 (area) and 1251 (geodetic datum).*

**Keywords:** *EPSG, Kosovaref01, Kosovo, CRS, Balkans zone 7, MGI 1901, geodetic datum, map projection.*

## **INTRODUCTION**

Coordinate reference systems (CRS) represents the mathematical model for location defining of spatial entities within the particular referent frame, which contain geodetic datum, and may contain map projection as well additional parameters. In practice it is known as spatial reference system (SRS) also, which is synonym of CRS. Geographic and projected coordinate systems are two types of CRS's that are used in practice, and coded for standardized usage in GI software.

Coordinate reference systems are defined by the OGC (1) simple feature access using well-known text representation of coordinate reference systems, and support has been implemented by several standards-based geographic information systems (OGC 2018), which can be referred to using EPSG codes (2) defined by the International Association of Oil and Gas Producers (3). CRS's are specified in ISO 19111:2019 “Geographic information — Referencing by coordinates”, prepared under the technical committee ISO/TC 211, which defines the conceptual schema for the description of referencing by coordinates, and describes the minimum data required to define the CRS's (4). ISO 19111 was not made for geodetic experts, it was made for producers and users of GIS, therefore the structure shall be clear and easy – but correct on a common level of abstraction (Ihde et al 2000).

The geographic information contains both, spatial and attribute data. The spatial component relates the features represented in geographic data to position in the real world, while the attribute data relates to alphanumeric description in attribute table/s as non-spatial parameter. Spatial references of geographic information fall into two categories: referencing by coordinates and referencing based on geographic identifier. In bellow figure 1, context of referencing by coordinates is shown, defined in ISO 19111 as Coordinate Referent System (CRS), derived from spatial schema defined in ISO 19107 and temporal schema defined in ISO 19108.

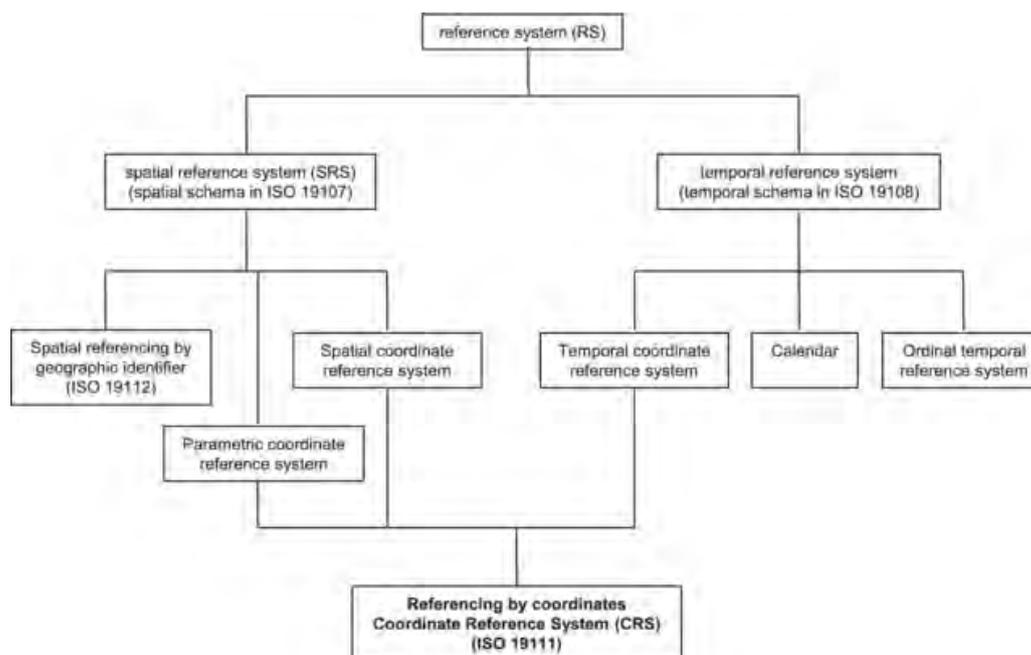


Figure 1. Context of referencing by coordinates (ISO 19111:2019)

Each CRS is associated with a local or global datum, and should support an operation that exposes the domain of validity of that system. Only for places within the domain of validity, the relationship between places and co-ordinates can be trusted. Outside the domain of validity, the reference system cannot be used (Staudinger 1999). Various CRS's were defined and implemented by authoritative bodies and organizations, which have a specific datum based on their definition (initialization). National mapping agencies decides for a map projection together with its underlying geodetic reference system (Voser 1999). The horizontal and vertical components of the description of a position in the space may sometimes come from different CRS's. This shall be handled through a compound coordinate reference systems (CCRS), which describes the position through two independent CRS's (Dunkley etAll 2001).

The European Terrestrial Reference System 1989 (ETRS89) is the geodetic datum for pan-European spatial data collection, storage and analyses. It is consistent with ITRS (IERS Terrestrial Reference System), defined with 1cm accuracy, and recognized as the most appropriate European geodetic datum to be adopted, which is now available due to creation of EUREF permanent GPS station network and validated EUREF observations. It is based on the GRS80 ellipsoid (5) and is the basis for the coordinate reference system using ellipsoidal coordinates. The projecting of ellipsoidal coordinates to cartesian coordinates cannot be performed without distortion in plan coordinate system, which can be controlled but cannot be avoided. Almost all European countries have adopted ETRS89 geodetic datum as base for their CRS's, while map projections are used based on the choice of National Mapping Agencies.

The Republic of Kosova as country located in the South-East Europe, has adopted its national CRS entitled "KOSOVAREF01" on year 2001, which is based on the ETRS89 geodetic datum. Before year 2001, the territory of Kosova as a part of former Yugoslavia's federation have been used the coordinate system locally known as "FryRef30" (internationally recognized as "MGI/Balkan zones 7"), adopted on year 1924 (Idrizi etAll 2018). The differences between the new and former CRS's are in utilized datum and ellipsoid, which can be seen in table 5, where it is recognizable that in the process of defining of parameters of the new CRS "Kosovaref01", in a period from 1999 to 2001, referent map projection followed by all its parameters has been obtained from older coordinate system "FryRef30" (Idrizi etAll 2009). Even though KOSOVAREF01 CRS was established on year 2001, until April 2019 it was not internationally coded as state CRS in EPSG database. By the acceptance of change request "EPSG 2019.042" from EPSG geodetic parameter registry, Kosova's CRS "Kosovaref01" was registered with nine EPSG codes (2).

The Kosovaref01 CRS first was materialized in field with geodetic network of first order called as "KosovaRef01 geodetic network", which later have been followed with establishment of geodetic network of second and third orders, as well height connection to existing height network.

## GEODETIC NETWORK KOSOVAREF01

Geodetic network "KosovaRef01" has been established on year 2001 by the Kosova Cadastral Agency with professional and technical support of Swiss federal office of topography. Measurements were conducted with static

method of GPS measurements in period between March 20<sup>th</sup> to April 12<sup>th</sup> 2001, by including the EUREF permanent network (EPN) stations of Graz in Austria, Matera in Italy, Sofia in Bulgaria, and Zimmerwald in Switzerland in order to integrate the observations into the ETRF (European Terrestrial Reference Frame) and ETRS89 (KCA 2001).

The network was established homogenously over the whole area with general baseline lengths of < 50km. It consists in total 32 points (22 existing points from older network of former Yugoslavia and 10 new established points), with distance between 15 to 25 km, which cover entire national area of the Republic of Kosova. The Root Mean Square errors and maximal values of geodetic network Kosovaref01 on orthogonal coordinates and ellipsoidal heights of point are shown in bellow table 1:

Table 1. Statistics of the GPS-measured 1<sup>st</sup> order reference Network KOSOVAREF01 (Kohli 2002)

Component	RMS	Maximum values
Easting	±2.5mm	±12.5mm
Northing	±4.4mm	±40.2mm
Ellipsoidal height	±8.7mm	±41.0mm

Aimed for performing observations campaign separately, network of 1<sup>st</sup> order (figure 2) is divided in eight sectors (figure 3) (Krasniqi 2004). All points were observed about 2 to 6 hours per session within one sector, which were connected between them by using the neighboring main and secondary station. Because of the reliability reason, second observation campaign was conducted 10 days later (Idrizi and Kabashi 2010).

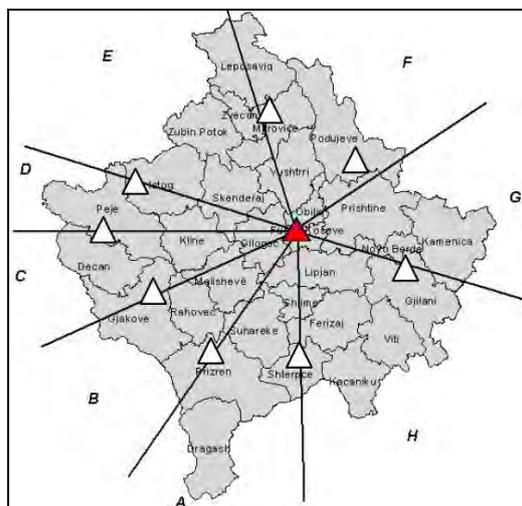


Figure 2. Kosovaref01 pints of 1<sup>st</sup> order (Krasniqi 2004) Figure 3. Sectors for network measurements (Krasniqi 2004)

The 2<sup>nd</sup> order of geodetic network Kosovaref01 contain 397 points, which started with measurements immediately after the 1<sup>st</sup> network was formalized, on June 2001, and have been completed on November 2002. Observations were performed with two sessions per day, in different period of day, in duration of 1 hour, by using two or three point of first order as referent stations (Idrizi and Kabashi 2010). Standard deviation of points of 2<sup>nd</sup> order is ±15mm (KCA 2013).

The 3<sup>rd</sup> order of Kosovaref01 network is treated as local network to be established in each city and settlement. The standard deviation of points of 3<sup>rd</sup> order is ±2cm (KCA 2013).

**Height system**

The official leveling network in former Yugoslavia was established on the beginning of 20<sup>th</sup> century as precise leveling, with the point of origin at the tide gauge in Trieste (Molo Sartorio) referring to mean sea level. I (first) Leveling of Height Accuracy (INVT) was revised by the Austrian precise levelling in period 1946-1960 on the territory of Yugoslavia. In a period from year 1970 to 1973, has been developed leveling network II (second) Leveling of Height Accuracy (IINVT) based on average sea levels over the period of 18.6 years at five tide gauges along the east coast of the Adriatic Sea (in Kopar, Rovinj, Bakar, Split and Dubrovnik), which was supposed to be used for the establishment of a new height system (KCA 2003), however IINVT has never been formalized in former Yugoslavia. After the phase

of IINVT there was no other organized levelling of high precision in the Serbian influenced areas of Vojvodina, Montenegro, Serbia and Kosovo. Unfortunately, the leveling alignments of IINVT mostly do not correspond with the alignments of the previous leveling, the Austrian precise leveling and with INVT, which makes better comparison of the benchmark's heights between these leveling impossible (Kohli 2002).

Height observations for 1<sup>st</sup> order geodetic network Kosovaref01 was performed in 23 out of 32 points, aimed to connect to orthometric heights from 12 points of leveling network IINVT of former Yugoslavia. As output of measurements, the orthometric heights for all 32 points of 1<sup>st</sup> order geodetic network have been calculated. Differences between ellipsoidal and orthometric heights lay in range from 44.19 to 45.62m, which theoretically should correspond with the geoid heights in each point. In absence of national geoid, calculated differences between ellipsoidal and orthometric heights have been compared with geoid heights extracted from EGG97 (European Gravimetric Geoid 1997), that are up to 46.5cm, with RMS=25.26cm (Kohli 2002), shown in figure 4. Due to the geoid anomalies, offset and/or slight tilt which might not be specific enough for these local studies, or due to errors in the levelled heights, in the eastern part generally a negative difference were detected, while in the western part it is the opposite, which means that some systematic behavior of the residuals exists.

Table 2. Height differences between GPS (ellipsoidal), levelling and EGG97

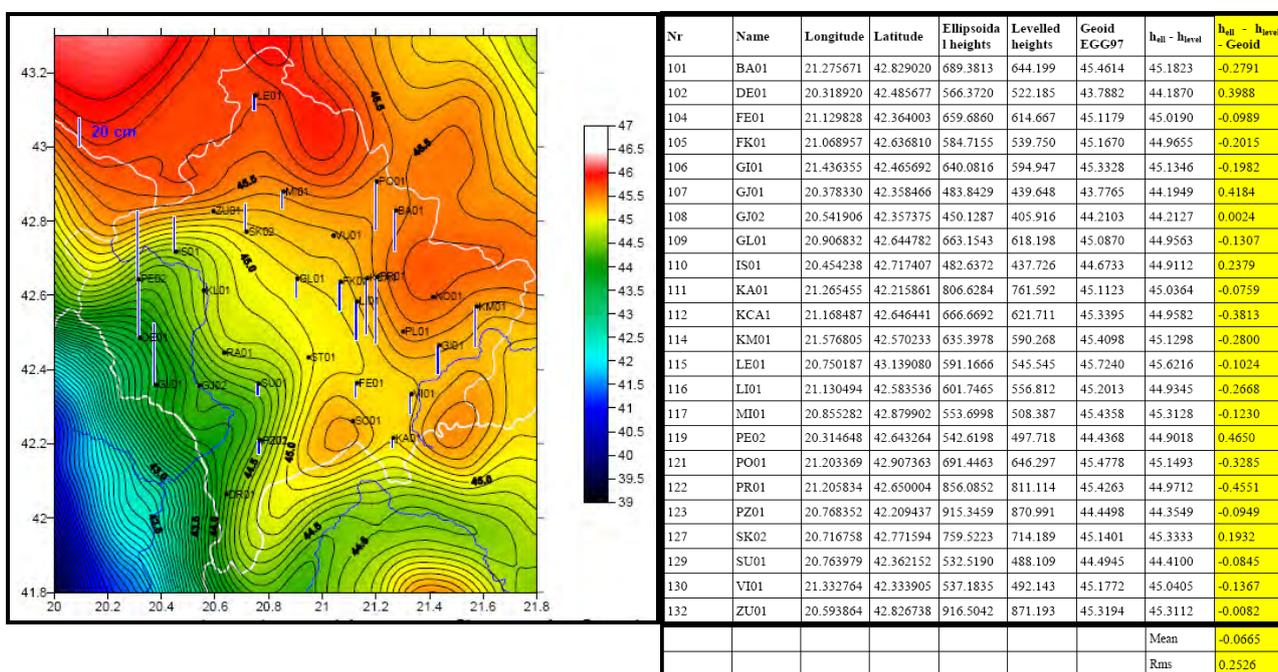


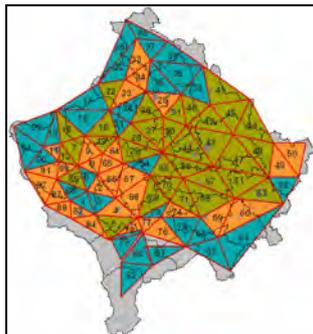
Figure 4. Geoid heights in EGG97 (8) and residuals differences of 1<sup>st</sup> order points of Kosovaref01 geodetic network

### Transformation of coordinates between old and new coordinate system

Transformation of coordinates between previous into new coordinate referent system, i.e. between “FryRef30” into “Kosovaref01”, has been realized by using Finite elements method, which is an appropriate method for homogenous and reversible transformations without gaps and/or distortions (Kohli and Jenni 2008). As final version of triangle network, in total 113 triangles (figure 5) were constructed and transformation parameters have been calculated for each triangle (KCA 2004). This methodology is fully automated in software under the KCA, and used for transformation of spatial data from old to new coordinate reference system. In figure 5 it is so clear that transformation accuracy of spatial data out from network area cannot reach the accuracy of spatial data based on the map scale as it is defined in bylaw regulations.

Beside the process of transformation with finite elements method, transformation parameters based on Helmert and Afine transformation have been calculated for entire area of Kosova, which are shown in next table 3.

Table 3. Transformation parameters between old and new CRS in Kosova



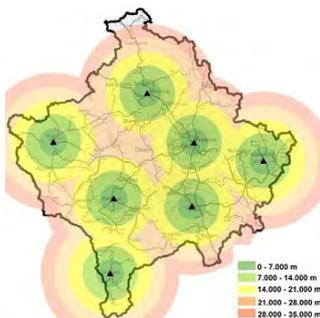
Helmert transformation (7)			
<i>DX</i>	628.54052 m	$\lambda$	-13.79189"
<i>DY</i>	192.25380 m	$\beta$	-.81467"
<i>DZ</i>	498.43507 m	$\gamma$	41.21533"
<i>Scale</i>	-17.40368 ppm		
Affine transformation (Bajrami 2012)			
<i>a</i>	0.99998270	<i>c</i>	6999435.08
<i>b</i>	0.00002853	<i>d</i>	603.036046

Figure 5. Map used for the planning of measurement campaign with provisional triangles

### Kosovo Positioning System (KOPOS)

From November 2012, position defining of spatial entities in the state CRS “KOSOVAREF01” within the area of the Republic of Kosova is available via Kosovo Positioning System (KOPOS), as GNSS (Global Navigation Satellite System) network of 8 (eight) virtual referent stations (figure 6 and table 4). It can collect data from GPS, GLONASS and GALILEO satellite systems, in order to enable to user’s calculation of the position/coordinates of spatial entities by offering services such as DGNSS, RTK and RINEX. Designing, establishment and maintenance of KOPOS is under the responsibilities of KCA, in according to Law on Cadastre of the Republic of Kosova (7).

Table 4. List of KOPOS stations and their geographical coordinates and ellipsoidal heights (7)



CODE	LATITUDE	LONGITUDE	ELL. H.
DRAG	42° 03' 43.85977"	20° 39' 16.32320"	1094.351
KAME	42° 34' 52.73833"	21° 34' 42.92311"	662.296
MITR	42° 53' 19.55551"	20° 51' 57.04548"	566.531
PEJA	42° 39' 41.30482"	20° 17' 18.50231"	581.464
KCAP	42° 38' 46.64737"	21° 10' 06.01842"	581.464
PRIS	42° 40' 12.72243"	21° 11' 30.61312"	709.004
RAHO	42° 23' 50.58087"	20° 39' 26.29440"	475.610
SHTI	42° 26' 3.003179"	21° 02' 18.65896"	623.998

Figure 6. Location of referent stations of KOPOS (7)

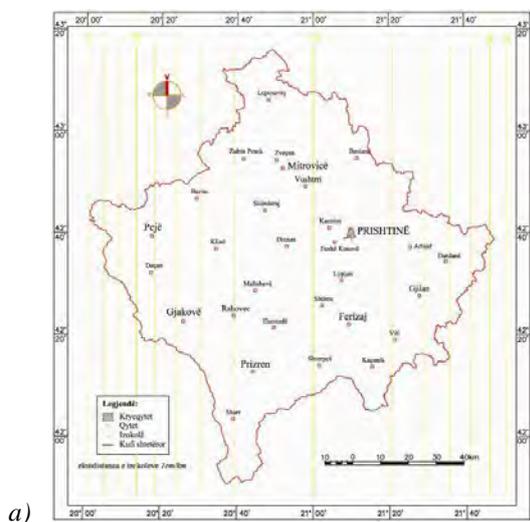
### COORDINATE REFERENT SYSTEM (CRS) “KOSOVAREF01”

As part of former Yugoslavia, from 30’s of last century the coordinate system established based on ellipsoid Bessel1841 and Gauss-Krüger projection with Central Meridian 21°, Scale factor at the central meridian 0.9999, False easting 7500000m, and False northing: 0m, locally known as FRYREF30 and internationally as MGI/Balkan zones 7 (EPSG 3906), was in official use until year 2001 (Idrizi etAll 2018).

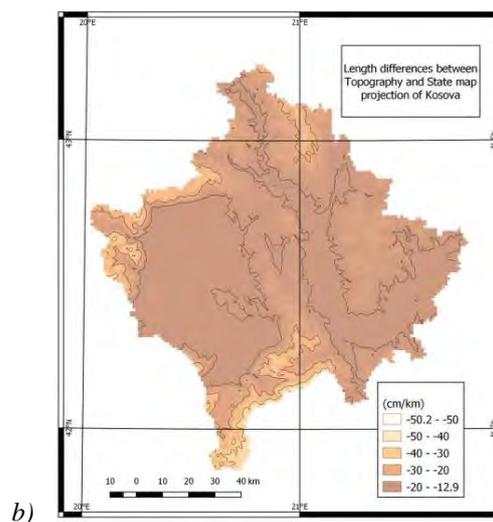
In order to establish mathematical model as precondition for supporting the coordinate system of new geodetic network of 1<sup>st</sup> order Kosovaref01, the state coordinate referent system (CRS) of the Republic of Kosova (KOSOVAREF01) was defined on year 2001, based on ETRS89 datum and Gauss-Krüger projection with -1dm/km distortion (scale factor 0.9999) along the central meridian (21°E), equator as origin of latitude, Greenwich as origin of longitudes, as well 7500000m false easting and 0m false northing values (Idrizi etAll 2009). CRS “KOSOVAREF01” is the legal and technical base for all official geodetic, topographic, cartographic and cadastral data in Kosova (7).

The differences between the new and former CRS’s are in utilized datum and ellipsoid, which can be seen in table 5, where it is recognizable that in the process of defining of parameters of new CRS “Kosovaref01”, in a period from 1999 to 2001, referent map projection followed by all its parameters has been obtained from older coordinate system “FryRef30”, probably without any sustainable scientific analyses (Idrizi etAll 2009), which resulted with projecting of

entire area of the Republic of Kosova with negative distortions (Idrizi etAll 2012). The range of map distortions is from -10cm/km along the central meridian up to -2.1cm/km at the western point (figure 7) and mean distortion is -8.7cm/km (Bajrami 2008), while horizontal lengths of 1km from topography surface are reducing their lengths (figure 8) with average value of -22.13cm/km, and range from -50.25 to -12.86cm/km (Idrizi etAll 2018). In next table 5 are shown parameters of both CRS's which have been in official use from 1924.



a) Figure 7. Map distortions in KOSOVAREF01 (Bajrami 2008)



b) Figure 8. Length differences between topography and map projection in KOSOVAREF01 (Idrizi etAll 2018)

Table 5. Coordinate systems of the Republic of Kosova from year 1924 up to day (Idrizi etAll 2009)

Name:	FryRef 30	KOSOVAREF01
Year of adopting:	1924	2001
Period of utilization:	1924-2001	2001-ongoing
Datum:	Harmannskögel	ETRS89
Ellipsoid:	Bessel 1841	GRS 80
Map projection	Gauss–Krüger	Gauss–Krüger
Projecting zone:	7th	7th
Width of the zone:	3°	3°
Prime meridian:	Greenwich	Greenwich
Central meridian:	21°	21°
Origin of latitude:	Equator	Equator
False easting:	7.500.000m	7.500.000m
False northing:	0m	0m
Scale factor:	0.9999	0.9999
Length units:	Meter	Meter

## INTERNATIONAL “EPS” CODING OF CRS “KOSOVAREF01”

EPSG Geodetic Parameter Dataset, also EPSG registry, is a public registry of spatial reference systems, Earth ellipsoids, coordinate transformations and related units of measurement. Each entity is assigned an EPSG code between 1024-32767, along with a standard machine-readable well-known text (WKT) representation. The dataset is actively maintained by the IOGP Geomatics Committee. Most geographic information systems (GIS) and GIS libraries use EPSG codes as Spatial Reference System Identifiers (SRIDs) and EPSG definition data for identifying projections and performing transformations between these systems, while some also support SRIDs issued by other organizations such as Esri (9).

The dataset was originally created by European Petroleum Survey Group (EPSG) in 1985 and was made public in 1993. In 2005, the EPSG organization was merged into International Association of Oil & Gas Producers (IOGP), and became the Geomatics Committee. However, the name of the EPSG registry was kept to avoid confusion. Since then, the acronym "EPSG" has become increasingly synonymous with the dataset or registry itself. Beginning with Version 5.3 and Version 6.1 on February 2002, all versions of the Database are remaining publicly available and downloadable in MS Access 2000 (Access 97 for v6.18 and earlier) format, while SQL scripts are available from version 6.4. (3).

The state CRS of Kosova “KOSOVAREF01” was officially recognized and registered in EPSG database with its own codes on 17<sup>th</sup> of July 2019, based on the change request EPSG:2019.042 submitted on 27<sup>th</sup> of May 2019, which resulted with international EPSG coding of KOSOVAREF01 as national CRS of the Republic of Kosova, and by removing Kosovo territory from Serbian international EPSG codes SREF98, SRB\_ETRS89 and SRB\_VRS12 (figure 9).



Figure 9. Change request EPSG:2019.042 for including KOSOVAREF01 in EPSG dataset (2)

KOSOVAREF01 is published and available by version “EPSG v9.7”, published on July 2019 and free downloadable in Access, MySQL, Oracle, and PostgreSQL formats via web page <http://www.epsg.org/EPSGDataset/Archives.aspx>. It consist of seven EPSG codes for the coordinate system (9138 for geocentric, 9139 for geographic 3d, 9140 for geographic 2d, 9141 for projectedCRS, 9142 for coordinate transformation from MGI 1901 to Kosovaref01, 9143 for coordinate transformation from MGI 1901 to WGS84, 9144 for coordinate transformation from Kosovaref01 to WGS84), one (1251) for datum, and one (4542) for the area. In bellow table 6 are given all EPSG codes that belongs to KOSOVAREF01, followed by WKT (well-known text) coding.

Table 6. International EPSG codes of the state CRS “KOSOVAREF01” of the Republic of Kosova

CODE	Type	WKT (Well-Know Text)
EPSG 9138	Geocentric	GEODCRS["KOSOVAREF01", DATUM["Kosovo Reference System 2001", ELLIPSOID["GRS 1980",6378137,298.257222101,LENGTHUNIT["metre",1.0]], CS[cartesian,3], AXIS["(X)",geocentricX,ORDER[1]], AXIS["(Y)",geocentricY,ORDER[2]], AXIS["(Z)",geocentricZ,ORDER[3]], LENGTHUNIT["metre",1.0], ID["EPSG",9138]]
EPSG 9139	Geographic 3d	GEODCRS["KOSOVAREF01", DATUM["Kosovo Reference System 2001", ELLIPSOID["GRS 1980",6378137,298.257222101,LENGTHUNIT["metre",1.0]], CS[ellipsoidal,3], AXIS["latitude",north,ORDER[1],ANGLEUNIT["degree",0.01745329252]], AXIS["longitude",east,ORDER[2],ANGLEUNIT["degree",0.01745329252]], AXIS["ellipsoidal height",up,ORDER[3],LENGTHUNIT["metre",1.0]], ID["EPSG",9139]]
EPSG 9140	Geographic 2d	GEODCRS["KOSOVAREF01", DATUM["Kosovo Reference System 2001", ELLIPSOID["GRS 1980",6378137,298.257222101,LENGTHUNIT["metre",1.0]], CS[ellipsoidal,2], AXIS["latitude",north,ORDER[1]], AXIS["longitude",east,ORDER[2]], ANGLEUNIT["degree",0.01745329252], ID["EPSG",9140]]
EPSG 9141	Projected CRS	PROJCRS["KOSOVAREF01 / Balkans zone 7", BASEGEOCRS["KOSOVAREF01", DATUM["Kosovo Reference System 2001", ELLIPSOID["GRS 1980",6378137,298.257222101,LENGTHUNIT["metre",1.0]]], CONVERSION["Balkans zone 7", METHOD["Transverse Mercator",ID["EPSG",9807]], PARAMETER["Latitude of natural origin",0,ANGLEUNIT["degree",0.01745329252]], PARAMETER["Longitude of natural origin",21,ANGLEUNIT["degree",0.01745329252]], PARAMETER["Scale factor at natural origin",0.9999,SCALEUNIT["unity",1.0]], PARAMETER["False easting",7500000,LENGTHUNIT["metre",1.0]],

		<p>PARAMETER["False northing",0,LENGTHUNIT["metre",1.0]],                  CS[cartesian,2],                  AXIS["easting (E)",east,ORDER[1]],                  AXIS["northing (N)",north,ORDER[2]],                  LENGTHUNIT["metre",1.0],                  ID["EPSG",9141]]</p>
EPSG 9142	Coordinate transformation from MGI 1901 to Kosovaref01	<p>COORDINATEOPERATION["MGI 1901 to KOSOVAREF01 (1)",                  SOURCECRS[                  GEODCRS["MGI 1901",                  DATUM["MGI 1901",                  ELLIPSOID["Bessel 1841",6377397.155,299.1528128,LENGTHUNIT["metre",1.0]],                  CS[ellipsoidal,2],                  AXIS["latitude",north,ORDER[1]],                  AXIS["longitude",east,ORDER[2]],                  ANGLEUNIT["degree",0.01745329252],                  ID["EPSG",3906]],                  TARGETCRS[                  GEODCRS["KOSOVAREF01",                  DATUM["Kosovo Reference System 2001",                  ELLIPSOID["GRS 1980",6378137,298.257222101,LENGTHUNIT["metre",1.0]],                  CS[ellipsoidal,2],                  AXIS["latitude",north,ORDER[1]],                  AXIS["longitude",east,ORDER[2]],                  ANGLEUNIT["degree",0.01745329252],                  ID["EPSG",9140]],                  METHOD["Position Vector transformation (geog2D domain)",ID["EPSG",9606]],                  PARAMETER["X-axis translation",628.54052,LENGTHUNIT["metre",1.0]],                  PARAMETER["Y-axis translation",192.25380,LENGTHUNIT["metre",1.0]],                  PARAMETER["Z-axis translation",498.43507,LENGTHUNIT["metre",1.0]],                  PARAMETER["X-axis rotation",-13.79189,ANGLEUNIT["arc-second",0.000004848137]],                  PARAMETER["Y-axis rotation",-0.81467,ANGLEUNIT["arc-second",0.000004848137]],                  PARAMETER["Z-axis rotation",41.21533,ANGLEUNIT["arc-second",0.000004848137]],                  PARAMETER["Scale difference",-17.40368,SCALEUNIT["parts per million",0.000001]],                  ID["EPSG",9142]]</p>
EPSG 9143	Coordinate transformation from MGI 1901 to WGS84	<p>COORDINATEOPERATION["MGI 1901 to WGS 84 (14)",                  SOURCECRS[                  GEODCRS["MGI 1901",                  DATUM["MGI 1901",                  ELLIPSOID["Bessel 1841",6377397.155,299.1528128,LENGTHUNIT["metre",1.0]],                  CS[ellipsoidal,2],                  AXIS["latitude",north,ORDER[1]],                  AXIS["longitude",east,ORDER[2]],                  ANGLEUNIT["degree",0.01745329252],                  ID["EPSG",3906]],                  TARGETCRS[                  GEODCRS["WGS 84",                  DATUM["World Geodetic System 1984",                  ELLIPSOID["WGS 84",6378137,298.257223563,LENGTHUNIT["metre",1.0]],                  CS[ellipsoidal,2],                  AXIS["latitude",north,ORDER[1]],                  AXIS["longitude",east,ORDER[2]],                  ANGLEUNIT["degree",0.01745329252],                  ID["EPSG",4326]],                  METHOD["Position Vector transformation (geog2D domain)",ID["EPSG",9606]],                  PARAMETER["X-axis translation",628.54052,LENGTHUNIT["metre",1.0]],                  PARAMETER["Y-axis translation",192.25380,LENGTHUNIT["metre",1.0]],                  PARAMETER["Z-axis translation",498.43507,LENGTHUNIT["metre",1.0]],                  PARAMETER["X-axis rotation",-13.79189,ANGLEUNIT["arc-second",0.000004848137]],                  PARAMETER["Y-axis rotation",-0.81467,ANGLEUNIT["arc-second",0.000004848137]],                  PARAMETER["Z-axis rotation",41.21533,ANGLEUNIT["arc-second",0.000004848137]],                  PARAMETER["Scale difference",-17.40368,SCALEUNIT["parts per million",0.000001]],                  ID["EPSG",9143]]</p>
EPSG 9144	Coordinate transformation from Kosovaref01 to WGS84	<p>COORDINATEOPERATION["KOSOVAREF01 to WGS 84 (1)",                  SOURCECRS[                  GEODCRS["KOSOVAREF01",                  DATUM["Kosovo Reference System 2001",                  ELLIPSOID["GRS 1980",6378137,298.257222101,LENGTHUNIT["metre",1.0]],                  CS[ellipsoidal,2],                  AXIS["latitude",north,ORDER[1]],                  AXIS["longitude",east,ORDER[2]],                  ANGLEUNIT["degree",0.01745329252],                  ID["EPSG",9140]],                  TARGETCRS[                  GEODCRS["WGS 84",</p>

		DATUM["World Geodetic System 1984", ELLIPSOID["WGS 84",6378137,298.257223563,LENGTHUNIT["metre",1.0]], CS[ellipsoidal,2], AXIS["latitude",north,ORDER[1]], AXIS["longitude",east,ORDER[2]], ANGLEUNIT["degree",0.01745329252], ID["EPSG",4326]], METHOD["Geocentric translations (geog2D domain)",ID["EPSG",9603]], PARAMETER["X-axis translation",0,LENGTHUNIT["metre",1.0]], PARAMETER["Y-axis translation",0,LENGTHUNIT["metre",1.0]], PARAMETER["Z-axis translation",0,LENGTHUNIT["metre",1.0]], ID["EPSG",9144]]
EPSG 1251	Geodetic datum	NO WKT available. <i>GML is available.</i>
EPSG 4542	Area	NO WKT available. <i>GML, polygon, area+polygon and map view are available.</i>
EPSG 2019.042	Add Kosovo data	NO WKT available. <i>Description:</i> Change of area code, removes Kosovo from SREF98, SRB_ETRS89 and SRB_VRS12 systems. <i>Entity Types:</i> Area; Datum; Coordinate Reference System; Coordinate Operation <i>Added areas</i> 4542-43, <i>datum</i> 1251, <i>CRSs</i> 9138-41 <i>and transformations</i> 9142-44. For areas 1298, 1321, 1711, 2066, 2370, 2830 and 2881, added Kosovo to description. For area 3534 changed name and description. For datums 1034, 1214 and 1216, CRSs 4073-75, 8682-85 and 8691 and transformations 4076-77, 7676 and 8893-94, changed area code from 3534 to 4543. For transformation 7675, added alias and changed area code from 3534 to 4543. <i>Report Date:</i> 2019-05-27 <i>Closed Date:</i> 2019-07-17

## CONCLUSIONS

As part of former Yugoslavia, from 30's of the last century, the coordinate reference system was established based on the earth referent ellipsoid Bessel1841 and Gauss-Krüger projection with Central Meridian 21°, scale factor at the central meridian 0.9999, false easting 7500000m, and false northing: 0m, locally known as FRYREF30 and internationally recognized as MGI/Balkan zones 7 (EPSG 3906), was in official use until year 2001.

The state coordinate reference system (CRS) of the Republic of Kosova (KOSOVAREF01) as independent country was defined on year 2001, based on ETRS89 datum and Gauss-Krüger projection with -1dm/km distortion (scale factor 0.9999) along the central meridian (21°E), equator as origin of latitude, Greenwich as origin of longitudes, as well 7500000m false easting and 0m false northing. This coordinate system is the legal and technical base for all official spatial data in Kosova.

Even though it was established on year 2001, until July 2019 it was not internationally coded as state CRS, in order to be used as standardized CRS for the Republic of Kosova. Upon the initiative to register it as official state CRS in EPSG database (<http://www.epsg-registry.org/>), change request with code "EPSG::2019.042" was accepted by the EPSG geodetic parameter registry, and Kosova's CRS was registered with 9 (nine) EPSG codes: 9140 (geographic 2d), 9138 (geocentric), 9139 (geographic 3d), 9141 (projectedCRS), 9144 (coordinate transformation from Kosovaref01 to WGS84), 9142 (coordinate transformation from MGI 1901 to Kosovaref01), 9143 (coordinate transformation from MGI 1901 to WGS84), 1251 (geodetic datum), and 4542 (area).

KOSOVAREF01 CRS is published and available by version "EPSG v9.7" from July 2019 as free downloadable database in Access, MySQL, Oracle, and PostgreSQL formats. It is now usable in all software which are using EPSG database for defining CRS of spatial data. In bellow figure 10, an example of latest version of QGIS software is given with Kosovaref01 as available CRS for utilization by users, which changed the previous state when users had to create Kosovaref01 as custom coordinate reference system definition.

Including KOSOVAREF01 as state CRS of the Republic of Kosova, affected to Serbian international EPSG codes SREF98, SRB\_ETRS89 and SRB\_VRS12 by removing Kosovo territory from them, as well to EPSG codes 1298, 1321, 1711, 2066, 2370, 2830, 2881, 3534, 1034, 1214, 1216, 4073, 8682, 8691, 4076, 7675, and 8893, recognizable in figure 9 (2), which in past period contained the area of Kosovo because of historical development of CRS's and geodetic networks in this area in the last century.

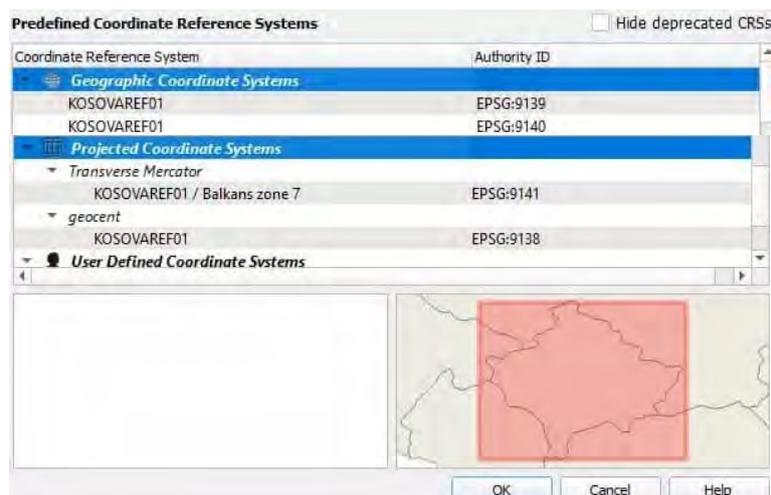


Figure 10. Example of QGIS software with 4 EPSG codes of KOSOVAREF01 (10)

International coding of KOSOVAREF01 by EPSG with separate codes for geographic 2d, geocentric, geographic 3d, and projected coordinate systems, geodetic datum, as well CRS's for coordinate transformation from Kosovaref01 to wgs84, coordinate transformation from mgi 1901 to Kosovaref01, and coordinate transformation from MGI 1901 to WGS84, gives an opportunity for standardized usage as CRS by institutions, organizations, researchers, business sector, academia, NGO and educational institutions, which will contribute to the wider standardized and easier usage of spatial data based on the geodetic network Kosovaref01 and KOPOS network developed in the Republic of Kosova, as well as mathematical base for spatial relation with spatial data developed in other CRS's for the territory of Kosova or neighboring areas. It will support the usage of state CRS within geodetic equipment for field measurements and post processing calculations software, as well for integrating georeferenced spatial data to other (non-geodetic) equipment for field data collection.

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<http://>

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## BIOGRAPHY



Mr. Bashkim IDRIZI, was born on 14.07.1974 in Skopje, Macedonia. He graduated in geodesy department of the Polytechnic University of Tirana-Albania in 1999. In 2004 he got the master degree of sciences (MSc) in Ss.Cyril and Methodius University-Skopje. In 2005 he had a specialization for Global Mapping in Geographical-Survey Institute (GSI) of Japan in Tsukuba-Japan. In 2007 he held the degree of Doctor of Sciences (PhD) in Geodesy department of Ss.Cyril and Methodius University-Skopje. He worked in State Authority for Geodetic Works from May 1999 until January 2008. During this time he appointed for head of cartography department in 2004, i.e. geodetic works. From October 2003 up to January 2008, he worked as a outsourcing lecturer in State University of Tetova, while from 205 to 2018 he worked as part time lecturer in the University of Prishtina. From February 2008 to October 2016 he worked as a cartography and

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# NECESSITY FOR GEOMETRIC CORRECTIONS OF DISTANCES IN WEB AND MOBILE MAPS

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## **Abstract**

*In this paper, the necessity for geometrical corrections of calculated distances in web and mobile maps is elaborated. Based on performed research analyses, in case of long routes, differences between distances calculated by web and mobile maps and traveled distance measured by car odometer are evident. For this study, many lengths longer than 200km have been measured by car during travel by our side, meanwhile the lengths for same paths have been calculated in many web and mobile maps produced by some global manufacturers.*

*Study resulted with two geometrical factors as potential generator of differences: 1. Geodesic distance over ellipsoidal height of route segments, and 2. Slope distances of route segments.*

*In our case study, both corrections have been calculated, and the corrected lengths were calculated in order to eliminate the influence of both factors to distances calculated by web and mobile maps.*

**Keywords:** web map, mobile map, ellipsoidal height, geodesic distance, slope distance, geometric corrections

## **INTRODUCTION**

The World Wide Web (WWW) is the most recent new medium to present and disseminate geospatial data, as virtually platform-independent, unrivalled in its capacity to reach many users at minimal costs and easy to update frequently. The common medium to access it is via navigation enabled by browsers. Web cartography is no different from cartography, but is restricted to the WWW as medium. Web maps are specific application-dependent context, influenced by the users, the providers, the viewing environments and the map contents, where the interaction among contexts defines the typical web map appearance (Kraak and Brown 2001), while the main purpose of web maps is to enable greater transparency in society (Degbelo and Kauppinen 2018). When it comes to the Web scale, these tools present drawbacks. First, they are designed for human visualization; hence they do not consider automatic processing, composition and reuse, thus hindering the automation of the process of creating, exchanging, combining and interpreting maps (Fionda etAll 2013). Furthermore, geo-media is also represented and includes such as maps produced by means of geographical information systems and web map mashups (Raber and Hurni 2019).

Web mapping is the process of designing, implementing, generating and delivering maps on the WWW. While web mapping primarily deals with technological issues, web cartography additionally studies theoretic aspects: the use of web maps, the evaluation and optimization of techniques and workflows, the usability of web maps, social aspects, and more (Neumann 2008). This may be possible by applying the suitable generalization process which consists to simplify the objects of the map and may transform the topological relations between them into other ones in real-time (Brahim and Okba 2015).

While laptops often are considered as mobile devices given their portability, smartphones and tablets present a new design context for cartographers and GIScientists given presumed mobility during use. Such mobile devices deliver maps and information as the user crosses the landscape, supporting navigation and providing local context while potentially splitting attention away from hazards in the environment (Roth 2018). Mobile phones and PDA's are becoming increasingly powerful and provide more and more functionality to the user. However, the user interface (UI) is still severely limited due to the small form factor of these devices. In terms of interaction, the well-established key-based interfaces are robust enough to navigate maps, but allow only a limited set of discrete movements and generally restrict the user's freedom (Winkler etAll 2007). Mobile Mapping Systems (MMS) have become quite popular even among the general public due to the success of web tools which allow street view navigation. Two great advantages are showcased with the development of an MMS based on the use of a smartphone – the much lower cost comparing with

other MMSs, and the much wider diffusion of these devices, which represents a potentially very large customer base (Masiero etAll 2016).

Providing mobile map users with relevant information about their surroundings based on their current trajectory is a necessary next step in providing them with the information they need or want without requiring direct interaction with the map, which can be dangerous or distracting, as well as time-consuming and annoying (Loeffler 2019). Mobile data is typically available in the form of so-called trajectories, i.e. sequences of individual 2D or 3D points with time stamps. In this way, for example, the traveled path of a hiker can be documented, the movement of a bird or a football player. The trajectories are recorded by GPS sensors or by observation and object tracking with cameras (Sester 2020). There are a number of related research areas across Geographic Information Science & Technology that offer insight into mobile map design: Location based services, Adoptive cartography, Volunteered Geographic Information, and locational Privacy (Roth 2018). In recent years, Located Based Service (LBS) has become one of the hotspots on the application of geographic information to the government and the public. Compared with the traditional web spatial information service system, service system of map information also put forward higher requirements of real time and veracity (Zhang and Li 2019). Finding the shortest path is often a central task (Veerubholta etAll 2015) in web maps and maps of navigation systems.

Path between two points in web maps, as well as respective applications in mobile phones, gives an opportunity to users to choose faster or shortest path, or more optional directions. Main target of this paper is length calculation in such web maps and respective maps that are available for usage via mobile phones.

Web based mapping services are using a modified version of Mercator Projection that is called Web Mercator [2] based on WGS84 ellipsoid (Bildirici 2015), known as Pseudo Mercator projection internationally coded with EPSG 3857 [1]. Due to large distortion values in Web Mercator projection, for example in 60° latitude the exaggeration is 4 time (Bildirici 2015), web maps and navigation/mobile maps make combination of cartographic representation and length calculation. While for cartographic representation the web Mercator projection is used, lengths are calculated in WGS84 ellipsoid in order to avoid the influence of map distortions, which represent the main objective of this paper.

During the use of the mobile navigation maps and for route planning in web maps for traveling by car, the difference between calculated and driven route lengths have been recognized. This was my main motivation for performed analysis of the differences between lengths in web map, navigation/mobile map and driven route. For this purpose, same route of about 230km was measured in five web maps, in their mobile applications, by two software, as well by car odometer. First idea of comparing the lengths between web/mobile map and car odometer, after recognition of differences between length values in different web maps and in two cases between same brand of web and mobile maps, research was extended to comparison analyses between some web maps, between web maps and mobile maps of same brand, as well between mobile maps of different producers.

## **MATERIALS**

For this research, online web maps, mobile map applications, GIS desktop software, as well distance measurement by car odometer were used.

From online web map platforms, google map [6], HereWeGo map [7], ViaMichelin map [8], Open Street Map [9], as well Bing map [10] have been used for performing this research.

From mobile map applications that offer directions, a google map [11], Here we go map [12], Via Michelin route planner [13], and Open Street Map [14] have been used for comparing calculated distances with web maps and driven distance measured by car odometer [3].

As GIS desktop software that offer distance calculations in ellipsoidal, in plan area with cartesian coordinates, true distances over a surface, and distances based on profiles, ArcMap [15] and QGIS [16] software have been used, while calculations based on math models have been performed in Microsoft excel software.

Altitude data and slope values of terrain along the route were obtained by ASTER GDEM with 30m spatial resolution[4], while geoid heights have been extracted from previous performed research study in this area (Idrizi etAll 2018).

## **EXPERIMENT**

After several cases of recognizing differences between planned route in free available web map such google map and driven distances longer than 200km, inspired me to check the reason of such differences. Very indicative data for systematic difference is equal prefix of distance differences, i.e. in each case driven length was longer than planned one in web/mobile map. This is clear indicator that discrepancy should be in the methodology for length calculation in web map and/or odometer of car.

As test data for performing analyses, a length of about 230km between Skopje (the capital city of North Macedonia) and ski center Borovets in Bulgaria with altitude difference of about 1100m, have been measured by all above mentioned web maps, mobile map applications, desktop software and by car odometer.

Table 1. Starting and ending point of route used for testing the differences

Point	Longitude	Latitude	East-UTM34N	North-UTM34N	Altitude - ASTER
Skopje-Chair	21°26'04"	42°00'47"	535972m	4651307m	266m
Borovets	23°36'19"	42°15'56"	714869m	4682536m	1335m

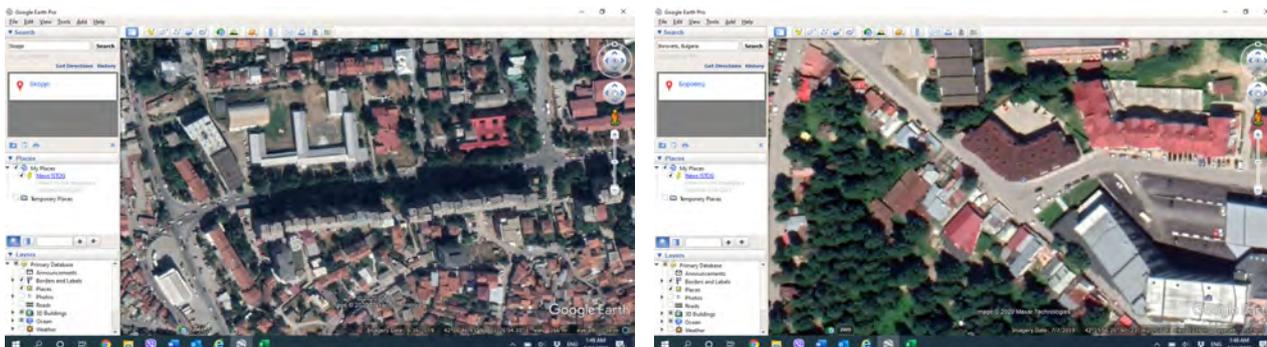


Figure 1. View from Google Earth of route starting and ending point, used for testing the differences

In order to have same route for comparison analyses, in five platforms of web maps and four in mobile map applications have been defined, based on driven route by car. Same route, have been exported by google map as line vector data as well as vectorized in GI software by using open layers, which resulted with less than 100m difference. Vector line of route driven by car have been used as data for performing analysis in GIS software.

In each web map (figure 2) and mobile map applications (figure 3), given in materials, based on predefined route driven by car, the length of the route has been obtained in automatic way by the applications. In such case, 9 values for same route have been obtained, which gives an opportunity to perform analyses of differences between them. In table 2 are given lengths from web maps and mobile map applications.

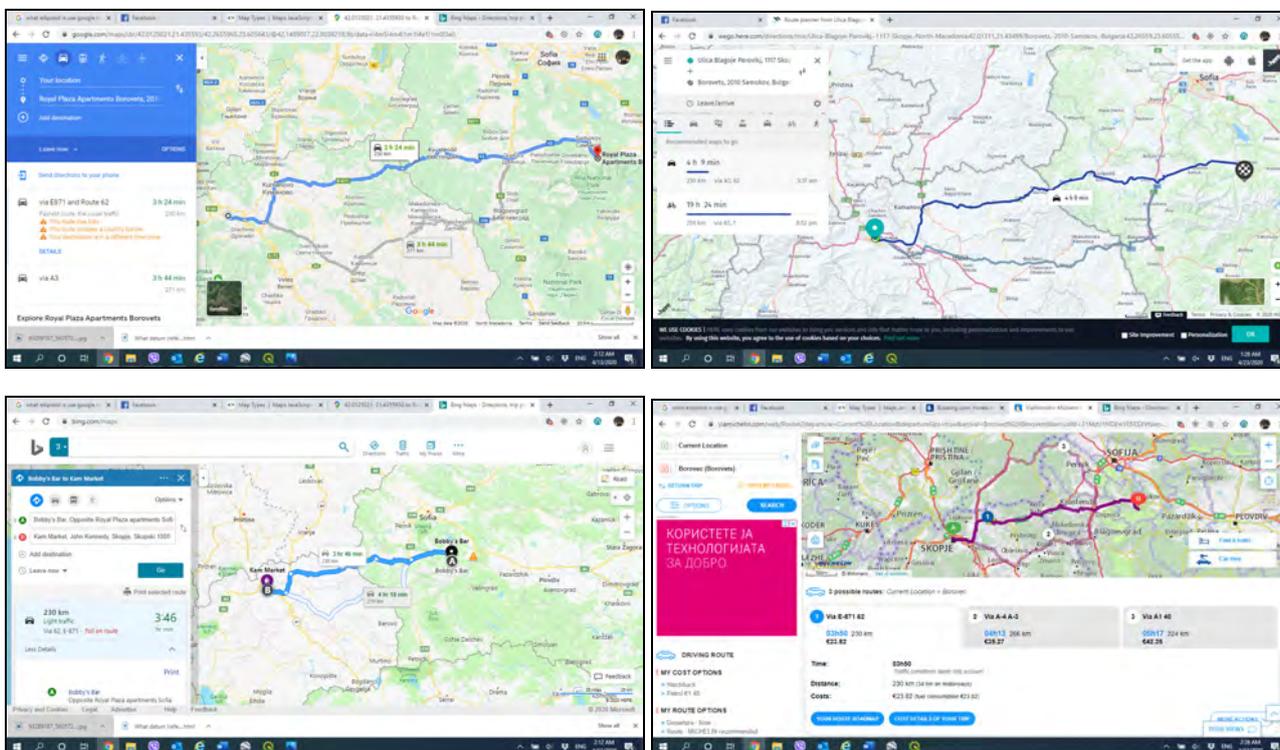


Figure 2. Same route direction by four web maps (Google, HereWeGo, Bing, ViaMichelin)

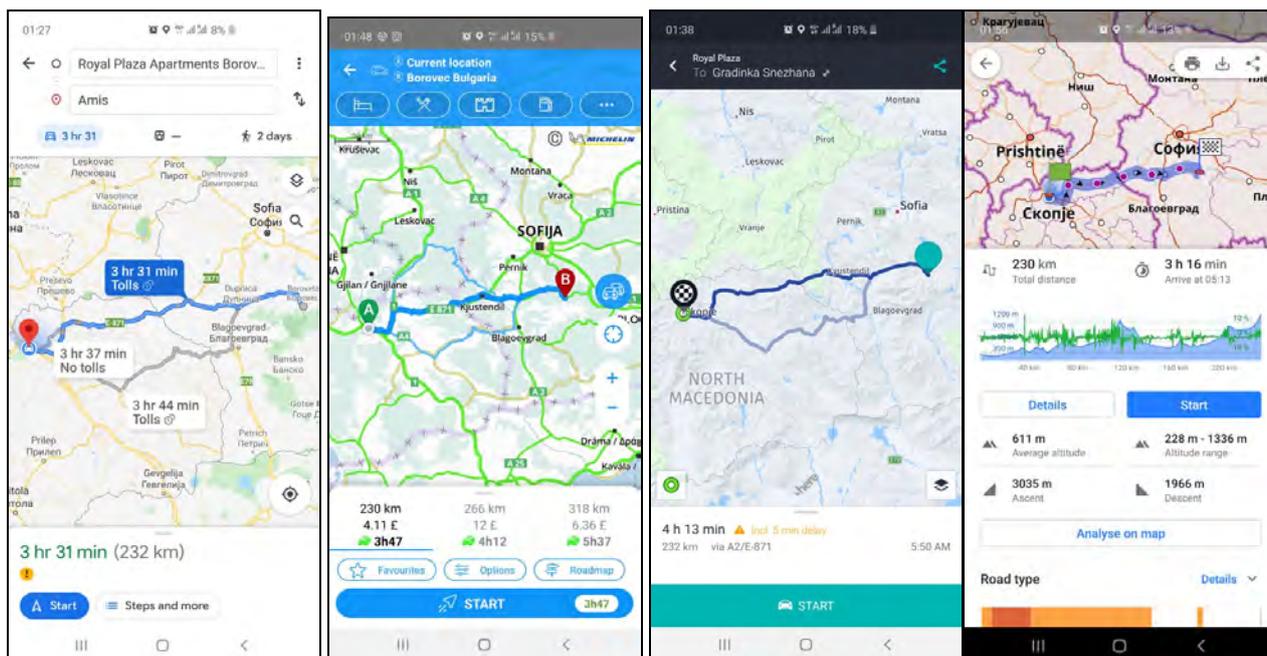


Figure 3. Same route direction by four mobile applications-maps (Google, ViaMichelin, HereWeGo, OpenStreetMap)

Table 2. Lengths of route calculated by five web maps and four mobile map applications

Web map	Length	Mobile map application	Length
Google map	230km	Google map	232km
HereWeGo map	230km	Here we go map	232km
ViaMichelin map	230km	Via Michelin route planner	230km
Open Street Map	230km	Open Street Map	230km + 2km “descent”
Bing map	230km		

Length of vector path between two points, have been calculated in two GIS software ArcGIS and QGIS. In ArcGIS, by using true distances over a surface option, slope length of vector line over the ASTER GDEM was calculated. By using QGIS software, two calculations have been performed: ellipsoidal length of vector line data over the WGS84 ellipsoid, and length of vector line in Web Mercator projection as used map projection for cartographic representation of web map. Three calculated lengths by using both software, are given in table 3.

Beside performed calculations in software and web/mobile maps, field/slope length of same path is calculated by using haversine formula [18] for Great Circle [17] in ellipsoidal height (figure 4) of points along the route, and slope data derived from ASTER GDEM [4]. In order to perform this calculation, vector line has been divided into 5103 segments. Each of 5103 segments, has passed bellow steps:

- a) Calculation of great circle lengths for each of 5103 segments over the WGS84 ellipsoid based on haversine formula [18],

$$a = \sin^2(\Delta\varphi/2) + \cos \varphi_1 \cdot \cos \varphi_2 \cdot \sin^2(\Delta\lambda/2)$$

$$c = 2 \cdot \text{atan2}(\sqrt{a}, \sqrt{(1-a)})$$

$$d = R \cdot c$$

Equation 1. “Haversine” formula to calculate the great-circle distance between two points

where:  $\varphi$  is latitude,  $\lambda$  is longitude,  $R$  is Earth's radius

- b) Calculation of mean ellipsoidal heights for each of 5103 segments based on ASTER GDEM and EGM2008 (Idrizi etAll 2018),

- b) Calculation of great circle lengths for each of 5103 segments over the mean ellipsoidal height (figure 2) of each segment (steps a and b → step c),
- c) Calculation of slope data (vertical angle) for each of 5103 segments based on ASTER GEDM,
- d) Calculation of slope lengths for each of 5103 segments, based on calculated lengths in *step (c)*, and calculated slope data (vertical angle) from ASTER GDEM in *step (d)*,
- e) Calculation of final length as sum of all slope lengths of 5103 segments from *step (e)*. Calculated length is given in fourth column of table 3.

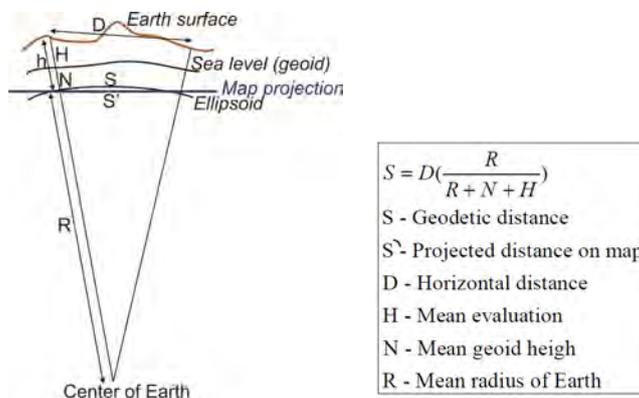


Figure 4. Scheme of length approximations from topography up to map projection through the sea level (geoid) and the referent ellipsoid (Idrizi etAll 2018)

On the other side, as field data, driven distance of 234.7km was obtained by the car odometer, which was later shortened by 650m length out of the route, driven during breaks within petrol stations/parking's. The final shortened length of route measured by car odometer is 234km, given in the last column of table 3. An odometer (or odograph) is an instrument used that measure the distance traveled by a vehicle, which works by counting wheel rotations and assume that the distance traveled is the number of wheel rotations times the tire circumference, and it is common to be of by several percent [3]. Odometers accuracy are typically proportional to speedometer errors [5]. In this research, impact of the accuracy of car odometer is not meter of analyses, therefore correction of traveled distance was not calculated. Traveled distance measured by odometer has been used just as indicator for differences between route direction lengths and traveled length.



Figure 5. Traveled distance, measured by car odometer

Table 3. Lengths of route calculated by QGIS, ARCGIS, Odometer and math model for Great Circle

Method	QGIS – ellipsoidal length (WGS84)	QGIS – length in map projection (Web Mercator)	ArcGIS true distance over a surface (ASTER)	Calculation by math model in Excel (ellipsoidal height and ASTER DEM)	Traveled distance by car odometer (Skoda Octavia)
Length	230.696km	311.310km	230.879km	232.218km	234km

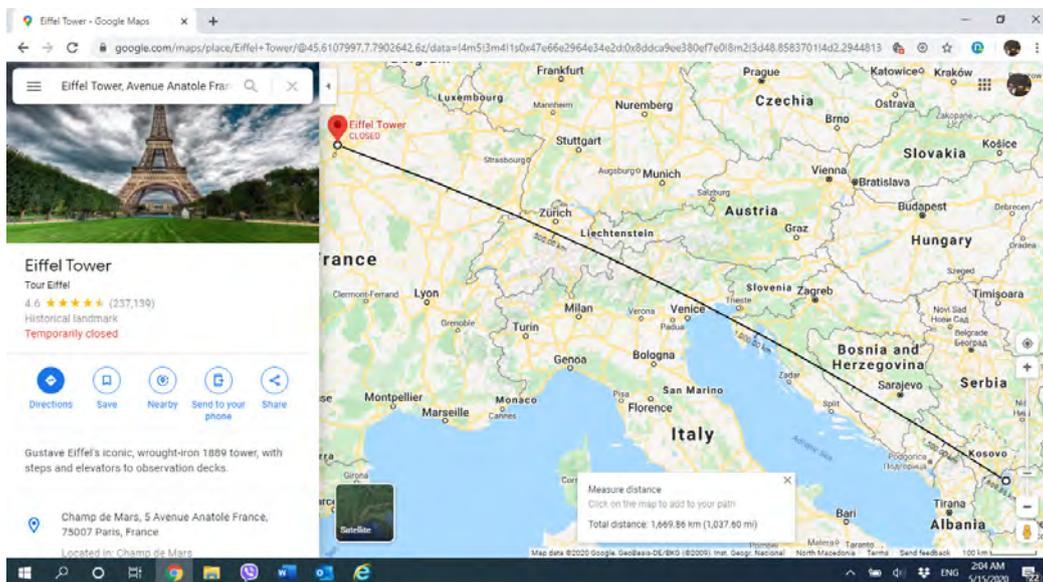
## DISCUSSIONS

By the above given calculations in this experiment, 14 results with 5 different values have been obtained, to be discussed and perform comparative analyses. Differences are very low, however those should be known and next challenge would be elimination of differences.

Five analyzed web maps (figure 3 and table 2) resulted with same calculated value of route length 230km. Given length is rounded to km (kilometer), which theoretically means that length is expressed with tolerance of  $\pm 500\text{m}$ . However, in a case of google map the difference between given length in google web map and calculated length of line vector data in QGIS as ellipsoidal distance which (as line vector data) has been exported from google map is 696m, which means that rounding of length is different from basic theory, because in such case length should be rounded to 231km. Due to all analyzed web maps gives same length, this means that all of them works with same mathematical model for measuring distances.

Lengths in web maps are shown as ellipsoidal distances based on mathematical models for calculation of great circle [18], and does not represent the distance in map projection. Since web maps uses Web Mercator map projection [2] for cartographic representation, in our case, length of line vector data is 311.31km, for about 81km longer than given length by web map (figure 3 and table 2). Such a kind of distance representation is contrary to cartometric principles, because spatial data in web map is shown in Web Mercator map projection while distances are given in WGS84 ellipsoid, however it is very useful for the target group of users because they are looking for the true-field distance and well compiled map.

Below is given an example (figure 6) from google map, in which measured distance between my location given in table 1 and Eiffel Tower in Paris-France is given as great circle of about 1670km in WGS84 ellipsoid, while google web map is in Web Mercator projection with code EPSG3857 [1, 2] in which the distance between same points because of map distortions (Bildirici 2015) is about 2392km. Same distance have been measured in QGIS software by using same platform (google map) as open layer, which resulted with different ellipsoidal length for 3.4km longer than the ellipsoidal distance measured direct in google map as web map [6]. Ellipsoidal length in QGIS was measured in EPSG7030 geographical coordinate system [1, 16].



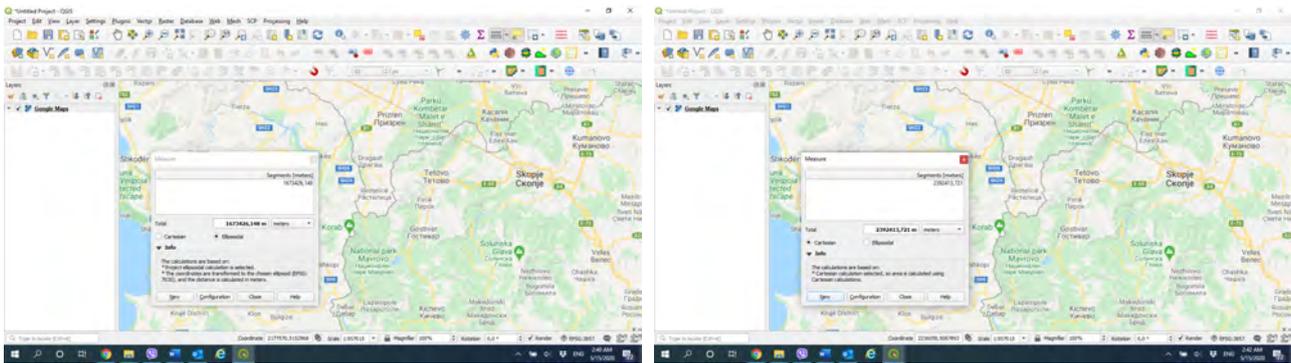


Figure 6. Results of same distance measurement in google web map [6] as ellipsoidal length (1669.86km), as well as in QGIS [16] as ellipsoidal (1673.43km) and Cartesian (2392.41km) lengths

Four analyzed mobile application maps (figure 4 and table 2) resulted with three values: google map and here we go with 232km, via michelin with 230km, while openstreetmap with 230km and descended length of 1966m. In this case lengths are rounded to km also, except the descended length in open street map rounded in meter.

From eight lengths of same route given in table 2, by excluding Bing web map, four in web and four in mobile platforms, differences between same brand of web map and mobile map application have been recognized. In a case of google maps, length in web map is 230km while in mobile map application is 232km. Same difference is recognized in Here We Go maps. In a case of ViaMichelin map, length is same in both (web and mobile) platforms, while in a case of Open Street Map length in both platforms is same (230km) with given additional value of descent of 1966m in mobile version with view of route profile (figure 4).

Two GIS software that gives opportunity for measurements over different surfaces, such as ellipsoid, relief and map projection, are used for testing same route as line vector data in order to get lengths in Web Mercator projection, over WGS84 ellipsoid, and over ASTER DEM. Results are given in table 3. Length in Web Mercator projection cannot be compared by above measured lengths in web and mobile platforms, since those are lengths over the Earth ellipsoid. Length over the ASTER GDEM cannot be compared with above measurements, because of the same purpose, while it will be compared with bellow value of length calculated by mathematical model. Ellipsoidal length obtained by QGIS software, is longer for 696m compared with web maps and mobile maps of Via Michelin and Open Street Map, while for about 1.3km shorter than mobile maps of google and here we go.

Calculated length based on the mathematical model defined in six steps (a to e) given in experiment part, is different with web maps, mobile platform of ViaMichelin, descended length in mobile version of OpenStreetMap, as well as with lengths measured by both software given in table 3. Its rounded value is equal to lengths of mobile version of google map, here we go map and non descended length version of open street map, given in second column of table 2, which seems that the mathematical model of length calculation in such platforms are taking into account the influence of slope lengths for calculation of route distances. Calculated length in step a by haversine formula, had same value as the length given in first column of table 3 (QGIS – ellipsoidal length), which should be rounded to 231km, however it is not clear the reason of rounding a length of 230.696km in each web maps to 230km. During literature review, the relevant information/math models on this issue were not found, therefore in this moment the analyses cannot go deeper in order to find the reason of differences.

Traveled distance as the only field data in this research, differs markedly from all above measured lengths, which is clear indicator for the necessity of harmonization between different map platforms even within web and mobile maps of same brand, as well adding additional geometrical corrections for measured lengths, in order to get real traveled distance. Since in experimental part the accuracy of odometer was not analyzed, measured length of 234km by car is excluded from discussions and comparative analyses, however it had crucial importance for performing of this research because the recognized length difference between web map and traveled distance by car was the main motivation for conducting of this study.

Data accuracy used in analyzed web and mobile maps are not taken into account in this study, because the relevant metadata which describes the quality of used data source in such platforms, even it is a very important criterion for analyzing differences between analyzed platforms were not found.

## CONCLUSIONS

Because the differences between distances calculated by web/mobile maps and traveled distance measured by car odometer are evident, the necessity for geometrical corrections of calculated distances in web and mobile map platforms is concluded by performed research and elaborated results of our case study. There are two geometrical factors which are generator of differences between the traveled route and calculated length distance by web and mobile maps: 1. Ellipsoidal height, and 2. Slope of terrain. Based on both geometrical factors, a system of six steps for calculation of real-slope (traveled) distance by web and mobile maps was established, which basically express a necessity of including calculation of geodesic distance over ellipsoidal height, and slope distances of each route segments.

In presented case study in this paper, it is clearly recognized differences between lengths calculated by different platforms, such differences: between web and mobile map platforms even by the same brand, between web maps and software-based measurements, between length calculated with formula and used platforms/software, between calculated and rounded lengths, as well as between web map and open layer in GIS software of same brand. Such differences arise the need for harmonization of models, first within the cartographic products of same brand, which should be followed by including additional geometrical corrections toward calculation of real-slope distance.

Web maps gives different information for geometrical values comparing with used model of map projection. Cartographic representation is compiled in Web Mercator map projection, while distances are shown as Great Circle lengths over the referent Earth ellipsoid WGS84. Basically, it is not in line with cartographic standards, but it is logical and smart solution because large distortions in Web Mercator projection would make them unusable for route planning and cartometric purposes.

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## BIOGRAPHY



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# INVESTIGATING THE IMPACT OF URBAN MORPHOLOGY ON URBAN HEAT ISLAND EFFECT IN SUBTROPICAL HUMID CLIMATE THROUGH REMOTE SENSE DATA

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## **Abstract**

*Urban morphology is one of the important parameters that dictate the land surface temperature in an area. This research analyses the difference in the impact of different urban morphology on surface heat island in the city of Chandigarh, India. Local Climate Zone classification system is employed to classify the urban area by WUDAPT method. This study assesses the thermal behaviour of mapped LCZ's using the land surface temperature retrieved from Landsat-8 data. The results show that LST in the city is consistent with the LCZ classes with higher LST observed in built-up LCZ classes. The unique thermal behaviour of the different LCZs provides indispensable information on the urban environment and its climatic conditions. This study provides directions to the urban planners by proposing the most suitable local climate zones to be developed while planning a new area to make it climate-resilient and guiding efficient distribution and design of built masses to maintain their maximum value of micro and local climate adjustment.*

**Keywords:** Local climate zone, Land surface temperature, Urban morphology, Landsat 8

## **INTRODUCTION**

Urbanisation has picked up rapid pace since dawn of industrial revolution. According to United Nations urban population has risen dramatically from 13% in 1900 to 46% in 2000 and is expected to reach 69% by 2050. This unprecedented and unplanned urbanisation has brought about an integral change in natural fabric influencing climate at global as well as local level. Urban Heat Island reflects the impact of changing landuse pattern and anthropogenic activities at local level.

Urban Heat Island (UHI) effect is the rise in temperature of urban environment in comparison to that of nearby rural areas (Oke, 1987). These heat islands have multidimensional impact on human health. Problems directly resulting from UHIs include increases in heat mortality and morbidity, increased infrastructure failure, increased drought and fire threat, increased stress to urban vegetation, changes to regional precipitation patterns, decreased urban air quality, and reduced outdoor quality of life for city dwellers (Moonen et al., 2012; Santamouris & Kolokotsa, 2015). Which in turn emphasize need to explore mitigating factors of this effect.

City size, urban morphology and geographical location, Weather, Topography and bluespace are the city specific features that effect UHI (Oke, 1987). This study explores the relationship between urban morphology and surface temperature. Local climate zone classification was developed to classify an urban area based on its morphology for climate studies (Stewart & Oke, 2012a). Local climate zones can be defined as regions of uniform surface cover, structure, material, and human activity that span hundreds of meters to several kilometres in the horizontal scale (Stewart & Oke, 2012). This classification scheme enables the researchers to compare and analyse the results of different areas by providing a common platform.

Traditionally study of thermal environment is carried out through ambient air temperature measurement. These point sourced air temperature measurement fails to provide spatially continuous thermal data. Recent advances in remote sense technology provide a viable solution by providing high resolution spatially continuous data (Cristóbal et al., 2018).

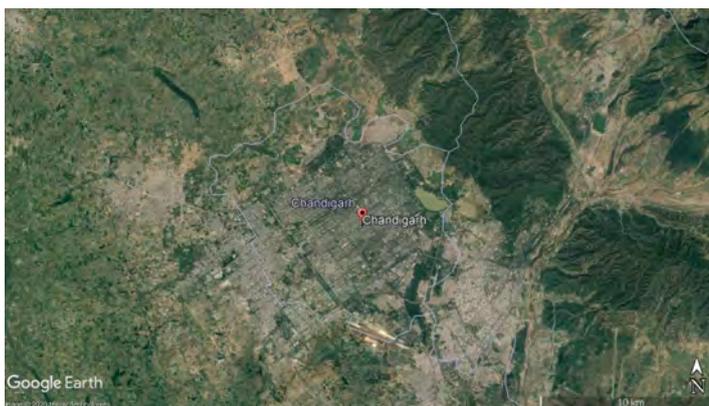
This study intends to explore the relationship between LCZ classes and LST in the city of Chandigarh, India. Images from Landsat 8 satellite is employed to retrieve the LST of the region and the study area is classified in different LCZ classes through WUDAPT methodology (Bechtel, Alexander, Böhner, Ching, Conrad, et al., 2015). The unique thermal behaviour of the different LCZ classes will provide indispensable information on the urban environment and its climatic conditions.

## MATERIALS AND METHOD

### Study Area

Chandigarh (30.74°N, 76.79°E) is a union territory and serves as the capital of two states namely Punjab and Haryana in India. It is located at an altitude of 321m and covers a total area of about 114 km<sup>2</sup>. It is one of the most rapidly growing city in northern India with population of 1,055,450 in 2011 and an average population growth of 4% per annum.

Chandigarh lies on the foothills of Shivalik ranges of lesser Himalayas. According to Koppen climate classification, it has a humid subtropical climate (Cwa) characterized by very hot summers, mild winters, unreliable rainfall and great variation in temperature. January is the coldest month with an average minimum temperature of 6.1°C and maximum of 20.4°C whereas June is the hottest month with an average maximum temperature of 38.6°C and minimum temperature of 25.4°C. Chandigarh experiences monsoon usually during July-September with an annual average rainfall of 1110.7 mm. August experiences the highest average precipitation of 307.5 mm whereas April is the driest month with an average rainfall of 8.5mm.



### Data

Imagery from LANDSAT 8 OLI/TIRS with horizontal resolution of 30 m is employed to conduct this study. To minimize the presence of clouds only 5 images obtained were selected from April 2019 to November 2019, as high cloud cover can lead to misclassification and false detection of land cover (Rasul et al., 2017). The satellite passes over the study area at 10:54 am IST.

Table 1: Details of Landsat 8 data

Image ID	Date (DD/MM/YYYY)	Cloud Cover (%)	Time (Indian Standard Time)
LC08_L1TP_147039_20181126_20181210_01_T1	26-11-2018	0.31	10:54
LC08_L1TP_147039_20181110_20181127_01_T1	10-11-2018	0.09	10:54
LC08_L1TP_147039_20190622_20190704_01_T1	22-06-2019	0.64	10:54
LC08_L1TP_147039_20190505_20190520_01_T1	05-05-2019	0.03	10:53
LC08_L1TP_147039_20190419_20190423_01_T1	19-04-2019	0.15	10:53

### Methodology:

To analyse the impact of urban morphology on urban heat island, the data obtained from LANDSAT 8 TIRS satellite is initially pre-processed in ERDAS Imagine 2018 software. The pre-processed data is then used to calculate Land Surface Temperature (LST) from improved mono window algorithm. The pre-processed Landsat 8 data is also used to classify the region in Local climate zones (LCZ) in SAGA GIS. Each LCZ class was then analysed with respect to their representative mean surface temperature.

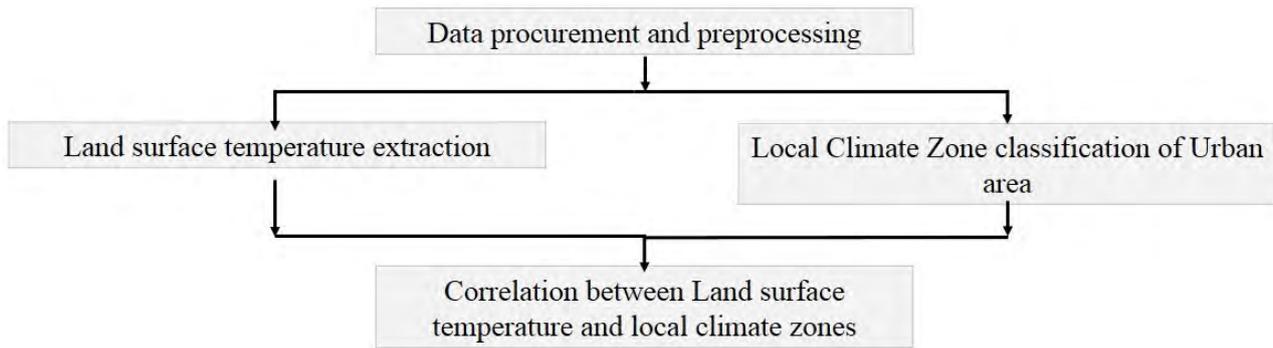


Figure 1: Methodology flow chart

### Land Surface Temperature retrieval:

The mono-window algorithm developed by Wang *et al.* (Wang *et al.*, 2015) is used to retrieve Land Surface Temperature from the Landsat 8 TIRS Band 10 data. Following equation is employed for the same:

$$Ts = [a_{10}(1 - C_{10} - D_{10}) + (b_{10}(1 - C_{10} - D_{10}) + C_{10} + D_{10})T_{10} - D_{10}T_a]/C_{10} \quad \text{equation (i)}$$

$T_s$  is the LST retrieved from Landsat 8 TIRS band 10;  $T_a$  stands for effective mean atmospheric temperature;  $T_{10}$  is the brightness temperature of band 10;  $a_{10}$  and  $b_{10}$  are the constants of the algorithm with value of -70.1775 and 0.4581 respectively.  $C_{10}$  and  $D_{10}$  are the internal parameters derived by:

$$C_{10} = \tau_{10}\epsilon_{10} \quad \text{equation (ii)}$$

$$D_{10} = (1 - \tau_{10})[1 + (1 - \epsilon_{10})\tau_{10}] \quad \text{equation (iii)}$$

Where  $\tau_{10}$  stands for atmospheric transmittance of Landsat 8 TIRS Band 10 and  $\epsilon_{10}$  is ground emissivity.

### Brightness Temperature ( $T_{10}$ ):

Top of Atmosphere thermal radiance (L) is calculated using Digital numbers ( $Q_{10}$ ) and Landsat 8 calibration coefficients.  $M_{10}$  is the multiplicative rescaling factor for Landsat 8 TIRS band 10 and  $A_{10}$  is the additive rescaling factor with values of 0.0003342 and 0.1 respectively.

$$L = M_{10}Q_{10} + A_{10} \quad \text{equation (iv)}$$

Planks radiance function was employed to convert thermal radiance (L) into brightness temperature ( $T_{10}$ ) employing the following equation:

$$T_{10} = \frac{K_2}{\{\log_{10}(1 + \frac{K_1}{L})\}} - 273.15 \quad \text{equation (v)}$$

$K_1$  and  $K_2$  are band specific thermal constants, which are 774.8853 and 1321.0789 respectively.  $T_{10}$  is the at sensor brightness temperature ( $^{\circ}\text{C}$ ).

### Effective mean atmospheric temperature ( $T_a$ ):

Linear relation proposed by Qin *et al.* (Qin *et al.*, 2001) for the approximation of effective mean atmospheric temperature ( $T_a$ ) from near surface air temperature ( $T_0$ ) is used. For mid latitude summer  $T_a = 16.0110 + 0.9262T_0$ . Temperature data from NOAA, (National Centers for Environmental Information) is used to obtain  $T_0$  for each day.

### Atmospheric Transmittance ( $\tau_{10}$ ):

Atmospheric transmittance is derived according to the linear relation mentioned by Wang *et al.* (Wang *et al.*, 2015). For Mid-latitude summer with water vapour content of 1.6-4.4 g.cm<sup>-2</sup> atmospheric transmittance is given by:

$$\tau_{10} = 1.0163 - 0.1330 w \quad \text{equation (vi)}$$

Water vapour content ( $w$ ) can be considered as  $2.5 \text{ g.cm}^{-2}$  for clear sky in mid latitude summer. Thus  $\tau_{10}$  is 0.6838.

**Ground emissivity ( $\epsilon_{10}$ ):**

Ground emissivity is estimated through NDVI threshold method (Yu et al., 2014).

Ground Emissivity ( $\epsilon_{10}$ )	NDVI
$0.973 - 0.047p_4$	$\text{NDVI} < 0.2$
$0.9863p_v + 0.9668(1 - p_v) + C_i$	$0.2 \leq \text{NDVI} \leq 0.5$
$0.9863 + C_i$	$\text{NDVI} > 0.5$

$C_i$  is the surface roughness coefficient;  $p_v$  is the fractional vegetation cover derived from NDVI by:

$$p_v = \left[ \frac{\text{NDVI} - \text{NDVI}_{\min}}{\text{NDVI}_{\max} - \text{NDVI}_{\min}} \right]^2 \quad \text{equation (vii)}$$

and

$$\text{NDVI} = \frac{\rho_3 - \rho_4}{\rho_3 + \rho_4} \quad \text{equation (viii)}$$

Where  $\rho_3$  and  $\rho_4$  are land surface reflectance of near infrared band and red band respectively.

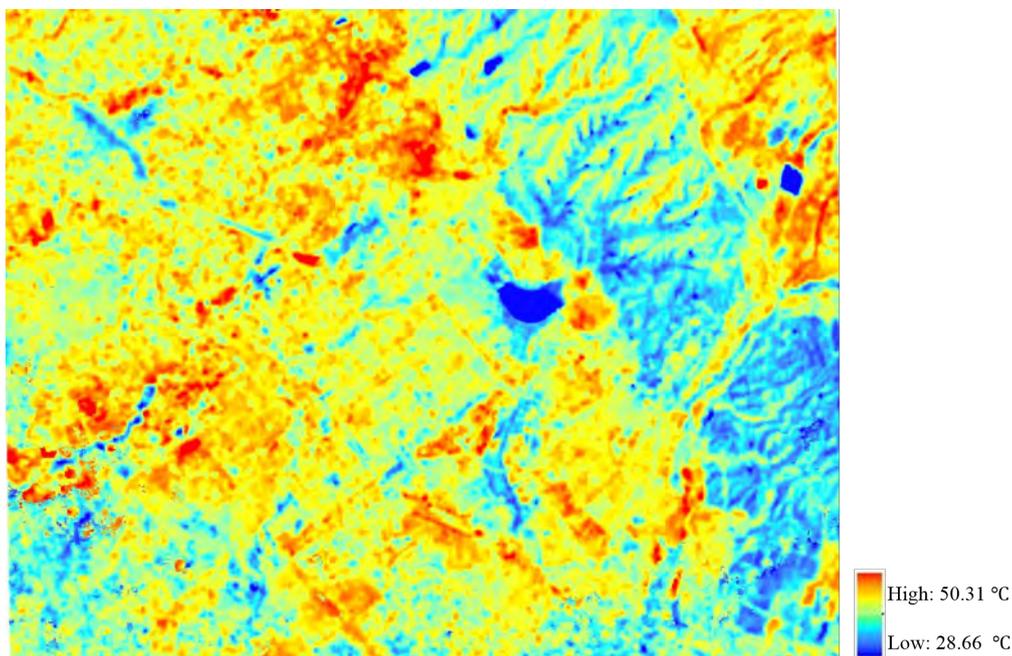


Figure 2: Land surface temperature map of Chandigarh

**Local Climate Zone Classification:**

It has been observed that climatic behaviour in urban area changes with change in surroundings (Oke, 1987). Researchers for urban climate study have proposed various classification scheme of the urban area based on morphological characteristics. From Chandler’s classification of Greater London in four parts in 1965 to Oke’s “Urban Climate Zones” in 2004, the classification schemes have evolved to incorporate parameters that are more just. This study adopts Local Climate Zone classification (Stewart & Oke, 2012b) to classify the designated urban area. This

classification scheme has a total of 17 categories in which the area is classified. These categories are based on morphology, surface cover, structure, material and human activity (Stewart & Oke, 2012a).

In this study, Local Climate Zone classification is carried out through Satellite image based WUDAPT method (Bechtel, Alexander, Böhner, Ching, & Conrad, 2015). This method can be broadly classified into two steps:

- i) Digitization of training areas: Training areas, representative of typical LCZ are identified using google earth. Every LCZ class identified has about 50 polygons as training area.
- ii) Classification in SAGA GIS: Random Forest classifier in SAGA-GIS is employed using the defined training area polygons of first step for classification of different LCZ in the study area.

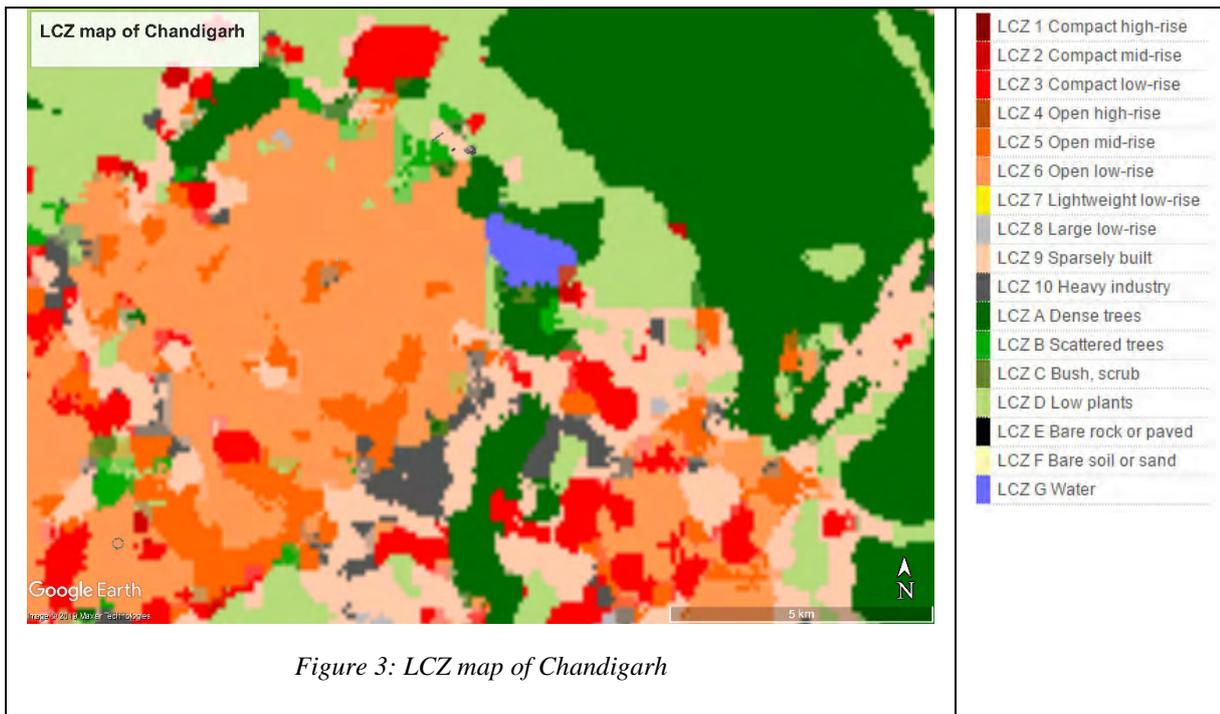


Figure 3: LCZ map of Chandigarh

## RESULTS AND ANALYSIS

### LCZ map of Chandigarh

LCZ map of Chandigarh developed by improved WUDAPT method is presented in Figure 2. It represents the morphological character of the region as well as specify the potential spatial pattern of surface temperature.

As shown in Figure 2, the vegetation is mainly concentrated around the waterbody in north east part of the region. The waterbody is an artificial lake called Sukhna lake. Dense trees (LCZ A) and low plants (LCZ D) dominate the region. The vegetation pattern is consistent with the geographical characteristics of Chandigarh.

Chandigarh is a planned city designed by Le Corbusier. It is reflected in Open low rise (LCZ 6) towards west of the lake. There are also many isolated urban settlements in the south east and north west part, which are mainly suburbs and prefecture-level cities that are possible heat sources of the region. These suburbs are extremely dense and compact so they are mainly classified into the LCZ 1–4 which have the potential to behave as high UHI intensity zones. Compact urban land cover is also found in the northern suburbs. The LCZ map also detects LCZ 10 (heavy industry) in southern part that are sources of anthropogenic heat.

### Relationship between LCZ and LST

Figure 2 shows the LST map of the study area. Large variations exists in the LST across the different LCZ classes. The LST of built-up LCZ classes is generally higher than that of the land cover classes, reiterating the high UHI intensity in urban areas. Compact mid-rise (LCZ 2) has the highest LST among the built-up LCZ classes with mean value of 32.5

°C. Compact low-rise (LCZ 3) have a mean LST value of 31.3°C. Sparsely built (LCZ 9) exhibits the least LST among the built-up classes with mean value of 27.7 °C.

Lower LST is generally observed in land cover LCZ classes due to the extensive pervious surface in natural land cover. LCZ G exhibits the lowest LST in the region with mean value of 22.1 °C. However, there are certain inconsistencies in LST of land cover classes due to the temporal difference in vegetation. LCZ B (Scattered trees) has the highest LST of 27.1 °C.

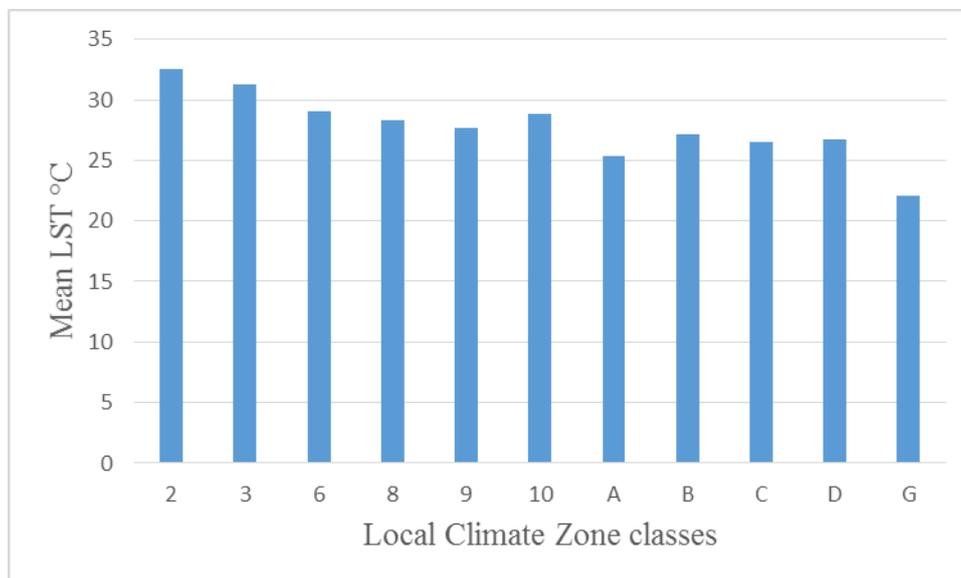


Figure 4: Mean LST of identified LCZ classes

## DISCUSSION

### Implications for urban planning

LCZ classification scheme is based on the impact of urban morphology on microclimate variation in a region. The maps in itself has the potential to indicate the spatial distribution of temperature regime within a city. Thus contributing to a much more climate sensitive urban design. It acts as a visualization tool for architects and urban planners, providing them a more indepth insight in the thermal environment and assisting them in decision making process. Moreover understanding of the LST behaviour of of diiferent LCZ classes help to minimize the impact of urbanisation.

The planned area of Chandigarh is predominantly open low rise and it showed the least LST of the built classes. Whereas the suburban area that consists of mostly compact mid-rise and compact low-rise exhibited the most LST. Thus stressing that more careful planning strategies are required for future urban development with respect to UHI mitigation. Further development should be avoided in these areas and green patches should be introduced in them to effectively mitigate UHI phenomenon. Green areas facilitate cooling through evapotranspiration. Areas exhibiting high LST, it is also important to improve the thermal environment through measures such as efficient energy use, building materials and other ecological measures (Osborne & Alvares-Sanches, 2019).

Integration of various climate risk resilience measures in urban planning is need of the hour. Chandigarh exhibits most of the heat related hotspots in its fringes, which can be handled by providing open space, preserving urban greenery and enhancing ventilation. Low building density is therefore preferred in order to maximize the cooling effect and prevent any blockage of ventilation from these areas.

### Limitation and Scope of future work

This study analyses the LST with respect to LCZ classes. This study is limited to just a single season and the LST is just limited to daytime. Further exploration in seasonal and diurnal variation of behaviour will help in better understanding of the thermal behaviour of different urban morphology. Stereo images can be used for better accuracy in urban morphology parameter extraction thus improving the LCZ classification. Air temperature data measured on-site will help in comprehensive understanding of the thermal behaviour of LCZ classes. As the LCZ classification scheme is

sometime not able to account for homogenous nature of development, future efforts should be made to refine and localize the LCZ classification for Indian cities.

## CONCLUSION

This study provides information about urban morphology and potential LST patterns and can thus help facilitate climate-sensitive urban planning and design. LST of the city of Chandigarh is retrieved from Landsat 8 datasets through mono window algorithm. The LCZ classification of the city is carried out through the WUDAPT methodology. The LST map of the region is then correlated with the LCZ classes of the city to understand the thermal behaviour of different LCZ classes.

Built LCZ classes exhibited higher LST than the landcover classes. LCZ 2 showed the highest mean LST of 32.5 °C and LCZ G had the minimum mean LST of 22.1 °C. Inconsistencies in LST variations were found in LCZ 9, A, B and C due to the highly variable urban morphology and the temporal variations in vegetation.

Results of the study further establishes the concept of LCZ and their thermal behaviour, which is in agreement to previous studies (Galal et al., 2020). This study will help urban planners and urban climate researchers to better understand the influence of urban morphology on local climatic conditions. LCZ maps can also be used in simulation for climate change studies.

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# CARTOGRAPHIC APPROACHES FOR VISUALIZATION OF SMART CITIES

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## **Abstract**

*Developing Internet of Things (IoT) technology has revealed the concept of smart city. IoT is a data network that objects communicate with each other through certain protocols without human intervention. Smart city is defined as a city that uses internet and communication technologies to make critical infrastructure components and services more conscious, interactive and efficient. Smart Cities Wheel, proposed by Cohen in 2012, is the method submitted by European Union. According to Cohen's methodology, the smart city model consists of six main characteristics. These characteristics are "smart economy, smart people, smart living, smart mobility, smart environment and smart governance". It is aimed to transform the collected spatial and related data into real-time intelligent information by revealing the concept of big data. The next step is to integrate these data into 3D Geographic Information Systems. These data must be modelled and visualized in 3D geovirtual environments. In this study and future studies, problems related to visualization have been identified as "determining supplies and demands of a smart city", "geospatial big data generalization" and "smart city visualization from a cartographic point of view". These main problems encountered on the way to building a smart city will be examined.*

**Keywords:** smart city, big data, map design, cartographic visualization

## **INTRODUCTION**

Considering the general situation of the world we live in and the conditions of this age, the crowded world population is an increasing source of problems. Increasing needs with the population led to the emergence of large cities over the years by directing people to live together. Continuous migration waves of the rural areas towards the cities, have caused uncontrolled increases in the population of the cities. This situation causes the existing urban systems to be insufficient in time and inadequate response to all areas of urban life within the framework of supply-demand balance.

All these negativities have led people to various searches. Undoubtedly, the greatest guide in this research and studies conducted is the technology that is always in the process of dynamic development and progress. The technology, which is developing and offering new opportunities, has started to be used as an effective solution tool for the solution of the intense confusion within the urban structure and as a result, the concept of "smart cities" has been brought to the agenda.

Making cities smarter, in other words, facilitating human life at the highest possible level, is possible by combining the technological systems with certain scales in the city. However, before that, the problems that cause blockages in urban life should be determined and analyzed from a wide perspective. Thanks to the detailed evaluations at different scales, the key concepts to be determined and the rational relationship networks to be established between them, it is of great importance to establish a conceptual operation chart of the concept of smart cities.

Within the scope of this study, the urban problems mentioned in the literature and the basic smart city components that reflect the starting points of these problems have been taken into consideration, a base for different solution scenarios has been established. Accordingly, it is aimed to prepare a conceptual infrastructure suitable for smart cities discipline and open for development. Based on the assumption that the concept of smart city is multidimensional, the main categories and subtitles in the literature have been created and possible complex relationships have been established. The problem of visualization is considered with the assumption that all data / information of the big data system created by this structure is collected, processed and its complex structure is solved.



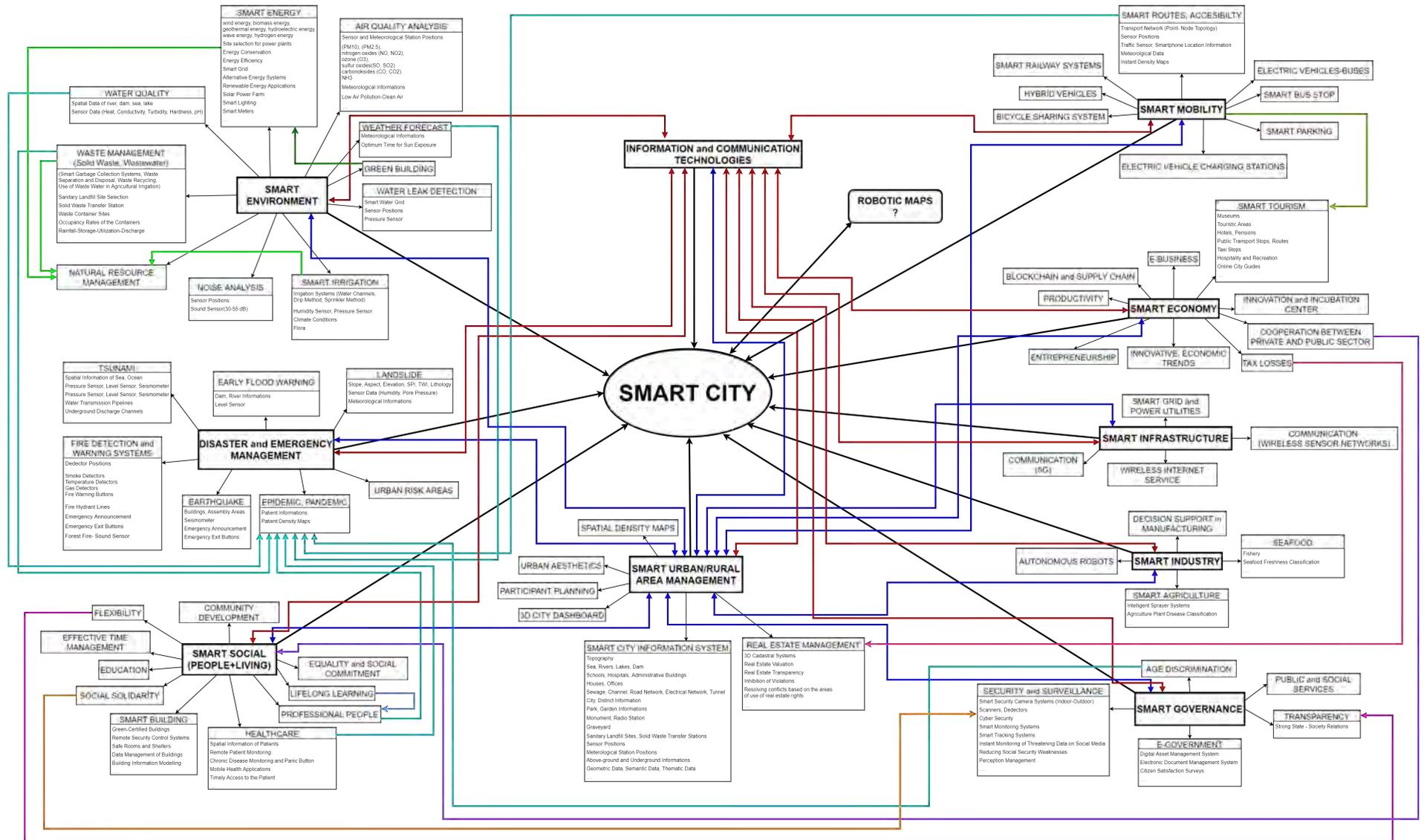


Figure 2. Smart City Components and (Partial) Relations

Considering the basic requirements of the city life with a complicated structure and the sensitive elements waiting to be solved, the main and sub components of the smart city scheme presented in this study were evaluated in necessary integrity. However, the creation of meaningful relationships between these components by cartographers and surveyors was another problem. Figure 2 shows the smart city characteristics and their interrelationships and common areas with each other. Moreover, even these relations, which are tried to be established for problems related to only health and tourism issues, have uncovered a very complex structure. In order to contribute to the constructive steps towards the future shedding light on the serious problems of urban life, the concept of the smart city and its relations should also be addressed with visualization issues.

## **CARTOGRAPHIC VISUALIZATION ISSUES FOR BIG DATA**

Cartography is the science, technique and art that researches the design (data/information collection, classification/categorization, modelling, generalization, symbolization, updating), production (printing, distribution, sharing environment -paper, screen, mobile phone, Web- etc.), use and user of all kinds of maps.

Science examines the relations between phenomena and objects, whereas art deals with objects in their relations with human (may lack of objective reality) using semantic, structural and psychological methods. Science and art comprehend both human and real world together. Aesthetic; in art and reality, is the science of the beautiful (beau). It is the science of artistic assimilation of aesthetic reality. Aesthetic, supports the objective properties of beauty, similarities in beauty and reality, and their perception by human beings. Beautiful is a basic category of the aesthetics. Beautiful forms are order, ratio, clarity. The goal in the beautiful is to reach reality (Ziss, 1977).

Map is an abstracted representation of the earth's reality, defined by symbols. Map is a symbolized representation of the earth's reality. However, it is not reality itself. It is a symbolized model of reality. Aesthetically, it is impossible to reach the reality. Efforts are always towards this direction. Technological developments are used in line with this objective.

The reality of the earth is distorted by cartographers and map makers, therefore there is no true map (Hardy, 1940; Ormeling, 2014). Generalization (simplification, exaggeration, elimination, amalgamation, aggregation, displacement), projection (compare merkator/winkel tripel projection, both depict the World), contour line/shading method (to increase the perception of the 3rd dimension) cause distortions. Here, the distortions caused by geodetic measurements on the earth have been neglected from the beginning. In addition to this situation, the map maker who creates maps and does not worry about visualization may create false information/perception due to “undemocratized distortions” (Ormeling, 2014; Field, 2020). For this reason, cartographers should design the cartographic truths with new technology.

Map design depends on the purpose, the collected data, information communication/sharing concern and visualization criteria (Howard et al., 2008; Kraak & Ormeling, 2011).

Thematic maps used to be printed and distributed colourful/black and white on general topographic maps that were previously printed in gray/colorless for cost reasons. They used to be multi-purpose maps (complex maps - not only a single topic), and there was an end product. Nowadays, with disappearing such a cost and the emergence of “carto-democracy” term, GIS analysts produce intermediate products, maps, analysis results, and single theme that they share their information for each other. In other words, instead of a complex (interrelated/multi-purpose) map, a single-theme (intermediate product) map is produced. With the same approach, mobile maps are generally designed as maps with limited inquiries on a single subject. Since analysis algorithms are developed, multi-decision systems and their relative complex maps can be produced. Meanwhile, cartographers deal with cartographic problems such as multipurpose/multiscale databases (multiple representation databases - MRDB), LOD (level of detail), and their presentations (Clarke, et al., 2019; Robinson et al., 2017; Roth et al., 2017). 2, 3, 4 Dimensional maps can be produced. Maps were used to represented manually and shades were used to display of heights. Map presentation concept has changed with developing science and technology, and now we make maps in 3D. Paper maps are replaced by screen and mobile phone maps. You can navigate, fly by or fly through it. You can automatically measure and calculate over it. Maps make you decide. Even, maps make you turn your way with ads into crazy shopping. Maps can show features which are invisible and maps can make us predict. Nowadays, robot has entered among map users.

Map presentation has still developing, but, it is not possible to auto-cartographic generalization based on scale and purpose for all earth objects and relations (Robinson et al., 2017; Roth et al., 2017). Machines still cannot put into practice the human-cartograph approach. The reason is that there is no aesthetic concern in automation or it cannot be put into practice. The robotic map does not need generalization/aesthetics. Robotic maps should be discussed as the subject of another study.

Nowadays, maps will come in our lives more than previously with the increasing needs of all living creatures. Cartographers will conduct new researches to increase human perception. Researches on the perception and cognition of digital maps should be added to the studies that were made for classical maps a long ago (Keskin et al., 2019; Robinson et al., 2017; Roth et al., 2017).

Cartographic traditional and conventional principles are still valid and applied. Map design is the application of visualization criteria depending on the purpose, data collected, information communication, sharing concern. Cartographic (spatial) visualization that develops besides scientific visualization thinks who, what, to whom, where, in what way, how to present. Cartographers are concerned about the purpose, scale, resolution, accuracy, quality, user level, the environment in which it is used, mapping methods, markings, static/dynamic information communication, cognition, and colourful/colourless presentation of a map. Cartographer evaluates the user according to age, gender, culture, physical limitations, professionalism, education and purpose, so he/she designs maps according to these objectives. Therefore, the design varies from user to user. Perception, cognition, culture and practical conditions are generally considered in interactive today's maps. Instead of a detailed user group, the general user is determined. This, in the new case, causes a different complexity in the stage of evaluating big data and presenting complex and dynamic knowledge. Therefore, cartographers will think again to solve presentation problems, especially because of the small size of the presentation medium. They should work multidisciplinary to better understand the presentations and effective use of interactive maps.

Technological developments such as visual analytics, artificial neural networks, data mining, simulation, machine learning, deep learning; computer calculations such as cluster and parallel computing, cloud computing, quantum computing; new platforms such as developing new visual methods and the partnership between artist and scientists contribute has been created. Artistic methods and techniques for geospatial big data will be improved through the creation of libraries to use in big data presentations, development of the artistic rendering system, artistic generation and dynamic link to conventional big data presentations (Robinson et al., 2017).

However, today, map users are also considered or even targeted as map makers producing map data. The new map reader/user will support their perceptual, cognitive and practical suggestions and experiences with interactive maps and visuals will be developed using real-time interaction and usability engineering with psychology and geography (Roth et al., 2017). Can Robot be both user and map maker at this stage? Cartographic expert systems should be prepared in order to carry out these situations and the help for new map maker. Then the production of wrong maps (Field, 2020) with carto-democracy will be replaced by the production of more accurate, easy and fast-to-understand maps.

New paradigm with new calculation techniques is the transfer of interdisciplinary knowledge with geo-spatial big data (huge data, various data, fast, dynamic, uncertainty problem etc.), complex spatial data and unstructured data. Using some technologies such as computer science, human-computer interaction (HCI), game design, virtual reality, information visualization, data mining, visual arts and etc., data collection, modeling and mapping operations, that is presentation, scale (abstraction, resolution, multiple scale, statistical analyzing), visual analytics, user/usability (cognitive testing) are practiced as the main concepts (Robinson et al., 2017; Roth et al., 2017).

Despite all the possibilities used to capture and measure big data, cartographers aim to think, discuss and develop on visualizing this information for users in the coming days. Robinson, et al. (2017) emphasized that there is no ideal solution yet. The map definition has not changed yet and it has own rules, conventions, and traditions. A “good map” design can be made if user demands and needs will be determined or already determined. However, nowadays, real-time dynamic data and constantly changing information should be updated and returned to the user as a service, and new criteria to be produced that are known as cartographically to be handled in the cycle should be developed.

The map is a simplified, abstracted version of complex earth reality. The cartographer should also direct and inform the user in this direction. If left on its own, the user wants to see many details together, but he/she may not be able to determine the query order, detail and abstraction level in order to prevent confusion. What the user demand will be, the easiest way for reaching this demand, the scenarios set up, after that the user can be directed by taking advantage of the cartographic cinema animation technical possibilities and use of dashboard besides the cartographic visualization possibilities of such scenarios (Robinson et al., 2017).

How to evaluate various, multiple, variable and continuous big data from social media, how much information to visualize and how to transform it into knowledge is a problem. This problem is also important for the fast and clear use of such data/information in the smart city system.

## SMART CITY VISUALIZATION PROBLEMS

In this age, the supply and demands change very rapidly with the developing technology. The concept of the smart city, shown in Figure 2 and established in the first section, should be considered in a multidisciplinary working way, relationships between the categories and components that will improve further, the main categories and components should be updated, developed, and the visualization problem -besides the existing solutions- should be considered.

Starting from the fact that the concept of smart city integrated with all these categories, it is necessary to have associations of main categories and subcomponents instead of individual scenarios. In this study, even when only two of the possible scenarios were tried to be established, it was observed that the event was confusing and cannot be solved only by cartographers and geodesists (surveyors). Geometric, statistical and semantic information with social content produced for smart cities should be evaluated in terms of visualization in the design of maps with multiple scales and resolutions of social statistics, generalization for cartographic abstraction, simplification, classification and symbolization.

According to the data type (point, line, area, volumetric and temporal) of the common information coming from the main categories and subcomponents in smart cities, the presentation should be selected, suggested and created depend on the user characteristics and demands with the help of an expert system. When this system is created; for point information; dot map, picture symbol map, graduated symbol map, reference or topographic map, for line information; network map, flow map, isopleth map, reference map, for areal information; choropleth map, chorochromatic map / area qualitative map, dasymeric map, hypsometric map, isoline map, stepped statistical surface map, reference map, for volumetric information; realistic perspective, simulated hill shading, gridded fishnet, stepped surface map, isopleth map, hypsometric map, image or orthophoto map, for time information; multiple views and animated maps can be used (Clarke, 2011; Kraak & Ormeling, 2011). There are also common characteristics in the map elements to be used. Expert systems, which take into account the design criteria outlined above, should be developed under the consultancy of a "City Science Board" to be established on a city basis. The City Science Board should include different kind of engineering disciplines, healthcare professionals, psychologists, lawyers, historians, geographers, geologists, sociologists, information scientists, financiers, educators, linguists, artists, as well as trained cartographers. Cartographers should take part in this committee where supply and demands are determined and they should always focus on information visualization and communication. Otherwise, cartographers should warn map makers especially about the issues outlined below.

Cartographers use functions, rules, and traditional methods for visualization. Simplification algorithms used for generalization are examples of these functions. While using the hill shading method from the northwest to represent the topography, the use of graduated (proportional) symbols to represent quantitative attribute data can be indicated as examples. On the other hand, to provide an analogy between the symbol and the object it represents, representing the object in its natural colors is just one of the rules applied by cartographers to produce more understandable maps (water with blue, mountains with brown). However, the use of all this information cannot be sufficient to achieve the desired result as "good map" unless it is known how to harmonize the maps to be produced, taking into account the scale, aim and user characteristics (Kraak & Ormeling, 2011).

Cartographic visualization basically depends on the scale of the map, its purpose, and the characteristics of the map's display medium. Due to the spatial database content, aim of the map, "generalization" appears to be a problem in visualization because of working with different scales. On the other hand, the thematic or topographic use of spatial data also changes its design. Presentation of the qualitative and quantitative characteristics of the data is another important design problem. In addition, the quality and consistency of data from different sources appears to be a major problem during data acquisition and map compilation (Robinson et al., 2017; Roth et al., 2017; Ulugtekin & Dogru, 2007).

Dynamic generalization of geospatial big data is necessary for visual analysis to be more understandable, readable and legible. The basic features of geospatial big data will affect the level of geometric and semantic generalization. Classical generalization rules are also valid for generalization of geospatial big data. In addition, the change of data from discrete elements to continuous phenomena and temporal changes should be taken into account. Generalization for big geospatial data is executed according to three situations. These are the situations that the data is quantitative, qualitative or continuous. Choropleth or proportional symbol maps are used for quantitative data whether absolute or relative. Robinson et al., (2017) propose the development of computer calculations for generalization of quantitative data. Smoothed surface is used for continuous phenomena. At this point, rendering becomes a challenge according to the level of generalization. If the data is qualitative, the information is discrete. Here, depending on whether the data is associative or dissociative, two situations occur that the data can be grouped or not. While even classical generalization has not been fully automated yet, generalization of dynamic geospatial big data is currently only a theory.

Attribute characteristic of the data is qualitative, quantitative and ordinal. Hierarchical sorting method is used for ordinal data. While qualitative data are classified at nominal scale, quantitative data are classified at interval and ratio scale (Kraak & Ormeling, 2011). In addition to these characteristics of the attribute data in map design, being continuous, discontinuous, absolute, relative affects the choice of symbols. These rules, known very well by cartographers, are often misapplied by GIS analysts.

Maps contain points, lines, area symbols and texts. Symbols are designed using visual graphic variables which are shape, size, orientation, texture, color, value, location. Each visual graphic variable has a different feature for effectively transmitting the spatial information and is often used for creating (small) screen map or classical map design in different combinations. Using an optimized number of colors in a map makes the map more understandable by establishing a bridge between map details and real objects using the natural colors of real objects. Contrast is also important because all information has a different significance on a map, so the objects should be visualized according to their level of importance, and that affects the choice of colors. Text is one of the most important elements of a map, which makes the map more understandable, readable and legible. However, there are several rules and traditional methods for using text on maps. For example, the difference between natural and artificial objects is distinguished by using italic characters for natural ones. Also, since the background color of the map is mixed with the foreground colors of the text, the readability and legibility of the map is increased by placing a shadow around the text (Dogru & Ulugtekin, 2006; Ulugtekin, & Dogru, 2007; Ulugtekin et al., 2008).

The cartographic theory and rules mentioned above are very well known by trained cartographers. However, since the new map makers lack of this visualization concern and information, they provide the knowledge they produce with great effort with a false and/or hard-to-read map. Changing map usage and map data today makes it compulsory to work with us (cartographers), related spatial disciplines and technology manufacturers. For this reason, it will be possible to reach the complex “smart city” concept accepted by the authors and will be possible to serve the user.

## RESULTS

Maps are prepared for the use of map users in order to increase the cognition of the spatial information provided. For this reason, map producers have to produce their maps by applying the cartographic design criteria effectively in order to provide more readable and easy understandable maps that enable the spatial and related information to be combined completely in the mapping process. These maps can then be used efficiently to support spatial smart city activities in decision making process and use.

Maps are used as communication tools to determine spatial relations. Unfortunately, since the majority of available softwares do not contain cartographic expert systems, maps produced by the map maker that does not have cartographic information cannot communicate properly with the user because they are not as efficient, readable and understandable as those produced by cartographers. However, the accuracy, readability and understandability of these maps are controversial issues.

Cartographic strategy in smart cities should be dynamic and data driven mapping in communication with other disciplines, developing the basic principles of design with new presentation possibilities (touch, gesture, voice interfaces), producing aesthetic and effective maps and/or improving the map maker productions. Researchers continue their research in this context.

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# HUNGARIAN AND ROMANIAN USER NEEDS OF BUILT-IN CAR NAVIGATION SYSTEMS

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## **Abstract**

*Navigation is an important element of passenger transport. As technology changed, navigation systems have also expanded and evolved. Since one of our most common everyday transport methods is cars, it is important to focus on their navigation devices. Their appearance has a great influence on how safe the driver can get from one place to another. Our hypothesis was that certain national peculiarities (infrastructure, culture, GDP) have influences on driving habits and built-in GPS usage. To examine this assumption, we created a Google Form – it is known to everyone and easy to use. Chosen countries for the comparison were Hungary and Romania. In addition, we were curious whether drivers are satisfied with their current built-in GPS. In general, users are satisfied with the features of the navigation interface and there is no great difference in the needs of the two countries.*

**Keywords:** questionnaire, built-in GPS, car navigation, comparison, Hungary, Romania

## **INTRODUCTION**

Ever since the need arose in humans to change their location, it was an important aspect how short, how economical or how spectacular the route was. Initially verbal or possibly written (graphic) instructions helped the traveller to achieve their goal. As the means of transport changed, so did the requirements for navigation equipment. The increasing pace of life has led to the need for faster and more automated tools. Nowadays most people use their mobile phones for navigation, but before the advent of smartphones there were "electronic" navigation devices. With the proliferation of automobiles, in-car navigation devices also appeared: the first one came out only 100 years ago, in 1909 (The Automobile 1909). Since then, built-in GPSs have undergone a major change, but their goal has remained the same: to support the driver to go from A to B in the best possible way. To get the information about this optimal route, from time to time the driver should look at – and if it is necessary, use – the interface. For a safe ride, this glance should take no more than a few seconds. Built-in navigation systems have the ability to make a complex impact on the relationship between users and their environment. Empirical and theoretical analyses show that the use of GPS alters the understanding of the world around people, their learning habits, their navigation techniques, their knowledge of spaces and places (Leshed et al. 2008). This shows how important it is to have the right amount of button/function/information on the display. As there are many developers, there are many interfaces too; however, there are also similarities among them. Examining these from a user perspective can help you determine whether drivers are satisfied with their current built-in device and, if not, what features can help improve these devices.

## THE QUESTIONNAIRE

### Background

The topic may seem superfluous, since navigation software companies are expected to meet user requirements. In contrast, the only study published in Hungary on this subject was 9 years ago. 109 people answered the 153 questions (Varga 2011). In Romania, however, we do not know any studies that deal with the topic. There is a study regarding habits in traffic that concerns the use of the navigation systems, but no more than that (Mihai 2018). There is poor coverage of this topic in other foreign literature as well: Al Mahmud's 2009 publication describes 15 interviewees who have all used only TomTom navigation. Naturally, the fact that there are no surveys about this topic does not mean that the built-in GPSs on the market are not suitable for the users. With this research we had a dual goal:

- On one hand, to find out whether drivers are satisfied with their current built-in GPS,
- On the other hand, to understand whether certain national peculiarities have influences on the driving habits, and especially on built-in GPS usage.

Hungary was chosen because the first author is Hungarian, and it was expected that she could get the most fill in the domestic area. For the country to be compared the main consideration was that the language of the country should be spoken exclusively by those who live within its borders. For example, a German-language questionnaire can be completed in both Austria and Germany – not to mention those who speak German as a foreign language worldwide. For this reason, Romania was a good choice also because the Department of Cartography and Geoinformatics at ELTE has a good relationship with Babeş-Bolyai University. The language of the questionnaire aimed at drivers in Hungary was Hungarian. The questionnaire for drivers in Romania was bilingual: as Hungarians make up the largest minority within the country, Hungarian was also available along with the Romanian language. In the remainder of the article, we do not distinguish between the two groups according to their nationality, but according to the country within the drivers live. Based on these we will talk about "Hungarian" and "Romanian" drivers.

In order to reach as many people as possible, we created a web questionnaire, a Google Form, which most users could be familiar with. The two questionnaires were published in two parts, but within one year. The first, fully Hungarian questionnaire was available for two months (December 2018 – January 2019) and more than 1000 fills were received during this time. The Romanian questionnaire was available for four months (October 2019 – January 2020) and it was filled by over 400 people.

### Structure

The two questionnaires contain the same structure and the same questions, but in different languages. However, there is one difference: the first question in the Romanian questionnaire concerns the language in which they would like to complete it: thus, this questionnaire contains twice the structure of the questions presented below (Figure 1).

Three separated "pages" were created. On the first page, we asked general questions that everyone had to fill out – there was only one criterion: a driver had to fill it. We asked a total of 17 questions: about half of them were personal (age, gender, education, etc.), while the other half were already related to driving habits (e.g. how often they drive under certain circumstances, how many kilometres they drive per year). The last two questions were asked about the existence and use of the built-in GPS. It depended on the answer they gave what kind of questions the answerer got next.

Those who answered "NO" to the usage question may have been those who have no built-in navigation, or who have it, just do not use it. Since this part of the respondents was less relevant to the research, we did not overload them – they had only three more questions.

The main part of the questionnaire concerned those who use built-in GPS. We divided the "YES" page into three sections: the first 16 questions were general, mainly asked about the system and the user's relationship ("Yes" questions). We also asked two questions about what they liked and missed in their navigation system. In the next part we tried to dig deeper and ask for smaller details (Detailed questions). After the 12 questions that were asked here, there was a volunteer section (we did not want anyone who got here so far to get tired of the questionnaire and quit without submitting, so we made it optional to fill out this part – which required a little more thinking). We were curious about two things: what the driver saw in the "map" view of his GPS, and if (s)he could put together the features that (s)he wanted to see. For these questions we gave options to choose from in advance, but also gave them the opportunity to give their own answer (Questions about the surfaces).

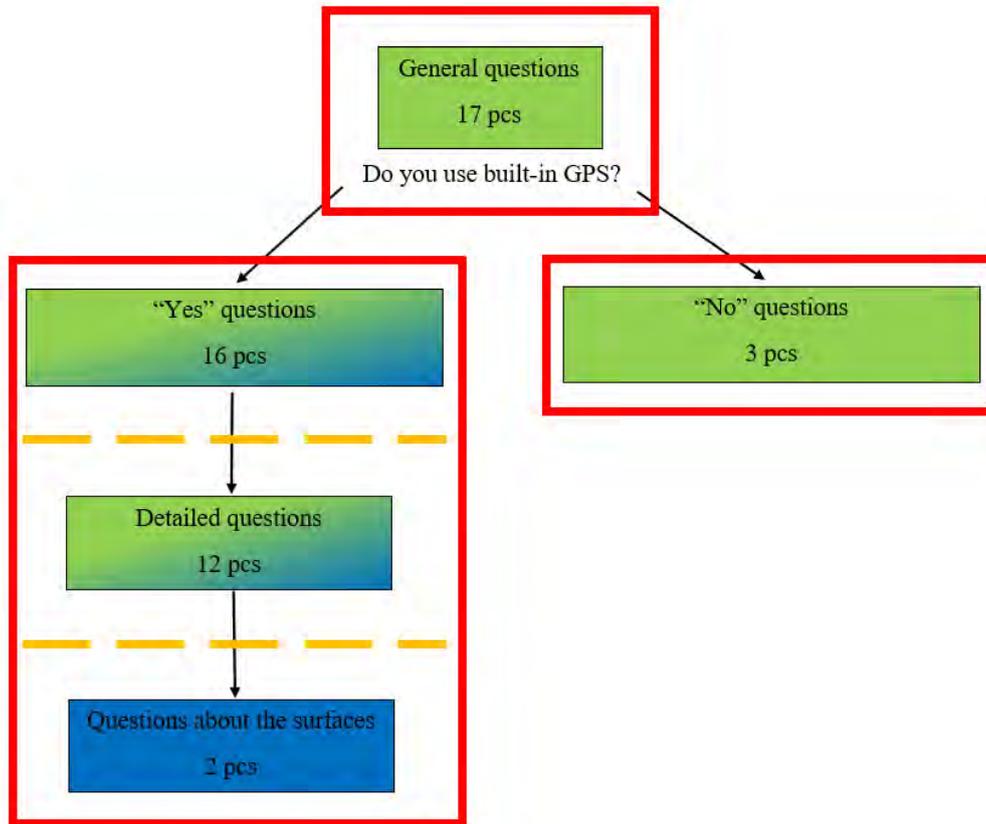


Figure 1. The structure of the questionnaire. Separated “pages” are marked with red, sections with orange. Required questions marked with green, optionals with blue.

## RESULTS

As shown in the figure above, we asked a total of 50 questions. Too many answers cannot be presented in an article, therefore we had to generalize – due to concentrating on the title of the article we abandoned the “No” questions, a significant part of General questions, “Yes” questions, and small part of Detailed questions.

From the general questions we only highlight those that are relevant to the article – that is, somehow connected to the built-in GPS’s interface. Of the two countries, people in Hungary bought fewer used cars (65–75%), but more people used someone else’s (e.g. parent’s) car, and only 20% had their own new car. In Europe, the average vehicle age is 10.5 years (ACEA REPORT 2018). In comparison, both countries are above this: the average age of Hungarian cars is ≈14, while Romanian cars are 13 years old. From this data, it was expected that few cars had built-in GPS. Interestingly, although Hungarian cars with built-in GPS are younger, Romania still has more built-in GPSs (Figure 2).



Figure 2. Proportion of users using built-in GPS – situation in Hungary on the left, in Romania on the right

## Appearance

We have provided 5 possible placement modes for the built-in GPS interface (Figure 3). With the first option, we wanted to favour left-handers in particular, as we assumed it would be easier for them to handle the surface on the left. The second place is behind the wheel on the dashboard. At the top of the center console is the number three GPS, in the center console itself, in its "usual place" has the number four, while the number five is the surface projected onto the glass. We wanted to know where the surface is now and where the drivers themselves would like to see it, where it would be most comfortable for them.

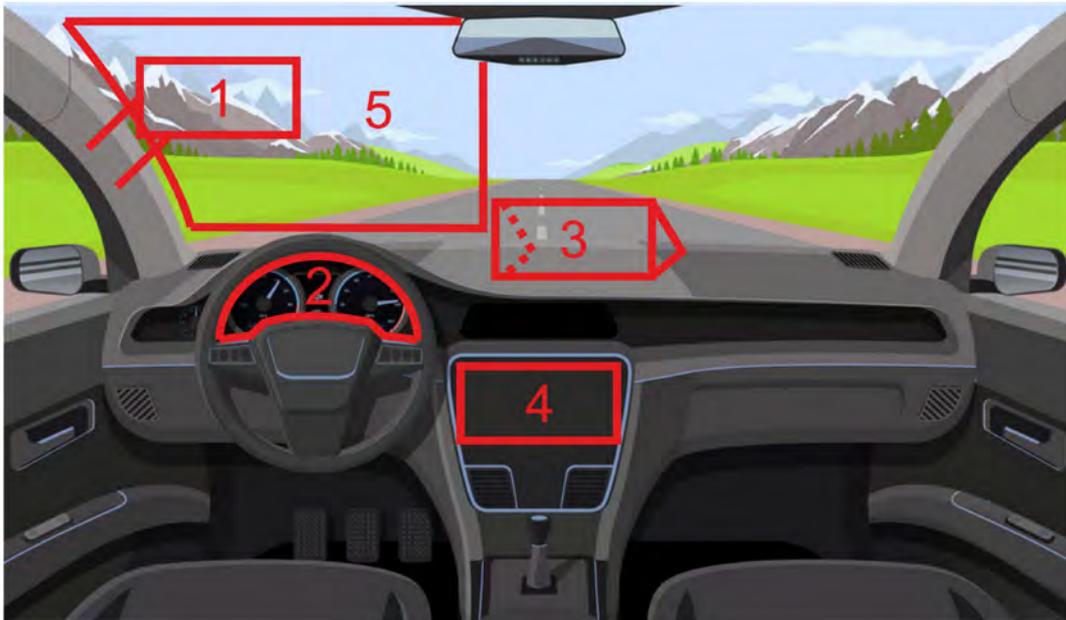


Figure 3. Possibilities for built-in navigation placement ([www.vectorstock.com](http://www.vectorstock.com))

Currently, "usual placed" GPSs are clearly dominating the market (Table 1). In contrast, the most comfortable position for the built-in GPS could not be easily decided neither among the Hungarians, nor among the Romanians. While Hungarians preferred options 2–5 equally, Romanians favoured options 3 and 4, but there is no clear winner neither here, nor there.

Table 1. Percentages of responses to the current and potential placement

Placement	Current interface - Hungarian -	Recommended interface - Hungarian -	Current interface - Romanian -	Recommended interface - Romanian -
1 (folding left)	0 %	4 %	0 %	0 %
2 (dashboard)	12 %	23 %	5 %	18 %
3 (foldable)	18 %	25 %	20 %	31 %
4 ("usual place")	66 %	24 %	74 %	35 %
5 (projected onto the windscreen)	4 %	24 %	1 %	16 %

The GPS data input method is largely the same in both countries: the touchscreen is around 76%, while navigation knob is  $\approx 20\%$ . Romanians are the majority with voice-controlled GPS, but forming only 5%. An interesting question from a cartographic perspective is what "view" drivers usually use. They had the opportunity to mark whether they used perspective or top view, or they oriented the map north. Because the directional view was not a separate option, we assumed that who did not specifically indicate the north orientation would use the directional view. Based on these it can be said that drivers generally use the perspective view in the direction of travel.

## Voice

There are two things regarding the sound: either the user is talking to the device or the device is talking to the user. For the former, the language may be interesting. For Hungarians: half of the device is in Hungarian, 12% navigates the user in other languages. 21% does not speak Hungarian, while 17% does not speak at all. For Romanians: almost 60% speaks the user's language, 20% another language. 13% does not speak Hungarian/Romanian and 10% is soundless. Based on these it can be said that there are more imported cars in Hungary than in Romania. For the latter, language is an exciting question too. In Romania a higher percentage can be used for voice guidance. In cases where it is possible to give voice instructions to the system, the percentage of those who use it is almost exactly the same in the two countries. 30% use it for address searching, the rest do not use this option. In addition to speech, click sound can be heard on the interface. Romanian devices make a much higher percentage of making "click" sound (77–56%) and most people are not disturbed by this feature.

## Subtleties

In the following, we publish the details of various functions of navigation systems and how they are used by drivers. In both countries, there are less than 10% who turn off "night mode" (and fewer people who do not even know it exists). GPS device offers in 80% of cases alternative routes when planning: more than 90% of drivers use this feature. 50% usually enter more intermediate destinations, either on the way or pre-typed. Often visited addresses are filled in by only 10% each time, the others either save them as favourites (most often addresses of family members/friends – many Romanians still save workplace address) or recall them from the history. There is a significant difference in the number of saved addresses: in both cases  $\approx 70\%$  store less than 10 pieces, however half of the Romanians, but 35% of Hungarians have less than 5 addresses.

It could be a cardinal question whether drivers use the surface while driving. This in itself presents dangers, but if the right amount and quality of information is available on the surface, the hazard can be reduced.  $\approx 60\%$  of drivers use the GPS while driving. The percentages are exactly the same in the two countries: 37% while driving, 32% standing at a red light and 30% uses the built-in navigation sideways off the road. The remaining one percent touches the interface regardless of traffic situation. More than 70% use the GPS to enter a new address – this is interesting because according to Table 2, the "Add new destination button" is not required by drivers directly on the interface.

Figure 2 shows that people in Romania are more likely to use built-in GPS. Hence, the question is whether drivers are looking for an up-to-date map (database) on the device. Figure 4 shows that a higher percentage (more than 75%) updates the database. They are aware that they have the opportunity to do this and are able to do it. There is also a big difference between drivers in the two countries regarding the frequency of the upgrade: while Hungarians do this every year or even less frequently, Romanians do it more often (even quarterly).

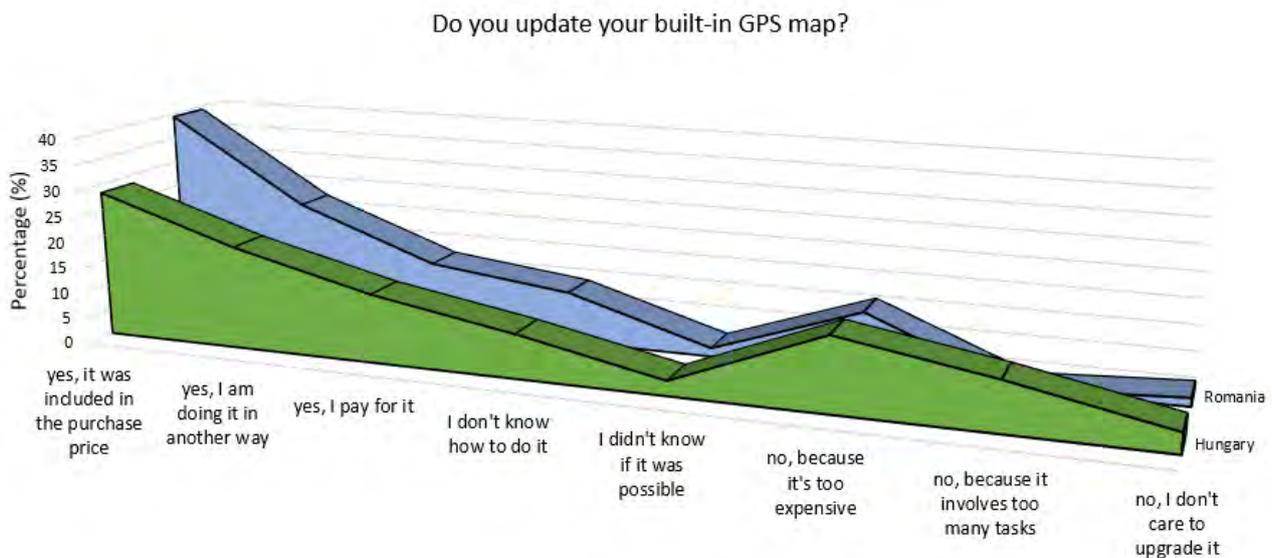


Figure 4. Update habits for drivers using built-in GPS

## DISCUSSION

The last two voluntary questions were about what the drivers see now and what they want to see in the "map" view of the built-in GPS. We gave the same possible answers for both questions, and the fillers also had the opportunity to respond personally. After comparing the answers of the two questions, the responses were divided into four groups: "have it, and want it", "have it, but do not want it", "do not have it, but want it" and "do not have it, and do not want it". With the help of these groups four user interfaces (*current/recommended*) for the two countries were created. As the purpose of this study was to examine the needs of drivers in the two countries, we illustrate the completed surfaces by country. The *current* one is shown on the left and the *recommended* one is shown on the right (see below). We got the *current* interface by merging the "have it and want it" and the "have it and don't want it" groups. A total of 24 functions were marked by the fillers and Figure 5 shows these in percentage distribution (based on the votes). Not all of them were depicted, only those for which at least 10% of the total number of drivers voted. We used all four groups to create the *recommended* interface, but we combined the values into two groups: I want = "have it, and want it" + "do not have it, but want it" and I don't want = "have it, but do not want" + "do not have it, and do not want it". We do not show all of them, we set a limit due to the number of votes. We drew a line, but we still illustrate where the number of 'no' does not exceed the 'yes' by one and a half times.

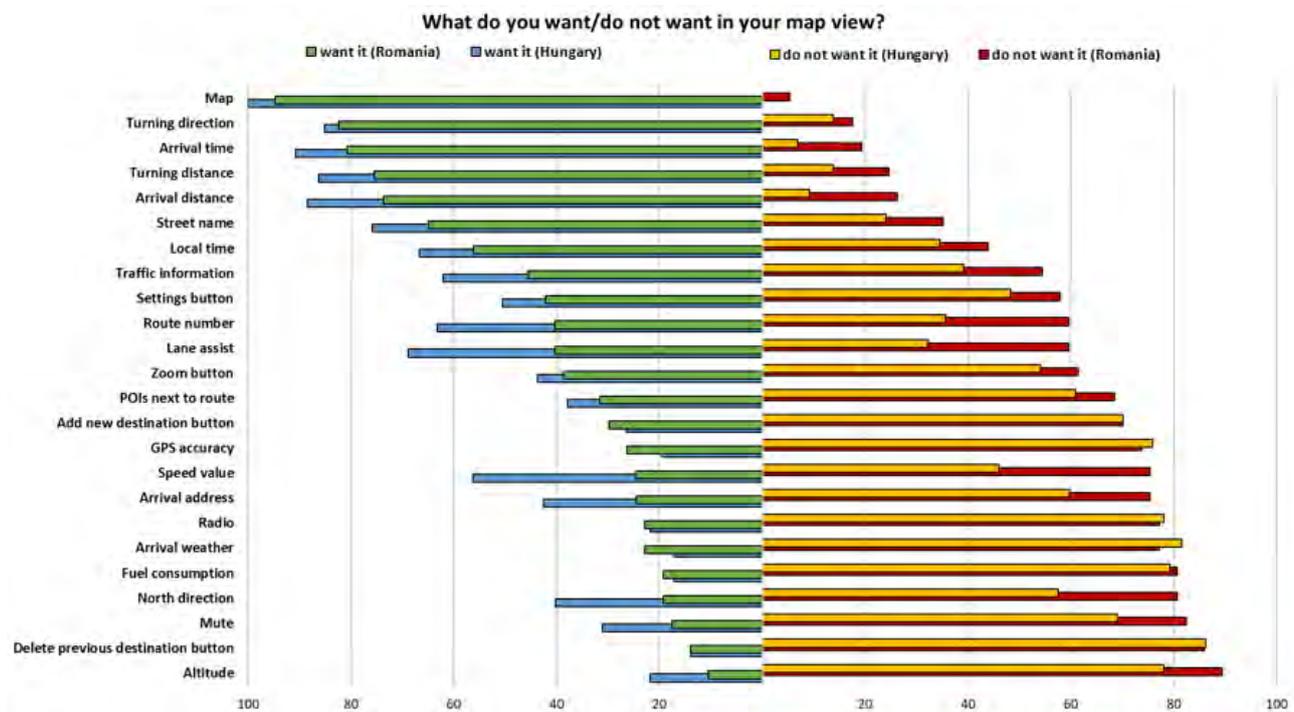


Figure 5. Possible functions in percentage distribution (based on votes)

In the following we demonstrate how each function was presented and according to what criteria – based on Figure 6/a. The general rule is, "the more important, the more it moves to the left" for the built-in GPSs, since the drivers are also on the left, that is, the most important information is closer to them. Since we traditionally start reading from the top left corner, it is advisable to move these functions to the top. (These habits are true for both countries.) During driving, apart from your current position, the next manoeuvre is the most important, which is why the turning distance and turning direction (along with the turning street name) are placed in this special location. The lane assist is presented as a pop-up and – as it is organically linked to the next manoeuvre – it is placed directly below the turning properties. The icon for our current position is located in the bottom-middle, so the driver can look as far off from the screen as possible; the speed of the vehicle and its altitude are related to this. Arrival address, distance and time are all important information, but the driver will only look at it if (s)he has to go on time; this explains why they were put in the bottom-middle. The local time, the radio, the zoom icon and the compass have no particular significance, but they were requested by the fillers; therefore, they were placed in farther locations. Although the mute button has a low proportion, it still occupies a more central position, mainly due to space saving. The other features are all related to the map itself and its content; street names, road numbers, points of interest (POI) along the route and traffic information are now visible to users on their GPS. The main menu and settings buttons are usually not on the display itself, but on the car's centre console, that is its language depends on the vehicle.

## Hungarian interface

NNG Ltd.'s user experience designers assisted us in the professional presentation of the data according to the above-mentioned aspects. In the diagrams below, we highlight features where the current interface (on the left) and the requested interface (on the right) are different. Table 2 compares the four surfaces relative to each other. According to Hungarian fillers, there are currently 19 features on their navigation interface. In contrast, they themselves would require only 15 features: they would like to leave out the altitude, POIs, mute, and radio button. In this case, although less information is displayed on the screen, there is minimal difference at first sight (Figure 6).



Figure 6. Hungarians' current interface on the left (framed in orange) and the requested interface on the right (framed in red), highlighting the features in which they differ (NNG Ltd.)

## Romanian interface

Romanians currently have 20 functions on display. They see GPS accuracy instead of altitude and have an "Add new destination button". For the latter, it is rather surprising that it does not appear on other interfaces, as drivers will prefer to use this button while driving as described in chapter *Subtleties*. In the Romanian recommended interface only 12 functions are located. They do not care about new the destination button, arrival address, GPS accuracy, mute, radio button, north direction, POIs and speed. The difference here is even more significant – not only compared to what Romanians currently see, but also to the needs of the Hungarians.

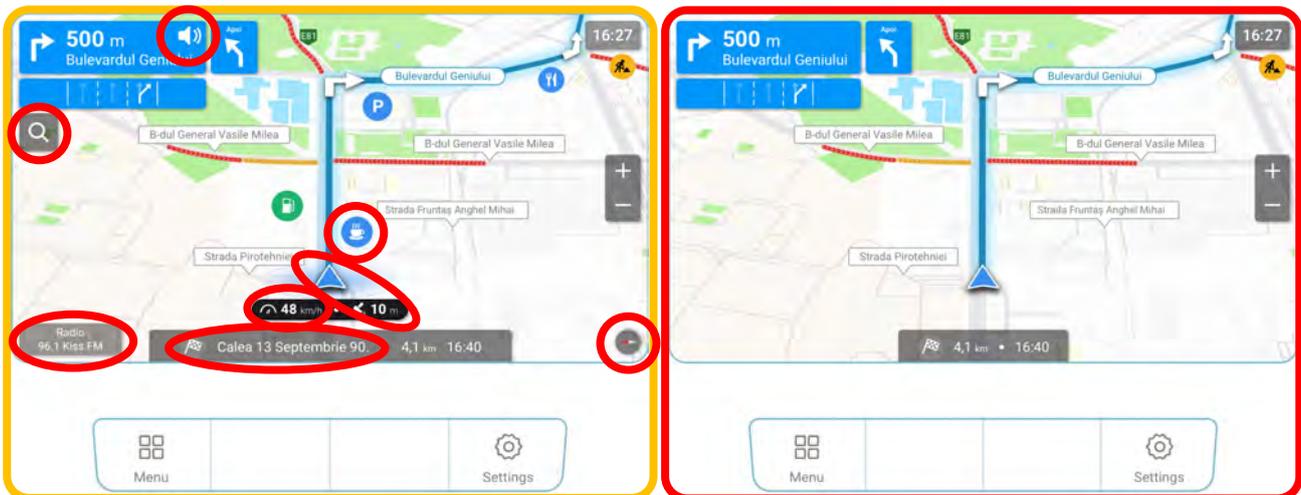


Figure 7. Romanians' current interface on the left (framed in orange) and the requested interface on the right (framed in red), highlighting the features in which they differ (NNG Ltd.)

Table 2. Functions highlighted by fillers, marked on which interface they appear

<b>Function</b>	<b>Current interface - Hungarian -</b>	<b>Recommended interface - Hungarian -</b>	<b>Current interface - Romanian -</b>	<b>Recommended interface - Romanian -</b>
Add new destination button			+	
Altitude	+			
Arrival address	+	+	+	
Arrival distance	+	+	+	+
Arrival time	+	+	+	+
Arrival weather				
Delete previous destination button				
Fuel consumption				
GPS accuracy			+	
Lane assist	+	+	+	+
Local time	+	+	+	+
Map	+	+	+	+
Mute	+		+	
North direction	+	+	+	
POIs next to route	+		+	
Radio	+		+	
Route number	+	+	+	+
Settings button	+	+	+	+
Speed value	+	+	+	
Street name	+	+	+	+
Traffic information	+	+	+	+
Turning direction	+	+	+	+
Turning distance	+	+	+	+
Zoom button	+	+	+	+

## CONCLUSIONS

Based on the results obtained from the comparisons of the two counties we can conclude:

- The results clearly show that the current, most common location of the built-in GPS (centre console) is not at all ideal for drivers. However, since there seems to be no obviously good place (but the navigation interface has to be placed somewhere), the current placement is just as acceptable as any other. In general, users are satisfied with the features of the navigation interface. Since they have never used anything else, the question is whether they do not know if they want other features or they really consider the current one. Nevertheless, if they could set up the device themselves, they would put fewer buttons on it. It can be said that – according to the users – currently the display is (more or less) cluttered.
- As for the two countries, more people have built-in GPS and younger cars in Romania (this is not surprising when comparing the GDP of the two countries). At the same time, more attention and energy is being paid by them to keep the GPS database up to date. For most questions there is no significant difference between the two countries. Their current navigation interface looks the same (fillers remember the same things), but Romanians would be satisfied with far fewer functions than Hungarians.

## ACKNOWLEDGMENTS

FV is supported by the ÚNKP-19-3 New National Excellence Program of the Ministry for Innovation and Technology.

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Béla Kovács, assistant professor at ELTE Eötvös Loránd University, Faculty of Informatics, Department of Cartography and Geoinformatics. He received his PhD degree in 2010, in topic: GNSS and the connection of former triangulation on Balkan Peninsula. Present research and teaching activities: autonomous navigation/driving systems, GNSS, connections between old maps and modern technologies, mobile mapping, multimedia and map visualization, field measurements and data collection, IoT.

# A NEW APPLICATION SCHEME TO ASSIST AUTONOMOUS CARS – THE CARNAV APPLICATION

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## **Abstract**

*Autonomous vehicles are well known today for many reasons. On the one hand, it is a technologically big (and interesting) challenge, on the other hand it raises several legal issues. We focused on a technical thing: we created a theoretical advisory support system which helps driving autonomous cars. This system may be needed if the self-driving car's own database is not up to date for some reason. The software informs the vehicle's control program about the upcoming traffic signs, traffic lights, crosswalks and any static element in the vicinity of the road that may affect the control of the cars. The program is currently running in simulation mode so it has not been tested in a live position (in a vehicle). Nevertheless, the substantive operation, the structure of the database and the operation of the program can be demonstrated.*

**Keywords:** *autonomous car, support system, database, digital map, CarNav*

## **INTRODUCTION**

Proper navigation, accurate information about the vehicle's current position are essential for driving a car. This is solved in the case of a human driver, because the knowledge of traffic rules, signs and the cognitive picture of our surrounding make these possible. Even on an unknown place, we have the help of a car map to build this inner image (KOVÁCS et al. 2019, VÖRÖS et al. 2019). If not, then only the objects of the environment we perceive are available.

An autonomous car is a vehicle what is controlled by digital technology without human intervention and is able to travel in road traffic. It senses the details of its environment, navigates and directs itself based on the perceived objects without harming its surroundings and itself (GUANG et al. 2018). In the case of a driverless car, continuous monitoring and evaluation of the environment simulates the activity of the human driver without its background knowledge. Of

course, this is not only important for navigation, but also because of the ever-changing or unexpected emergencies (Figure 1).



Figure 1. The interior of a driverless car and the road objects detected by the cameras (The Tesla Team 2016)

The environment where cars move is extremely complex – the moving car and the environment has a close connection to each other (CERVERO and KOCKELMAN 1997). Of course, there are also static parts such as traffic signs, traffic lights, intersections, road signs, sidewalks and edges. Some parts of them have no effect on traffic (e.g. signs indicating the proximity of a hotel or a hospital), while others have a fundamental influence on the machine or human driver (pedestrian crossing, compulsory direction, stop sign, etc.). Currently, these objects (traffic lights or signs) are still essential for the vehicle to travel, but they are not expected to be needed when a significant number of self-driving cars are on the road. Instead of these computer programs will communicate with the vehicles directly (BEGG 2014) and/or sends signals – e.g. high quality digital maps (WAGNER et al. 2014). In addition, there are dynamically changing objects in this environment, such as other moving vehicles, irregular or hesitant pedestrians, stray animals or falling objects from trucks, etc.

It would take off a significant burden from the automatic driver if the current position of the car could be compared continuously with a "smart" map - available in the background -, which also contains several important information about the progress. Detecting them on the go requires large resources. Of course, the suddenly changing environment must be perceived (other cars, pedestrians, etc.), but no barely or slow-moving objects, because they are available on the digital map (intersections, signs, traffic lights, etc.).

For example, if we know that we are now on a main road where traffic lights are placed and its end is indicated by a priority sign, it is enough to detect only the way we are going on and where we are. We know in advance - for example - where a priority sign is expected to appear. Digital maps are available (such as Google Maps, Bing Maps, OpenStreetMap), but they also contain a lot of unnecessary objects. At the same time, basic data which are essential for a driverless car are missing (e.g. pedestrian crossing, traffic signs, traffic lights). Therefore, we have created a map data structure that contains all the data needed to control the autonomous car. We have also created an experimental software that stimulates the vehicle's movements and continuously monitors the content of the digital map to demonstrate what objects are located near the current position of the car within an adjustable distance. It sends information to the controller, which in this case only means displaying the expected objects. The following describes the structure of the database and the operating mechanism of the software (PÁL et al. 2019).

## MATERIALS AND METHODS

### Creating the dataset

To create the database, we had to do a survey in a sample area to measure all the objects that could affect (even to the smallest extent) the self-driving car. The sample area was the downtown of Budapest (capital city of Hungary) – there are a lot of traffic signs, lights and other objects that affect traffic, so a lot of traffic situations can be simulated. However, it does not contain data that would appear on a traditional digital map, such as labels, watercourses, green spaces, famous objects (theatres, museums, restaurants, etc.). Since this software is in the pilot phase (which can later be used for educational purposes), the main consideration was that we can create it ourselves and free. Therefore we used the department's RTK-GPS to measure more than 600 above mentioned objects (Figure 2). Because we measured in a densely built-up area, we assumed that the accuracy of the measurement would not be ideal. We tried to choose the measurement time accordingly, but so it was that we measured with an accuracy of ~1 meter. The database avoided not only the coordinates of the points and the "meanings" of the objects, but also the street to which the meaning of the object refers (e.g. signpost).

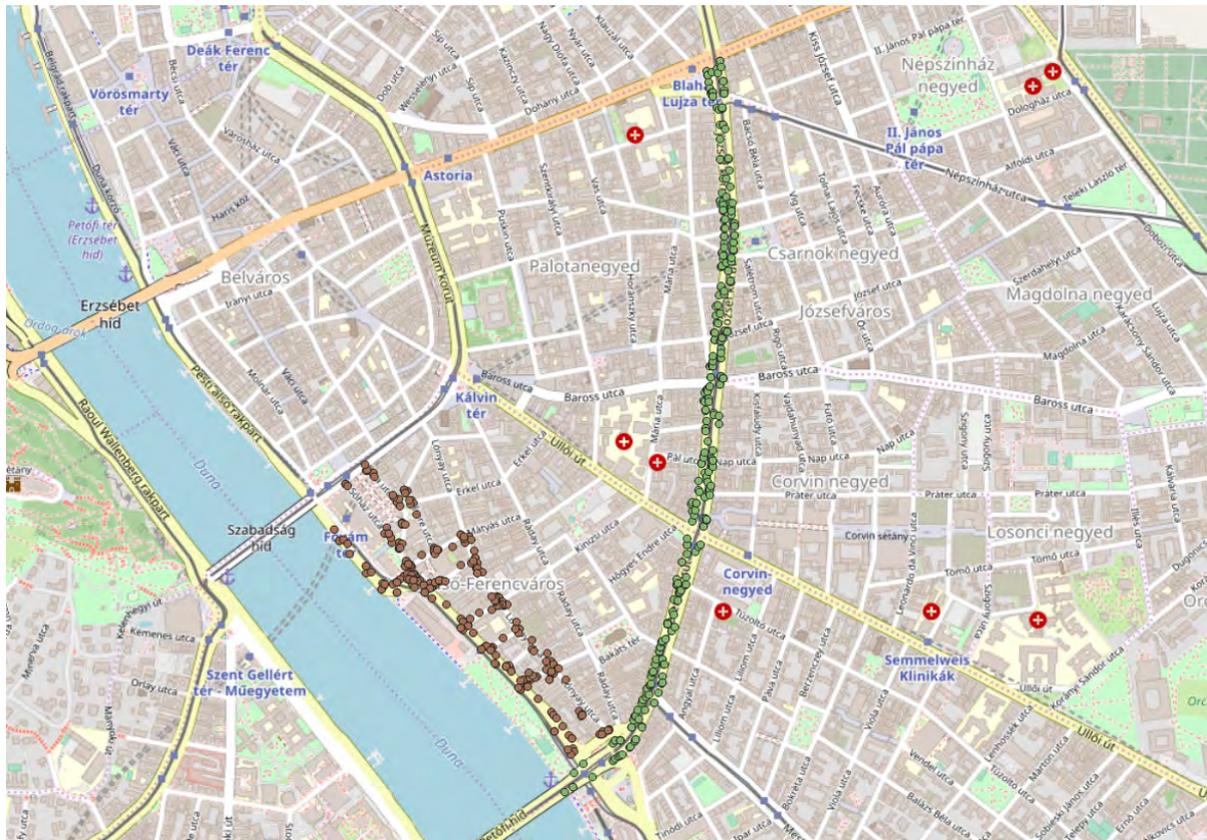


Figure 2. The surveyed ~600 points in the sample area (center of Budapest, Hungary)

### The dataset

Map data and traffic signs data are stored in PostgreSQL 9.6 (+ PostGIS extension) open source database manager, which has extensive spatial functionality. These functions are especially important because the vehicle's position and the exact street will have to be continuously determined during the movement of the car (this phase is currently undeveloped, but the work done so far predicts this goal). It looks obvious at this point, but the position on the map is just a sight. In order to determine the name of the street during the navigation procedure, we need to carry out continuous spatial queries, we need to know which street of our current position is closest to. This is needed because when we come across a traffic sign (which can be achieved by calling spatial functions) we can determine on which street the sign is valid (the one that we are on, or we found only a sign of a crossing street, which may also be important when approaching an intersection).

The required data is stored in five tables: districts (*bpdistrict*), borders of blocks (*bpblocks*), main streets (*bpmainstreets*), streets (*bpstreets*), traffic signs (*traffic\_tables*) and their code table (*traffic\_table\_codes*). We

emphasize that *bpdistrict* and *bpblocks* tables are for demonstration purposes only, so we disregard for their presentation. The basic data for the problem are included in the other tables: *bpmainstreets*, *bpstreets*, *traffic\_tables* and *traffic\_table\_codes*. The fields and contents of these tables are shown below.

### Main streets of Budapest

In the *bpmainstreets* table (Table 1) we only store the track of the streets (a simple graph), not the complete geometry (e.g. road width). However, we store the street names (street field, string type) that the car controller needs to determine on which street we are driving. When it detects in motion that there are one or more traffic signs nearby, it must be able to decide which sign applies to us, and which one to the crossing roads.

Table 1. Example of the data table containing main streets (*bpmainstreets*)

	gid	layer	street	geom
	[PK] integer	character varying (17)	character varying (31)	geometry
1	1	mainstreets	route 11	01050002...
2	2	mainstreets	route 11	01050002...
3	3	mainstreets	route 11	01050002...
4	4	mainstreets	Árpád bridge	01050002...
5	5	mainstreets	Árpád bridge	01050002...
6	6	mainstreets	Árpád street	01050002...
7	7	mainstreets	Árpád street	01050002...

### Streets of Budapest

In the *bpstreets* table (Table 2) we also store only the track of all the streets available and accessible for cars without exact geometrical parameters. We should store the names of the streets to help the autonomous car to determine on which street we are going. Creating a database of this size - uploading the entire street network of Budapest with real data - is far beyond the possibilities of a research and development project. Only large companies specialized in data upload can do this task. Of course, there are such products on the market, thus, if actual product development had been done, these databases could have been purchased or created.

Table 2. Example of the data table containing streets (*bpstreets*)

	gid	layer	geom
	[PK] integer	character varying (17)	geometry
1	1	mainstreets	01050002...
2	2	mainstreets	01050002...
3	3	mainstreets	01050002...
4	4	mainstreets	01050002...
5	5	mainstreets	01050002...
6	6	mainstreets	01050002...
7	7	mainstreets	01050002...

### Traffic signs of Budapest

In the *traffic\_tables* table (Table 3) the first column contains the primary key (*gid*). In the *geometry* field called *geom* contains the location of the RTK-measured traffic signs. During the survey X, Y coordinates were measured but the PostgreSQL converts the two values to binary. The *code* points to a code table (*traffic\_table\_codes*) that lists the table types with their code and text description.

Table 3. Example of the data table containing traffic signs (point objects)

	<b>gid</b>	<b>geom</b>	<b>code</b>
	[PK] integer	geometry	integer
1	1	0101000020945...	1
2	3	0101000020945...	1
3	5	0101000020945...	1
4	6	0101000020945...	1
5	8	0101000020945...	2
6	10	0101000020945...	2
7	11	0101000020945...	1

Table 4. Example of database containing traffic signs (*traffic\_table\_codes*)

	<b>name</b>	<b>code</b>
	character varying	[PK] bigint
1	Priority mandatory	1
2	Stop! Priority mandatory	2
3	No thoroughfare!	3
4	No-entry by vehicle	4
5	No-entry by motorcycle	5
6	No-entry by bus	6
7	No-entry by lorry	7
8	No-entry by bike	8
9	No-entry	9

The *traffic\_table\_codes* table (Table 4) lists the possible traffic control signs with their code (*code*, primary key) and text description (*name*, string field).

## RESULTS

Schematic operation of the system: the program called *CarNav* is a C# application that uses Postgres/PostGIS database manager. Its purpose is to track the car's movement, to detect its current position, and to determine which way the car is going. It performs spatial queries continuously while moving to find nearby traffic signs and other static elements. These spatial queries led us to choose Postgres/PostGIS because its spatial functionalities are well-designed, reliable and fast.

An important feature of the software is the determination of the user's current location with the help of a GPS. In the development phase we use a hobby device that is connected with the testing computer with a serial-USB cable. This is due to maintain the stability of the connection. The CarNav translates the binary NMEA data (National Marine Electronics Association). These contain important information about the physical state of the satellites, but we only need the simple lat/lon coordinates. By performing queries to continuously monitor our position, we are ready to take the software into real traffic.

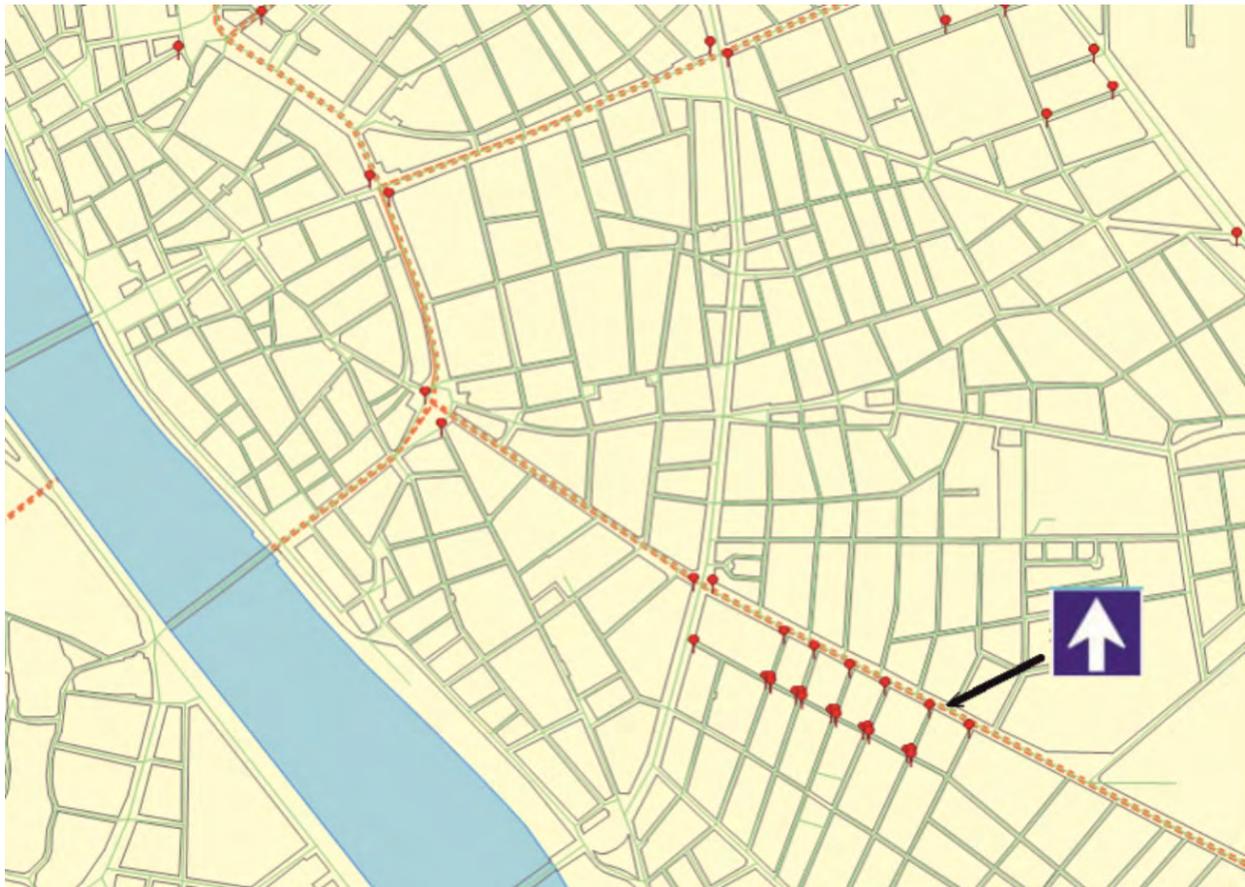
The program is currently running in simulation mode: there is no built-in computer - that the program could run on - in a car, however, substantive operation can be demonstrated. Consider the following: if the car's position (X, Y coordinate) changes, then the *Coordinate\_Changed* event will take place. There are two processes built into its event handler. One determines which road is closest to the car's position. Then we call the *selectNearestStreet* method to execute the following spatial SQL command:

```
SELECT street, ST_Distance(ST_GeomFromText('POINT(X Y)', 23700), geom) AS  
distance  
FROM bpmainstreets ORDER BY 2 ASC LIMIT 1
```

This command will give us a street name that is closest to our X, Y position. Then we need to collect traffic signs located within a predetermined distance (*searchRadius*) that contains for which street they are valid to (that is why we had to call *selectNearestStreet*). Then we call the *LookforNearPoints* procedure, which executes the following SQL command:

```
SELECT gid, traffic_table_codes.name, traffic_tables.code  
FROM traffic_tables, traffic_table_codes  
WHERE st_dwithin(traffic_tables.geom, st_setsrid(st_point(coord.X, coord.Y),  
23700), searchRadius)  
AND traffic_table_codes.code = traffic_tables.code  
ORDER BY  
ST_Distance(traffic_tables.geom, st_setsrid(st_point(coord.X, coord.Y), 23700))
```

In both SQL commands, the 23700 is the EOVS system's EPSG code in the *spatial\_ref\_sys* table of PostGIS. Figure 3 shows the *CarNav* system during operation, when it finds and shows a one-way street sign.



*Figure 3. The small dots indicate the position of some traffic signs.  
The one-way street sign has just been found with the spatial query.*

## CONCLUSION

The main goal of the research is to achieve safer autonomous driving conditions: the upgradeable map GIS database in the car's memory is an additional tool that contributes to lower threat to human life. Depending on our vehicle's current position, *CarNav* does the following: continuously determine on which route we are going. This is a result of the following spatial query: the nearest street to our current position collects traffic signs around the car (e.g. 30- or 50-meters buffer zone). The attribute data of the traffic signs also include the street name that it refers to, so we can choose a sign from the dataset that applies to the road where we are, and which belongs to the correct crossroad. This is important at any intersections (priority to the right). The future maintenance of this data system is also in our hands: human work can be replaced by point cloud analysis and later by upgrading self-driving cars to be able to collect data.

## ACKNOWLEDGEMENT

EFOP-3.6.3-VEKOP-16-2017-00001: Talent Management in Autonomous Vehicle Control Technologies – The Project is supported by the Hungarian Government and co-financed by the European Social Fund.

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## **BIOGRAPHY**

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Márton Pál received his MSc degree on cartography at Eötvös Loránd Univeristy, Budapest, Hungary. His PhD research is about geotourism mapping and evaluation systems, but also participates in projects concerning experimental cartography and cartographic aspects of autonomous driving. Spatial databases, webcartography and smartphone application development also belong to his interest.

István Elek is a habil. associate professor at the Eötvös Loránd Univeristy, Faculty of Informatics, Dept. of Cartography and Geoinformatics. His research topics are the topological database structures, evolutionary computing and the navigation problem for autonomous vehicles.

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# ESSENTIAL TRAFFIC ELEMENT ATTRIBUTES FOR NAVIGATIONAL DATABASES OF AUTONOMOUS CARS

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## **Abstract**

*There is a struggle nowadays to make traffic less dependent on people. Numerous traffic situations and elements highlight the importance of a background navigational database in the memory of autonomous cars to reach higher safety. The autonomous car needs the same amount of information as a human driver. The background software ought to work synchronously with the sensors of the car as the meaning of a sensor-perceived element is the same as an element in the database. The real-time perception of the vehicle can provide information about the spatial validity of each traffic sign. That's why there is a need for distinctive attributes for each sign. These help to decide in junctions, on roads with multiple lanes, overpasses, and in other risky situations whether the sign is relevant to us or not. This theory is built in the 'CarNav' C# software that applies real-time GPS connection and the prepared database.*

**Keywords:** *autonomous vehicles, autonomy, spatial database, traffic attributes*

## **INTRODUCTION – BRIEFLY ABOUT AUTONOMOUS DRIVING**

Perhaps the most important invention of the 19-20<sup>th</sup> century is the automobile. Citizens throughout the world use vehicles daily for different purposes (Thrun 2010). The first plans of self-driving cars emerged early, nearly parallel with the start of car manufacturing. An autonomous vehicle is able to perceive the objects in its surroundings. It is achieved with the help of different sensors: long, short and medium-range radars, LiDARs, cameras, ultrasound devices and GNSS technologies (*Figure 1*). Using this perceived data, the vehicle can navigate individually without human intervention, as well as identifying obstacles and different traffic elements (Silverio 2019, Guang et al. 2018).

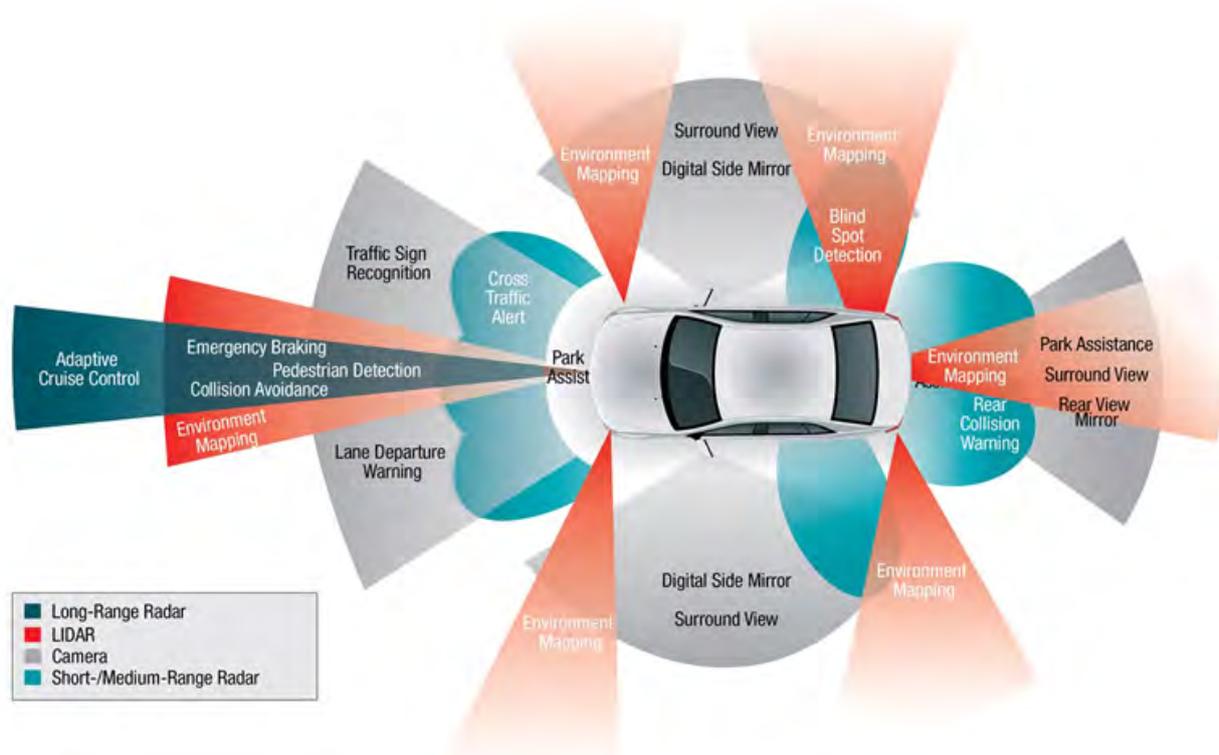


Figure 1. Essential elements perceiving the environment of an autonomous car (Wendt and Cook 2018)

However, the reliability of this identification is an important matter. The human driver can easily process even the large number of elements thanks to the experience and knowledge on rules. The perceiving process of an autonomous car can be easily harmed by outer effects: a large tree or a tall vehicle hides the important traffic sign, the sign is broken or just stolen. In these cases, the perception-based sensors lose inevitable information and may cause risky situations. Our preceding studies propose a suggestion for these situations (Pál et al. 2019, Elek et al. 2019).

## WHAT IS CARNAV AND WHAT IS ITS CONCEPT?

Although autonomous transport and driving can be more easily used in large, open areas (e.g. countryside motorways and highways) large cities and densely built-in areas lack the solution of creating safe conditions for autonomous driving. We proposed a passive background cartographic database (DB). This is a relational DB that has tables with traffic signs, a street map of Budapest and GPS measured data. A Postgres/PostGIS database was created from these tables (Elek 2011).

The CarNav is a C# application that uses this spatial database to help the automated vehicle in navigation. Our hypothesis that a live digital map in the background memory of the self-driving car can enhance safer transport. The environment where cars, other vehicles and pedestrians move is very complex, and its elements are continuously in a relation with each other. These relations and events are processed by the human driver in normal circumstances, but autonomous cars have their sensors to do it. The dynamic and static traffic conditions are highly depended on the density of built-in areas and these mean a struggle for automated driving as the number of objects to be perceived is increased. The detected elements and situations are communicated to the main computer of the vehicle that handles it and modifies its route according to them. But there might be some extraordinary situations – especially in the aforementioned highly built-in territories where GPS signals are quite unreliable sometimes – when the car simply does not detect something, or it is unable to handle the information. Risky situations for automated vehicles are related to this missing of action: e.g. in case of suddenly appearing pedestrians, missing traffic signs and unidentifiable objects.

The digital map of CarNav tries to help self-driving cars in these situations by using a dataset of traffic signs in its spatial tables. The chosen sample area of the database is the inner city of Budapest, Hungary in order to simulate the density and difficult traffic situations. The traffic signs were located and measured by an RTK-GPS device that basically ensures a few centimetres accuracy. More than 600 elements were recorded this way (Figure 2). This dataset was connected with the newly produced vector street map of Budapest. The C# application is connected with a GPS

device, and shows the current position of a car on the map. When we approach an element of the database (e.g. a stop sign), the software sends a warning to the car's main computer.

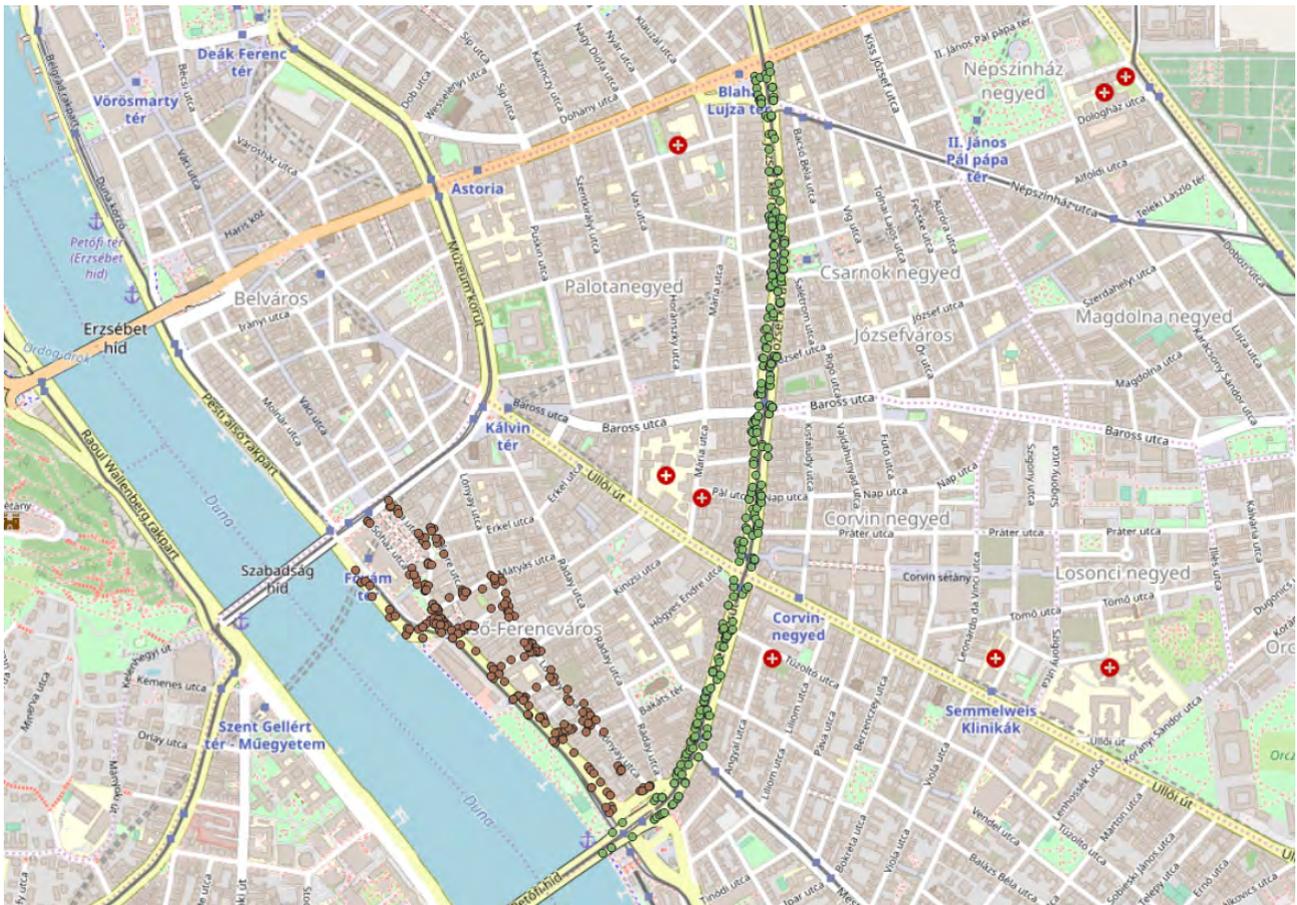


Figure 2. The sample area with the measured database elements (on an OpenStreetMap background).

This warning is redundant in most of the times, because the sensors of the car may perceive a large percentage of traffic elements. But the aforementioned risky situations may lead the car to miss or misinterpret some elements. In this case, redundancy can be lifesaver as the CarNav warns the car with the data from its background spatial DB. The reliability of the software is highly depended on the accuracy of the GPS measurements and the age (last update) of the database.

## TRAFFIC ELEMENTS AND ATTRIBUTES OF THE NAVIGATIONAL DATABASE

The Postgres spatial database of CarNav is consisted of six tables: *bpblocks*, *bpdistrict*, *bpmainstreets*, *bpstreets*, *traffic\_table* and *traffic\_table\_codes*. The *bpblocks* contains the built-in areas and the *bpdistricts* is consisted of the district boundaries of Budapest. Table *bpmainstreets* are the main routes and important roads highlighted in the city, while *bpstreets* is made up by all streets that are accessible by car.

The elements of *bpstreets*, *traffic\_table* and *traffic\_table\_codes* have the highest importance during (autonomous) driving as they contain essential cartographic data.

### Table *bpstreets*

This table was edited for all Budapest area. It is a line graph of Budapest's streets. The base for gathering and producing this enormous dataset was OpenStreetMap (OSM), where many vector street features can be found and downloaded. The OSM street map was then repaired and extended with the help of Google Maps and satellite images. As the database is made only for autonomous vehicles, only elements that are accessible by car were recorded.

The geometry of *bpstreets* is stored in an SHP file (Figure 3). This file was connected then to the Postgres database as a table. Every feature of this layer is considered as a potential place for car traffic. As our position is essential for the determination of an approaching traffic sign, there are two attributes that are recorded in this table. Attribute *name*

contains the name of the streets. It is connected to the *traffic\_tables* spatial table as every traffic sign is valid only on the certain road that we are driving on. If the live GPS connection of CarNav shows that we are on e.g. József Attila street, only the traffic signs relevant to this street appear as a ‘warning’ for the car. Attribute *one\_way* indicates if a street is only available for one-way traffic. This is important because of the various location of traffic signs on these streets: the start of a one-way street is always marked by a sign, and the end is marked by another sign that prohibits the car from advancing. Every other traffic element on these streets are valid only for the entry direction.



Figure 3. Elements of table *bpstreets* (red) and *bpdistricts* (green)

### **Table *traffic\_tables***

This table includes every measured traffic element on the sample area (inner city of Budapest, *Figure 2*). This table stores the geometry of each point feature, the street that the sign is valid on (connected with table *bpstreets*) and the code of the traffic sign (connected with table *traffic\_table\_codes*). These attributes ensure that one sign is only valid for only one street – practically for the street on which the car drives.

During the RTK measurements we struggled to reach the highest accuracy as possible. The southern sides of the roads in the sample area produced less precise measurements because the sky was hidden by tall buildings. Eventually the error limit did not exceed 1 meter anywhere. This is enough for the vehicle, because there is a buffer zone around every measured traffic elements in which the warning is available for the main software of the car. We have tried to acquire free data (e.g. point clouds, databases of road maintenance companies) to provide the dataset for all Budapest, but unfortunately, we did not succeed.

### **Table *traffic\_table\_codes***

This table does not have any geometry. It has a primary key that is connected to table *traffic\_tables*. The other attribute is the name of the measured traffic element. There are 32 types of elements (mainly signs) recorded in the database (*Figure 4, Table 1*).



Figure 4. The traffic sign types that were recorded in the database. Their names can be found in Table 1

Table 1. The recorded types of traffic signs

ID	Name	ID	Name	ID	Name
0	Cyclists prohibited	15	Driving faster is prohibited	30	Begin of a speed limit zone
1	Warning for a danger	16	Disabled parking site	31	Multi-lane road
2	Multi-lane road with bus lane	17	Settlement information sign	32	End of a speed limit zone
3	Mandatory direction	18	Turning left prohibited	33	Uncontrolled crossroad warning
4	Begin of a parking zone	19	Parking house	34	Stop and give way to all drivers
5	Parking prohibited	20	Road with one-way traffic	35	Warning for a curve to the right
6	Entry prohibited	21	End of the priority road	36	Warning for a bad road surface
7	Give way to all drivers	22	Entry prohibited	37	Parking is allowed
8	Bus stop	23	Begin of weight limit zone		
9	Taxi stop	24	End of weight limit zone		
10	Warning for a road narrowing	25	Pedestrian crossing		
11	Warning for roadworks	26	End of pedestrian path		
12	Parking and stopping prohibited	27	Warning for a traffic light		
13	Traffic light	28	Mandatory direction for buses		
14	Begin of a priority road	29	Buses prohibited		

The CarNav software shows the real-time position of the car in the vector map and makes the warning possible using icons. The search radius is pre-set for 30 metres, as cars in the left side of a multi-lane road also need the sign information on the right side of the road. When we reach this search radius during driving, an icon of the referenced traffic sign appears in the upper right corner of the software window. This simulates the warning of CarNav.

## CONCLUSIONS

Our CarNav software is one of the projects and research topics about increasing the safe driving with cars operating without human intervention. We tried to propose a cartographic-GIS solution for the unreliability of autonomy in densely built-in areas.

The chosen sample area and the recorded traffic elements shows the diversity that an autonomous vehicle has to struggle with. We suppose that a passive background cartographic database can produce mostly redundant data that is able to save lives in risky situations. We tried to build up a multi-table database that focuses on traffic situations that can affect the transport of a self-driving car.

We hope that our presumptions and solution proposals reach the big manufacturing companies who have the capability of producing traffic element databases with less effort by the use of different sensors throughout the cities. It is very important, that tables consisting traffic elements have to be refreshed regularly, as many signs are valid only for a short period of time – e.g. road construction. The developing technology of autonomy and the communication between self-driving cars may lead to the semi-automated update of these databases – beyond inevitable human check.

## ACKNOWLEDGEMENT

EFOP-3.6.3-VEKOP-16-2017-00001: Talent Management in Autonomous Vehicle Control Technologies – The Project is supported by the Hungarian Government and co-financed by the European Social Fund.

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# TRAFFIC MODELLING FOR THE SMART CITY OF PILSEN

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## Abstract

*The contribution describes Traffic Modeller ([www.trafficmodeller.com](http://www.trafficmodeller.com)) - a web map application for monitoring, analysis and prediction of traffic in a metropolitan area. The technical solution of Traffic Modeller is provided. This includes the mandatory and optional input data sources (such as road network, socioeconomic data describing behavior related to transport, real traffic measurements), the algorithms processing the measurements and traffic flow modelling algorithms. As an output of Traffic Modeller, various interactive maps portraying historical, current and predicted traffic data can be obtained. The paper includes the development and deployment of Traffic Modeller application for the smart city of Pilsen.*

*Traffic Modeller outputs can play a crucial role in city policy-making. The resulting maps allow city planners to study the traffic behaviour while modelling various road network parameters (e.g. road closures, road capacity) and explore the effects of the changes in traffic flows in near real-time. The second part of the contribution describes typical use cases which can help policymakers in making smart, data-based and informed decisions.*

**Keywords:** traffic modelling, Traffic Modeller, TraMod, dynamic map, web map, policy-making

## 1. INTRODUCTION

The objective of this paper is to present a software solution for responsive traffic modelling - Traffic Modeller. Traffic Modeller (<https://trafficmodeller.com/>) is an open-source, client-server based solution, which is being developed at the Department of Geomatics of the University of West Bohemia (<http://geomatics.zcu.cz/>) in close cooperation with SME's EDIP (<http://www.edip.cz/>) and HSRS (<http://www.bnhelp.cz/>) and the Plan4all association (<https://www.plan4all.eu/about/>). The development of Traffic Modeller is driven by a close collaboration with the City of Pilsen; namely it's Department of Information Technology Administration (<https://www.sitmp.cz/>).

The key functionalities of Traffic Modeller include:

- Calculation of traffic volumes in a transport network in near real-time (depending on the size of the road network and server capacity calculation the time may vary from seconds to minutes).
- Implementation of three algorithms for the traffic assignment providing optimal calculation schema for every use case.
- Calculation a what-if analysis with user-defined scenarios which may include:
  - edit of road free-flow speed;
  - edit of road capacity, e.g. road/lane closure;
  - edit of road segment geometry, e.g. change of intersection layout;
  - addition of a new road segment, e.g. construction of a new city ring road.

The way how Traffic Modeller provides the introduced functionalities is explained further in this paper. The paper is structured as follows. Chapter State of the art describes the existing contemporary solutions and how they differ from Traffic Modeller. Chapter *Fundamentals of Traffic Modeller* includes input data, mathematical principles and algorithms used. In addition to that the way how Traffic Modeller tackles the cartographic visualization challenge is explained. The deployment of Traffic Modeller in the City of Pilsen is then described in the following chapter. The paper is concluded by the pros and cons of the designed and developed solutions, lessons learned, and the plan for future research & development.

## 2. STATE OF THE ART

This chapter describes the current state of knowledge, novelty and research uncertainty. First of all, the leader existing commercial solutions for traffic modelling are as follows:

- the PTV company offers a whole platform for transport and traffic modelling (<https://www.ptvgroup.com/en/solutions/products/>) including:
  - Visum for macro-modelling of traffic,
  - Vissim for microscopic and mesoscopic traffic simulation, and
  - Optima for combination of offline traffic modelling with real-time data,The PTV solutions are based on the Component Object Model.
- macro-modelling toolbox OmniTRANS (<https://www.dat.nl/en/solutions/transport-modelling-omnitrans>)
- Transport and land use modelling software Cube (<https://www.citilabs.com/software/cube/>) covering all aspects related to transport planning, engineering, and land use.
- Aimsun (<https://www.aimsun.com/>) mobility modelling software to analyse traffic from a single intersection to an entire region.
- EMME (<https://www.inrosoft.com/en/products/emme/>) transport forecasting system for planning the movement of people.

There exist other software solutions which are less common in Europe.

Traffic Modeller provides an open-source alternative to these commercial solutions for macro-modelling of traffic. Traffic Modeller is not the only alternative. There are other research teams focusing on the scientific aspects of traffic modelling all over the world. Here follows a list of the most relevant research activities:

- DYNAMIT 2.0: a real-time model system for network management and emergency response designed by a team from MIT (<http://its.mit.edu/dynamit>) with focus on dynamic traffic models, see details in [Lu et al., 2015].
- Imperial College London design and develop Matlab toolbox for Computing of Dynamic User Equilibria (DUE) on Large-Scale Networks, see [Han et al., 2018].
- SUMO is an open source, highly portable, microscopic and continuous traffic simulation package designed to handle large road networks. It is mainly developed by the Institute of Transportation Systems at the German Aerospace Center (<http://sumo.sourceforge.net/>). The SUMO development seems to have been discontinued since 2012, see details in [Behrisch, 2011], [Krajzewicz, 2012].
- Multi-Agent Transport Simulation (MATSim, <https://www.matsim.org/>) is being developed at ETH Zurich (<https://www.ivt.ethz.ch/en/research/matsim.html>). MATSim offers a framework for demand-modelling, agent-based mobility-simulation (traffic flow simulation), re-planning, a controller to iteratively run simulations as well as methods to analyse the output generated by the modules. Details in [Horni et al., 2016].
- Transport & Mobility Leuven NV (TML, <https://www.tmleuven.be/en/>) conducts applied research to support policy decisions. Their research is focused on traffic, passenger and freight transport and the related economic impact and environmental problems. The team works on both macroscopic and microscopic traffic models.
- The Rodos project at IT4Innovations center (<http://www.it4i-rodos.cz/>) focuses primarily on online monitoring of traffic flow data and traffic management.

Although the research teams usually openly offer their results, a practical use of the results vary. The authors of Traffic Modeller (<https://trafficmodeller.com/>) believe that in comparison to the above mentioned projects, the advantage of Traffic Modeller lies in offering the following features:

- open code coming from the latest scientific research used for designing and development of the server calculations,
- advanced graphical user interface (GUI) in frontend developed according to carefully designed workflows in close cooperation with the mentioned commercial partners,
- thorough testing of the set of backend and frontend modules by the pilot user - the City of Pilsen.

The cooperation of the university research team with commercial partners and the City of Pilsen is supported by various EU and Czech research programmes. The research team started to work on this research topic in the EU CIP project OpenTransportNet in 2014 and is currently funded by two H2020 projects (PoliVisu and DUET) and a project of the Technology Agency of the Czech Republic (TRAFFO). See acknowledgment section for details.

## 3. FUNDAMENTALS OF TRAFFIC MODELLER

Traffic Modeller uses a traffic model to simulate traffic flows. A traffic model is understood as a mathematical model of real-world traffic which determines the volume of traffic (number of vehicles) on sections of the road network (in the model represented by a directed graph).

This chapter describes the fundamental building blocks of Traffic Modeller - blocks which are needed to build the traffic model and use it for simulations: computation of traffic flows. This includes the input data, explanation of computational principles, the traffic model itself, computation algorithms used and a description of outputs.

### 3.1. Input data

Similarly to any other modelling software, Traffic Modeller requires a certain type of input data. Input data can vary in detail and accuracy which later influences the reliability of the output. In this chapter, we will describe what are the mandatory input data, which data are obligatory, and how the accuracy of each data type influences the model computation. Please note that this article can not encompass all data model information. In order to examine all required attributes please see the database schema (<https://gitlab.com/kolovsky/traffic-modeler-rest/-/blob/master/database/schema.sql>).

Any traffic modelling requires two inputs:

- *Road network*. Well defined and topologically correct road network is the fundamental constraining graph structure, which describes the allowed movements within a modelled area of interest. Any topological discontinuity between road segments will result in an inaccurate model since there will be no car flow possible across that network node. Apart from the topology it is also crucial that traffic parameters of the road network reflect the real-world behaviour. Quite often the free-flow speed is confused with the speed limit which may result in unrealistic demand on such a road segment. The traffic capacities of each road segment are also crucial because it is an important part of the cost function and determines its shape. Road capacity in a city may be hard to estimate since the bottleneck of city traffic are usually crossroads and not the straight road segments themselves. However, inaccurately set segment capacity can easily result in a model where all cars are driving through a small suburban street with speed bumps or traffic lights while highways are left with no demand. With Traffic Modeller it is also possible to take special turn restrictions into account (using the so-called *turntable* described in the reference schema).
- *Traffic generators* represent the supply and demand of car trips in the previously described road network. Traffic generators are not required to have an explicit spatial component but have to be connected to one of the network nodes via a foreign key in the database. You can imagine the traffic generators as a parking lot next to an office building and the node as a driveway from the parking lot. The number of car trips (during peak hour) may come from different demographic sources and should reflect various local parameters such as a number of residents, number of schools and accessibility of public transport.. Each traffic generator may represent a city district, building block, or a single driveway – depending on the granularity of the data and the desired level of detail. With more granular traffic generators there is a trade-off with computation time.

The road network and traffic generators are the core parts of building a high quality traffic model. However, real behavior of traffic is immensely complex and it is therefore advised to enrich these minimal input requirements and use also other possibly optional data types (see [Ortuzar and Luis, 2011] for details):

- *The Origin-destination matrix* (OD matrix) consists of cells representing the number of car trips from the origin (row) to the destination (column). This shows the distribution of the aforementioned supply and domain of traffic generators across the network. If the attributes provided for traffic generators and calibration measurements are precise, the OD matrix can be estimated - however, not in real-time (usually several days are needed).
- If the OD matrix has already been calibrated then there is no need for additional *calibration measurements*. But in any other case, a calibration process should take place. The calibration process uses *calibration measurements* of traffic volumes to confront and adjust the calculated traffic model (see chapters below) to observed reality. Traffic measurements (also called traffic census) are usually acquired at neuralgic points of the traffic network. The data for such a traffic census can be gathered by various sources (ANPR cameras, road built-in sensors, manual census, ...). No matter the source, calibration measurements need further post processing steps to clean observational or systematic errors, to aggregate or harmonize observations to the same granularity and to provide statistical assessment.

### 3.2. Principle of computation

As it was already mentioned, the model consists of:

1. *road network* (sections of roads are represented by edges and intersections by nodes of a directed graph),
2. *traffic districts* (zones) - a defined part of the land bounded by a polygon and represented by a centroid.

The calculation of the model consists of 4 steps (see Fig. 1):

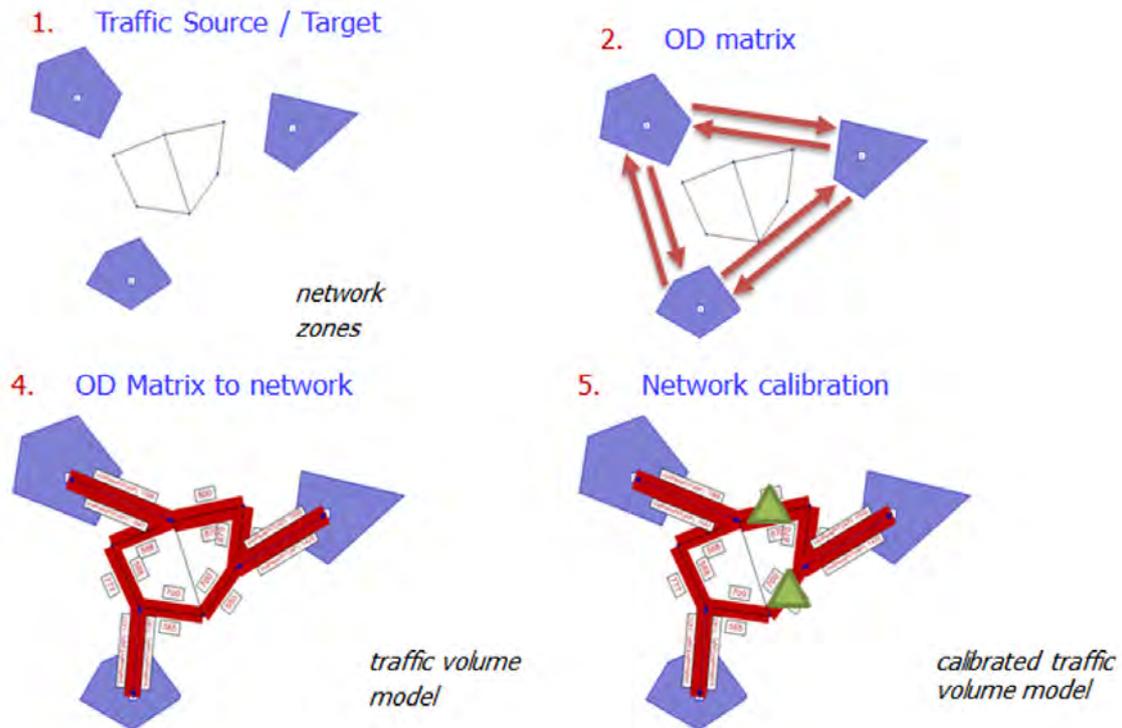


Figure 1. For steps of traffic model calculation

1. Definition of the *road network* (directed graph), traffic zones, and their centroids. Each zone has specified parameters characterizing the volume of traffic it produces.
2. Calculation *Origin Destination matrix* (OD matrix) representing the volume of traffic (number of trips) between zones. Based on the parameters of the zones and the matrix of their distances, the OD matrix is calculated (there are various calculation methods, for example the gravity model).
3. In multimodal models, the matrix is now divided according to the mode of travel (individual, public transport, bicycle, ...)
4. Assigning the *OD matrix* to the *road network* - the algorithm searches for the most convenient path over the network for each centroid relationship (more details below). The output is the traffic volume on each section of the road network.
5. The last step is to *calibrate* the model - like any mathematical model, the traffic model must be calibrated. This is a comparison of the calculated traffic volume on selected segments of the road network and the real traffic volumes (determined by the traffic survey). Both the parts of the model - road network and the OD matrix are calibrated.

### 3.3. Model of traffic volumes on the road network and algorithms used

A traffic model consists of two crucial sub-models: model of trip distribution and a model of traffic assignment.

Let  $G = (V, E)$  is a directed graph, where  $V$  is a set of nodes and  $E$  is a set of edges. The set  $Z$  is the set of zones. The pair of zones  $(i, j)$  is called origin-destination (OD) pair and the set of OD pairs is  $W = Z \times Z$ . The paths between the zones create set  $P$ .

#### *Trip distribution model*

The classical gravity model is used as the trip distribution model. The distribution model estimates the number of trips between the zone  $i$  and the zone  $j$  than the number of trips is

$$Q_{ij} = O_i D_j A_i B_j f_{ij}$$

subject to

$$\sum_j Q_{ij} = O_i$$

$$\sum_i Q_{ij} = D_j$$

where  $O_i$  represents the number of trips origins in the zone  $i \in Z$ ,  $D_j$  is the number of trips ends in the zone  $j \in Z$  and the coefficients  $A_i$  and  $B_j$  are the balancing factors that are determined during the iterative proportional fitting procedure. The most important part of the equation of distribution equation is the deterrence function  $f_{ij}(c_{ij})$  where  $c_{ij}$  is the cost (travel time) between the zones. The shapes of the deterrence function are described in [Ortuzar and Luis, 2011].

#### *Traffic assignment model*

The classical traffic assignment model (traffic assignment problem - TAP) is used. Let the cost  $c_e$  of the edge is dependent on traffic flow  $x_e$

$$c_e = c_e(x_e)$$

where  $c_e(x)$  is a cost function. The definition of the TAP is based on the first Wardrop's principle. This principle says: For all used paths from the source node to the destination node the travel time must be equal and this travel time must be minimal [Wardrop, 1952]. All pairs must meet with this condition.

Mathematically, the TAP can be defined as variational inequality (VI) as [Smith, 1979], [Dafermos, 1980]

$$\sum_{p \in P} c_p(x_p^*)(x_p - x_p^*) \geq 0, \forall x \in \Lambda$$

where  $x = (x_p: p \in P)$  and  $\Lambda$  is the set of feasible flows

$$\Lambda = \{x > 0: \sum_{p \in P} x_p = Q_{ij} \forall (i, j) \in W\}$$

where  $Q_{ij}$  is one cell of ODM related to  $(i, j) \in W$ .

The future research will be focused on dynamic traffic assignment. The dynamic traffic assignment consists of two submodels: Dynamic User Equilibrium (DUE) and Dynamic Network Loading (DNL). Some variant of the Link Transmission model (LTM) will be used as DNL because it takes into account the queues and spillback (e.g.,

[Yperman, 2007], [Raadsen et al., 2016], [Himpe et al., 2016]). As DUE, the destination-based route-choice DUE will be used.

### ***Algorithms for TAP solution***

There are a lot of algorithms for a TAP solution. The algorithms can be split into three categories:

- Link-based algorithms. This category is represented by the Frank-Wolfe algorithm [Frank and Wolfe, 1956] and their modifications.
- Path-based algorithms. These algorithms are faster than link-based but they are memory demanding.
- Bush-based algorithms. The youngest category. These algorithms are the fastest.

Traffic Modeller implements the path-based algorithm by [Jayakrishnan et al., 1994] and bush-based B algorithm by [Dial, 2006] with some improvement by [Nie, 2010]. The implementation of the B algorithm is fully parallelized by [Potužák and Kolovský, 2020].

The B algorithm uses the decomposition of the problem to bushes. The bush is the acyclic subgraph of  $G$  related to origin zone. The bush contains only flow from the origin zone to all other destination zones. Each bush is equilibrated by shifting the flow from the minimal path to the maximal path. The minimal and maximal paths are found by topological order in the acyclic bush.

### ***Algorithm for ODM calibration***

The method by [Spiess, 1990] with some adjustments is implemented by Traffic Modeller. This method uses the steepest descent with a longstep for the object function minimization. Some adjustments are described in [Kolovský et al., 2018]

### ***Implementation***

All the algorithms are implemented in Java or Scala programming language. Whole application is based on Spring Boot and PostgreSQL with extension PostGIS.

## **3.4. Outputs and visualizations**

In common (desktop) traffic modelling software (Visum, CUBE, OmniTrans) the emphasis is on outputs for traffic engineers. The most used graphic expression is the traffic flow map. The thickness of the line corresponds to the volume of traffic (Fig. 2)

However, such outputs are difficult to understand (and not attractive) to the general public and political representation. They prefer illustrative - colorful and moving expressions. Therefore, an approach was chosen that will allow presentation using a web application, and thus provide:

1. easy operation, accessibility,
2. dynamics - moving on the timeline,
3. better understanding - in addition to the volume of traffic (number), the level of service (exhaustion of capacity) is also displayed in a color scale.

The transfer of the outputs of the traffic model to the Internet brought not only positive responses but also some problems.

- the general public's approach has resulted in higher demands for the model to agree with reality,
- the capacity of the road (and thus its color at a certain traffic intensity) is inaccurate - the capacity of the road network in the city is given more capacity of intersections, which, however, the model can not accurately take into account.

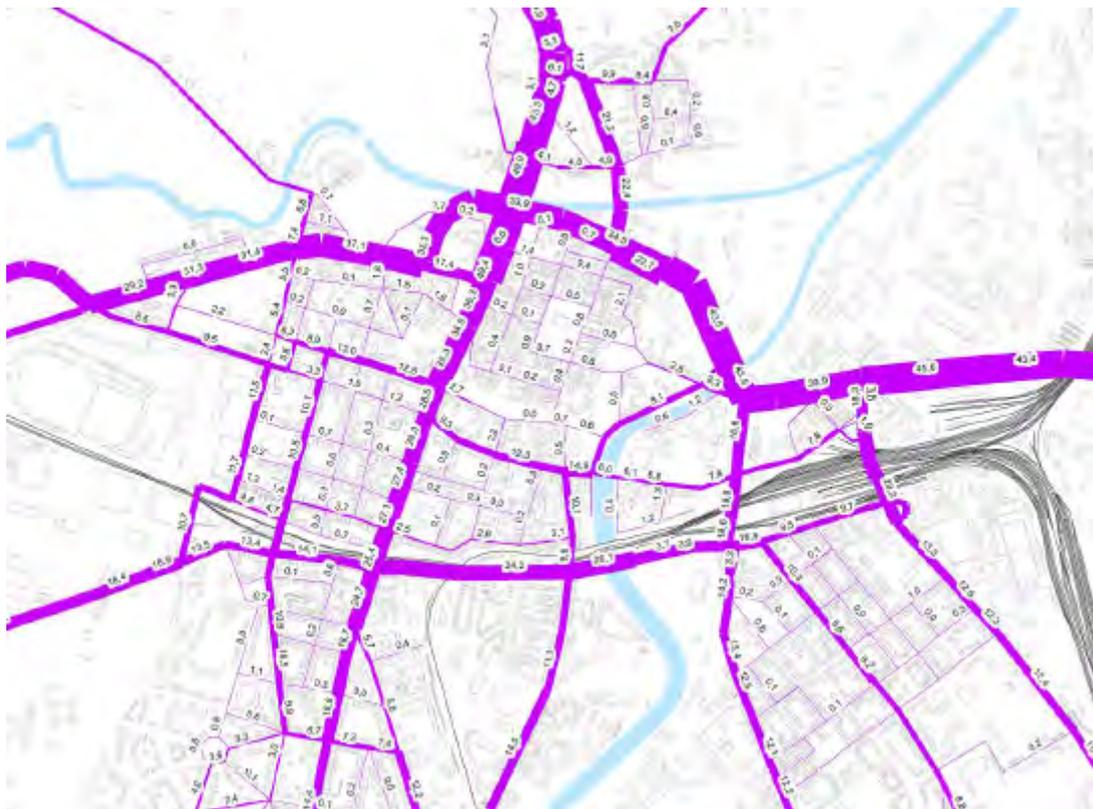


Figure 2. Traditional traffic flow map (center of the Pilsen city)

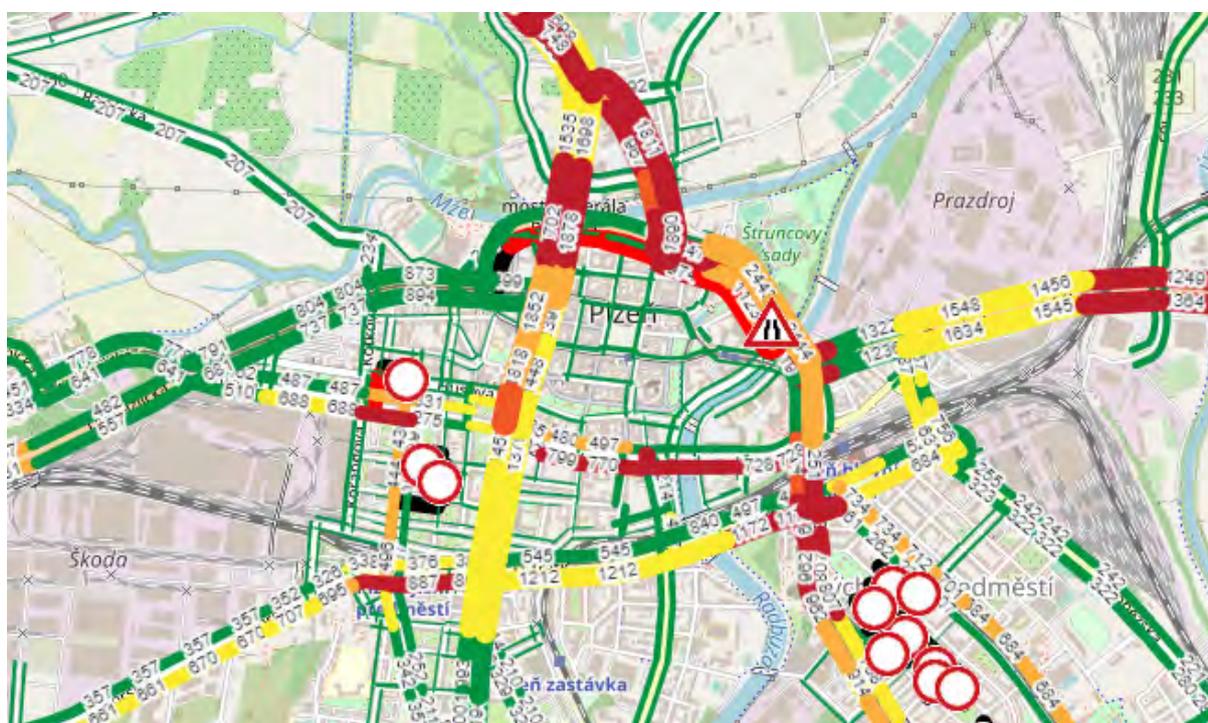


Figure 3. Traffic flow map in Traffic Modeller (center of Pilsen city)

Daily (as well as weekly and annual) variations in traffic volume were used to move the model over time. These were processed from sensor data located in the roadway at each intersection controlled by traffic lights. The data allows you to calculate how road traffic changes during the day, week and year. A time slice of traffic flow map in Traffic Modeller is shown in figure 3. Next, figure 4 shows the daily variations of traffic volume.

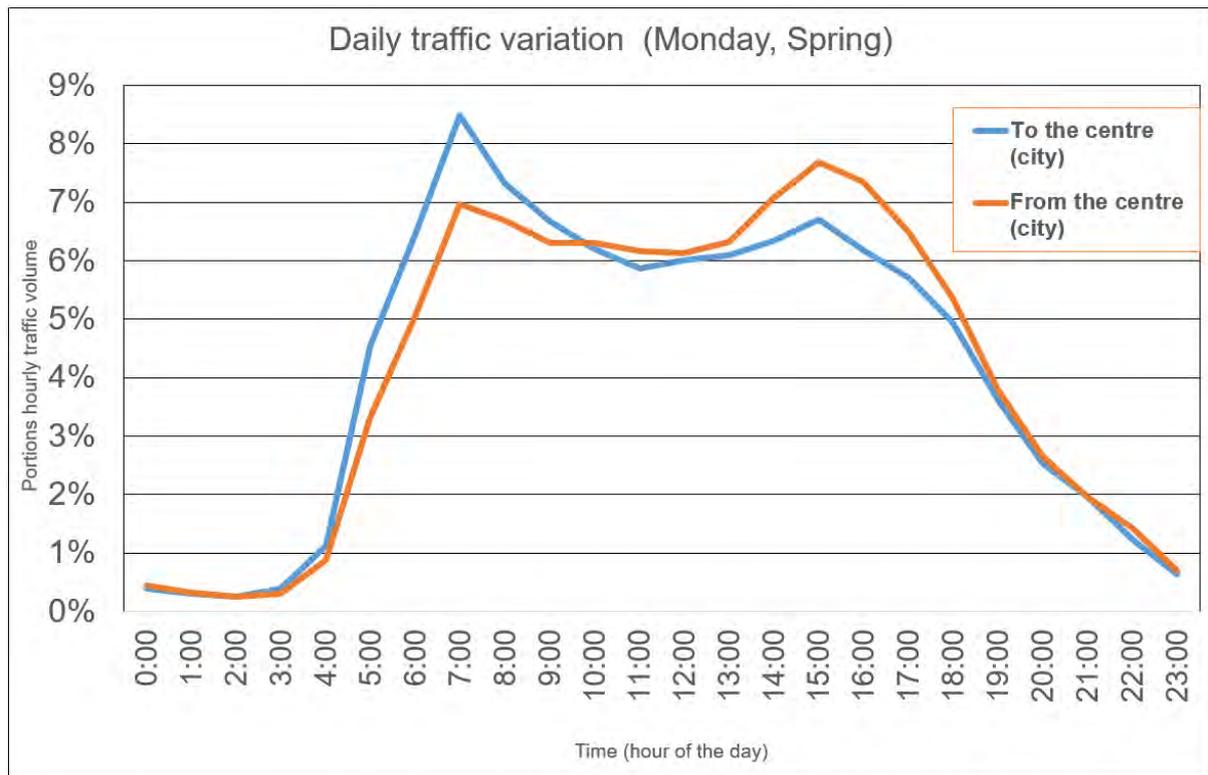


Figure 4: Daily variations in traffic volume

#### 4. THE GOOD PRACTICE EXAMPLE IN THE SMART CITY OF PILSEN

As stated in the previous chapter, Traffic Modeller development and testing would not be possible without reliable traffic data. The first large pilot region became the city of Pilsen. Pilsen is a mid-sized city in West of Bohemia with a population around 170 thousand people and approximately 530 cars per 1000 person of population. Without full outside traffic ring the city center tracks a lot of transit traffic, especially between north and south of the city. All of which contributes to annual average daily traffic to be around 20 thousand in one direction of travel for the most frequented roads in the inner city. (<http://www.svsmp.cz/dopravni-pruzkumy/informace-o-doprave-v-plzni-za-rok-2018.aspx>)

The default traffic model for the city of Pilsen consists of 339 traffic generators shaping 339 x 339 OD matrix, 10 533 road segments and 4 723 nodes. The model was designed and then calibrated using a dataset of 250 million observations from 627 road built-in sensors, with a 90 seconds granularity in time. A whole year period was processed in order to provide capture traffic variations during different hours, days in a week and even seasons.

Firstly, Traffic Modeller Pilsen Web App (see the public version - without the experiment modelling functionality - here: <https://intenzitadopravy.plzen.eu/>) offers Pilsen policymakers web visualization of the Pilsen default traffic model (Fig. 5 a - Default traffic model). This model is the result of an in-depth calibration and correction so that it as closely as possible reflects the average weekday peak hour. This model can be additionally visualized in the form of any specific hourly traffic volume (e.g. June, Sunday from 5 pm to 6 pm).

The core of Traffic Modeller Web App is however the computation and visualization of user-defined traffic experiments. The user story for experimenting with the traffic model is as follows: the user creates an experiment that acts as a container for at least one, but usually more traffic events. Once an experiment is created the user can further create a new event. When creating a new event user can first fill some optional attributes (name, description, and from/to date) and then by clicking in the map selecting those road segments which attributes are to be changed for the experiment. Once segments are selected, users can then choose if free-flow speed and/or capacity of those segments should be altered. When these edits are saved, the experiment can be modelled and within a couple of seconds users can see the impact of tested changes in the network. (Fig. 5 b - Experiment traffic model) Afterward, this process can be easily repeated with slightly changed parameters To allow better comparison between various experiments, Traffic Modeller Web App also offers special visualization, *Differential traffic map*, which shows the difference in traffic

volumes (Fig. 5 c - Difference in traffic volumes). City policymakers might for example decide that closing the whole street entirely is not ideal and that 50% capacity for a longer time period is a better solution for that particular road reconstruction.

The above-described user story represents the core of Traffic Modeller Web App, however, as city traffic is not operated by a single user we had to extend this user story with additional functionalities. These functionalities were not part of our original design but were added during development thanks to user testing done by city employees at the information technology department at the city of Pilsen. Those user demanded functionalities are:

User management with user roles for adding new events only without the option to experiment with the model needed for other public organizations (e.g. waterworks department) that may request but have no need for traffic modelling it self; visualization of live traffic from sensors, storing, and visualization of historical hourly traffic volumes from sensors (these historical volumes can also be compared using the Differential traffic map).

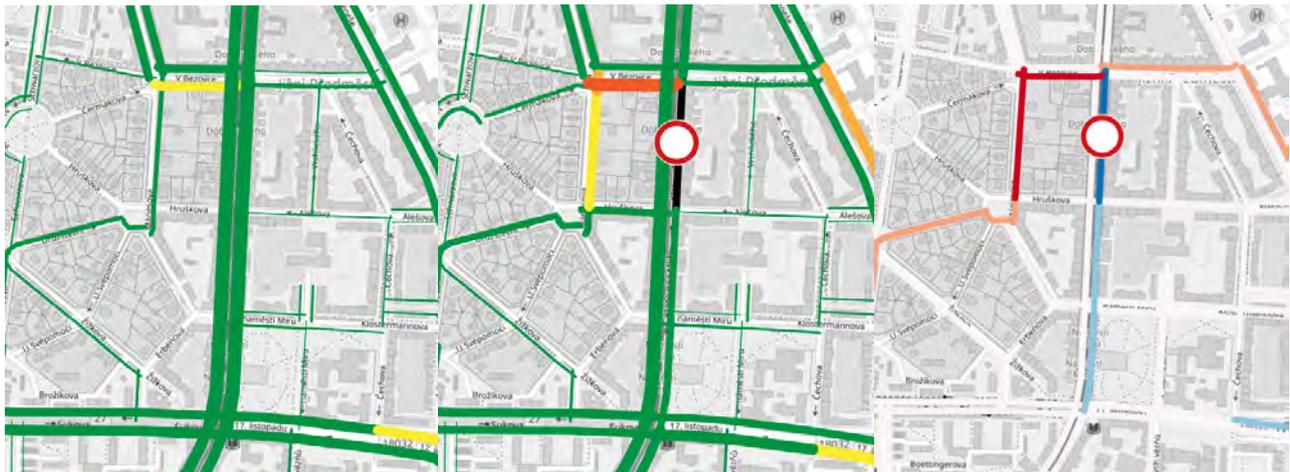


Figure 5. a) Default traffic model on the left, b) Experiment traffic model in the middle, c) Differential traffic map on the right.: red - more traffic after closure, blue - less traffic after closure  
(Please note that despite only streets with significant traffic being visible, all streets are used for the traffic modelling)

## CONCLUSIONS AND FUTURE RESEARCH

The contribution introduces the current state of geotechnologies used for traffic modelling. Traffic modelling is a crucial part of the smart city and digital twin concepts. The fundamentals of the Traffic Modeller are described and a good practice example is demonstrated in the smart city of Pilsen. The authors have learned the following lessons which will be reflected in the future research and developments.

Traffic modelling is extremely sensitive to relevant input data. In order to calculate a good quality traffic model, it's important to have:

- a proper information from traffic generators from which the origin-destination matrix is calculated,
- an accurate shape of the modelled network,
- allowed (respectively prohibited) turns in junctions properly set,
- each network segment (and ideally also each junction) set with adequate capacity and free flow speed,
- a robust traffic census dataset for calibration.

The results as presented in the Pilsen use case are close to reality and are used for data driven decisions in policy making. Please note that an updated information about the status of the Traffic Modeller for the city of Pilsen is maintained at <https://plzen.trafficmodeller.com>.

The future research and development of the Traffic Modeller will focus firstly on the implementation of algorithms for dynamic traffic assignment, as mentioned at the end of Section Traffic assignment model. The next step will be to improve the user experience by redesigning the frontend application to streamline the workflows and graphical user interface. This turns out to be a cutting edge for the success of the Traffic Modeller. User experience, especially of the policy makers, can help in spreading the software in the future. The future research and development include extensions of the Traffic Modeller calculating noise and pollutants produced by road transport.

## BIOGRAPHY



**Karel Jedlička:** The theoretical background of Karel's research lies in modeling, analysis, and even simulation using multidimensional (geographic) data structures. In particular, Karel actively researches on 3D and 4D aspects of Geographical Information Systems. Karel focuses on influence on transport to the city life, by designing and developing interactive traffic models for Digital twins of Smart cities. Karel has been leveraging his skills in various EU projects since 2007. Karel usually acts as a leader of small research or technical team in the project.



**Daniel Beran** graduated from the University of West Bohemia (UWB) at Faculty of Geomatics in 2018 with an Ing. degree (eq. to MSc). Since 2014 he has been active in various H2020 projects (OpenTransportNet, PoliVisu, DUET). In 2015 Daniel joined the Traffic Modeller team working as data manager and GIS analyst. Since 2018 he is undergoing a PhD study program at the UWB exploring classification of LiDAR point clouds. In 2018 and 2020 Daniel was a guest researcher at TU Delft and TU Wien respectively. He is a part time GIS teacher at Pilsen highschool of civil engineering. He has experience in GIS, traffic modelling, 3D visualization and point cloud processing.



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## 5. ACKNOWLEDGEMENTS

The work on Traffic Modeller and the authorship of this contribution was supported by:

- PoliVisu: Policy Development based on Advanced Geospatial Data Analytics and Visualisation. H2020-SC6-CO-CREATION-2017. Grant agreement no. 769608
- DUET: Digital Urban European Twins for smarter decision making. H2020 (DT-GOVERNANCE-12-2019-2020). Grant agreement no: 870697
- TRAFFO: Innovative Approaches to Mathematical Traffic Modelling for Sustainable Development of Cities and Regions. The Technology Agency of the Czech Republic. Programme: DOPRAVA 2020+. Grant agreement no: CK01000096

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# A CONCEPTUAL FRAMEWORK FOR USING GEOSPATIAL BIG DATA FOR WEB MAPPING

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## **Abstract**

*In cartography, the term “Big Data” (BD) has been started to use in the last decade. The recent development of GIS and web technologies have expanded and empowered cartography by providing actual, steadily growing and complex data and information, increasing the spatial and thematic accuracy of the contemporary maps. The primary purpose of the cartographic approach is to maximize the value of a user-oriented map rendering of the web map content. Based on this approach and taking into account the technological advances, the authors describe which part of BD can be utilized for new mapping products and services. A conceptual framework encompassed several stages of multi-source data handling, separate stages of data management and data analytics, as well as data transformations from the real world into the map is described following the web-map creation process. The potential to use commercial web GIS platforms and free and open-source software solutions for Web mapping (WM) are discussed. The challenges that faced the modern cartography for creating better and cheaper cartographical multi-dimensional and multi-layered map products for less time on different map scales are shortly outlined. Some examples of good and imperfect web map productions are shown in the context of BD visualization. Existing obstacles in the automatisisation process of map production, more in-depth understanding of the visualized map content adding Virtual Reality / Augmented Reality (VR / AR), usage of cloud technologies and supercomputers with software platforms for map creation are also recognized.*

**Keywords:** cartography, map design, Big Data, geovisualization, GIS Web mapping

## **INTRODUCTION**

Cartographic science and practice provide opportunities for learning, making and using maps across a wide range of human activities. From many centuries the cartography spreads information about the ambient world to the map users starting from simple graphics, made on the walls and grounds, going through the traditional paper map and attaining to the modern interactive 2D/3D/4D cartographic representation. Modern cartography gains the advancement of Information and Communication Technologies (ICT). It combines interdisciplinary achievements of mathematics, statistics, data acquisition, data mining, and programming to extract insights and information, which are represented in interactive and innovative methods. It has led to the creation of numerous digital tools and techniques that enhance the accuracy and temporal resolution of traditional maps.

Nowadays, cartography exploits the potential of Geographic Information System (GIS) and web technologies as advanced tools for the map-making. GIS has reached a new level; they become mobile and massive, and thus accessible to more users and not only professionals. In this respect, the Web mapping (WM) and GIS technology and applications,

considered as an integral part of modern cartography, can help to deal with “Big Data” issue. BD is a term that can mean almost anything, with an emphasis on the trend of large-scale data storage and processing (Jurney, 2015). Availability of high-throughput data collection technologies, such as remote sensing, mobile devices, and diversity of sensor networks contribute to rapidly growing of data sets becoming BD pervasive in all research fields. Big data is a term meaning large amounts of geospatial data that can be georeferenced and used for flexible solutions, allowing their processing, analysis and visualization on the map.

Recent trends of transition from paper maps to electronic and the emergence of web map services impose new challenges in front of modern cartography to utilize ICT achievements and meet requirements of map users. Against the backdrop of massive and widespread information-gathering tools, modern cartography is becoming extremely attractive. The new era of Big Data, the GIS and Web mapping products and services includes cartographers, ICT professionals, developers and providers of GIS / Web geospatial data and software platforms, international standardization organizations, the private sector, politicians, governments and geo-communities. Sometimes it is difficult to draw the line where the sphere of ICT end and cartography begins. Many IT professionals are taking on the role of cartographers. Modern cartography is becoming increasingly important and has gained much interest from expert and novice map users. WM gives opportunities to professional cartographers to represent the information coming from BD resources (Poorthuis, 2018) and to reach to different kinds of users: from young kids to older people; from the tourist to decision making’ professionals. Cloud computing, in computer science, is a model for providing ubiquitous and convenient network access on-demand to a collective pool, configurable computing resources (for example, data networks, servers, storage devices, applications and services - both together and separately). Supported by the emerging needs and principles for interoperability of geospatial data, standardization and pragmatism in visualization, many open platforms for the development of WEB GIS-mapping products and services are emerging. The continuous technological progress and the development of modern science allow innovations and automation of cartographic processes. Cloud technologies are a new stage in the web-cartography.

Modern cartography has not a limitation to provide intelligent solutions for maps’ creation using big data from different devices and for the needs of different users. In this context, the International Cartographic Association (ICA, <https://icaci.org/>) established the Commission on ubiquitous mapping, based on real-world map interaction and ICT-based context-aware mapping services. Robinson et al. (2017) created a research agenda for making maps from BD after a long discussion of four Commissions members of ICA. It is focused on big data volume, velocity, variety and veracity. Other commissions such as Generalization and Multiple Representation and Geospatial Analysis and Modeling focus their research and practical experience on the multi-scale issues and automated map generalization, spatial analysis and data mining with strong links to geovisualisation and visual analytics (<https://icaci.org/commissions/>).

This paper aims to present in general the cartographic approach for a Web mapping design using multi-sources Geospatial Big Data (GBD). The basic elements of map content are briefly described, such as the perception of geospatial abstractions, map scale, symbol system, generalization, map design and use of a portion of BD for GIS / GIS Web mapping purposes. The potential to use commercial web GIS platforms and free and open-source software solutions (FOSS) for Web mapping is shortly outlined. Recent international efforts of the Standards Development Organisations to develop standards and unification of GBD for mapping purposes is considered. Contemporary GIS and WM platforms significantly improve BD visualization, but, in some cases, map-makers cannot represent properly the main cartographic content that the users can perceive the map. A few examples of good and imperfect web-map productions in a combination of advanced visualization tools are shown to demonstrate the potential of WM using BD. Based on literature review, a conceptual framework that encompasses several stages of data acquisition, data extraction, cleaning and annotation, data integration and aggregation, data transformation, data modelling and analysis, interpretation, and visualization is presented. Finally, the process of mapping automation, a deeper understanding of the visual content of the map with the addition of VR / AR, the use of cloud technologies and supercomputers with software mapping platforms are also discussed in the context of the further development and modernization of the map production.

## **GEOSPATIAL BIG DATA AND CARTOGRAPHY**

The concept of BD refers to the collection, analysis, storage, processing, visualizing, etc. of significant amounts of heterogeneous data from multiple sources (Filchev et al. 2020). Usually, data sets are complex with different formats and have spatial and temporal attributes. BD includes types of structured, semi-structured and unstructured data (Bandrova et al., 2014). Any scientist dealing with huge data sets can define the term BD and usually reflects in its definition specific aspects of the subject field. In the field of geosciences, several definitions can be found in the scientific literature. Snijders et al. (2012) define BD as a data set which cannot be captured, stored, manipulated without the existing software. Kalema and Busobozi (2020) define BD, including structured and unstructured data with exponential growth. Everts (2016) takes attention to the size of BD, which in 2012 volume from several dozen terabytes

goes to many Exabyte in 2016. Dedić and Stanier (2017) include semi-structured, in addition to structured and unstructured data. A new definition came from De Mauro et al. (2016) which says: “Big Data is the Information asset characterized by such a High Volume, Velocity and Variety to require specific technology and analytical methods for its transformation into value”. Even more, Robinson et al. (2017) think that the definition of BD is nebulous. During the last decade definition of BD with the number of V's have increased continuously starting with 4 Vs, 10 Vs and even presented it with 42 V's like the ultimate answer (Shafer, 2017).

From the cartographic point of view, BD are considered as a mix of structured, semi-structured and unstructured geodata. At the 27th International Cartographic Conference in Rio de Janeiro, Brazil in 2015, the President of the International Cartographic Association, Georg Gartner, announced the trend of using “big data” in map-making technologies. The big challenges for geosciences, and in particular for cartography is to except richness of content of the continuously growing BD flow and followed processes of data preparation, extraction, cleaning, integration, aggregation, analysis, and presentation. Accuracy, dimensionality, quality and interactivity are also particularly important for the needs of cartographic products in addition to the four main properties of BD such as volume, variety, speed and reliability.

- Accuracy means the degree of correct information and data which can be projected or referred to a coordinate system used for map projection;
- Dimensionality means a measure of spatial, time and characteristics extent of the information represented to the map. These BD characteristics allow the creation of 2D, 3D, 4D to multi-dimensional map;
- Quality means a high value of the collected data and information that is displayed on the map;
- Interactivity means the level of the computer respond to the user's input (Wang et al., 2018).

In the past, the collection of primary information for creating cartographic products has taken a long time and was costly. Now all stages in the collection and preparation of source data are carried out at a high technological level and take not so much time. Today, everyone can become a participant in the geodata collection. With technological advancements related to the processing and visualization of geospatial data, the map becomes an interface between the user and the data. Several years ago, GIS technologies had not enough capacity to manage and process BD because of variety in terms of formats, increasingly big amount of volume and complexity of knowledge (Wang et al., 2018). Today professional cartographers face the challenges to finding a way to deal with GBD (see, e.g. Filchev et al., 2020). These include the collection, manipulation and visualization of large-scale geoinformation for different users and purposes with a multidisciplinary approach.

## **BASIC ELEMENTS OF MAP CONTENT**

The dimensionality of the map poses a new challenge for map-makers to represent spatial information in the 3D, 4D virtual world, and to include the time and animations as a modern way of representation in GIS web map applications. The new areas in the development of modern cartography show that the map is not just a flat representation of the real environment. In the BD era, the definition of the map must retain the basic features of the map that distinguish it from other earth images and representations. Therefore, here a definition is suggested, which states: “the map is a mathematically defined multi-scaled, multi-layers geolocated, generalized drawing, representing the earth (or other planets) surface, objects and phenomena by symbol system.” Additional drawing, images, audio, video, animation, and other attributes, giving quantitative, qualitative or other information, could be geolocated and attached to the main map content. The main elements of the map, whose presence or absence improves or degrades the quality of the cartographic product are discussed below.

- **Perception of geospatial abstractions**

Abstraction is a basic process preceding the creation of any cartographic product, through which geographical spatial objects or phenomena considered as geospatial data and geoinformation are depicted on the map. Different level of abstractions may distinguish: conceptual, geometric, semantic, graphic, visual, and cognitive. A specific problem is the degree of abstraction with changing the scales of maps when the same content is visualized. For example, if different aspects of the abstraction are ignored, it may be difficult to perceive the map content when navigating through the web geoportals changing its scale.

- **Map design**

The art is a term that still exists in some map definitions and more often in the description of cartography. Map design does not concern only “art” as a part of cartography but also some cartographical aspects and rules of map-making. In ancient ages, most of the maps have been collected as art products. In traditional cartography, the map design still exists. With the widely available and easy-to-manage GIS, many maps have emerged, most of which are drawings or

graphics rather than maps. Maps should attract user attention, and they should like them, and not only provide a possibility to read and understand. In this case, the maps will become more and more popular to any type of users. Vozenilek (2019) describes map design as an aggregation of thought processes, which includes three phases: map proposal, drafting and compilation. Colours and labelling are essential elements in the map design, and they are chosen during the process of map creation. RGB (red, green, blue) colour system is better to use when web maps are created on the base of BD. There is a need to keep principles of association in the object context, i.e. appropriately chosen symbol. Map texts are essential to be readable, and they have to be appropriately placed on the map according to the cartographical rules and norms.

- **Multi-scale map**

Every map has to have a clearly defined scale/s, which is/are shown, and users can make the necessary measurements. The scale means a relation between any line on the map and its real size on the earth surface. It can be represented on a map by three different ways: bar-scale or graphical, verbal and representative fraction. Jiang speaks about the smallest and the largest scale in the context of scaling hierarchy (Jiang, 2018). This is adopted in web map platforms where users can use differently scaled maps in the same territory (Vozenilek, 2019). It means that the map is a multi-scaled. Degree of resolution is defined as a scale in the cartographical context of BD (Robinson et al., 2017). The same approach is used for web mapping, e.g. changing of the scale means changing the degree of resolution and the level of details. It can be represented in different dimensional map representation: 2D, 2.5D, 3D, 4D, etc.

- **Generalization**

The BD era provokes the rising of map-making from professional cartographers and the need for developing BD generalization rules. BD and the expanding demand for new maps for a variety of devices means the development of the generalization of datasets and as well integration of skills (Yao et al., 2017). Cartographic generalization always exists as it depends on the purpose of the map representation. The generalization is a process of deliberately transforming existing geospatial data and information or their symbolization into a more abstract representation. Another aspect of generalization is dimensionality, which is a measure of spatial, temporal and characteristics extent of the information represented on the map. Each map should be generalized as many times as the number of specified scales in which to produce.

- **Symbol system**

To make maps using BD sources does not mean that cartographers will not use cartographical symbol systems. In many GIS applications and web map platform, examples with and without symbol system can be found (see Fig. 1 without a legend, Fig. 2 with a legend). The symbol system is the language of the map, and it is needed to perceive by the map's content from the users. The user can understand the information presented very quickly and in the right way, having the ability to read the map, analyze and make decisions on a topic, such as crisis management in emergencies (Konecny, 2005, Klimczak, 2016; Dobrinkova et al., 2016, Zhang et al., 2017; Kuka, 2018). The symbol system should be well defined and to give the necessary qualitative and quantitative information about objects and phenomena depicted on the map. In the case of BD representation on a web map, the visualization should be done in a separate window, easily accessed for the users.



Fig. 1 Web map without a legend

(Source: <https://news.google.com/covid19/map?hl=en-US&gl=US&ceid=US:en>)

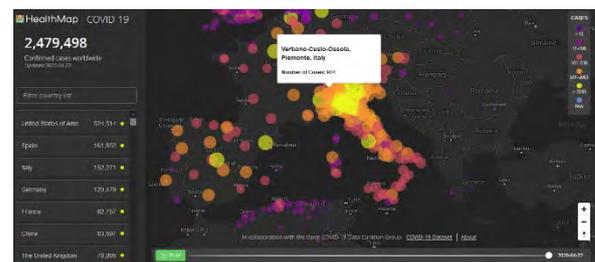


Fig. 2 Web map with a legend

(Source: <https://www.healthmap.org/covid-19/>)

## WEB GIS PLATFORMS AND BIG DATA STANDARDS

### Software platform for GIS Web mapping using Big Data

Nowadays, a multidisciplinary approach should apply to exploit the BD availability and to find appropriate software for their managing and processing. Although some authors declare that current GIS is still used for the needs of

conventional cartography (Bandrova et al. 2019), the recent technological advancements provide methods and tools to create multi-dimensional web maps dealing with BD. Cartography uses different software systems and platforms to capture, analyze, manipulate and visualize geodata. Map-makers apply conventional cartographic methods and GIS to produce 2D maps and atlases. The same principle is used to address the challenges of utilizing BD: GIS in combination with programming applying artificial intelligence methods in a cloud environment.

Over the last few years, in addition to commercial Web GIS platforms (Fu and Sun, 2010), free and open-source software solutions (FOSS) provide great opportunities to exploit the potential of GBD. These solutions allow creating a web map or a 3D scene using website visualization libraries such as Leaflet, Modest Maps and Polymaps. Free GIS mapping software contains various useful options for creating interactive web maps that can define map content, customize interactive and visual features, and maintain an opportunity for internet browsers or mobile applications. Some of them have well-prepared documentation, making it an excellent choice for beginners, and there are several community-contributed examples out there on the Internet for when you get stuck, as well as many cases on the project homepage.

In recent years, GIS has developed significantly, using multi-dimensional analysis tools and web servers. Geospatial technologies have applied GBD for enhanced analysis in many environments and social-economic fields, e.g. climate modelling and analysis, disaster recovery and response, location analytics, retail and e-commerce, banking, health insurance, disease surveillance, etc. GIS web technologies have provided sophisticated cartographic tools for developing applications using unstructured and structured geodata. Most of the web map platforms enable using advanced numerical algorithms and artificial intelligence methods to analyze information into a GIS environment, to model the processes visualized, and predicting different parameters in real-time depicted on overlaid map layers. Often, WM platforms provide additional access to reports, respond to user queries, and provide analyses and forecasts of processes or phenomena displayed on web maps. Kim (2018) declares that the mapping technologies expect BD and especially those that keeping dynamic updates of the data. In (Jiang, 2018) a cloud-terminal integrated GIS platform architecture for spatiotemporal BD, which contains large-scale virtual storage, distributed computational framework, cloud computing and integration, stream data processing, 3D and virtual reality is proposed. This multi-type platform makes it possible to use spatio-temporal big data, enhancing the analysis and visualization in various information systems in real-time. Cartographers need such advanced technologies and tools for map applications not only to update existing classic maps but also to make cartographic products more detailed, reliable and informative for map users, including capabilities to perform real-time analyses and prognoses.

Cartographers can use web map platforms or build a similar one by their sources. One of the most robust and well-known web map platforms is Excel E-Maps 2.0. A good practice to use Google Maps web platform comes from BigDataEarth; a company specialized in making hazard, exposure and risk layers, creating maps and reports for Australia and the US (<https://www.bigdataearth.com/>). Thanks to the Street View mode, street images and virtually walk through many cities of the world can view using Google mobile maps. Besides, the application can determine the coordinates of the user using the base stations of cellular operators, as well as using the GPS module built into the cell phone.

ESRI, as one of the leading GIS companies, declares that it can manipulate with BD providing integration of the sensor data, cloud services, robust data management and analytic capabilities (Gutierrez, 2016). Working with ESRI products, any organization can capture the power of real-time data and put it to work. ESRI actively promotes modern mapping technology in the ArcGIS software products known to all cartographers. For the unprepared user, ArcGIS offers possibilities for the automated design of data based on an analysis of their type and the underlying cartographic material used. ArcGIS as a platform makes geospatial functionality available in any application, any device, anywhere and anytime.

Another world-famous Web mapping platforms are OpenStreetMap, HERE maps, Wikimapia. Although these platforms offer cloud-based map services and provide millions of users with geographic information, criticism of them comes from their cartographically oriented products. Skopeliti and Stamou (2019) encourage all these well-known platforms to improve cartographic representation in the context of map projections and the datum, including legend, multiple map views in the same window, scale, generalization, font lettering, colours, map design, etc.

Veenendaal et al. (2017) show the developments of WM from the static online map to the highly interactive, multi-sourced WM services that have been moved to cloud computing platforms. They found three essential elements implied in WM: geodata and their visualization (maps), geospatial software and the WWW. The challenges for cartographers are connected to the new technologies and cartographic principles needed to effectively WM design.

We have a significant amount of bad and good examples of WM. Bad ones are usually available when no cartographic principles are applied to the large amount of data collected from remote sensing platforms, sensors, surveying methods, mobile companies, volunteer information, and more. Deogawanka (2014) shows that traditional GIS is often insufficient

for meaningful interpretation of BD in real-time. She explains that general intelligence had failed to trace Osama bin Laden (see Fig. 3). Not a lot of information can be found and used by the map on this figure.

The result is different when the author of the map uses cartographical types of visualization. Mapping tornado migration and using BD, Nelson (2018) uses impressionistic choropleth, weighted mean centre movement diagram and multiple small types of multi-dimensional representation of the phenomena. Even receiving enough good results, the 12 locations of tornadoes for every month could be improved with map graticule visualization.

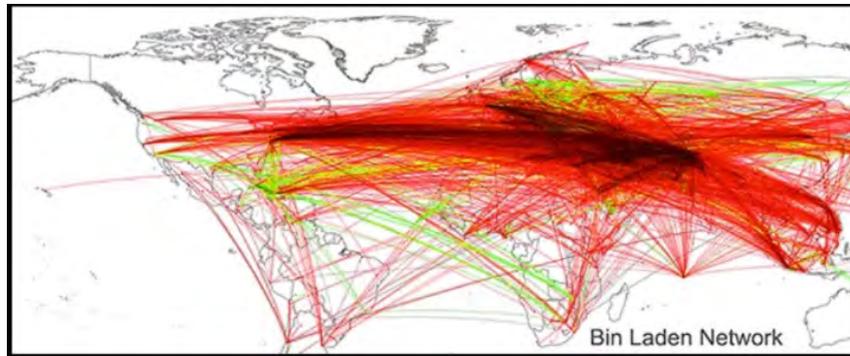


Fig. 3. A bad example of using BD for WM representation (Source: [www.gislounge.com/empowering-gis-big-data/](http://www.gislounge.com/empowering-gis-big-data/))

The Australian government provides a free online map-based tool through the portal <https://nationalmap.gov.au/>, which allows access to different spatial data from the government agencies. “NationalMap” refers to the data servers of the data contributors, directly taking that data and presenting it overlaid over a map. This web-map tool is one of the good examples of cartographic visualization of BD (see Fig. 4).

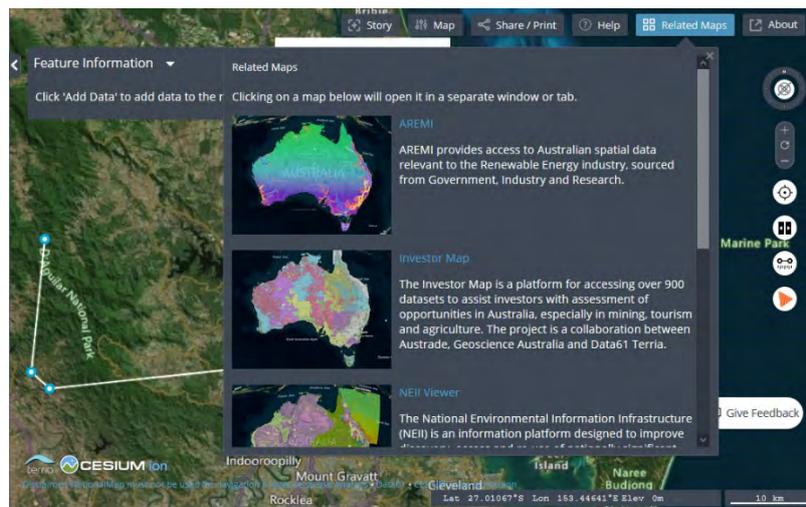


Fig. 4. An example of a well-designed geoportals using BD with WM representation (Source: <https://nationalmap.gov.au/about.html>)

## Developing Big Data standards

Among the cartographic society, there are not so many examples for evaluation of map products and Web mapping services. In some cases, the mass-produced cartographic products not always are with the necessary qualities. In one case, the Bulgarian Cartographic Association in 2017 adopted general rules for the issue of a quality certificate for a cartographic product, by which its qualities are evaluated by professional cartographers (<https://cartography-gis.com/en/>). The leading indicators for evaluation include:

- Proper design of the basic elements of the map;
- Correctly set of map projection and correct determination of its parameters according to the Bulgarian laws and regulations in the field of cartography and the scientific principles of cartographic design;
- Correctly defined and marked the map scale;

- Visualization and inscription of geographic coordinates and or rectangular grid;
- Properly generalization of the map content depending on its scale and theme;
- Correct depiction of the hydrographic elements in respect to graphics, colours and inscriptions;
- Properly depiction of linear, area and point objects in the map and legend;
- The inscriptions (layout and fonts) should be designed according to cartographic design rules;
- Colour layout in associative correspondence with the depicted objects and phenomena;
- Conformity of the legend with the depicted objects and phenomena;
- Design of the cartographic product according to the user needs.

A Map Review Form was published in *Cartography and Geoinformation Journal*, Croatia. The form intended to determine whether a map qualifies for a certificate of the Croatian Cartographic Society. The questionnaire consists of 24 questions, starting with “Does the map title correspond to its content?” and ending with “Are map aesthetics adequate?”. A reviewer may also consider other map elements, if they are present, including titles and designations of neighbouring sheets, object index (list), additional diagrams and graphs, multilingualism, inserted map, extended map, etc. If the map is a digital product, one needs to consider eight other details, e.g. “What file format (pdf, tiff, jpeg, bmp, gif, ...) is the map in?” and “Is it possible to interact with the map?”. A reviewer may also consider additional elements, if they are present, such as a dynamic map, animation, sound and other multimedia capabilities. At the end of the form, a reviewer states the final opinion and recommendation, which may include steps necessary for the map to be certified or perhaps published in the *Cartography and Geoinformation journal* (Frangeš, 2016).

Publishers of maps, atlases or other cartographic products, receiving such a certificate, will avoid potential errors and inaccuracies and will provide users with properly presented cartographic information (Bandrova et al., 2019). The “Big data” sharply raise the question of their standardization and unification, especially for mapping purposes. If they are delivered in formats that do not coincide with each other, then it turns out that the process of creating maps will not accelerate, but slow down. On August 19<sup>th</sup> 2017, the Big Data Value Forum (EBDVF) has an official liaison with ISO IEC JTC1 WG9 Big Data Standards group now merging into the newly established JTC 1/SC 42, Artificial Intelligence, which are tasked with developing the Big Data Reference Architecture for ISO. In 2019 ISO published document ISO/IEC 20546:2019 (2019), which provides a terminological foundation for Big Data-related standards. It is a conceptual overview of the field of BD, its relationship to other technical areas and the concepts ascribed to BD.

When dealing with practical issues related to environmental management decisions, the OGS standards had some limitations for producing high-quality cartographic representations and opportunities for visualization of spatial information. In the framework of two major European projects, namely ORCHESTRA (Open Architecture and Spatial Data Infrastructure for Risk Management) and SANY (Sensors Anywhere), appropriate solutions for cartographic visualizations based on open standards have been created (Iosifescu-Enescu et al., 2010). Within the SANY project, the interoperability of in situ sensors and sensor networks is subject to monitoring the dynamic nature of spatial information and its presentation in the form of maps. The cartographic extensions for the Symbology Encoding (SE) standards allow the expression of cartographic rules with spatial operators and advanced filtering of layer masking functions, the flexible symbolization of points and patterns and gradients for all spatial characteristics. Also, there are opportunities for creating thematic maps with extensions for intuitive choropleth and generating different types of diagrams.

## **A CONCEPTUAL FRAMEWORK USING GEOSPATIAL BIG DATA FOR WEB-MAPPING**

In the era of BD, the map created by traditional cartographic methods was transformed into computationally based means of map production. Several aspects depending on the type of GBD and information characteristics should account in web-map creation, such as multi-dimensionality, generalization, scale, and formats of data transformations from the real world into the map. Considering different types of BD, the structured data have a high level of accuracy and correctness. It has a high level of organization, usually in databases, making it predictable, easy to organize and very easily searchable using basic algorithms. A massive array of data of various types of devices and sources such social networks, mobile phones, etc. that can interact with each other via wireless communication protocols as well as those with Internet access capabilities are collected for map-making tasks. It has been claimed that 95% of big data are unstructured. They are not organized in any discernable manner and have no associated data model. Unstructured data are uncertain, often provided by different map users or volunteers in very diverse formats and methods. Semi-structured data lies somewhere between the two types. This data is not conforming to the structure associated with typical relational databases. But, it may have different attributes associated with it, such as metadata, which allows elements contained to be addressed.

For each stage of processing and management of the three types of GBD, it is necessary to apply a systematic cartographic approach and design of optimal algorithms to derive maximum value from them. The goal of GBD management is to ensure a high level of data quality and accessibility to cartographic products. The process of working with GBD can be divided into several stages such as data collection and recording, data extraction, cleaning and annotation, data integration and aggregation, data transformation, data modelling and analysis, interpretation and visualization. Each of those phases can again categorize into two sub-phases as data management phase and analytics phase. Data management involves techniques, tools and technologies that support the data management to capture and store data and to do the changes and take it for the analysis phase. Analytic methods are used to analyze and extract value from GBD for web-mapping. For example, an entire architectural framework that includes the development of theoretical, mathematical, artificial intelligence, statistical methods for analysis, modelling, interpretation and visualization into cloud Web GIS environment is presented in (Jiang, 2018) and BD visualization is considered by Poorthuis (2018).

## **5. Steps for Web map creation**

The separate stage is considered as two sub-phases of data management and data analytics. Depending on multi-dimensionality, generalization, scale, and formats of data transformations from the real world into the map, different type of GBD and information characteristics are analyzed during the web-map creation process.

Diversity of modern cartographic methods for map creation as a model of abstraction of reality depicted in a suitable scale and directed to user needs are available. Current trends of improving Web mapping include several directions of development: automation of data manages processes; automation of computing and construction the mathematical base of the map; advancing techniques for compilation and preparing map originals for publication. A framework of operational steps that utilize GBD to create web maps by modern GIS tools combined with intelligent processing methods is briefly outlined (see Fig. 5), that includes:

- **Gathering structured, semi-structured, unstructured GBD**

The first stage of preparatory work includes collecting, systemizing, studying and scientifically collating of BD from different sources. Depending on the purpose and nature of the map, an appropriate selection of the available BD should be performed following cartographic principles and methods and keeping the main elements of map content, described before.

- **Classification of structured data**

Depending on the map theme and its aim, the process of classification of structured data should be done to achieve clear differentiation of the objects or phenomena representation. This activity will form the numbers of layers which will be used in GIS / Web GIS mapping. For straightforward cartographic representation, the hierarchy database storage and classification are proposed by several authors (Woodsford and Hardy, 1997; Konecny and Bandrova, 2006; Tomaszewski, 2016). Having such classified information, the cartographer could design a particular symbol system for different cartographical purposes. Example of such type of data classification is done for mapping geo-information for early warning and crises management activities (Woodsford and Hardy, 1997).

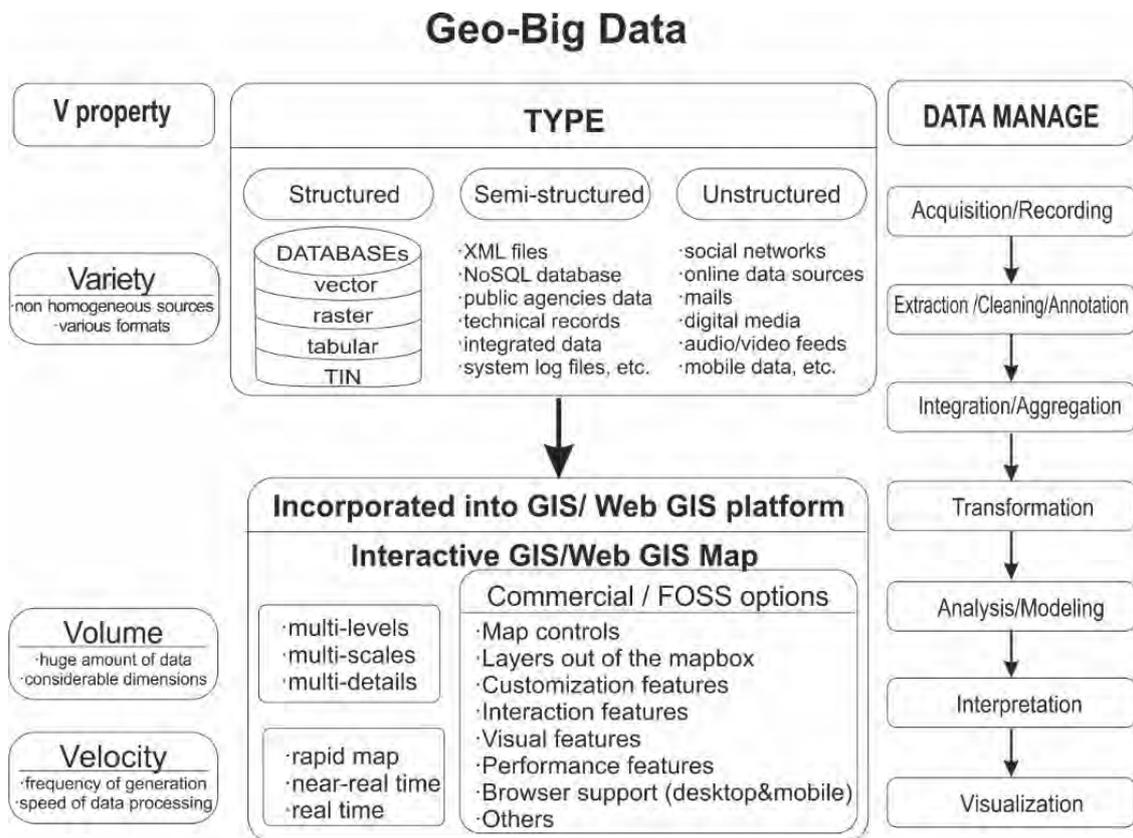


Fig. 5. A framework of structured, semi-structured and unstructured data in GBD environment and its use for GIS/Web GIS mapping

- **Semi-structured data validation and generalization**

Semi-structured data does not obey the formal structure of data models associated with relational databases (Iosifescu et al., 2010). This data could gather from qualified specialists or by other human activities. It could be validated by geo-specialists and generalized to be mapped according to specific rules (Sester, 2005). A suitable example of a validation dataset of CORINE land cover is LUCAS (Land Use and Coverage Area frame Survey) (See et al., 2017). Another one is a framework developed by COBWEB uses automatic validation applications by data quality indicators for metadata (Meek et al., 2016).

- **Unstructured data generalization and validation**

The working process will be the same as with semi-structured; often, it is a lengthy and costly process. The semi- and unstructured data after generalization and validation could be used as additional information (qualitative and quantitative) attached to the mapped structured data. Also, the data received from volunteers, or VGI will become increasingly powerful, may have the highest potential power. Therefore, algorithms must be found for their structuring and use (Antoniou et al., 2017).

- **Structured Data integration**

Today it is essential to solving a problem to integrate spatial data, gathered from different periods, used for various purposes, came from different sources, different scales, different accuracies, different Datum, different projections (Ulubay and Altan, 2002). As well the process of graphical data integration (different vector formats, raster and text) should be well defined by various software applications. The data integrity and its consistency in the process of creating maps should be preserved.

- **Defining of a mathematical base of the map**

Map projection choice is the first step in data visualization. It is an essential process for correct distribution and minimisation of the map deformations in 2D representations and for achieving measurements possibilities in 3D ones. Some map makers can say that the map projection is predetermined. If it is not predetermined, it depends on the map size, the scale, shape and location of the region of interest on the globe. Depending on the purpose, equivalent,

conformal and compromising projections are used (Klauer, 2000). The correct map projections parameters are the next important task which will minimize distortions of the represented territory. The selected scale of the map will reflect all other cartographic tasks such as generalization, symbolization, design and cartographic content.

- **Defining level of details (LoDs) and scales**

Determining the number of levels of details and the number of map scale changes will result in a corresponding number of newly created maps. The higher number of LODs results in better representation of any information on the maps to achieve maximum utility of depicted content. Another item is the combination of map scale and measuring tool. In this “scale mode, the scale indicates the correct scale, for example, at the centre of the map. It can be updated with every pan, zoom or resize operation the user performs, and can further update to compensate for map distortion caused by the map projection” (Rasmussen, 2009).

- **Structured data generalization = number of LODs**

Structured data should generalise so many times as the number of LODs is defined. The projected LODs are correspondent to the time and cost of the map creation. Some authors determine map generalization as “adapting the content and the level of detail of a map to suit its scale and purpose” (Jones and Ware, 2005). In Web mapping, every zoom should have a different level of details and a different scale. Otherwise, an unacceptable effect of overlapping objects will appear.

- **Determine the map content according to the LODs**

The map content should be different at each level of details and more detailed on a larger scale. The visualization of objects/phenomena should not overlap at any LODs to the varying scale of the maps. The representation of map content should be understandable and readable to users. There are various definitions of LoDs: City GML standard (Open Geospatial Consortium, 2012) defines 5 LoDs, NAVTEQ, an American company – 4 LoDs, BLOM (Geomatics Company from Norway) – also 4 LoDs, Bandrova and Bonchev (2013) defined 6 LoDs. All of them are connected to 3D city models/maps but related to the specific content.

- **Creation of symbol system**

The cartographical principles should be used in symbol system creation. Some authors (Punt et al., 2006) pay attention to the rule-rich symbolism, the high degree of mapping control, and the dynamic generation of presentation geometry through geometric effects and marker placement styles. Adherence to all these principles contributes to the clarity of the presentation, which is essential for modern mapping. The symbols should match the symbols in the legend on the map. The legend should be easily accessible to the user.

- **Objects and phenomena compositions**

Objects and phenomena composition will create the map content and connections between all represented data. They should be correctly georeferenced, with high accuracy represented and showing the latest received actual data for them. Very often, F GIS (Floating GIS) projects could be found, which means that some GIS projects have indeed turned into because of the wrong georeferencing. These should be designed in high accuracy of all topographic and thematic layer (Misra, 2010).

- **Including semi- and unstructured GBD**

Semi- and unstructured datasets will be used to add qualitative and quantitative information to objects and phenomena represented on the map. This data should be geolocated and georeferenced. It could include video, audio, images, text, and other data in appropriate formats. Other examples for this topic are web children maps and atlases, as well as ArcGIS StoryMaps where every map maker could record audio and upload images or videos to her/his map.

- **GIS/Web GIS map visualization**

Interactive GIS/Web GIS platforms give to the user so much information that cartographers did not use in the era of the traditional map-making. The professional GIS / web GIS map visualization will represent the BD and other map content step by step in an informative, interactive and attractive way using good map design. Existing obstacles in the process of automating the production of maps for a deeper understanding of the visualized content of the map, adding virtual reality / augmented reality (VR/AR) can be overcome by using modern GIS web software platforms, cloud technologies and performing geospatial big data analytics in real-time on supercomputers. With the advent of GPS technology nowadays, the understanding of users about a map, whose initial thought often leads them to navigation systems, has changed. For years, mobile navigation maps have greatly facilitated the orientation processes in urban and suburban environments, and soon the introduction of augmented reality can be seen in applications such as Nearest Tube (Graham, 2009), Google Street View, and more (Savova-Georgieva, 2018).

## CONCLUSIONS

In the modern world, the ancient cartography becomes one of the most advanced science using the computer science technologies and big data, coming from remote sensing, GPS, mobile companies, sensors, volunteers and many other sources. Reducing the cost of launching satellites in orbit together with increased coverage, availability of images, and better accuracy and frequency of the footage by UAV will significantly improve the quality and efficiency of Web mapping through automated image recognition.

The challenges of map makers now are to create better and cheaper cartographical products for less and less time. GIS / Web GIS mapping provides excellent opportunities for practical usage of GBD and its visualization on a very large scale (even up to 1:1) as well as 3, 4 and multi-dimensional maps, multi-layered maps, animated, with audio and video presentations. The development of modern cartography is determined by the processes of automatization of map production, more profound understanding of the visualized map content adding VR/AR, usage of cloud technologies and supercomputers with software platforms for map creation. This capability is used to capture, aggregate, classify, analyze and manipulate GBDs to maximize the useful value and integrate them into state-of-the-art maps based on cartographic science and experience. The collections of GBD and its storage, broadband internet connectivity, enlarged computer processing capabilities, and advanced analytical methods assure new possibilities to reuse and combine with newly generated GBD from different sources in the Web mapping process.

Modern cartography does not have limitations in the context of the creation of dynamic cartographical products using BD. But there is room for improvement of the mapping capabilities and for solving the problems of modern cartography. They concern ensuring the relevance and completeness of GBD worldwide and responding to the needs of users for more up-to-date and complete maps, regularly maintained due to the ever-changing environment. The role of cartographers is to actively participate in the overall processes of obtaining insightful information from GBD and its proper integration into automated cartographic production in the Web GIS environment. The efforts of the cartographic community should be directed on everyday work. Several ICA Commissions have to gather their research in several directions which will improve cartographical storage, analyses, manipulation and visualization of BD:

- Precise definitions of cartographical terminology should be done to correspond to contemporary science;
- Cartographical principles and indicators should be clearly defined;
- Standards in WM should be created;
- Good practices and examples should be popularized;
- National mapping agencies have to work in the above directions on a national, regional and international level;
- Joint international and domestic projects should be proposed for achieving the above-pointed tasks.

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## BIOGRAPHY

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# GIS, BIG DATA AND MAPPING IN DISASTER MANAGEMENT

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## **Abstract**

*Disaster management is an important global problem and is a major challenge, especially in the case of large-scale disasters which affecting many continents, regions, states and many different risks. Disaster can be conceived as a time and space-based event that results in different consequences for the population which affected in terms of economic, social and human life. Based on high evolution and development of technology, today's large volumes of data came from different sensors, including satellite sensors, smartphones, social media, internet of things (IoT), GNSS Global Navigation Satellite System, various tracking device, etc.. Where it is left to imply about that any person or device or sensor is a potential data generator and that in large volumes. The summary of all these data, whether created, captured, or repeated, is BIG data. In report of International Data Corporation (IDC) this large and growing volume of data referred to as Global Datasphere. Data is experiencing an extraordinary increase according to the IDC, in end of 2018 volume of globally BIG data estimated to be around 33ZB (Zettabytes) while in 2025 it is expected the data volume will be around 175ZB (Reinsel, Gantz, & Rydning, 2018). These data can be put into practice for monitoring, analysis and real-time implementation in disaster management. GIS and cartography can't ignore this trend so these disciplines will have to adapt and create methodologies and tools for BIG data. In this research, we have present theoretical aspects and the definition of these terms.*

**Keywords:** Big data; Geospatial; GIS; Cartography, Disaster Management;

## **INTRODUCTION**

Humanity has experienced many disasters throughout history, they have existed since the beginnings of our existence. They continue to happen without warning and are perceived to be ever increasing as to their size, complexity, frequency, and economic impact.

Disasters suddenly result in widespread economic and social consequences for affected populations, usually including physical injuries and hardship, loss of life, injury, sickness and other adverse effects on the physical, mental, emotional and social of humans, disruptive social and economic, along with property damage, asset and infrastructure destruction, environmental degradation, loss of services, failure of administrative and operational systems, and many more. The disaster can be conceived as a time-focused and space-based event that results in the above-mentioned consequences.

Since then, humans there have been attempts to forecast, prevent and manage disasters. Such events date even from the holy books as is the story of Flood forecasting at Noah's ark, where can be good and important lesson for us (Coppola, 2015). But above all, in case of these events, we need to care about a information or data about a disaster event. In Noah's story, the holy books show that flood information was divine. But today we cannot have it, but even if we have such divine claims, it would be unreliable to undertake the concrete steps for disaster management. "Access to information is critical to successful disaster risk management. You cannot manage what you cannot measure" – Margaret Wahlstrom. But today we can use various resources to take a decision about disaster management. In disaster, we can face many problems such as location, resources, knowledge, processes, cooperation etc. To identify these problems, we should try to answer questions like: What type of disaster? Where will it happen? And how hard will it be? These and other are the questions that form disaster management. All disasters have a temporal and geographic footprint that identifies the duration of impact and its extent on the Earth's surface. Location might have the biggest influence on disaster management response, and preparedness should facilitate a good response. To define the location, we will need to interdependent the resources of many geospatial data as well imagery, maps, data sets, tools, and procedures that tie every event, feature, or entity to a location on the Earth's surface and use this information for purpose of disaster management. Based on high technological evolution, today's huge volumes of data come from various sensors, including satellite sensors, smartphones, social media, Internet of Things IoT, Global Navigation Satellite System GNSS, various traces, radio frequency identification RFID, etc. Given these advances, we are

increasingly aware that any person or device or sensor is a potential data generator and creates complex sets of data currently called BIG Data (Coetzee & Rautenbach, 2017) (Noble, 2019). One of the most important data is the location, which is one of the basic elements. The same was the main topic from the time of Aristotle. Location must be expressed in some standard and readily understood form, such as latitude-longitude, street address, or position in some coordinate system. But BIG Data may include location in direct form in standard structures (sometimes known as traditional geospatial data source), but in most cases includes indirect information about location or unstructured data, where we have to develop the methods and tools for extracting location from this unstructured data (MacEachren, 2017).

## DISASTER MANAGEMENT, GIS AND BIG DATA

### Definition of Disaster

There are many researches and scientific papers about defining the term disaster. According to Turner, et al. (Turner & Pidgeon, 1997) and Shaluf, et al. (Shaluf, Ahmadun, & Said, 2003) no definition of disaster is accepted universally, this is because of the disaster's definition dependent upon the discipline using the term. While United Nations International Strategy for Disaster Reduction (UNISDR), in the publication of Terminology for Disaster Risk Reduction, Disaster define as "A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources" (UNISDR, 2009). A disaster is a function of the risk process (UNOG, 2004). It results from the combination of hazards, conditions of vulnerability and insufficient capacity or measures to reduce the potential negative consequences of risk, and expression with below equation.

$$(Vulnerability * Hazard) / Capacity = Disaster$$

(IFRC, International Federation of Red Cross, 2018)

Hazard is a potentially damaging physical event, phenomenon or human activity, which may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. Hazards can be single, sequential or combined in their origin and effects. Each hazard is characterized by its location, intensity and probability (Makoka, etj., 2005; UNOG, 2004). The conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards.

### Classifications of Disaster

Of all these widespread consequences of disasters, there is a need to classify them. They can be classified in several ways, depending on and based on their origin or cause, the extent of the disaster area, the way of occurrence, the duration, the number of victims (Rutherford & Boer, July 1983), (Marinova, 2014).

Classification according to origin:

- natural (floods, earthquakes, landslides, volcanoes, droughts, hurricanes, winter storms, tsunami, etc.),
- anthropogenic (explosions, transport accidents, chemical spills, willful acts such as arson or terrorism). etc.)

Classification according to territorial coverage:

- local (landslides, avalanches)
- regional (floods, hurricanes)
- global (earthquakes, tsunamis)

Classification according to the way of appearance:

- rapidly incurred (unexpected disasters which are impossible to predict)
- slowly incurred (occur very slow)

Classification according to duration:

- sudden – last seconds or minutes

- fast –last hours or days
- those that last for several months

In addition to the term disaster often other terms are used like emergency, crisis, catastrophe, but they are not the same things. The sudden nature of the event and the damage caused are the common features of all three terms, though emergency is not always of a sudden nature. UN- International Strategy for Disaster Reduction (UNISDR) in their report the terms crisis and emergencies refer to as the same terms. The analysis of authors Al-Dahash, et al. 2016 (Al-Dahash, Thayaparan, & Kulatunga, 2016) reveals that the sudden nature of the event and the damage caused are the common features of all three terms, though emergency is not always of a sudden nature. Further, many common features have been identified between disaster and crisis, so that they can be used interchangeably up to a certain extent. Also, by analyzing the relationships between the terms, the authors conclude that both a crisis and an emergency would lead to a disaster if neglected or mismanaged. All these definition is necessary in cartography and to cartographers for mapping object in multi-aspects, phenomena, processes and their results (Bandrova & Konecny, 2013).

### Definition of BIG Data

The BIG Data is a new term, development and rapid evolution of literature about that, has obstruct the development of a universally accepted definition. Definitions and explanations of BIG data may be different depending on the discipline used. Mauro, et al., 2016 (Mauro, Greco, & Grimaldi, 2016) in their research, the definition of BIG Data have categorized into four groups depending on where the phenomenon is focused: 1. Attributes of Data, 2. Technology needs, 3. Overcoming of Thresholds, 4. Social Impact. They also conclude that the core of the concept of BIG Data includes these aspects:

- ‘Volume’, ‘Velocity’ and ‘Variety’ to describe the characteristics of Information;
- ‘Technology’ and ‘Analytical Methods’, to describe the requirements needed to make proper use of such Information;
- ‘Value’, to describe the transformation of information into insights that may create economic value for companies and society.

They also have proposed for a consensual definition as: “Big Data is the Information asset characterized by such a High Volume, Velocity and Variety to require specific Technology and Analytical Methods for its transformation into Value.” (Mauro, Greco, & Grimaldi, 2016) According to them, an easy conceptualization of BIG Dates is built on three of the above mentioned Vs. Until the BIG data phenomenon is still evolving, researchers are suggesting to use other characteristics of “Vs” as: veracity, variability, viability, visualization, value (Noble, 2019).

*Table 1 Eight common Vs of BIG data (Noble, 2019)*

	<b>Vs</b>	<b>Description</b>
1	Volume	Massive amount of data collected
2	Velocity	Rate at which data arrives, is stored and retrieved for processing
3	Variety	Diverse structure and forms of data
4	Veracity	Trustworthiness of data
5	Variability	Changing nature of data
6	Viability	Relevance of the data
7	Visualization	Comprehensibility of data
8	Value	Data translated into learning, knowledge creation or economic gain

A more sophisticated BIG Data definition is that the data is very large, complex and very dynamic that traditional tools for gathering, storing, managing and analyzing are insufficient (Tsou, 2015).

For cartographers, a definition of Big Data is needed to include the complexities of human dynamics and spatiotemporal analysis. Cartographers can adopt the mapping concept to combine, integrate and reference multiple layers of data together and explore their dynamic spatial patterns in maps and visual graphs.

Geospatial BIG data is a special type of large data, where location data can be categorized in two classes. The first is geolocalized the big data at which the location is an additional, accessory attribute. These data are also known as traditional geospatial data or structured geospatial data, which may be points, such as GPS location by smartphones or client addresses from business intelligence systems. While the other category of geospatial BIG data are based on data in which location, shape, size, orientation, and spatial relationships are integral to unstructured data. These data come from sources such as sensor networks, collections of textual report, high resolution images from drones and satellites, and 3D laser scans. In the context of geospatial BIG data, space and time are naturally interconnected, as many large data sources include temporary information.

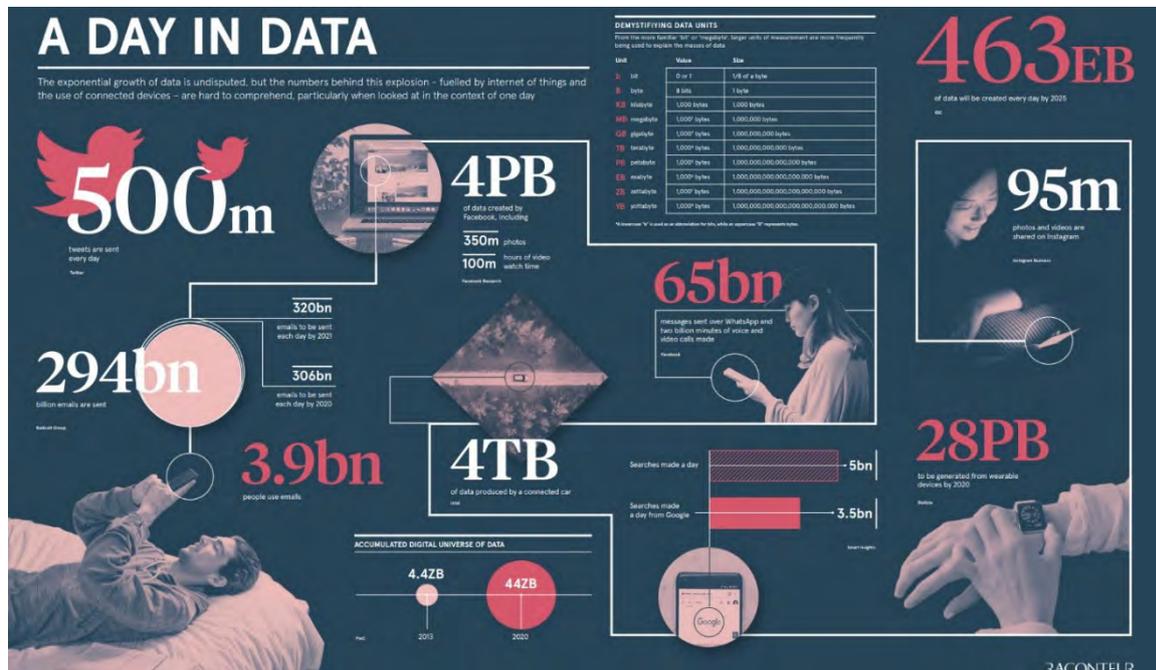


Figure 1 Infographic Raconteur,2019, it gives a picture of this new data reality, A Day in Data (Raconteur, 2019)

## CARTOGRAPHY AND GIS FOR DISASTER MANAGEMENT

People and societies have consistently made great efforts to reduce exposure to the consequences of disaster. So in a word they try to respond to disasters where all this effort is aimed at disaster management. Archaeologists have discovered and shown that our ancestors also faced many of the same risks that still exist today: starvation, inhospitable elements, dangerous wildlife, violence at the hands of other humans, disease, accidental injuries, and more. These early inhabitants did not, however, sit idly by and become easy victims. Evidence indicates that they took measures to reduce, or mitigate, their risks. The mere fact that they chose to inhabit caves is testament to this theory. Various applications of disaster management appear throughout the historical record. The story of Noah’s ark from the Holy Books, for example, is a lesson in the importance of warning, preparedness, and mitigation (Coppola, 2015).

Disaster Management is an applied science which research, by systematic observation and analysis of disasters, to improve measures relating to prevention, mitigation, preparedness, emergency response and recovery (Carter, 2008). In disaster management can face many problems such as location, resources, knowledge, processes, cooperation etc. To identify these problems, we should try to answer questions like: What type of disaster? Where will it happen? And how hard will it be? These and other are the questions that form disaster management. All disasters have a temporal and geographic footprint that identifies the duration of impact and its extent on the Earth’s surface. Location might have the biggest influence on disaster management response, and preparedness should facilitate a good response. To define the location, we will need to interdependent the resources of many geospatial data as well maps, imagery, , tools, data sets and procedures that tie every event or entity to a location on the Earth’s surface and use this information for purpose of disaster management. Location must be expressed in some standard and readily understood form, such as street address, latitude-longitude, or position in some local coordinate system. Today GPS is a very cost-effective way of associating an event, or entity with a location and, thus, of making data geospatial. Consistent use of this kinds of data sets makes possible their integration for a variety of purposes, including display as maps and use for modeling, procesing and analysis . Although the greater value of geospatial data is given by location, which is an essential part of any item of geospatial data, it is the ability to link a location to the properties of events, or entities at that location (National Research Council of National Academies, 2007).

Given that location and geospatial data can be made easier with the advancement of technology cartographic data may be digitally and wirelessly delivered in finalized form to the device in the hands of the user or he may derive the requested visualization from downloaded data in situ. One such prominent advance includes the possibility to derive maps very quickly immediately after the data has been acquired by accessing and disseminating maps through the internet. Real-time data handling and visualization are other significant developments as well location-based services, mobile cartography augmented reality. While the above advances have enabled significant progress on the design and implementation of new ways of map production over the past decade, many cartographic principles remain unchanged; the most important one being that maps are an abstraction of reality. Cartography is essential in many aspects of human societies. Disaster management is an example, where cartography plays a crucial role in all stages of the disaster management cycle. In the recovery phase, quick production of imagery of the affected area is required using depictions which allow the emergency teams to understand the situation on ground from a glance at the maps. Important on-going developments supporting the rescue work in the recovery phase are map derivation technologies, crowd sourcing and neo-cartography techniques and location-based services. The role of cartography in the protection phase of the disaster management cycle has always been crucial. In this phase risk maps are produced which enable governors, decision makers, experts and the general public alike to understand the kind and levels of risk present in the near and distant surroundings. Modern cartography enables the general public to participate in the modelling and visualizing of the risks their neighborhoods may suffer from on a voluntary basis. Modern cartography also helps to quickly disseminate crucial information. In this sense cartography is most relevant. Without maps we would be “spatially blind”. Knowledge about spatial relations and location of objects are most important for handling disasters and crisis situations or simply to be able to make good decisions. Cartography is also most contemporary, as new and innovative technologies have an important impact into what Cartographers are doing. Maps can be derived automatically from geodata acquisition methods such as laser scanning, remote sensing or sensor-networks (Gartner, 2014).

GIS can integrate information from different sources, scales, accuracies, and formats into a single source; and they could facilitate modeling, mapping and spatial decision support. These systems can be used for training in the preparedness phase, or in responding to actual disasters (Erden & Coskun, 2010). GIS can be a powerful tool for analysis purposes because each phase in the disaster management life cycle is geographically and spatially related to each other. According to Thomas et al (2003), geo-technologies are at the center of the disaster management life cycle and GIS support the decision-making process by providing people with a tool for assessing and analyzing the geographic nature.

### **GIS and Disaster Planning, Preparedness and Cartographical Response**

In this part of the paper we focus is on introducing the GIS and cartographic concept for disaster preparedness, and continuing to GIS for disaster planning, given the close link between readiness and planning. One time with this part we also enter the entrance as it is also the first phase of disaster management cycles. Why should we have planning and preparedness? For example, when a disaster event occurs, it is not the time to meet to make plans and establish operations such as acquiring essential base data layers, conducting GIS training, formulating data-sharing agreements with other organizations, or running what-if scenarios. These types of activities must be done before an actual event occurs. Introducing new concepts, datasets, technologies, and ways of conducting disaster management activities during a disaster response can divert precious time, attention, and resources away from time-critical, pressing needs. Thus, it is essential that proper plans are in place before an event occurs (Tomaszewski, Geographic Information Systems (GIS) for Disaster Management, 2015). The term preparedness, however, is itself somewhat problematic as it implies some measurable level that can be achieved. For example, stating that one is well prepared—what does that really mean? Preparedness levels are difficult to measure when one considers that disasters operate at multiple scales and the multitude of factors that influence preparedness such as culture and history (Phillips , Neal, & Webb , 2012).

From a mapping and spatial thinking perspective, also consider how prepared or perhaps more accurately, underprepared, average citizens are in terms of using maps to make decisions and understand situations they might face. For example, in today’s world, most people rely so heavily on their Global Positioning System (GPS) devices, they are unable to make routing decisions or other navigation tasks if GPS capabilities are not available to them. If power, the Internet, or even general use of phones, tablet computers, and other technology support mechanisms are lost, serious problems can occur because people rely too much on such technology and not being able to function without it. Although disasters manifest themselves in a wide variety of forms based on numerous underlying hazards coupled with the idiosyncrasies of people, places, culture, and history, it is prudent to prepare and curate certain map data sets common to all disaster situation types. These map datasets can be considered reference data layers as per the conversations on different map types. From these essential reference map layers, other layers particular to a geographic context can be included to address specific needs and disaster management functions. Always must carry and remember, that as you develop your own data resources through disaster planning activities, it is essential to maintain proper and updated metadata so that the data you create or acquire is easily shared and understood by others that may need to use it. Although data is at the core of GIS, it is equally important that planning and preparation activities are

conducted around GIS technology itself. For example, some commercial GIS technology requires regularly updated licenses to continue working with the technology, and require management of general IT computer issues such as operating system upgrades, virus protection, and other activities to keep computing infrastructure running. If you are the “GIS person” that has to work with an IT support person, it is very important to develop a good relationship with the IT support person so that your GIS technology is in place and ready to go when a disaster occurs. Additionally, the time afforded during the planning phase is a good time to stay up to date on the newest trends in GIS technology as new features are constantly being added, revised, and modified as the technology grows. Thus, it is important to stay up to date on new technology, new datasets, and other aspects of GIS that are potentially relevant to disaster management activities. Common GIS Tasks for Disaster Planning and Preparation Activities can be:

- Evacuation Route Planning
- Evacuation Zone Planning
- Public information and Citizen Participation
- Scenario Modeling to Answer What-If

Finally, in addition to basic disaster preparedness communications to citizens, is the idea of preparing citizens to think spatially and understand how to use maps and other spatial navigation devices during a disaster situation. As discussed previously in this book, the continued increase of devices such as smartphones with built-in GPS capability is creating a societal effect where many citizen are less capable of spatial navigation and reasoning without assistance from a GPS device. It is important that people still understand how to use paper maps as these are what will be available in the event that there is no power or ability to use GPS.

Disaster response is perhaps the most widely known disaster management cycle phase outside of professional disaster management practitioner communities. For example, when very large disasters or even catastrophes occur, images of destroyed buildings, burning streets, and displaced people are often what the news media shows. Most disasters generally do not have high levels of chaos and the people affected generally display a high level of resilience and calm (Phillips , Neal, & Webb , 2012). Regard disaster response is most publicly visible use of GIS and mapping in general. For example, natural hazards such as hurricanes are often portrayed in the news media using maps that show the estimated time of landfall and these maps serve as a type of citizen early warning.

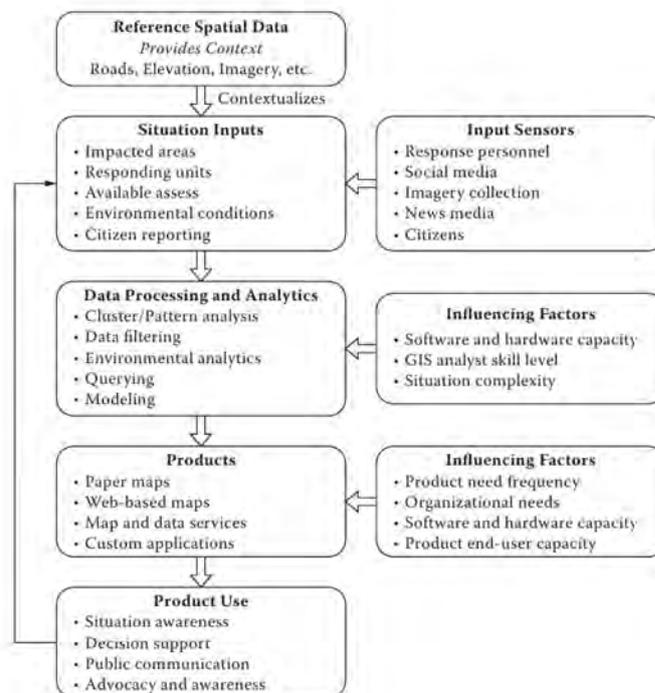


Figure 2 A disaster response GIS product framework. Source (Tomaszewski, *Geographic Information Systems (GIS) for Disaster Management*, 2015)

Furthermore, maps and GIS are often used by the news media to portray how a disaster situation and its subsequent response are being handled by various disaster management practitioners. Finally, maps and GIS can conjure images of

large command centers and emergency operation centers with large screens portraying maps that are the embodiment of situation awareness and coordination activities. Like the others cycle, the incredibly wide variety of potential disaster situations make it difficult to predefine all types of GIS and disaster response activities. Unlike the fundamental question of "who, what, where, when, why and how" that GIS answer, during the disaster response the answer to the questions "where and what" are the most important. The time-sensitive nature of disaster response also dictates that maps and other spatial support devices are capable of keeping up with the time-sensitive nature of the disaster response situation and be able to generate disaster response GIS products that are readable and consumable for relevant audiences that need them, like Thematic Maps, Spatial Statistics, Hot Spot Mapping, Density Mapping, Real-Time GIS. It is important to consider disaster response GIS products. In figure below a disaster response GIS product development framework. Reference data collected during the planning phase. Referenced data provide essential context and ultimately contextualize a variety of situation inputs derived from a variety of input sensors. Situation inputs themselves may then be processed and analyzed using a variety of techniques such as clustering pattern analysis discussed in this chapter and other GIS analytical techniques. Data processing and analytics will also be influenced by factors such as the specific software used, the computing hardware power available, the skill level of the GIS person, and the situation complexity. After being processed and analyzed, specific products then can be developed. Development of specific products is also influenced by factors that must be accounted for.

To ensure a successful planning and response effort for emergencies, there are a set of critical elements that are important at all response levels from the local to the national. Testimony to the committee identified a number of geospatial elements that were especially relevant. These are identified and explained below (National Research Council of National Academies, 2007):

- Integration,
- Human Services,
- Training,
- Data Access,
- Data Quality,
- Data Gathering,
- Data Improvement,
- Information Delivery,
- Hardware and Infrastructure.

## **GIS AND DISASTER RECOVERY AND MITIGATION**

Disaster recovery is final phase of disaster management. Disaster recovery is focused on the transition of the built environment, business, people, and their communities back to a state of acceptable operation after an event such as an earthquake or hurricane, which requires long-term planning and commitment to achieve recovery goals. Disaster recovery will operate at varying space and time scales subject to the nuances of the places undergoing the recovery. For example, disaster recovery can also be seen as a part of the disaster response phase in the case of short-term recovery efforts such as returning people that have been temporarily displaced to their homes. Furthermore, disaster recovery can be viewed as a disaster planning activity in terms of developing plans for recovery such as contracts for debris removal that are implemented once an actual disaster occurs or making observations of disaster zones using remote sensing technologies to measure redevelopment progress. There are a wide range of roles that GIS can play in the recovery process. For example, GIS may be called upon to identify areas for redevelopment projects or to recalibrate vulnerability models to help predict future disaster impacts. Furthermore, long-term disaster recovery often does not receive the media attention that other disaster phases do, such as disaster response. Thus, the use of GIS must be developed to a capacity that it can remain available and operational for the duration of a long-term disaster recovery and not simply be a novel technology that is used to help with the disaster response but then forgotten about once the immediate disaster situation stabilized. This issue is particularly pronounced at the international level when disasters strike countries that have a low existing state of GIS capacity including lack of computing infra- structure, reference datasets, skilled GIS personnel, lack of effective disaster management culture, and other context-specific issues that require external GIS support and assistance, which may eventually disappear once the initial recovery and stabilization has occurred. Thus, any GIS assistance provided for long-term disaster recovery must also include plans for the long-term sustainability and transition of GIS capacity to relevant stakeholders. Long-term disaster recovery makes for novel use of GIS in the overall disaster management cycle in that the process of rebuilding, redevelopment, rethinking, and

planning of communities are clearly connected to GIS roots in geography, planning, and overall spatial thinking. Figure below taken from the US Federal Emergency Management Agency (FEMA) National Recovery Framework, is a helpful guide for outlining various geographical aspects of disaster recovery. The specific uses of GIS are support mechanism for these geographical aspects of disaster recovery. For example, in the short-term recovery stage of transition from mass care and sheltering to regular housing, GIS can be used for location-specific planning and coordination such as identifying people in specific shelters, identifying specific locations to which they can be moved, and monitoring the rebuilding and redevelopment of houses and neighborhoods (Tomaszewski, Geographic Information Systems (GIS) for Disaster Management, 2015).

Geocollaboration is the idea of using maps, spatial representations, and map annotations to facilitate processes of collaboration that themselves are spatial in nature (Tomaszewski, Geocollaboration, 2010). Although relevant to all disaster management phases, the idea of geocollaboration can play a particularly important role in disaster recovery as a means to coordinate the spatial activities of a variety of actors involved in long-term recovery.

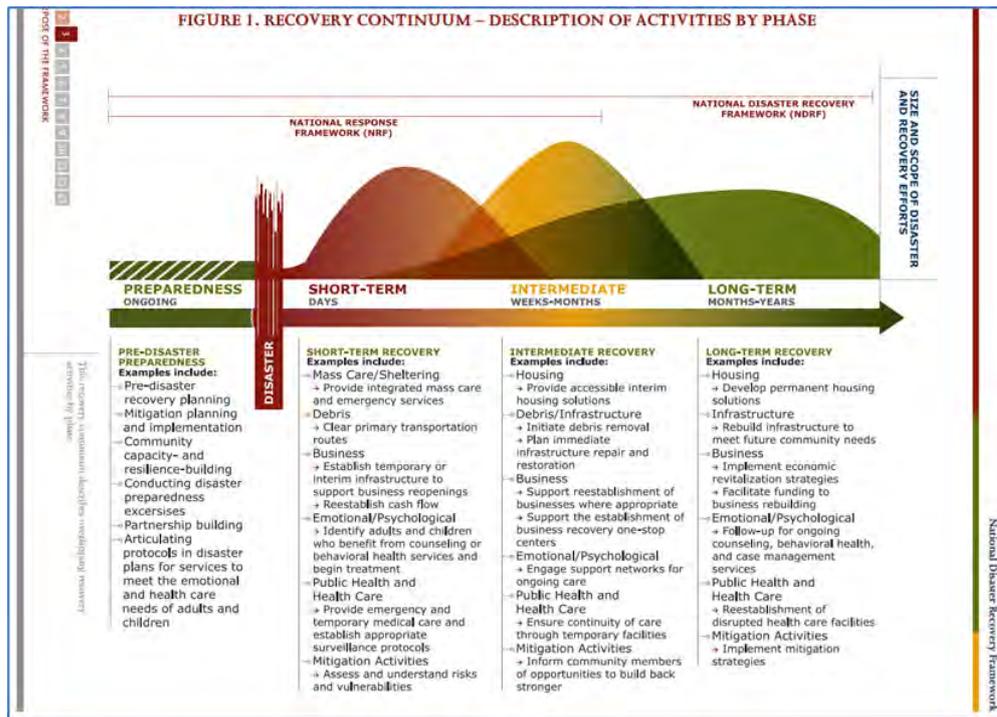


Figure 3. Recovery continuum – description of activities by phase source: (FEMA, 2011).

A disaster mitigation activities can be intertwined with disaster recovery activities. The reason for this is that, as the built environment, the community, and any other aspects of a local geographical context are recovered, restored, and replaced, it is the optimal time to incorporate mitigation strategies, for example, reconstructing buildings to be more resilient to earthquakes or moving houses outside of flood zones. Disaster mitigation has been defined as “the capabilities necessary to reduce loss of life and property by lessening the impact of disasters” (US Homeland Security, 2013). GIS can play a particularly important role in disaster mitigation activities through the modeling of hazard and risk scenarios to identify potential physical, virtual, and social vulnerabilities, that can ideally be mitigated or reduced through increased resilience efforts. As an example, using earthquake risks, GIS data layers can be created that inventory housing characteristics such as building material and structural types in relation to the location of earthquake fault lines and landslide risks to determine how vulnerable the built environment is to a potential earthquake. Like all disaster management cycle phases, disaster mitigation is no different in that the use of GIS for disaster mitigation will be sensitive to the nuances and idiosyncrasies of the underlying people, places, culture, history, and overall geographic context being represented and analyzed in GIS. Furthermore, disaster mitigation for GIS often requires interdisciplinary connections across multiple areas such as earth science, sociology, and environmental science. These interdisciplinary connections between GIS and other disciplines are very important in that that the use of GIS for disaster mitigation activities must be guided by clear understanding of the underlying scientific principles and processes inherent in a wide range of natural and man-made hazards, incident types, and underlying vulnerabilities.

## CONCLUSIONS, CHALLENGES AND FUTURE ACTIVITIES IN DISASTER MANAGEMENT

This research explores concepts and theoretical definitions of disasters, their management, role of cartography and GIS in disaster management and the impact of BIG data on the challenges that await this discipline. As long as we have seen that there is no standard definition for BIG data, we may consider that they are structured and unstructured volumes of large data that cannot be easily captured, stored, manipulated, analyzed, managed and presented by traditional hardware, software and database technologies. Researching and creating new and efficient methodologies for processing Geospatial BIG data will minimize the problems of response teams to make the right decisions, where in most cases so far these decisions are based on incomplete and inaccurate information. Now with BIG data and their analysis it becomes easier to send real-time information to residents when approaching a disaster. With BIG Data we can analysis of the area where the elderly population is concentrated and how can they be evacuated (Joshi, 2017).

Processing, analyzing and visualizing geospatial BIG data in disaster management is becoming more and more important, especially the trend of increasing the use of various personal or social, scientific devices that are the most potential generator of BIG data. In report of International Data Corporation(IDC) this large and growing volume of data referred to as Global Datasphere. They have published that by the end of 2018 the volume of BIG data globally is estimated to be around 33ZB (Zettabytes) until in 2025 the data volume is expected to be 175ZB (Reinsel, Gantz, & Rydning, 2018).

Therefore, cartography and GIS need innovation in the field of processing, analysis and visualization of BIG Data and they should strive for the increasingly sophisticated handling of this data either in terms of methodology, software and hardware.

One of the other challenges is access to these data in the event of disasters. Big Data and other necessary geospatial data are scattered across intuitions, agencies and organizations. So in such cases there are many impediments to rapid access, the skilled personnel needed to work with the BIG data and tools are often not available in sufficient quantity but also on constantly changes in technology environments, causing confusion. Except that the data may be in different institutions and organizations they may also be in different professions (National Research Council of National Academies, 2007).

Regarding that the collection of geospatial BIG data is being made quite easily thanks to advancements in sensors and communication technology, special attention should be paid to building platforms for the sharing of this collected data (Jae-Gil Lee, 2015).

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# DEVELOPING OF THE ALBANIAN GLOBAL MAP DATASET; CASE STUDY: RASTER LAYERS

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## **Abstract**

*One of the main aims of the infrastructural organization of geospatial data is to provide users to be capable to acquire complete, exact and updated dataset at the right time. This is necessary for providing of an ideal environment, where all stakeholders can work collaboratively in an effective way, in order to solve environmental issues and to fulfill their target goals.*

*Data standardization of Global Map as contributor of GSDI and GEOSS have been analyzed through developed Albanian GM dataset. As main components that were taken into consideration for performing research analyses are data and metadata, technology, institutional framework, policies, interoperability, network services, search opportunities, and data sharing within GSDI.*

*The necessity of infrastructural organization of geospatial data in global level, by including official geospatial datasets developed by the national mapping organizations, for environmental monitoring, protection, and early warning management in international level, are the main findings of this research study.*

**Keywords:** *Global Map, Albania, GM raster data, land use, land cover, elevation, vegetation*

## **INTRODUCTION**

The main purpose of Global Mapping (GM) project is global data collection of geospatial data from all states and interested organizations to develop and to have easy access to digital geographic information at global level of scale 1:1.000.000, aimed to be used to equip the implementation of international/global agreements and conventions for environment protection, supervision of major phenomena of the environment and encourage economic growth. GM also intend to contribute in development of spatial data in global level (GSDI-Global Spatial Data Infrastructure, www.gsdi.org).

The Republic of Albania within the project for the compilation of the global map is represented by the State Authority for Geospatial Information (ASIG), as the responsible institution for Albania's cartography at the national level. Preparation of Albania's GM data has been proceeded in academic level within the PhD study research in geodesy

department of the Polytechnic University of Tirana, with aim to support, help and improve young cartography in Albania. It was published officially on July 14th 2016 (Lubishtani, Idrizi 2016).

Existing topographic maps in scale 1:25.000, high resolution orthophoto images, as well as the official data from governmental institutions has been utilized as source data for Albanian GM datasets. In this paper in details will be presented whole process of data preparing, quality and outputs of Albania's GM data, with focus on raster data DEM, land cover, land use and vegetation with 100m spatial resolution.

## GLOBAL MAP

Global Map is a set of digital maps that accurately cover the whole globe to express the status of global environment. It is developed through the cooperation of National Geospatial Information Authorities (NGIAs) in the world. An initiative to develop Global Map under international cooperation, the Global Mapping Project, was advocated in 1992 by Ministry of Construction, Japan (Idrizi 2005).

Due to negative experiences of international world map with a scale of 1: 1,000,000 dating from 1891, the development of technology and the need for recognition of global geospatial data and these data are as update, in 1992 in RioDeZhaniero in Brazil was proposal creation world global digital mapping in scale 1: 1,000,000 (Idrizi 2005).

The main purpose of this project is global data collection of geospatial data from all states and interested organizations to develop and to have easy access to digital geographic information at global level of scale 1:1.000.000. It is aimed to be used to equip the implementation of international/global agreements and conventions for environment protection, for supervision of major phenomena of the environment and encourage economic growth (Nagayama 2016). GM also needs to contribute in development of spatial data (GSDI-Global Spatial Data Infrastructure, and GEOSS-Global Earth Observation System of Systems).

Since the world as a whole is divided into different continents and countries that follows the various institutions which produce geospatial data with the same or different standards, it is thought that these geospatial data to have same standards, so they can be used, to be exchanged to reach the analysis of a problem more easily and with low cost. The primary objective of Global Map project is to contribute to the sustainable development through the provision of base framework geographic dataset, which is necessary to understand the current situation and changes of environment of the world (Sasagawa etAll 2017).

Global Map is fundamental digital geospatial information being developed to cover the whole land of the globe. It is an effort central to the Global Mapping Project. The purpose of the Global Map is to accurately describe the present status of the global environment in international cooperation of respective National Mapping Organizations (NMOs) of the world, aimed for (Idrizi 2006):

- Monitoring and early warning systems for natural disasters;
- Developing ecosystem, drainage basins framework for environmental assessment;
- Monitoring and management of natural resources;
- Quantifying trans boundary issues;
- Assessment of the trends of environment changes;
- Rapid response capability/early warning;
- Local, national and multinational physical development planning;
- Environmental priority setting, analytical studies over large areas and
- Informed decision-making of policy makers with a strategic database.

The benefits of participation in Global Mapping include: Joining the world community of surveying and mapping organizations will facilitate the acquisition of the latest information and knowledge of digital geographic data development and service (Idrizi 2018); it would also facilitate to raise the status of the organization by active participation in international activities and the contribution to sustainable development which is the final goal of Global Map.

There are two series of Global Map. One is National and Regional version which each participating NMOs are basically in charge of development of their own Global Map. The other is Global Version which is developed by using satellite imagery with cooperation between participating NMOs and supporting stakeholders. Global version covers only in vegetation layer and land cover layer (Lubishtani 2018).

GM national and regional version database contains four vector layers (population centers, transportations, drainage and boundaries) and raster layers (land cover, land use, vegetation and elevation) at scale 1:1.000.000 for vector and with spatial resolution of 30" (arc seconds of longitude and latitude) for raster layers (Lubishtani, Idrizi 2016).

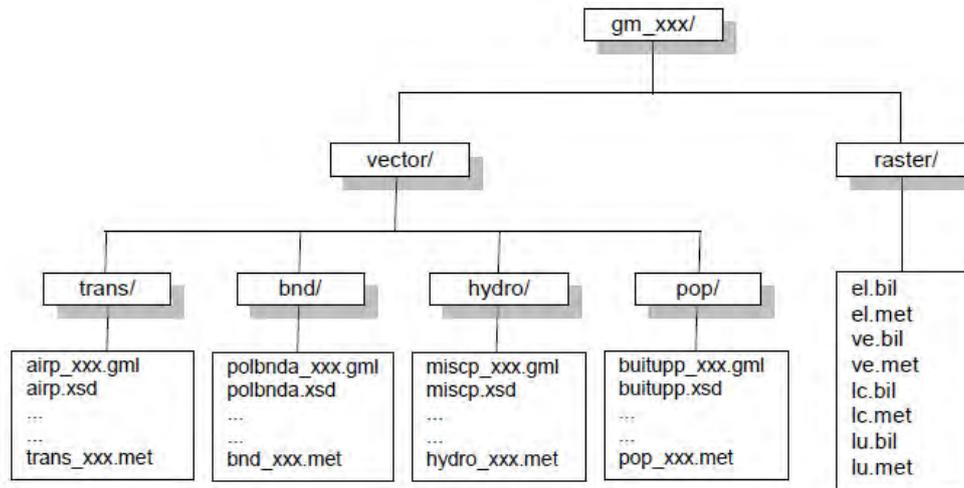


Figure 1. Directory Structure (Global Map Specifications Version 2.2)

GM data structure is defined on Global Map specification documents 1.1, 1.2, 1.3, 2., 2.1 and 2.2, based on ISO/TC 211 international standards. i.e. ISO19136 for GML format, ISO 3166 for nation codes, ISO 19115 standard of metadata of V2 by using ISO 19139 for encoding, ISO 15046 standard of metadata of V1, ISO639 for language code, and ISO8601 for date code (Idrizi etAll 2011). In next figure scheme of GM standards is given:

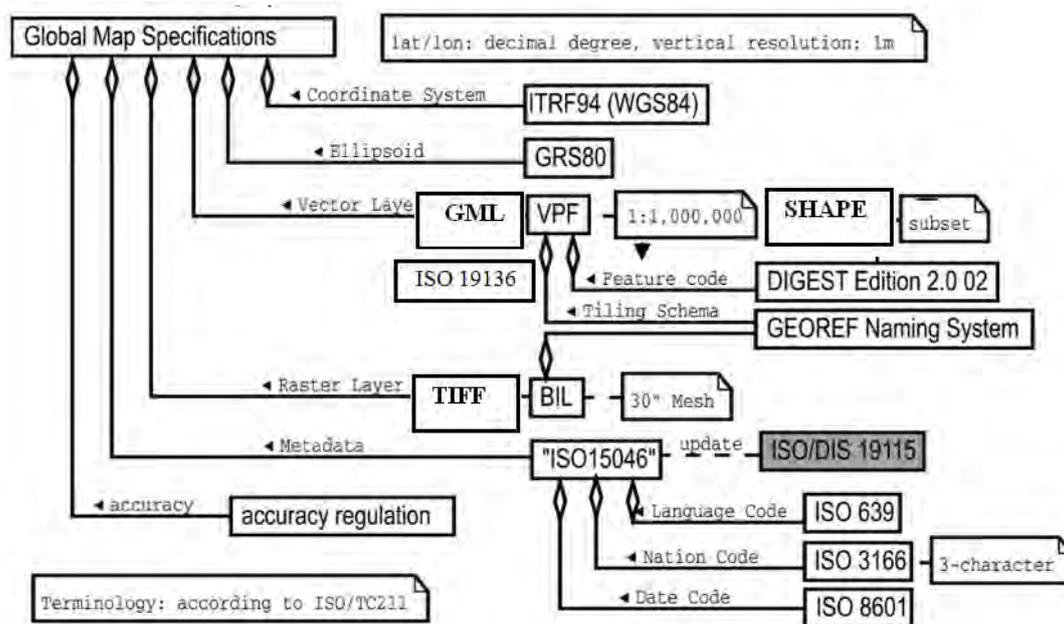


Figure 2. Scheme of GM standards (Idrizi etAll, 2011)

Despite the maps prepared in local/national standards, Global Map dataset enable (Idrizi, 2006):

- All data of Earth to be in one place;
- With the same attributes;
- In the same format;
- In the same coordinate system;
- In the same scale and
- With similar accuracy.

Increasing demand and the need to be qualified data geospatial and their use for achieving a result set and necessary and cost as little as possible, many European countries and the Balkans have handed over the data as geospatial on the global map with a scale of 1 1.000.000 and as such as Macedonia in 2006, Romania in 2009, Bulgaria in 2009, Kosovo in 2010 and Albania in 2016. All

European countries have joined the GM through EuroGlobalMap ([www.eurogeographics.org](http://www.eurogeographics.org)), unless countries like Montenegro, Belarus and Bosnia and Herzegovina are not joined GM (LubishtanietAll 2018). Currently, 168 countries/16 regions participate in the Project. Among them, data of 114 countries/8 regions have been released. Version 2 data are for 90 countries/4 regions (GM newsletter, no.81, 2016).

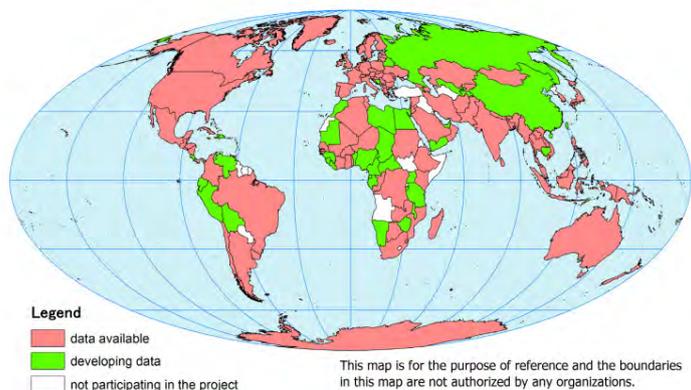


Figure 3. Coverage of countries with Global Map datasets (GM newsletter, no.81, 2016)

## GLOBAL MAP DATASET OF ALBANIA

The Republic of Albania participate in global mapping project since 30.06.2016 in Level B (*Level B* mean that institution will prepare the data set of own country), represented by the State Authority for Geospatial Information (ASIG), as the responsible institution for Albania's cartography at the national level. Preparation of Albania's GM data has been proceed in academic level within the geodesy department of the Polytechnic University of Tirana, with aim to support, help and improve young cartography in Albania. Existing topographic maps 1:25.000, high spatial resolution orthophoto images, as well as the official data from governmental institutions has been utilized as source data (Lubishtani, Idrizi 2016).

[www.iscgm.org/aboutus/ngias.html](http://www.iscgm.org/aboutus/ngias.html)

Country or Region	Organization	Details
Africa		
		See more
Asia		
		See more
Europe		
Republic of Albania	State Authority for Geospatial Information	Released
Andorra	Ministry of Urbanism and Environment	EuroGlobalMap
Austria	Federal Office of Metrology and Surveying	EuroGlobalMap
Belarus	The State Committee on Property of the Republic of Belarus	Direct
Belgium	National Geographic Institute General Administration of Patrimonial Documentation	EuroGlobalMap
Bosnia and Herzegovina	Federal Administration for Geodetic and Real Property Affairs Republic Authority for Geodetic and Property Affairs of Republic of Srpska	
Bulgaria	Geodesy, Cartography and Cadastre Agency	Released
Croatia	State Geodetic Administration of the Republic of Croatia	EuroGlobalMap
Cyprus	Cyprus Department of Lands and Surveys	Direct+Euro
Czech Republic	Czech Office for Surveying, Mapping and Cadastre	EuroGlobalMap
Denmark	Danish Geodata Agency	EuroGlobalMap
Estonia	Estonian Land Board	Direct+Euro
Finland	National Land Survey of Finland Finnish Geodetic Institute	EuroGlobalMap
France	National Institute of Geographic and Forest Information	EuroGlobalMap
Georgia	The State Department of Geodesy and Cartography	Released
Germany	Federal Agency for Cartography and Geodesy Working Committee of the Surveying Authorities of the Laender of the Federal Republic of Germany	Direct+Euro

Figure 4. Part of list of participants in GM project ([www.iscgm.org](http://www.iscgm.org), 30.06.2016)

Albania is one of the last European countries that has published database at Global Map, exactly on 14th July 2016 has published the vector and raster database according to technical specification V2.2. Official source data that have been used for developing Albanian GM dataset were supplied by official governemantal institutions: State Authority for Geospatial Information (ASIG), Institute of transportation, Albanian Institute of Statistics (INSTAT), Military Geographical Institute of Albania, and Ministry of Urban Development (Lubishtani, Idrizi 2016).

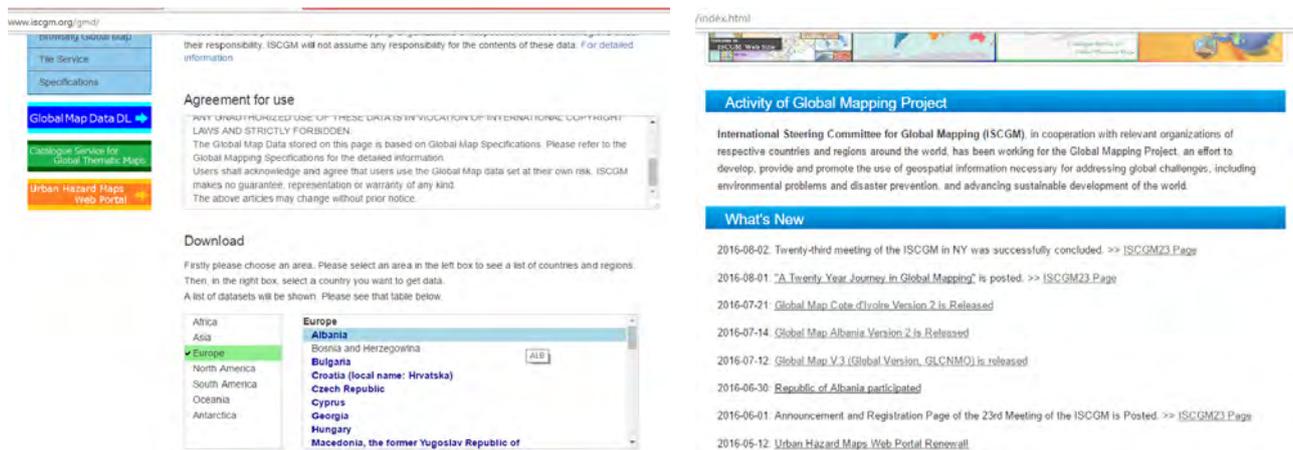


Figure 5. Albanian GM data (www.iscgm.org/gmd, 30.08.2016)

## GLOBAL MAP RASTER DATASET OF ALBANIA

Global Map raster data is in simple binary raster format without the embedded header – BIL (Band Interleaved by Line) format, pixel information stores band by band for each line, or row, of the image. Vegetation, Land Cover and Land Use are in 8 bit unsigned data and the elevation data in 16 bit signed in Motorola (big-endian) byte order. On October 10th 2008 the existing GM raster data (national/regional version) has been published in TIFF format also, which is more simple and user-friendly format (Idrizi etAl 2010).

All layers are identified with two letters, which explain the name of layer (el – elevation, ve – vegetation, lc – land cover, lu – land use). The file names have the form ww\_XXX.zzz where:

- ww identifies the theme,
- xxx identifies the country code which is defined at ISO 3166 Nation Code, and
- zzz is the extension identifying the data (bil or tiff) or the header (hdr).

Raster grid cells are arrayed on a horizontal coordinate system in degrees of latitude and longitude referenced to ITRF94 and GRS80, with 30" spatial resolution, and tiling dividing system by second pair with 1° by 1° standard GEOREF division (Idrizi etAl 2011). The following groups of features are stored as raster layers:

**ELEVATION:** The vertical distance between the surface of the earth and the standard sea level that the nation has defined. Vertical units represent elevation in meters above Mean Sea Level (MSL). The elevation layer is in a Band Interleaved Line (BIL) format with 16-bit elevation value and 30" horizontal grid spacing. The values of elevation are represented in meters, in which the codes -9999 are areas masked with the sea.

**VEGETATION:** Percent tree cover data by an integer value from 0 to 100 will be as vegetation layer. For Vegetation layer, a modified water legend with 20 classes is adopted.

**LAND COVER:** GLCNMO global legend are used for land cover layer. Land cover is the observed (bio) physical cover on the earth's surface (Di Gregorio and Jansen, 1998). In Global Map specification the codes of Land Cover Characteristics of GM V1/V2 national/regional version is adopted for International Geosphere-Biosphere Programme (IGBP). IGBP has 17 Land Cover classes. The global land cover layer is product of a collaboration between USGS and the University of Maryland, Department of Geographical Sciences.

**LAND USE:** Codes developed for the Global Map are adopted. Land Use is a series of operations on land, carried out by humans, with the intention of obtaining products and/or benefits through using land resources (de Bie 2000).

Classification of land cover data was made in two ways: one was global classification and the other was national/regional classification. Land cover global version dataset contain 20 land cover classes, and another additional class with code 255 which represent the areas without data. In table 7 are represented the comparison between the Land cover classes in national/regional with 17 and global version with 20 classes (Idrizi etAl 2010).

Table 1. Types of raster data of GM V1/V2 national and regional version (Idrizi etAll 2010)

Land Cover		Land Use		Vegetation	
Description	Code	Description	Code	Description	Code
Evergreen Needleleaf Forest	1	Forest	10	Tropical rainforest	10
Evergreen Broadleaf Forest	2	Mixture	20	Hydrotropic forest	20
Deciduous Needleleaf Forest	3	Grassland/shrub	30	Grassland in tropical or sub-tropical zone	30
Deciduous Broadleaf Forest	4	Agricultural area	40	Semi desert in tropical or sub-tropical zone	40
Mixed Forest	5	Wetland	50	Desert in tropical or sub-tropical zone	50
Closed Shrublands	6	Barren area	60	Evergreen thick-leaved forest	60
Open Shrublands	7	Built-up area	70	Evergreen broad-leaved forest	70
Woody Savannas	8	Drainage/water	80	Deciduous broad-leaved forest	80
Savannas	9	Ocean	90	Grassland in temperate zone	90
Grasslands	10			Semi-desert in temperate zone	100
Permanent Wetlands	11			Desert in temperate zone	110
Croplands	12			Northern coniferous forest	120
Urban and Built-Up	13			Tundra	130
Cropland/Natural Vegetation Mosaic	14			Water body	140
Snow and Ice	15			Ice and snow	150
Barren or Sparsely Vegetated	16			Wetland	210
Water Bodies	17			Mixed forest	220
				Mixed land	230
				Non natural	240
				Unclassified	250

Table 2. Comparison between classes of Land Cover global and national/regional versions (Tateishi 2005)

Land cover global version	Land cover – national and regional version
1. Broadleaf Evergreen Forest	2. Evergreen Broadleaf Forests
2. Broadleaf Deciduous Forest	4. Deciduous Broadleaf Forests
3. Needleleaf Evergreen Forest	1. Evergreen Needleleaf Forests
4. Needleleaf Deciduous Forest	3. Deciduous Needleleaf Forests
5. Mixed Forest	5. Mixed Forests
6. Tree Open	8. Woody Savannas 9. Savanna
7. Shrub	6. Closed Shrublands 7. Open Shrublands
8. Herbaceous, single layer	10. Grasslands
9. Herbaceous with Sparse and Tree/Shrub	
10. Sparse Herbaceous/Shrub	16. Barren
11. Cropland (herbaceous crops except rice)	12. Croplands
12. Rice, paddy	
13. Cropland/Natural Vegetation Mosaic	14. Cropland/Natural Vegetation Mosaics
14. Tree-Water (Brackish to Saline)	11. Permanent Wetlands
15. Wetland	
16. Bare area, consolidated (gravel, rock)	16. Barren
17. Bare area, unconsolidated (sand)	
18. Urban	13. Urban and Built-up
19. Snow/Ice	15. Snow and Ice
20. Water Bodies	17. Water Bodies

According to point 3.2.2 (data structure) of GM specification V2.2, the raster data with higher resolution can be developed, such as 3 or 15 arc seconds, in order to enable resampling procedure with 30 arc-second data. In a case of Albanian raster dataset of GM data, we used the highest option of spatial resolution, and four raster layers have been developed with spatial resolution of 3 arc-seconds, which is equal to about 100m spatial resolution.

### Land cover dataset of Albanian GM

IRS, SPOT, Landsat and RapidEye satellite images, dual coverage, orthophotos, and topographic maps 1:25000 are used for developing Land Cover dataset for Global Map of Albania. The classes which are included for Albanian land cover dataset are: 2,3,5,6,7,8,9,10,11,13,15,16,17,18,20, and 255, while not included classes are: 1,4,12,14, and 19. In below table are given countet areas of Albanian national area with land cover classes according to GM specification 2.2.

Table 3. Coverage of Albanian national area with Land Cover classes according to GM Specification 2.2

Value	Count	Area [km2]	Value	Count	Area [km2]	Value	Count	Area [km2]
2	967749	6332	8	521750	3414	15	12537	82
3	139143	910	9	427294	2496	16	27441	180
5	65632	429	10	228933	1498	17	32167	210
6	91671	600	11	722383	4727	18	113523	743
7	556290	3640	13	432418	2830	20	54343	356
255	61	1						

### Land use dataset of Albanian GM

For creating of land use of Albania, high resolution orthophoto images, Landsat, CORINE, and topographic maps 1:25000 were used. The classes which are included for land cover are: 10, 30, 40, 50, 60, 70, 80, and 255, while 20 and 90 classes have not been included. In below table are given countet areas of Albanian national area with land use classes according to GM specification 2.2.

Table 4. Coverage of Albanian national area with Land Use classes according to GM Specification 2.2

Value	Count	Area [km2]	Value	Count	Area [km2]
10	1264195	8272	60	59608	390
30	1734267	11348	70	113523	743
40	1154801	7556	80	54343	356
50	12537	82	255	61	1

### Vegetation dataset of Albanian GM

Based on results derived from analyses and processing vegetation of Albania's GM, the vegetation dataset of Albania have been developed based on high resolution orthophoto images, LandsatTM/NDVI and topographic maps 1:25000. In next table are given countet areas of Albanian national area with vegetation classes according to GM specification 2.2.

Table 5. Coverage of Albanian national area with Vegetation classes according to GM Specification 2.2

Value	Count	Area [km2]	Value	Count	Area [km2]	Value	Count	Area [km2]
1	710	5	34	4988	33	67	45926	301
2	1471	10	35	6234	41	68	44559	292
3	2268	15	36	8731	57	69	43663	286
4	964	6	37	11475	75	70	38053	249
5	587	4	38	10125	66	71	30884	202
6	3143	21	39	9156	60	72	37892	248
7	2030	13	40	9143	60	73	53247	348
8	1416	9	41	9373	61	74	50257	329
9	3559	23	42	11509	75	75	53798	352
10	3840	25	43	14314	94	76	47448	310
11	2782	18	44	14078	92	77	47513	311
12	1904	12	45	10292	67	78	34341	225
13	1314	9	46	8254	54	79	31759	208
14	1426	9	47	10925	71	80	47174	309
15	2974	19	48	12504	82	81	54030	354
16	2901	19	49	15347	100	82	45190	296
17	2711	18	50	18690	122	83	38140	250
18	1759	12	51	18973	124	84	38006	249
19	1475	10	52	22143	145	85	35801	234
20	2045	13	53	18120	119	86	29234	191
21	3027	20	54	15236	100	87	32376	212
22	4651	30	55	19454	127	88	32163	210
23	7761	51	56	17943	117	89	28933	189
24	6606	43	57	15282	100	90	34453	225
25	6999	46	58	14508	95	91	53468	350
26	5057	33	59	18467	121	92	47557	311
27	3012	20	60	25519	167	93	40501	265
28	2317	15	61	22452	147	94	31879	209
29	2635	17	62	17767	116	95	19630	128
30	3209	21	63	24617	161	96	17510	115
31	3851	25	64	34639	227	97	22347	146
32	4571	30	65	42349	277	98	24926	163
33	5995	39	66	45375	297	99	14493	95
						100	1976	13

## Elevation dataset of Albanian GM

For creating of elevation of Albania, SRTM with 90m spatial resolution have been used as basic data, which later have been adjusted with 1d transformation based on list of official ground control points of Albanian geodetic network. In bellow table are given countet areas of Albanian national area with graduated classes in every 100m altitude.

Table 6. Albnian national areas divided with 100m altitude graduated areas

Elevation [m]	Count	Area [km2]	Elevation [m]	Count	Area [km2]	Elevation [m]	Count	Area [km2]
0-100	730235	4778	901-1000	247577	1620	1801-1900	50835	333
101-200	312268	2043	1001-1100	226168	1480	1901-2000	37290	244
201-300	180074	1178	1101-1200	211187	1382	2001-2100	25254	165
301-400	299275	1958	1201-1300	188625	1234	2101-2200	16063	105
401-500	282245	1847	1301-1400	164729	1078	2201-2300	9075	59
501-600	260960	1708	1401-1500	135296	885	2301-2400	4533	30
601-700	248671	1627	1501-1600	109197	715	2401-2500	1877	12
701-800	230532	1508	1601-1700	86368	565	2501-2600	570	4
801-900	266031	1741	1701-1800	68050	445	2601-2700	165	1
						2701-2749	16	1

Results derived from analyses and processing of land cover, land use, vegetation and elevation layers of Albania's GM, are shown in four maps figures 6 to 9 (Lubishtani etAll 2018).

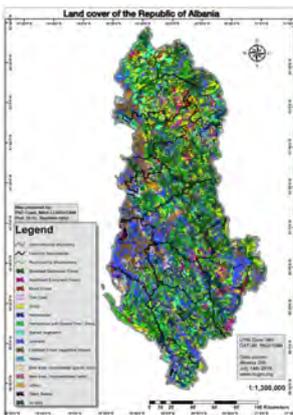


Figure 6.  
Land Cover layer

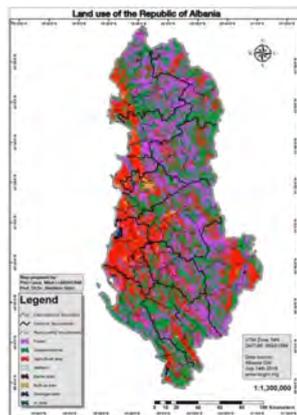


Figure 7.  
Land Use layer

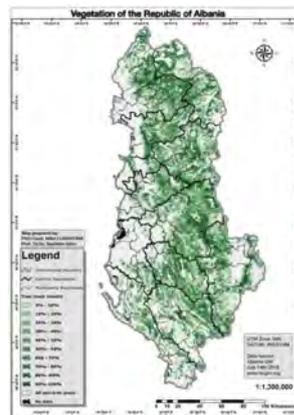


Figure 8.  
Vegetation layer

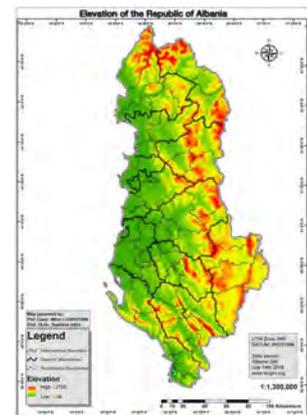


Figure 9.  
Elevation layer

## CONCLUSIONS

Modern trends in the world such as globalization, across all aspects of human life and the management of all possible techniques in the world, and in geodesy as a science, has ordered to create a single map of the world where all countries of the world will be presented with several sets data and substrates and homogeneous standards.

Characteristic of the GM is that all the data on the Earth are in one place, with the same structure, in the same format, on the same coordinate system, the same volume and with similar accuracy.

The GM data covers the entire land area with a spatial resolution of 1 km for raster data and scale 1:1,000,000 for vector data, and are in line with the specifications of the International Steering Committee for Global Mapping. Global mapping is an international collaborative initiative through voluntary participation of national mapping organizations of the world, aiming to develop globally homogeneous geographic data set, and to establish concrete partnership among governments, private sectors, data providers and users to share information and knowledge for sound decision-making.

Climate change is a process by which facing the world in these days, and automatically create a need that we geospatial data global of which can manage a various emergency situations such as natural disasters, floods, earthquakes,

mudslides, volcanoes etc. With the Global Map dataset being in digital form, it lends itself to various data manipulation and for modeling real life situations.

Global Map dataset may have limited uses at national and local scales. However, Global Map dataset is needed to address global, regional, trans-boundary and in many cases national concerns.

Albanian GM dataset as case study of the research aimed for performing analyses of infrastructural organization of geospatial data in global-intercontinental level, have been developed within PhD research study of Milot Lubishtani (Lubishtani etAll 2020), first author of this paper, under the supervision of prof Bashkim Idrizi, second author of this paper, at the Polytechnic University of Tirana, in cooperation with the Agency for Geospatial Authority of Albania (ASIG), in year 2016 ([www.asig.gov.al](http://www.asig.gov.al)).

Involvement by an organization in the project in generally is categorized in three levels, i.e. as Level A, B and C. Level A means that institution will prepare the data set of own country and other countries, the Level B mean that institution will prepare the data set of own country, and the Level C mean that institution will give all necessary data, preparation will be done by ISCGM (Idrizi etAll 2010). The Republic of Albania participate in global mapping project since 30.06.2016 in Level B, through State Authority for Geospatial Information (ASIG). State Authority for Geospatial Information (ASIG) and geodesy department of the Polytechnic University of Tirana as represent from PhD Candidate developed vector and raster data for GM version 2 for Albania and the data was published in [www.iscgm.org](http://www.iscgm.org). The Republic of Albania within the project for the compilation of the global map is represented by the State Authority for Geospatial Information (ASIG), as the responsible institution for Albania's cartography at the national level. Preparation of Albania's GM data has been proceed in academic level within the geodesy department of the Polytechnic University of Tirana, with aim to support, help and improve young cartography in Albania. Existing topographic maps in scale 1:25.000, high resolution orthophoto images, as well as the official data from governmental institutions has been utilized as source data. Albania is one of the last European countries that has published database at ISCGM, exactly on 14<sup>th</sup> July 2016 has been published the vector and raster data base according to technical specification V2.2.

Global Map data is now downloadable from the web site of UNGIS (<http://ggim.un.org/IGIF/overview>), mostly intended for non commercial use. If someone tries to use these data for commercial purposes must obtain permission from the relevant institution that has developed the data, otherwise, each unauthorized use for commercial purposes is in conflict with the law on copyright and related rights which is prohibited and punishable by (Idrizi etAll 2010).

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<http://>

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[www.iscgm.org](http://www.iscgm.org)

[www.eurogeographics.org](http://www.eurogeographics.org)

[www.asig.gov.al](http://www.asig.gov.al)

<http://ggim.un.org/IGIF/overview/>

## BIOGRAPHY



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# A SURVEY ON THE INTEGRATED DISASTER REDUCTION SERVICE IN BIG DATA ERA

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## **Abstract**

*In recent years, geospatial big data has attracted great attention from industry, academia, research and government sectors, and even has triggered a lot of industry changes. Geospatial big data for the integrated disaster reduction provides new ideas and methods for emergency management and decision making. At present, there are some problems in Chinese disaster reduction services. Too much emphasis has placed on decision-making and not on early warning. In addition, the technology, system and application integration of disaster reduction services is not enough. This paper analyses the concepts and characteristics of the integrated disaster reduction service, mainly reviews the key technologies in the integrated disaster reduction service, including integrated perception, location, integration and comprehensive scene simulation of emergency information such as disaster events, various disaster-bearing bodies and the disaster-pregnant environment, and knowledgeable disaster reduction services. Besides, the integrated disaster reduction system is introduced with the consideration of the demand for disaster prevention and reduction services. The developed system for the integrated disaster reduction services can solve the integrated perception, positioning, integration and simulation of the scene, and intellectualized disaster reduction services and other technical problems. Finally, the bottleneck problems and technical challenges of the integrated disaster reduction service are discussed.*

**Keywords:** Disaster Reduction, GIS, The Integrated Disaster Reduction Intelligent Services

## **1 BACKGROUND**

The International Federation of Red Cross and Red Crescent Societies (IFRC) defines disaster as a sudden, catastrophic event that severely disrupts the function of a region or society, resulting in loss of manpower, material resources, economy and environment exceed the ability of the region or society to use its own resources. The occurrence of such events does not mean a disaster in itself, but when it affects areas that cannot withstand the impact of such events, disasters often follow.

The development of big data and disaster mitigation technology has opened up new possibilities for disaster management and emergency response. The big data of geographical conditions and GIS provide basic support for emergency response, and the big data of positioning and navigation provide guarantee for emergency rescue. The big data of Internet public opinion also plays an important role in disaster assessment. Watson et al found that big data analysis and mining can help emergency rescue to obtain more valuable information, which has a positive impact on emergency response, because big data can enrich situational awareness and provide important basis for rational decision-making, such as material scheduling, resource allocation, public opinion control, etc. [7]. In addition, Athanasia and Meier et al. paid more attention to the contribution of big data to emergency response. Studies have shown that big data has a positive impact on pre-disaster monitoring and early warning [8][9]. After researchers found that in recent years, the attention of disaster big data technology research has also been significantly increased. The success of big data has prompted practitioners and scholars to recognize the effect of big data in emergency management [11].

This paper analyzes and summarizes the integrated and comprehensive disaster reduction technology in the context of big data. The first part introduces the background of integrated disaster reduction technology; the second part analyzes the characteristics of disaster big data; reviews the concept and progress of integrated disaster reduction technology, including the acquisition and management of disaster information, the integration and analysis of emergency information, construction and simulation of disaster model, emergency comprehensive decision-making and services and other technologies; and introduces the research progress of the integrated disaster reduction intelligent service system platform; finally, the integrated disaster reduction technology and services are summarized and prospected.

## 2 FEATURES OF INTEGRATED DISASTER REDUCTION TECHNOLOGY

The traditional disaster prevention and mitigation methods are relatively simple, and cannot fully integrate relevant technologies to guide disaster relief, while integrated disaster reduction intelligent services will fully connect and integrate the key technologies of geographic information, Internet of Things, and Internet systems, provide smart infrastructure, achieve comprehensive perception, technology integration, ubiquitous interconnection, and intelligent disaster relief. Therefore, the characteristics of comprehensive disaster reduction intelligent service technology are mainly reflected in the following five aspects:

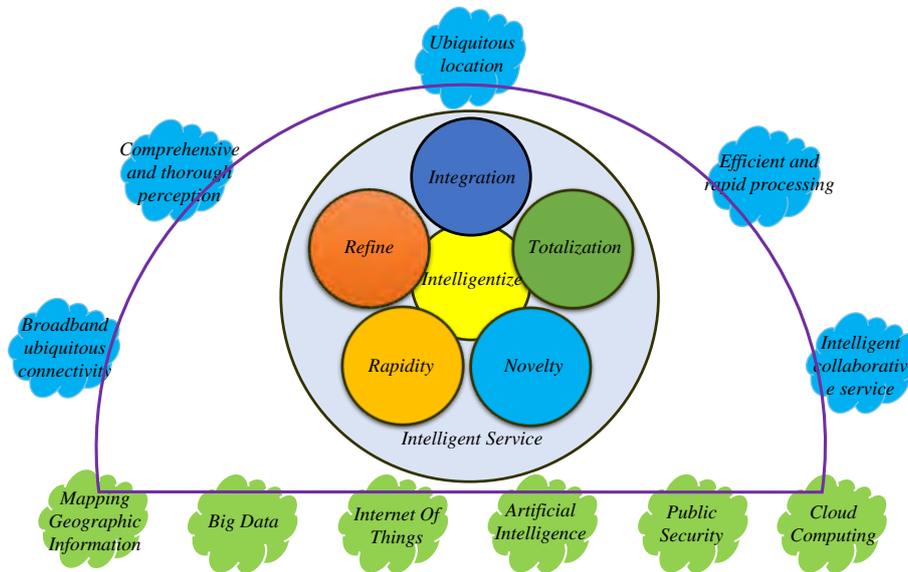


Figure 1. Features of disaster technologies

1. Comprehensive and thorough perception. Through sensing technology, we can realize monitoring and comprehensive perception of all aspects of urban safety management. Smart emergency uses various types of sensing equipment and intelligent systems at any time and any place to intelligently identify and stereoscopically sense the all-round change of information such as urban environment, status and location, monitor potential sources of danger, merge and analysis perception data , And can be intelligently integrated with emergency business processes, and then respond proactively to promote the harmonious, safe and efficient operation of key cities in the city.

2. Ubiquitous interconnection of broadband. In the city's comprehensive intelligent disaster reduction, the development of various types of broadband wired and wireless network technologies is the comprehensive interconnection and interaction of things, and people and things, people in cities which provides basic conditions for all types of cities to apply at anytime, anywhere, on demand. As a "neural network" of smart cities, broadband ubiquitous networks have greatly enhanced the ability of smart emergency as an adaptive system for information acquisition, real-time feedback, and intelligent services anytime, anywhere.

3. Positioning everywhere. In a complex disaster environment, how to accurately locate rescuers and rescuers in real time will directly affect the efficiency of rescue. Based on GNSS, Bluetooth, UWB, WIFI and other positioning terminals, high-precision indoor and outdoor seamless positioning can be achieved to obtain real-time and accurate location information ,using a multi-location system collaboration platform to collect, transmit and process the information collected by various positioning system data collection terminals to provide real-time and effective location service information for emergency decision-making and command systems.

4. Efficient and fast processing. The integrated disaster reduction intelligent service system is a complex integrated system. The application of a new generation of comprehensive perception technology has increased the city's massive data. Based on cloud computing, through the application of intelligent fusion technology to achieve the storage, calculation and analysis of massive data, and the introduction of a comprehensive integration method, through human "wisdom" participation, greatly improve the ability of decision support. Dacheng Smart Project based on cloud computing platform will constitute the "brain" of smart emergency. The integration and development of technology will further promote the combination of "cloud" and "end", promote the development from personal communication,

personal computing to personal manufacturing, and promote the realization of intelligent integration, anytime, anywhere, on-demand and arbitrary applications, further highlighting personal participation and user power.

5. Intelligent collaborative service. Comprehensive disaster reduction intelligent service is a comprehensive system engineering. In the face of complex disasters, different departments and systems of the city can achieve information sharing and collaborative operation, more intelligently disaster awareness, analysis and disposal, making full use of resources, making the best urban development and management decisions, timely prediction and response to emergencies and disasters.

### 3 COMPREHENSIVE DISASTER MITIGATION TECHNOLOGY STATUS

Big data has always played an important role in disaster management and emergency response. According to the role of disaster information in the emergency response process, the integrated disaster reduction technology can be divided into four categories, disaster information acquisition and management, emergency information fusion and analysis, disaster model construction and simulation, emergency decision-making and integrated services. Disaster information is generally obtained through perception equipment, such as positioning equipment, sensors, remote sensing images, etc.; the disaster information collected is stored in various databases through Beidou, communication network, Internet, Internet of Things and other transmission networks; through emergency information fusion and analysis Technology processes data, builds disaster models, simulates disaster scenes, and provides support for decision-making and emergency services.

Integrated indoor and outdoor positioning under emergency conditions refers to the seamless integration of the global positioning system, indoor positioning system, and networking positioning system in a disaster environment by integrating multiple information carriers such as Beidou, communication, Internet, and sensor networks. The indoor and outdoor positioning accuracy is better than the real-time location information of 1 meter.

In natural disasters and man-made disasters, personnel location information plays an important role in emergency rescue. For this reason, location is one of the most critical contents of emergency response and disaster monitoring [6]. For example, applications in various emergency situations, such as vehicle positioning [7] and home surveillance [8], require location awareness. Due to the characteristics of GPS not working, irregular signal propagation, and dynamic environment, indoor positioning is still a huge challenge [9]. In the past few decades, a lot of research work has been devoted to solving this localization problem. The information sources of these indoor positioning technologies are diverse, mainly related to hardware devices, such as infrared [10], ultrasound, Bluetooth [11], radio frequency identification [12-13] (Radio-Frequency Identification, RFID) and WLAN [14].

The rapid integration of multi-source data is based on the basic geospatial data of the disaster area. It integrates multi-modal disaster information integration, multi-scale spatial information integration, disaster information and spatial information integration, and realizes the large-scale map and indoor scene multi-scale data visualization Fusion, to meet the data fusion accuracy better than 0.5 meters, to provide integrated and comprehensive disaster reduction intelligent services with consistent spatial and temporal data resources.

Scene fusion and enhanced visualization Use the acquired laser point cloud data and image data of the disaster area to quickly reconstruct the three-dimensional indoor and outdoor integrated scenes of the disaster scene, visualize the scenes and real-time observation data and simulate and analyze the information, and enhance the visualization of the movement to achieve the scene of the disaster scene Rapid modeling and simulation and dynamic expression of the whole process of disaster emergency response.

Lee et al. [27] proposed a dual graph theory method to abstract indoor space into a "room-room" model constructed by nodes and edges according to the spatial three-dimensional relationship, construct an indoor three-dimensional topology mechanism, and mainly apply to indoor road network modeling [11, 28] [21,22]. Yuan et al. [22] proposed a "door-door" model in which the door is an abstract node and the edge represents the connectivity between the door and the door. Its planned walking path is closer to the way people walk. The comprehensive integration of VRGIS, Internet GIS, and networked virtual reality provides many advantages for disaster analysis, emergency training, and spatial decision-making. SWOT (Strength, Weakness, Opportunity and Threat) analysis of the application of VR in fire evacuation was carried out. L. Gamberini et al. [29] used a virtual environment to measure fire emergency response. When fire emergencies occurred, quantitative and qualitative analysis of participants' behaviors and their patterns were found, and the virtual environment was found to be adequate for simulating emergency situations and effectively training participants [5]. Li et al. [30] developed an immersive virtual reality system for emergency rescue training. The training system is referred to as ERT-VR (emergency rescue training virtual reality, ERT-VR for short). Define, formalize and visualize the content of geographic data in emergency management and combine it with process modeling and process analysis [31]. For the clear needs in disaster emergency scenarios, the mapping work should be

implemented with appropriate technologies, such as adaptive selection and completion of integration methods, processing methods, process control, and graphical representation according to user needs.

Adaptive fast drawing through knowledge extraction and expression of multi-granularity integrated drawing data, establish emergency drawing knowledge rule library, data processing model library, map decoration template library, dynamic thematic symbol library, multimedia resource library (video, audio, pictures, Animation, etc.) and other databases, to establish adaptive personal map space, build "subscription", "order", "custom" and "intelligent" four participatory mapping technology frameworks to achieve cross-media push and combination adaptive fast Emergency mapping service.

Typical disaster model construction and management for typical disasters such as earthquakes, floods, geological disasters, urban fires, traffic accidents, and building collapses, a distributed and heterogeneous model library of typical disasters is established, through multi-hazard model coupling and disaster model group aggregation services 1. Autonomous model services, realize the integration and linkage of multiple types of disaster models, and improve the active and dynamic service capabilities of models in multi-stage decision-making activities for comprehensive disaster reduction.

#### 4 INTEGRATED DISASTER REDUCTION INTELLIGENT SERVICE SYSTEM

Taking six types of disasters such as earthquakes, floods, geological disasters, urban fires, traffic accidents, and building collapses as research objects, the integrated disaster reduction intelligent service prototype system uses a loosely coupled system architecture system based on microservices under a unified standard, which can better Realize the integration of heterogeneous systems, emergency equipment positioning and real-time access and storage of sensor data, the integration of related resources, combined with situational awareness and cross-media integration display technology to achieve enhanced visualization of the three-dimensional scene of the disaster scene, and realize multiple types of emergency equipment, 3D space calibration and linkage visualization of rescuers and major scenes. For emergency rescue decision-making, command scheduling, and information release, it provides a comprehensive integrated disaster reduction intelligent service architecture that supports full-space positioning, heterogeneous integration, scene visualization, model calculation, and deduction. At the same time, according to different business needs, different emergency disaster reduction applications can be quickly customized to meet the diverse needs of different industries, regions, and departments, and provide rapid function customization for the development of demonstration applications.

Figure 5 shows the main functions of the integrated disaster reduction intelligent service prototype system. Figure 5 (a) shows indoor and outdoor high-precision personnel, vehicles and equipment positioning modules, which realizes the integration of hardware and software for positioning equipment and various Adaptive switching of indoor and outdoor high-precision positioning methods; Figure 5 (b) shows the three-dimensional scene modeling and visual expression module, which realizes rapid modeling and display of emergency disaster scenes, dynamic simulation and analysis, enhanced expression and exploration, etc.; Figure 5 (c) shows the spatial analysis and deduction module of the disaster model, which realizes the integrated linkage, on-demand and dynamic aggregation of multiple types of disaster models, and forms a task-oriented, emergency semantic-driven disaster model analysis service; 5 (d) Demonstrated the integrated disaster reduction intelligent service module, including fast adaptive mapping service, knowledge mapping service and active push service, etc. The adaptive fast mapping function utilizes various forms and rich connotations of emergency mapping knowledge rule sets, and is integrated with engineering 'S participatory mapping engine dynamically matches to achieve rapid production of disaster maps. Disaster knowledge map and active push service through ontology construction and knowledge map representation of typical disasters such as earthquakes, fires, traffic accidents, floods, building collapses, geological disasters, etc., and according to the disaster event background, type, scale, location, event, The development situation and other specific situation information are pushed in layers and categories.



(a) Indoor positioning

(b) 3D Visualization



(c) Active push

(d) Adaptive rapid mapping

Figure 5. The Platform of Integrated Comprehensive Disaster Reduction Intelligent Service System

## 5 PROSPECT OF COMPREHENSIVE DISASTER REDUCTION TECHNOLOGY

Big data technology provides new ideas and methods for people to analyze and solve problems. The era of big data provides an extremely convenient way for sharing, integration, analysis, mining, and decision-making of comprehensive disaster reduction services. In-depth application of new concepts, new technologies, and new methods such as networking, cloud computing, artificial intelligence, and mobile communications in the field of comprehensive disaster reduction, comprehensive disaster reduction data acquisition methods, transmission efficiency, application deployment methods, service models, data production and processing methods, target users After that, profound changes have taken place, leading to the popularization of disaster big data acquisition. For example, during the new coronary pneumonia, the location and movement trajectory information of new coronary pneumonia patients uploaded by the public have prevented the spread of new coronary pneumonia to a certain extent; The model is diversified and the analysis service is integrated, which brings new opportunities and challenges to the development of integrated disaster reduction services.

### 1. Multi-modal aggregation and integration of fine-grained disaster data

At present, the granularity of disaster data integration is relatively coarse, and it is usually implemented in the form of a data layer. With the diversification of disaster big data sources and the increasing frequency of updates, the granularity of disaster big data integration will continue to be refined, and will no longer be limited to certain data layers, but will be refined to entities and vertices [33].

### 2. Distributed disaster management big data hyper-converged storage management

The explosive growth of disaster-related big data, the extremely rich data sources and the variety of data types make the data storage capacity larger and the requirements for data presentation higher. Traditional databases are also difficult to store such a huge amount of data. There is an urgent need to study the efficient storage and indexing technology based on machine learning and artificial intelligence, so that the data management process can configure and adjust itself, and realize the support of "data" and "efficient query".[34]

### 3. Intelligent analysis and mining of multi-dimensional disaster big data

Big data technology is becoming more and more mature, and it is possible to analyze and mine huge disaster big data based on multi-dimensional, multi-level, multi-group and multi-factor [35]. Using modern technology platforms such as big data and cloud computing, research on emergency decision-making methods based on broad knowledge coupling, distributed disaster public opinion information acquisition and analysis methods that take into account the characteristics of time and space, and accurate simulation analysis methods of typical disasters driven by dynamic sky and ground observation data Provide decision support for disaster model construction, early warning analysis, post-disaster assessment, emergency rescue, etc.

### 4. Knowledge-based disaster data big data active smart service

"Internet +" and "Big Data ×" use information communication technology and Internet platform, will definitely reshape the emergency rescue work mechanism and ecology, comprehensive disaster reduction services will inevitably shift from extensive supply to precise supply, big data drives "Internet + government services "The integrated disaster reduction service will be more intelligent, convenient, human-oriented and experience-based to meet the personalized, customized and diversified comprehensive decision-making service needs of users.

## 6 CONCLUSION

At present, the integration of big data, cloud computing and other information technologies with geographic information services has brought new opportunities and challenges to the development of comprehensive disaster reduction government affairs [36]. Based on the summary of researches on comprehensive disaster reduction services and aspects in recent years, this article expounds the characteristics of comprehensive disaster reduction technologies, and analyzes and prospects the theoretical issues, key technologies, development trends and other aspects involved in comprehensive disaster reduction technical services in the era of big data. Introduced the integrated comprehensive disaster reduction intelligent service prototype system, and pointed out the development trend of multi-modal aggregation and integration of disaster situation big data, hyper-converged storage management, intelligent analysis and mining, active smart service. This will promote the development of integrated disaster reduction service technology application and comprehensively improve the national comprehensive disaster prevention and mitigation protection capabilities.

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# DETECTION OF FLOODED AREAS WITH RADAR IMAGE ANALYSIS

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## **Abstract**

*Storms and tornados generally occurs naturally without much of human intervention, and cause severe damage to life and property. They will be on a very short timeline and will not be stopped by people after they occur. For this reason, speed is an important factor in determining the damages that occur. In this regard, radar satellites are advantageous because they can capture data in all weather conditions. Within the scope of the project, India Channai region was selected, which experienced a major flood disaster in November-December 2015. In this study, it is aimed to determine disaster losses by texture analysis on the Image. Five different images were used to analyze the flood damages. Backscatter values for radar images were analyzed in all magery. The scattering differences between before and after the disaster were calculated and statistically analyzed. The results are visualized in Google Earth Engine Cloud Platform.*

**Keywords:** *Flood Mapping, Remote Sensing, Google Earth Engine*

## **INTRODUCTION**

Storms and tornados are among the significant disasters generally occur naturally without much of human intervention. They cause severe loss to the life of people and their property. The long-term forecasting and controlling the intensity of these disasters are impossible. During November and December 2015, many parts of Southern India had been severely affected due to floods. An extensive land portion was inundated in which agricultural fields and buildup lands are the most impacted land-use types. The severe flood disrupted the daily activities of people and even caused the death(Web1). The impact could have been minimized if the extent of flood and its intensity is observed timely. Remote sensing technology plays a crucial role in disaster early warning, especially in the case of flood caused due to cyclonic storms and tornados. In which Microwave remote sensing technology is quiet handy in estimating the extent of flood and its intensity compared to other remote sensing technologies (e.g. Optical). The traditional option is proven ineffective due to its limitation to work under clouds and rains. The active remote sensing system outpost the performance of passive sensors during extreme weather conditions. One of such kind is Synthetic Aperture Radar (SAR), studies (Ayala-Silva and Twumasi, 2004; Aosier et al., 2007; Wang et al., 2010; Richards et al., 1987, Fransson et al., 2002, Ermert et al., 2012, Eriksson et al., 2012, Gokaraju and Turlapaty, 2015) used radar imaging and performed flood analysis based on the backscattered values.

On the other hand, the processing of remotely sensed data requires high-performance computing environment. Which generally occupy ample storage space and needs a powerful software package for performing analysis. Since the time consumes in processing is crucial and preferred to be the least. An adequate system which maps the extent of flooded areas at near real-time is essential for timely response and management. Cloud computing is suitable for the

requirement, which only requires an active internet connection leveraging the requirement of advanced hardware and softwares. With the help of this technology disaster, mapping studies can be performed with minimum infrastructure. In this study, the researchers have used Google Earth Engine platform to process, visualize and analyze the data obtained during the floods in Chennai happened during November and December 2015.

## MATERIAL AND METHODS

### Material

We have used Google Earth Engine cloud computing platform (shortly known as GEE) to process the data, to visualize the results. GEE is an open-source tool available for the research community by Google LLC. The users can work on the JavaScript language coding platform which allows user to store and process a large volume of data using its machines. The processed data can easily be visualized on Google Maps. There is also an option to export the processed or unprocessed data to the user's cloud drive or directly downloadable to the user's Personal computer. The data catalogue of GEE contains many types of data including satellite imagery, meteorological, topographical and demographic data.

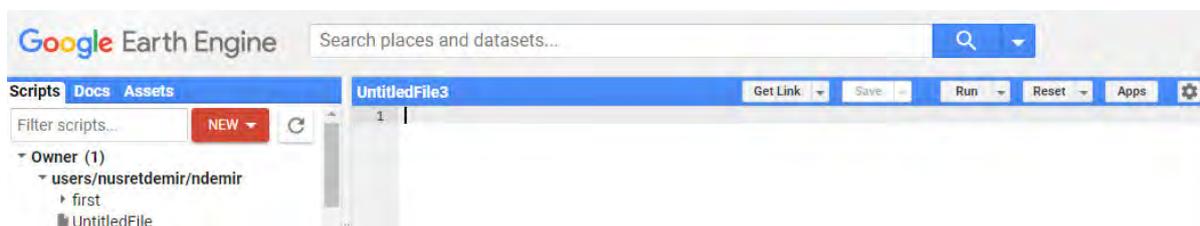


Figure 1. Google Earth Engine code editor

In this study, we have Synthetic Aperture Radar Imagery Sentinel 1 images. Sentinel 1 images are made available to the public for free by the European Space Agency's Copernicus Program. The data can also be downloaded through Sentinel Hub service. However, in our case, we have directly called the output data in GEE without downloading them in our m

The properties of the used Sentinel SAR image is shown in Table 1.

Table 1. Specifications of Radar Images

<b>Sensor</b>	Sentinel 1 A & B
<b>Image type</b>	Synthetic Aperture Radar
<b>Ground Sample Distance</b>	10 m.
<b>Data type</b>	Ground Range Detected
<b>Orbit</b>	Descending
<b>Polarization</b>	VH

The images acquired before and after the flood were used in the study in order to identify the extent of inundation during November and December 2015.

## Method

The whole process is performed in GEE. The process workflow is shown in Figure 2.

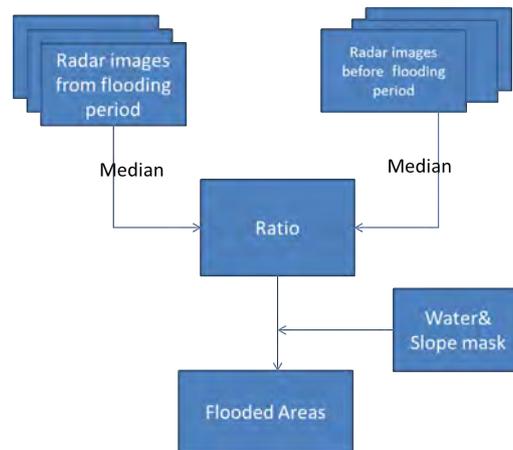


Figure 2. Processing workflow

The process starts by downloading datasets. The method used in this study is different from the methods given in the literature. Here, the first Image is generated by using all available Sentinel 1 SAR data during the reported flooding period between '2015-11-05' and '2015-12-17'. The median value of the pixels from each dataset is calculated, and a new flood image has been created. The other Image which represents non-flood case has been created using the same idea with the use of any time period which has no flood between '2015-08-01' and '2015-08-30'. Again, the median value of each pixel has been calculating and generated a new non-flood image. Then, the speckle filter is applied on both image sets with calculating the mean focal value of the pixel value in 50 m circles for all images.

The areas which have already water surfaces and the regions where the slope is high should be excluded from the process. For exclusion of the already existing water surfaces (lakes, rivers etc.), a water mask has been created. To eliminate these water surfaces from the result, we have used the dataset of 'JRC Global Surface Water Mapping Layers, v1.1'. This dataset is stored in GEE, and created with the use of Landsat images with the use of 3,865,618 frames from Landsat 5, 7, and 8 from the dates between 16 March 1984 and 31 December 2018 (GEE referans). The second mask is created to mask out the areas where the slope is higher than 5% which is not expected to have flooded. The used dataset is HydroSHEDS which contains provides hydrographic information with three arc-second resolution.

After masking out the existing water surfaces and the steepest areas, for detection of the flooded areas, the ratio between the first and second-period images is calculated. The pixels which have the ratio larger than 1.25 are selected as flooded areas as suggested by UNI-SPIDER(Web3). The calculated affected area is calculated with multiplying 10 m resolution value with the total number of pixels found as flooded areas.

## RESULTS

First, the images used to detect the flooded areas have been created. One Image has been created with the use of the all available images from the dates during the flooding disaster. And other is from the time when no flooding event has been occurred during August 2015. The median values of all pixels are calculated. The calculated median images for the disaster and non-disaster period are shown in Figure 3.

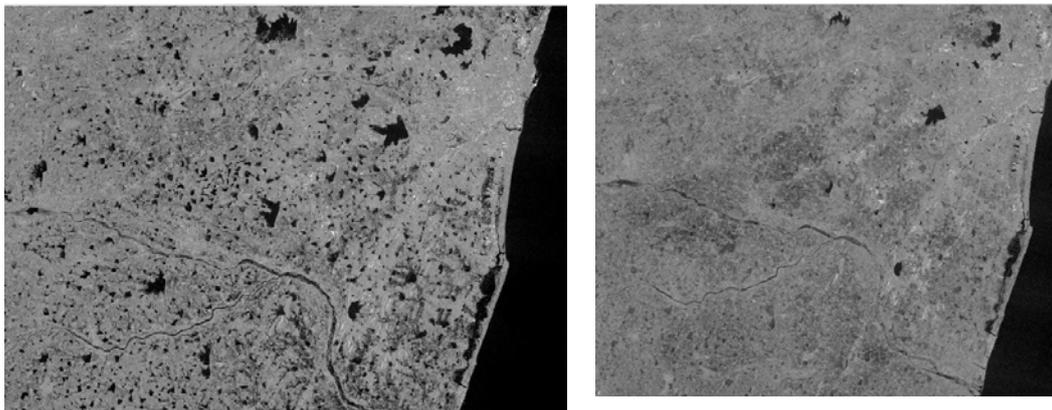


Figure 3. Image from flooding period (left), Image from before flood period(Right)

As shown in Figure 3, the flooded areas appear darker than the predisaster Image because of the radar energy absorption happened over the water surface hence creates a darker appearance on the images. The existing water surfaces The used water mask is created with JRC Global Surface Water Mapping Layers (JRCGSWML) data and can be found in Figure 3. The occurrence band is selected, and the parameter is set as %50, which means the water content on the surface is present more than half a year.

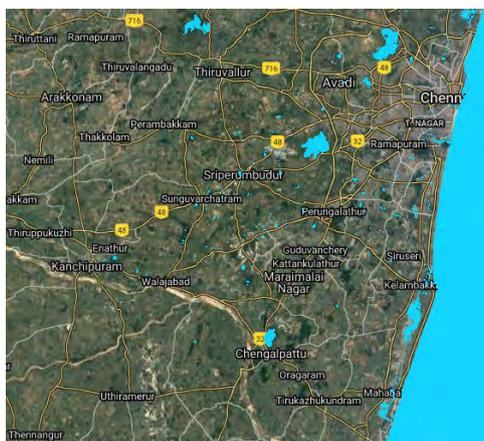


Figure 4. shows water mask used derived from JRCGSWML (existing water bodies are represented in blue)

As shown in Figure 4, the water surfaces are detected, and they were excluded from the result of the flooded area. On the other hand, the areas where the slope is higher than 5% are excluded as well (Figure 5).

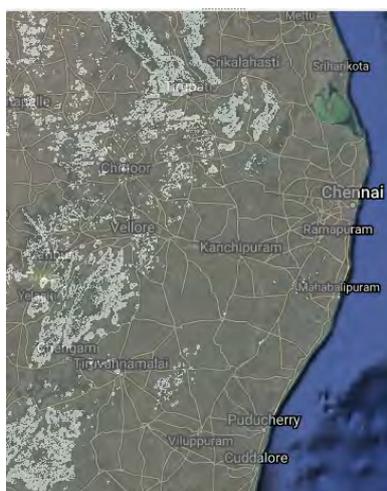


Figure 4. Represents the areas with steep slope (>5%) in light grey

The ratio between the flooding and pre-flood images gives the change rate for each pixel. The ratio image is shown in Figure 5.

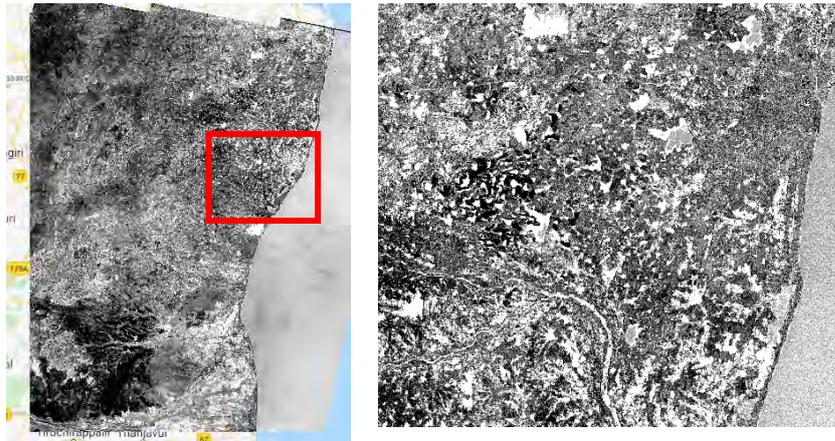


Figure 5. The ratio image created with flood and pre-flood images. Left( the test area), Right: Zoomed view from the red rectangle.

As shown in Figure 5, the affected areas appear brighter with a higher rate of change. A threshold is used to separate the flooded and non-flooded areas. The threshold 1.25 is recommended by United Nations Spider program for disaster mapping studies. A part of the detected flooded regions is found in Figure 6.

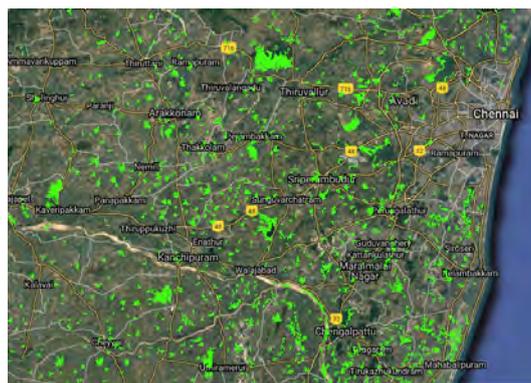


Figure 6. The detected flooded areas

The ratioed Image detecting flooded areas are shown in Figure 6. As a result, the total affected area is calculated as 62518 hectares in the area of interest.

## CONCLUSIONS

India, as a country faces severe floods frequently, and quick detection of flooded areas has a critical role in the management of the post-disaster situation. Radar images have more significant potential with their capabilities to operate and acquire datasets in all weather conditions, which is a significant advantage for the flood mapping studies. Thus without any limitation, the areas affected can be detected with active remote sensing technology. The processing time is also critical for quick management in the affected regions. Therefore, cloud computing environments are useful sources. In this study, we have used and recommend to use Google Earth Engine platform to load, process, visualize the data, results and calculate the total affected area in the region of interest. The assessment is somewhat tricky since the ground truth of the damaged areas is almost impossible. Therefore we share the code to allow the reproduce the results, which is available through following link:

## ACKNOWLEDGEMENTS

This research has been supported by the Turkish Council of Higher Education, the project-based Mevlana Exchange program.

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# **STRATEGIES OF DISASTER RISK REDUCTION ON THE BACKGROUND OF U.N. GGIM AND DIGITAL BELT AND ROAD EFFORTS**

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### **Abstract**

*The paper aims for the contemporary strategic development of the Disaster Risk Reduction (DRR) area defined by the U.N. DRR conference in Sendai, 2015, and other related conferences like the 2017 Global Platform in Cancun. There are also highlighted U.N. Sustainable Development Goals (SDGs) 2015-2030. DRR Sendai framework is inextricably linked with the main U.N. SDGs document. Paper investigates synergies between indicators of SDGs and Global indicators of Sendai Framework. The importance of geographical aspects and new data initiatives U.N. GGIM and DBAR, the essential parts in the building of the Global Data Ecosystem, are described. The cartography potentials for SDGs and the importance of using volunteers and Volunteer Geographic Information (VGI) for DRR and Crisis Management are commented on, and the examples of using VGI data and open-access platforms for the Humanitarian OpenStreetMap Team and Missing maps project are described.*

**Keywords:** disaster risk reduction, GGIM, digital belt and road, SDGs indicators, global Sendai Framework indicators, improvement of strategies, the role of cartography

## **1. INTRODUCTION - DRM AND DRR**

The Leaders' of the United Nations (U.N.) "2017 Global Platform for Disaster Risk Reduction" in Cancun, Mexico (Global Platform, 2017), recognise that globally, direct economic losses attributed to disasters are increasing significantly, having over the last decade reached close to US\$1.4 trillion. Indirect economic losses magnify the figure further. Losses to countries' capital stock, including housing, infrastructure, productive assets and livelihoods, and impacts on health and education have had significant fiscal implications, hindering economic growth and development (Global Platform, 2017, <https://www.unisdr.org/conferences/2017/globalplatform/en>). In previous publications, it was shown how interest about the development of Disaster Risk Management (DRM) and Disaster Risk Reduction (DRR) changed, and the development of scientific and new technological solutions has increased (Konecny M. et al., 2011; Konecny et al., 2020)

With the growing of disaster problems in last few years the line connected with global warming processes have been enhanced. Especially after tsunamis in SE Asia in 2004 and new approaches to the problems defined in the Hyogo Framework for Action (Hyogo Framework, 2005) were successfully developed. One of the important aspect have been ideas about creation of culture to be able to live with risks of disasters which should be also based on people-concentrated systems of Early Warning (EW) and gradual development of the new, wider concept of DRR which respect all knowledge gain from DRM but enriching it by more social oriented approaches.

## Definitions of DRM and DRR

According to updated “2009 UNISDR Terminology” (Terminology of UNISDR, 2016) and modified Terminology of U.N. DRR (2019) we respect these definitions.

**Disaster risk management** is the application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses. **Disaster risk reduction** is aimed at preventing new and reducing existing disaster risk and managing residual risk, all of which contribute to strengthening resilience and therefore to the achievement of sustainable development. By other words, disaster risk reduction is the policy objective of disaster risk management, and its goals and objectives are defined in disaster risk reduction strategies and plans.

New concepts and strategies are developing and also improving by changing the scientific and data frameworks in which new approaches are applied. We are living and doing now everything in Big Data era (Bandrova et al., 2014; Filchev et al., 2018), and with efforts to create smart solutions (Kubicek et al., 2018; Stachon et al., 2016; Shen et al., 2020; Yang et al., 2018), development of Data-driven Geography (Miller and Goodchild, 2015; Palma et al., 2016) and new approaches in various disciplines, like agriculture (Reznik et al., 2017) or soils (Feiden, 2011) all together created new knowledge and technological situation with new potentials for solving DRR problems. A very important fundamental aspects of the process are various data concepts and building of new quality data arsenals. Critical efforts for the contemporary world are Sustainable Development Goals defined by U.N. in 2015 as “2030 Agenda for Sustainable Development” defining 17 tasks and newly accompanied by sets of indicators and DRR Sendai goals and global indicators. It is not easy to combine them (Scott and Rajabifard, 2017; Metternicht et al., 2019; Metternicht et al., 2020) but all this effort is creating the real situation we can start to feel how is our planet breafing and developing.

## 2. SUSTAINABLE DEVELOPMENT GOALS (SDGS) AND INDICATORS

SGDs are defined in the document the U.N. Sustainable Development Goals 2015-2030. U.N. General Assembly on August 12, 2015, published document titled "Transforming our world: the 2030 Agenda for Sustainable Development" (United Nations General Assembly, 2015) there are defined 17 SGDs (see also Figure1 and part 7 of this paper). 1. End poverty in all its forms everywhere; 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture; 3. Ensure healthy lives and promote well-being for all at all ages; 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all; 5. Achieve gender equality and empower all women and girls; 6. Ensure availability and sustainable management of water and sanitation for all; 7. Ensure access to affordable, reliable, sustainable and modern energy for all; 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all; 9. Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation; 10. Reduce inequality within and among countries; 11. Make cities and human settlements inclusive, safe, resilient and sustainable; 12. Ensure sustainable consumption and production patterns; 13. Take urgent action to combat climate change and its impacts; 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development; 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss; 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels; and 17. Strengthen the means of implementation and revitalise the Global Partnership for Sustainable Development.



Figure 1: U.N. Sustainable Development Goals 2015-2030. Source: United Nations Brussels Team (2018).

The critical step ahead is a fact that 17th goals are accompanied by 169 targets, 232 global indicators to follow-up and review progress to know real state of the art of our planet according to measured characteristics. Implementation of these efforts is expected by implementation via national planning processes, policies, strategies and frameworks. Measuring and monitoring will be done by statistics, geospatial information, Earth observations and other Big Data.

The U.N. Statistical Commission, as a functional commission of Economic and Social Council (ECOSOC), was asked to develop the global indicator framework. The overarching principle of the 2030 Agenda for Sustainable Development is that no one should be left behind. Data which is high-quality, accessible, timely, reliable and disaggregated by income, sex, age, race, ethnicity, migration status, disability and geographic location and other characteristics relevant in national contexts should support implementation at all levels; the 2030 Agenda also included the need to exploit the contribution to be made by a wide range of data, including Earth observations and geospatial information.

Although the development of the Global indicator framework has primarily been based on a statistical data input-output approach, the need for 'geographic location' in a new era of data needs is well recognised. Many national statistical offices now understand that geospatial information, Earth observations and other Big Data are able to provide new and consistent data sources and methodologies to integrate multiple 'location-based' variables to support and inform official statistics and the indicators for the SDGs. Geography and location provide an important link to enable a richer picture of our countries, and what is happening in and across them. It enables data from diverse sources to be brought together to unleash their combined power in analysis and decision making. To meet the ambitions and demands of the 2030 Agenda, it is necessary for the Global indicator framework to adequately and systematically address the issues of alternative data sources and methodologies, including geospatial information and Earth observations in the context of geographic location (IAEG-SDG, 2016).

On February 2020 with the intention to facilitate the implementation of the Global indicator framework, all indicators are classified by the Inter-Agency and Expert Group on SDG Indicators (IAEG-SDGs, 2020) into three tiers based on their level of methodological development and the availability of data at the global level, as follows:

- Tier I: Indicator is conceptually clear, has an internationally established methodology and standards are available, and data are regularly produced by countries for at least 50 per cent of countries and of the population in every region where the indicator is relevant.
- Tier II: Indicator is conceptually clear, has an internationally established methodology and standards are available, but data are not regularly produced by countries.
- Tier III: No internationally established methodology or standards are yet available for the indicator, but methodology/standards are being (or will be) developed or tested.

All indicators are equally important, and the establishment of the tier system is intended solely to assist in the development of global implementation strategies. For tier I and II indicators, the availability of data at the national level may not necessarily align with the global tier classification, and countries can create their tier classification for implementation. The tier I and II indicators' metadata are available in the metadata repository (<https://unstats.un.org/sdgs/metadata/>). Tier III indicators require work plans to be developed outlining the methodological development of the indicators for approval by the IAEG-SDGs. The current tier III work plans are available here (<https://unstats.un.org/sdgs/tierIII-indicators/>).

As of December 11 2019 the updated tier classification contains 116 tier I indicators, 92 tier II indicators and 20 tier III indicators were accepted. In addition to these, there are four indicators that have multiple tiers (different components of the indicator are classified into different tiers).

### **3. DISASTER RISK REDUCTION SENDAI GOALS AND GLOBAL INDICATORS**

In the Third U.N. World Conference on DRR, March 14, 2015, in Sendai, Japan, The Sendai Framework for Disaster Risk Reduction 2015-2030 was adopted (United Nations General Assembly, 2015b). The U.N. DRR conference is a culmination of contemporary state-of-the-art approaches to solving problems of risks and disasters on our planet. As never before the conference in its materials mentioned the role of ICTs, GIS, remote sensing, mapping, sensors, volunteer geographic information, etc.

In Sendai framework, four new priorities of action are defined:

- Priority 1: Understanding disaster risk;
- Priority 2: Strengthening disaster risk governance to manage disaster risk;
- Priority 3: Investing in disaster risk reduction for resilience;
- Priority 4: Enhancing disaster preparedness for effective response and to “Build Back Better” in recovery, rehabilitation and reconstruction (United Nations General Assembly, 2015b).

DRR Sendai framework is inextricably linked with the main U.N. SDGs document (explained above the text). The terminology of Open-Ended Intergovernmental Expert Working Group on Indicators and Terminology Relating to Disaster Risk Reduction (OEIEWG, 2017) was established by the U.N. General Assembly via resolution 69/284 and adopted on June 3 2015 for the development of a set of possible indicators to measure global progress in the implementation of the Sendai Framework. Report of the working group defining indicators and targets were endorsed by The U.N. General Assembly Resolution A/RES/71/276 on February 2 2017 (OEIEWG, 2017). The report is coherent with the work of the Inter-Agency and Expert Group on Sustainable Development Goal Indicators (IAEG-SDGs), and the update of the publication entitled “2009 UNISDR Terminology on Disaster Risk Reduction” (Terminology of UNDRR, 2019).

Recommendations of the OEIEWG on Global indicators for the global targets of the Sendai Framework aim to operationalise seven indicators (A-G). They have been selected and as well as related and reflected to the SDGs items no. 1 - Poverty, 11 – Sustainable Cities and 13 – Climate Action (Figures 1 and 2).

On December 15, 2017, The U.N. Office for Disaster Risk Reduction (UNISDR) had launched a process for monitoring implementation of the Sendai Framework. The Sendai Framework Monitor started measuring of progress towards the mentioned SDGs items. It is a management tool to help countries develop disaster risk reduction strategies, make risk-informed policy decisions and allocate resources to prevent new disaster risks. The Sendai Framework Monitor can contribute to the Target E of the Sendai Framework related to the development of actionable national and local disaster risk reduction strategies by 2020.



Figure 2: Seven Global Targets of Sendai Framework for Disaster Risk Reduction. Source: Policy Area Secure (2018).

A set of 38 indicators was identified to measure global progress in the implementation of the Sendai Framework.; the will measure progress in achieving the global targets of the Sendai Framework, and determine global trends in the reduction of risk and losses. The scope of monitoring has been categorised in a number of ways:

- Global and Custom targets and indicators:
  - The seven global targets (A - Mortality, B - Affected people, C - Economic loss, D – Damage, E – Countries, F – International cooperation, G - Availability) and thirty-eight global indicators will measure progress made by all countries on disaster risk reduction by the year 2030. These will contribute to the global analysis of the country-level information submitted by countries and documented in the biennial Global Assessment Reports.
  - Additionally, the custom targets and indicators are nationally defined instruments by the Member States to measure their progress against the four priorities of the Sendai Framework. They are based on the priorities of respective countries and will be reflected in the national DRR reports of the countries.
- Input, Output and Outcome level targets and indicators:
  - Input level: Nationally defined, appropriate public policy indicators to measure the implementation of the 4 Priorities and the Sendai Framework in general
  - Output level: Nationally defined targets and indicators to measure the reduction of risk and increase in resilience
  - Outcome level: Global targets and indicators as described above, which are objective and comparable

#### 4. INTEGRATED MONITORING OF THE GLOBAL TARGETS OF THE SENDAI FRAMEWORK AND THE SUSTAINABLE DEVELOPMENT GOALS

The Sendai Framework targets and indicators contribute to measuring disaster-related goals and targets of the 2030 Agenda for Sustainable Development of above mentioned SDGs (PreventionWeb, 2020, <https://www.preventionweb.net/sendai-framework/sendai-framework-monitor/common-indicators>). Their desired outcomes are a product of complex and interconnected social and economic processes with overlap across the two agendas.



Figure 3: Integrated Monitoring of the Global Targets of the Sendai Framework and the Sustainable Development Goals. Source: PreventionWeb (2020).

The realisation of all above-mentioned steps needs highest quality data coming from existing or just developing Spatial Data Infrastructures (SDI), monitoring of all kinds (ground-based or remote sensing) and their up-grading according to agreed rules (like in Copernicus or INSPIRE cases).

## 5. DIGITAL DATA CONCEPTS AND ARSENALS: U.N. GLOBAL GEOSPATIAL INFORMATION MANAGEMENT (U.N. GGIM) AND DIGITAL BELT AND ROAD INITIATIVE (DBAR)

All modern concepts of dealing digital data are based on the concept of SDI, which started by the formulation of National SDI by former president Clinton (2004) in USA. In fact, at the same time, crucial steps have been done in Australia and New Zealand, which are keeping and formulating fresh initiatives up to date. From important efforts and results should be mentioned: Global Map, Global Spatial Data Infrastructure Initiative and Association (GSDI and GSDIA), Global Earth Observation System of Systems (GEOSS), Digital Earth (D.E.), Copernicus and INSPIRE which authors mentioned in previous publications (Konecny et al., 2020), and newest breaking through initiatives are - U.N.Global Geospatial Information Management (U.N.GGIM) and Digital Belt and Road.

### U.N. GGIM

A newly established Global Data Ecosystem by the U.N. Global Geospatial Information Management (U.N. GGIM) will support the realisation of the SDGs, including all aspects linked with DRR. It helps to develop the global understanding of geospatial information (G.I.) and, in a second step, its coordination, coherence and implementation. The vision is to position G.I. to address global challenges and missions to ensure that G.I. and resources are coordinated maintained, accessible, and used effectively and efficiently by member states and society to address key global challenges in a timely manner. Gregg Scott defined the data needs for the 2030 Agenda as follows (Scott, 2018): “The scope of the 2030 Agenda requires high-quality and disaggregated data that are timely, open, accessible, understandable and easy to use for a large range of users, including for decision making at all levels. There is a need for a reporting system on the SDGs that would have benefit from the subnational (local) to the national level; and allow for global reporting that builds directly on the data shared by countries. It is important to create an opportunity for countries to directly contribute to global reporting. While the challenges are immense, the digital technology that is available today allows the necessary transformation. An aspiration is to strengthen countries’ national geospatial and statistical information systems to facilitate and enable a ‘data ecosystem’ that leverages an accessible, integrative and interoperable local to global system-of-systems.”

The U.N. GGIM is the newest initiative to qualitatively improve the potential to solve the problems of the world, including DRR. Further efforts are needed to strengthen monitoring at the local level, develop the necessary metrics, and make risk information open, accessible, sharable across data platforms, and duly disaggregated to support efforts to leave no one behind. The implementation of the UN-GGIM Strategic Framework on G.I. and services was recognised

as instrumental to the monitoring of the Sendai Framework and the SDGs also during 2017 Cancun Global Platform conference.

## **DBAR**

Both relatively new activities have been initiated by Silk Belt and Road Initiative (BAR). Digital Belt and Road Program (DBAR) is a pioneering international venture to share expertise, knowledge, technologies and data to demonstrate the significance of Earth Observation Science and Technology and Big Earth Data applications for large-scale sustainable development projects. The extensive geographical scope of the "BAR" initiative calls for smart uses and applications of Big Earth Data in the design, development and implementation of diverse projects related to infrastructure improvement, environmental protection, disaster risk reduction, water resource management, urban development, food security, coastal zone management, and the conservation and management of natural and cultural heritage sites. DBAR is committed to implementing projects and actions relevant to the 17 Sustainable Development Goals (SDGs) adopted by the United Nations in September 2015 (United Nations Brussels Team, 2018). It will also strive to integrate green, low-carbon and sustainable approaches to social and economic growth that are vital for the implementation of the Paris Agreement (UN FCC, 2016). See also Konecny et al. (2020).

## **6. STRATEGIES IMPROVEMENTS IN DRR REALISATION**

The realisation of existing strategies in SDGs and Sendai DRR is monitored and gradually realised. The particular example are activities of the Global Platform for Disaster Risk Reduction (GPDRR).

The GPDRR was established in 2006 (U.N. General Assembly resolution 61/198) is the world's foremost gathering of stakeholders committed to reducing risk and building the resilience of communities and nations to disasters. The Global Platform is recognised as the leading forum at the global level for strategic advice, coordination, partnership development and the review of progress in the implementation of international instruments on disaster risk reduction, in particular the Sendai Framework for DRR (2015-2030). Launched in 2007 and convened every two years, the Global Platform is characterised by a format that facilitates dialogue and exchanges among all stakeholders, both governmental and non-governmental. Furthermore, the Global Platform outcomes contribute to the deliberations of U.N. governance bodies and mechanisms, such as the General Assembly, the ECOSOC and the High-Level Political Forum on Sustainable Development, and especially for the follow-up processes to U.N. conferences and summits, in particular the 2030 Agenda and its Sustainable Development Goals (Global Platform, 2017). In the Chair Summary (2017) "From Commitment to Action" ([https://www.preventionweb.net/files/53989\\_chairsummaryofthe2017globalplatfor.pdf](https://www.preventionweb.net/files/53989_chairsummaryofthe2017globalplatfor.pdf)) were examined and assessed the results of realisation of four priorities of the Sendai Framework.

For this paper, it is important that in Priority 1: Understanding disaster risk is in point 8 said: Methodologies and guidelines for the collection of data to build and maintain national disaster loss databases and conduct risk assessments need to be strengthened and developed into global standards for use by the public and private sectors in the efforts to implement the Sendai Framework. In point 9 is the request of practical examples regarding the use of open data platforms that present geo-referenced risk information across hazards and exposure data in open source and interoperable formats which need to be documented and shared. This includes documenting the cost-effectiveness and the multiple sustainable development benefits of such open risk data platforms for the public and private sector. In point 10, there are countries encouraged to incentivise the collection of risk information by local authorities, which can enable higher levels of data disaggregation. When consolidating the data nationally, it is recommended to preserve similar levels of disaggregation. In point 11 is requested that risk assessments should include data on displacement as well as data disaggregated by sex, age, income and persons with disabilities. Further improvement is required to achieve this. Identified good practices include the connection and active engagement of stakeholder groups who are already compiling such data through the household survey or other means. In point 12 is statutes that risk information is the foundation for awareness-raising and the development of educational material on disaster risk. Risk assessment and its guidance can be strengthened through the systematic integration of indigenous and traditional knowledge and practices. Point 13 highlights that there is inconsistent availability of risk information to drive effective multi-hazard early warnings. The number of countries compiling data on casualty risk and developing scenarios to establish thresholds for impacts-based warnings needs to increase. Point 14 says that risk information of the exposed population, including aspects of vulnerability and the identification of people with special needs, is required to target warnings and identify suitable communication channels. Progress in this area will need to be measured against Target (G) of the Sendai Framework. Point 19 highlights that Volunteerism continues to be a fundamental resource which needs to be leveraged and supported. The critical role in this regard of the Red Cross and Red Crescent movement was repeatedly emphasised.

But as cartographic and geoinformation specialists, we have the potential to develop so-called volunteer geographic information (VGI) which can progressively better improved practical acts in catastrophic situations.

## 7. THE ROLE OF GI SCIENCES AND CARTOGRAPHY

There are two world operating organisations United Nations, the International Strategy for Disaster Reduction (U.N. ISDR) and the Integrated Research on Disaster Risk (IRDR). There are also activities of prominent World research organisations, members of the International Science Council (ICSU). The working group and later Commission on Cartography for Early Warning and Disaster Risk Management were founded inside International Cartographic Association - ICA (in 2004 resp. in 2007 arranged by M. Konecny). Very fruitful were also The International Society for Photogrammetry and Remote Sensing (ISPRS) which started organisation of GI4DM conferences (Sisi Zlatanova); last one was organized in Prague (Lena Halounova, Orhan Altan); and The International Federation of Surveyors (FIG) which organised at the time of Working Week 2016 in Christchurch, New Zealand the conference Recovery from Disaster (Chryssy Potsiou).

The mentioned activities are essential components in disaster prevention, prediction, response and management, as well as in planning and monitoring for sustainable development. New technologies and institutional arrangements are now playing a prominent role during decision-making. International cooperation and partnerships are key to achieving integral, comprehensive and inclusive approaches to effective DRR, resilience-building and sustainable development. They also highlighted that the data needed for DRR must integrate different sources of information, including: household surveys, government censuses, geospatial and Earth observations data, administrative registers, quality of services surveys, volunteered geographic information (VGI), Big Data, etc. This also includes listening of the people affected or potentially affected by disasters and integrating them in a systematic manner in the planning and decision-making process.

### The Sustainable Development Goals and Cartography

The mentioned ongoing cooperation between international political, research and other bodies (e.g. U.N., ICA, etc.) can be extended and intensified. Such cooperation can be documented on the cooperation between U.N. and most important international cartographic umbrella organisation – ICA (see Figure 4). Activities of the most active Commission on Cartography in Early Warning and Crises Management (founded by prof. Konečný) provided general concept to:

- Provide leadership in the development of concepts, ontologisation and standardisation for early warning, hazard, risk and vulnerability mapping.
- Promote the cartographic use of remotely sensed and other geospatial data for early warning and crisis management through scientific conferences, seminars and workshops.
- Investigate the psychological condition of end-user given by their personal character and situation and psychological condition of rescued persons (with support of ubiquitous and adaptive mapping).
- Foster quality mapping and cartographic modelling, including state-of-the-art visualisation technologies, geospatial processing and publishing tools, for early warning and crisis management through topic related publication activities.
- Participate and contribute to global initiatives in early warning and crisis management through the maintenance of a website, newsletters and social network channels.
- Promote the development of dynamic and real-time cartographic visualisation concepts and techniques for enhanced operational early warning activities through active collaboration with governmental authorities.
- Establish and cultivate professional networks for the exchange of information among stakeholders in the domains of crisis management and early warning.
- Develop mechanisms of command and control systems integration as well as improve real-time data-centric intelligence based on sensors for purposes of Crisis Management.
- Develop mapping methodologies and technologies for EW&CM in children perspectives. Promote the process of teaching, understanding and using maps for EW&CM in children aspects.

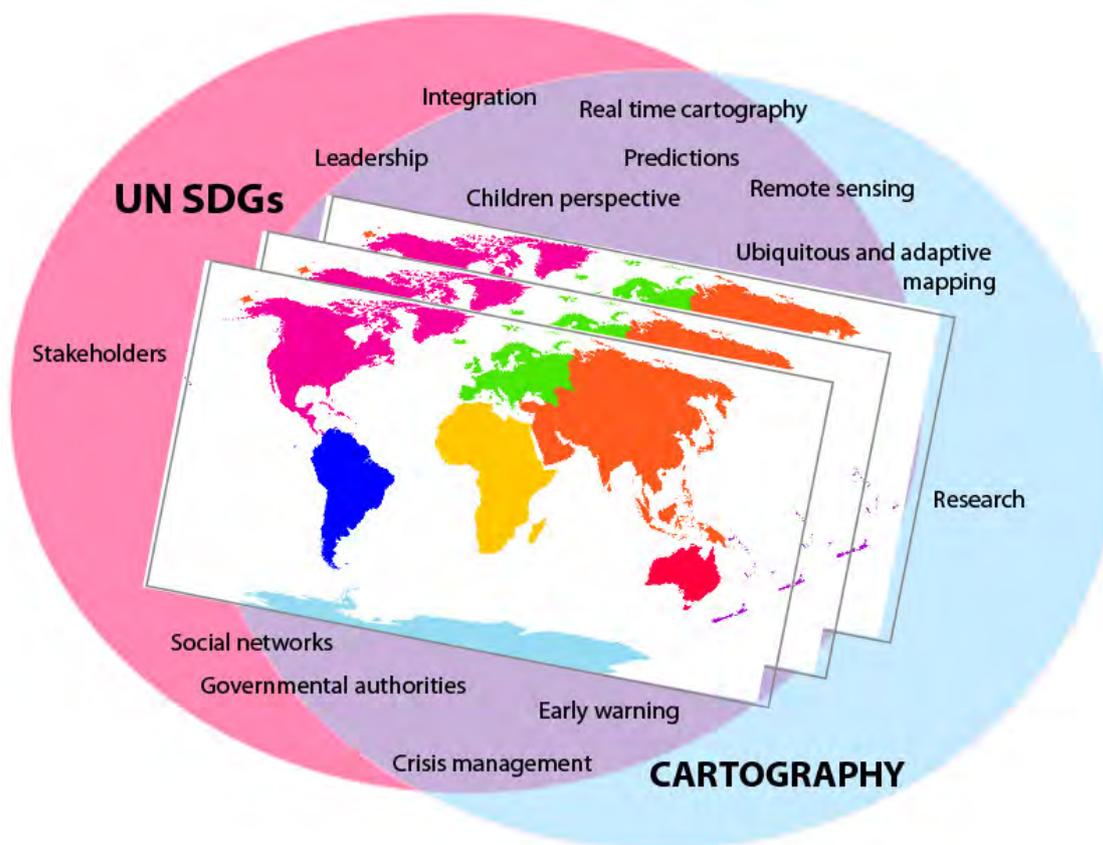


Figure 4. Concept of cooperation and overlaps of Agenda – example of U.N. and ICA. Source: own work.

The cartography and cartographers are able to provide the support for DRR on several levels. At first, there are methods and activities providing the spatial data. Secondly, the tools for spatial analysis and last but not least, the cartographic visualisation. Following text, bring examples of the possible contribution of cartography to the U.N. Sustainable Development Goals (see part 2) on mentioned levels.

Goal 1: End poverty in all its forms everywhere

- Provide data about the spatial distribution of poverty, social protection, etc.
- Visualise the most vulnerable areas.

Goal 2: Zero Hunger

- Provide the data about the spatial distribution of hunger, soil quality, arable land and agriculture production temporal development and fluctuations.
- Visualise the areas vulnerable to soil erosion, areas with a decrease of production.

Goal 3: Ensure healthy lives and promote well-being for all at all ages

- Provide data about the health status of the population. Provide near real-time data on possible pandemic development.
- Visualise the regions with the decreasing average age. Visualise the trajectories of pandemic spreading.

Goal 4: Quality Education

- Provide data about the availability of different levels of education in different regions.
- Visualise the development of education rate.

Goal 5: Achieve gender equality and empower all women and girls

- Visualise the spatial differences in gender equality regarding the access to education, equal salaries etc.

Goal 6: Ensure access to water and sanitation for all

- Provide the data about the water resources, actual or possible water contamination.
- Identify the most vulnerable inhabited areas.
- Visualise the areas with water shortage.

Goal 7: Ensure access to affordable, reliable, sustainable and modern energy

- Identify the promising areas for clean energy (solar, wind, etc.) production.
- Visualise the spatial distribution of renewable energy sources and share on energy consumption.

Goal 8: Promote inclusive and sustainable economic growth, employment and decent work for all

- Visualise the areas with economic regression and possible vulnerable areas.
- Goal 9: Build resilient infrastructure, promote sustainable industrialisation and foster innovation
- Collect the data about spatial infrastructure development.
  - Identify the areas without sufficient infrastructure.
  - Visualise the areas vulnerable to damages on infrastructures caused by natural or human disasters.
- Goal 10: Reduce inequality within and among countries
- Identify the areas with inequalities within and among countries.
  - Visualise the temporal development of outlier countries.
- Goal 11: Make cities inclusive, safe, resilient and sustainable
- Identify the unsafe zones in the cities.
  - Visualise the spatiotemporal patterns of inhabitants.
- Goal 12: Ensure sustainable consumption and production patterns
- Visualise the spatiotemporal changes of consumption and production patterns
- Goal 13: Take urgent action to combat climate change and its impacts
- Provide the data about the spatial distribution of the air and water temperatures, moisture and other characteristics.
  - Identify the most vulnerable areas to the climate changes.
  - Visualise the spatiotemporal changes of temperature of air, water bodies, etc.
- Goal 14: Conserve and sustainably use the oceans, seas and marine resources
- Provide the data about the water pollution, changes of the water level, etc.
  - Visualise the most polluted and threatened water bodies.
- Goal 15: Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss
- Provide the data about the spatiotemporal changes of forests, deserts, etc.
  - Identify the most vulnerable areas.
  - Visualise the historic data and possible development.
- Goal 16: Promote justice, peaceful and inclusive societies
- Visualise the most conflict threatened regions.
- Goal 17: Revitalise the global partnership for sustainable development
- Provide one of the universal communication channels between the nations.
- Spatial data and visualisations activities connected with the SDGs 3, 10 and 16 are presented on example VGI for DRR and Crisis Management (see next part).

### Using volunteers and VGI for DRR and Crisis Management

The main role of G.I. Science in DRR is creation, providing and sharing of spatial data and providing analyses of data. The development of electronics, networks, databases, data sharing brings new possibilities for data collection, management and providing. However, there is a big gap between technological and financial possibilities of developed and developing countries. The third world faces to the big number of disasters, both natural and man-caused. Infrastructure and number of experts for DRR available in these countries are very inappropriate to solve such amount of critical situations. The possible way how to bridge this problem is using of volunteers – both for disaster risk reduction and crisis management (see Figure 5).

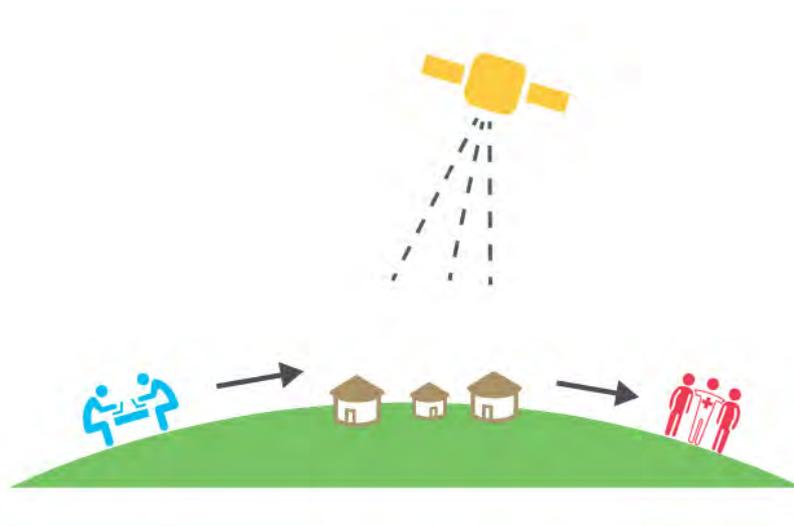


Figure 5. General concept of VGI (GIS Unit, Médecins Sans Frontières). Source: HOTOSM (2014).

In recommendations from Cancun (Global Platform, 2017) remind above is mentioned, among others:

- people affected by disasters should be integrated into the decision-making process,
- VGI data should be integrated as a new source of data,
- used data should be open-access and accessible through common platforms and portals

Example of such using of volunteers (including locals), using VGI data and open-access platforms are Humanitarian OpenStreetMap Team (HOT, <https://www.hotosm.org/>) and Missing maps project (<https://www.missingmaps.org/>). Both projects are not competitive; they are complementary and deeply connected to each other. HOT is one of Missing Maps project founder. They are examples of connections and differences between crisis management and disaster risk reduction.

Haiti was heavily hit by earthquake in January 2010. Number of victims is estimated to more than 100,000 (some estimates placing the number as high as 316,000). Rescue teams and humanitarian aid was transferred into Haiti in very short time. However, organisation of rescue work and distribution of humanitarian aid was very problematic because of destroyed infrastructure and also because of lack of maps and information. One reason was that Haitian government and authorities were also heavily hit. Buildings of national mapping agency of Haiti (Centre National de l'Information Géospatiale-C.N.I.G.S) collapsed, destroying most of the SDI and killing its director along with five staff members (Clark and Guiffault, 2018).

Volunteers solved the lack of available maps with using OpenStreetMap platform – free, editable map of the world. Mappers produced map of Port-au-Prince precise enough for humanitarian work (Meier, 2015). Effectivity of this action led to foundation of Humanitarian OpenStreetMap Team (HOT) in August 2010. OpenStreetMap data is updated and analysed by HOT and various tools are developed for the needs of humanitarian organisations in Third World countries with the lack of quality data. HOT usually works as a response to crisis. It is an example of mapping for disaster management. Any organisation is allowed to ask for mapping some area that is important for its work.

Missing Maps project was founded in 2014. Its founders are British and U.S. Red Cross, Doctors without borders (MSF) and also above mentioned Humanitarian OpenStreetMap team. Many other organisations, universities etc. joined the project since that. The goal of this project is mapping the most vulnerable places in the developing world where MSF or other humanitarian organisations plan to work. Typical example is planning of vaccination campaign. It is an example of mapping for disaster risk reduction.

HOT and Missing Maps use volunteers in three steps:

1) Map drawing: remote volunteers along the world map the focus area from safety of their homes using internet and freely available remote sensing imagery. It is important that the goal is not cartographically complete map. Only the most important data for humanitarian work are mapped. It means that needed data can be prepared very quickly:

- villages – to know where people live,
- ways and tracks – to know how to get to village,
- buildings – to know how many people live in village.

2) Field mapping: volunteers from the local community verify remotely mapped data and add information that is not visible from air – source of water, which house is school etc.

3) Using the map in field. Volunteers – specialists (doctors, humanitarian workers etc.) use the data to organise effectively their field work. One story can be described as example.

Yellow fever outbreak occurred in slums on the suburb of Kinshasa (DRC) in August 2016. Population density in that area is 36,000 hab./km<sup>2</sup>! No official map of slums existed (8,000 buildings were on the map of the whole Kinshasa). Volunteers from HOT and Missing Maps prepared the quality map of that slums (76,000 buildings were added in 15 days), so vaccination was fast and well organised. MSF vaccinated 720,000 habitants in 10 days and critical situation was solved (GIS Unit, 2017).

Very interesting is investigate how are cartographic approaches used in various countries. In the Czech Republic are in international cooperation investigated dynamic mapping methods in Big Data era developing heterogenic spatial data and creation of maps in real-time (Kubicek et al., 2018). Fire and Rescue Service of the Czech Republic compiles every year the Statistical Yearbook. In this Yearbook are beside the standard maps, the maps which reflect the current hot topics on the field of emergency management (Fire and Rescue Service, 2020). Chinese Academy of Surveying and Mapping (CASM) is elaborating intelligent mapping services for DRR purposes (Liu et al., 2018). Interesting and helpful atlases are created in Russia (Rotanova et al., 2016). Switzerland has long tradition of solving DRM and DRR and methodological approaches are often accompanied by maps (e.g. Federal Department of Foreign Affairs, 2020). In

Bulgaria appeared high quality and actual maps about development of situation with COVID-19 in Europe (Fig. 6), DataMap-Europe Ltd. (2020).

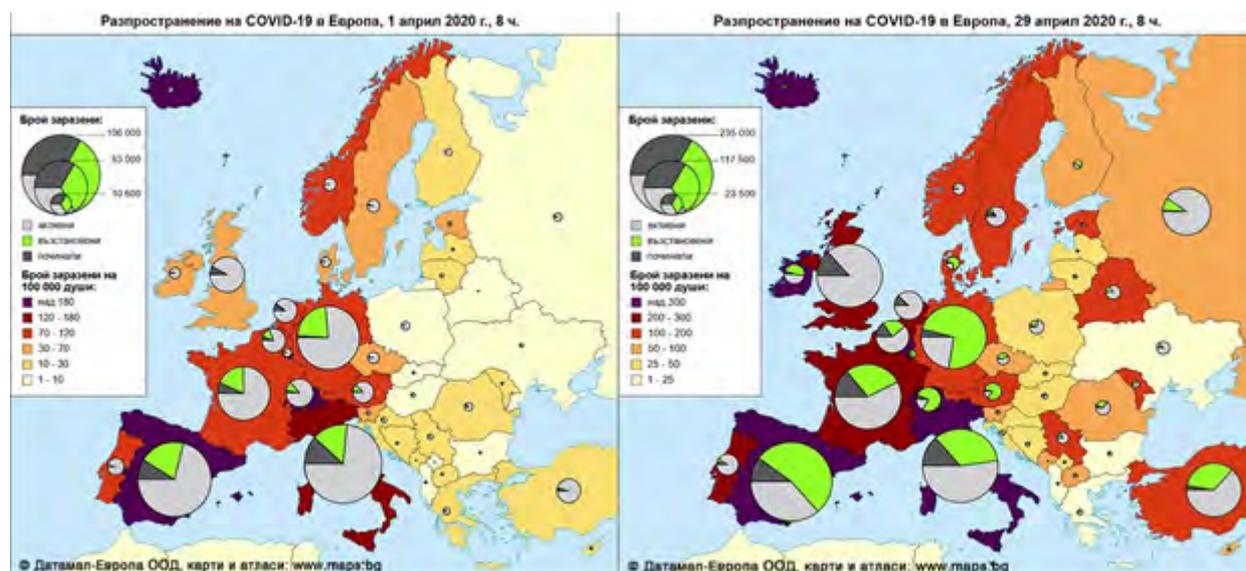


Figure 6. Maps represent the development of the COVID-19 in Europe from between April 1 and April 29. Source: DataMap-Europe Ltd. (2020)

## 8. CONCLUSIONS AND RECOMMENDATIONS

The main task for the future is to emphasise aspects of cartographic communication in the context of early warning and disaster management such as the use of remotely sensed and other geospatial data, including concepts of Volunteer Geographic Information (VGI) and Public Participation Geographic Information Systems (PPGIS), cartographic modelling of state-of-the-art visualisation technologies, geospatial processing and publishing tools, dynamic and real-time cartographic visualisation for enhanced operational early warning and DRR activities through active collaboration with governmental authorities.

Big official platforms for the collection, management and providing of data for like U.N. GGIM, DBAR, GEOSS, Copernicus and others aim to make data available for disaster management and disaster risk reduction. Their efforts can be successfully supplemented by using of VGI data from free and open sources created by enthusiastic work of volunteers.

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# MOTIVATING GOOD PRACTICES FOR THE CREATION OF CONTIGUOUS AREA CARTOGRAMS

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## **Abstract**

*Cartograms are maps in which the areas of regions (e.g., countries or provinces) are proportional to a thematic mapping variable (e.g., population or gross domestic product). A cartogram is called contiguous if it keeps geographically adjacent regions connected. Over the past few years, several web tools have been developed for the creation of contiguous cartograms. However, most of these tools do not advise how to use cartograms correctly. To mitigate these shortcomings, we attempt to establish good practices through our recently developed web application go-cart.io: (1) use cartograms to show numeric data that add up to an interpretable total, (2) present a cartogram alongside a conventional map that uses the same color scheme, (3) indicate whether the data for a region are missing, (4) include a legend so that readers can infer the magnitude of the mapping variable, (5) if a cartogram is presented electronically, assist readers with interactive graphics.*

**Keywords:** Cartogram, style guidelines, web-based mapping application

## **INTRODUCTION**

Visualizing quantitative data associated with geographic regions is a common task in cartography. Conventionally, quantitative data are shown on choropleth, dot-density, or proportional symbol maps (Dent et al., 2008). Typically, these maps are based on standard map projections (e.g., a transverse Mercator or Albers projection) so that the regions' boundaries have shapes that look familiar to most readers. The most salient feature of a region on a map is arguably the size of the area that the region occupies. However, the area of a region on a conventional map is usually not related to the data the map aims to communicate. For example, Vienna occupies only 0.5% of the area in the choropleth map of Austria in Figure 1a, where Vienna is abbreviated as "WI". Even though the color legend indicates that Vienna is densely populated (data from Wikipedia, 2020a), it is not immediately apparent from the choropleth map how large Vienna's population size is in comparison with the population of other regions.

Cartograms promise a way to overcome the limitations of conventional thematic maps (Raisz, 1934; Hennig, 2013). On a cartogram, every region has an area proportional to its numeric data value. For instance, on the cartogram in Figure 1b, Vienna occupies 21.4% of Austria's area, which accurately represents Vienna's share of the nationwide population. In addition to scaling all areas in proportion to population, the cartogram in Figure 1b is also contiguous (i.e., all neighbors on the conventional map projection in Figure 1a are also neighbors in Figure 1b, and vice versa). Several algorithms have been proposed that create contiguous cartograms (e.g., Dougenik et al., 1985; Merrill et al., 1992; Gusein-Zade and Tikunov, 1993; Sun, 2013). The example in Figure 1b was generated with the fast flow-based method by Gastner et al. (2018), but the principles we propose in this paper are not specific to contiguous cartograms produced with this technique.

Contiguous cartograms have often been criticized as difficult to read because they inevitably appear distorted when they are compared to traditional maps (Fotheringham et al., 2007; Eckert et al., 2008; Woodruff, 2008). We argue that the difficulty is partly caused by the way cartograms are often presented. In this paper, we propose a set of guidelines for the presentation of cartograms that should alleviate some of the concerns about their use. We advocate the adoption of these practices to ensure that cartograms are used appropriately and remain accessible to readers. We also describe the cartogram web application go-cart.io (Gastner, 2020) that nudges users to adhere to these guidelines.

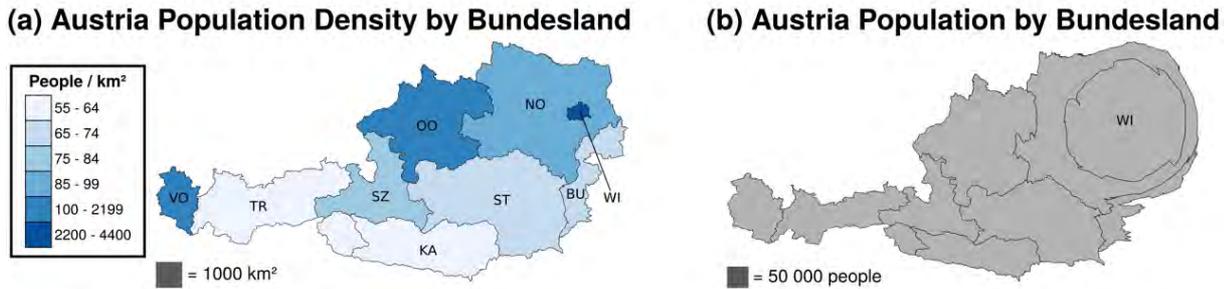


Figure 1. Two maps that visualize the population distribution of Austria by federal state (Bundesland). (a) Choropleth map of the population density. (b) Cartogram in which areas are proportional to population size.

## PREVIOUS WORK

In recent years, several software tools have been developed for the creation of cartograms. Markowska and Korycka-Skorupa (2015) conducted an evaluation of five existing cartogram generation tools: Cartogram Utility for ArcGIS (ESRI, 2007), ScapeToad (Andrieu et al., 2008), OpenGeoDa (Anselin and McCann, 2009), MapViewer (Golden Software, 2010), and MAPresso (Herzog, 2005). They assessed whether these five tools contain certain features that may help users to better read and generate cartograms. Cartogram Utility for ArcGIS and ScapeToad received the highest scores. For example, these cartogram tools were the only two in the list that enabled users to save and export the cartograms as vector graphics. However, not even these two cartogram generators intend to guide users towards proper use of cartograms. None of the available software informs users whether their data are suitable to be shown on a cartogram, how to handle missing data, or how to add meaningful legends.

Clear guidelines for the proper use of cartograms have generally been lacking in the cartogram literature. A noteworthy exception is a user evaluation by Dent (1975). Based on experimental results, he advises to label all administrative units on the cartogram, show a conventional map as an inset in the cartogram, and provide an “anchor stimulus”. The intention of the anchor stimulus is to allow map readers to convert between cartogram areas and the numbers that the areas represent. Dent (1975) presents as an example a population cartogram of the northeastern United States. The anchor stimulus in his example takes the form of a square next to the cartogram that is accompanied by the label: “represents 1,500,000 persons”. We show a similar anchor stimulus in the cartogram of Austria in Figure 1b.

Since the publication of Dent’s (1975) guidelines, cartograms have become a more frequent form of data visualization, but only few cartogram designers have strictly followed his advice. The news media nowadays often adopt cartograms as visualizations accompanying their online content. Some of these cartograms indeed contain an inset map (Los Angeles Times, 2012; New York Times, 2012) or an anchor stimulus (Fairfield, 2008), but the use of these features is not universal. It is understandable that there has been no uniform approach to presenting cartograms so far because their production has required manual adjustments specific to each individual data set. Because of the increasing interest in cartograms, it is timely to implement Dent’s (1975) guidelines as an integral part of software that can automate many of the steps needed to convert raw data into a cartogram. A fresh look at the problem also presents an opportunity to establish best practices for cartograms that are presented on a computer screen rather than on printed paper.

When cartograms are shown in a web browser, we can take advantage of modern web technologies (e.g., D3.js or AJAX) to add new elements of interactivity that have the potential to make cartograms more understandable and more enjoyable to users. On news portals, there are already many online cartograms that allow readers to explore the data interactively (Byron et al., 2008; Clark and Houston, 2012; Los Angeles Times, 2012; New York Times, 2012; The Telegraph, 2015; Franklin et al., 2016; BBC News, 2019; Kommenda et al., 2019). There are three categories of interactive features that either have been implemented on these websites or have been proposed in the cartogram literature: animations, linked brushing, and infotips. Animations can help visualize how one map morphs into another. Ware (1998) strongly advocated the use of animations that show a continuous transformation from a conventional map to a cartogram and vice versa. In an experiment, she found that participants with access to animations were more likely to give correct answers, though at the expense of a longer response time. While an animation only displays a single map at a time, linked brushing enables users to compare a cartogram shown alongside a corresponding conventional map. Linked brushing is a mouse-hover effect where the user pointing at one region on the conventional map causes the corresponding region on the cartogram to be highlighted (e.g., by changing its color) and vice versa. Dykes (1997), Haining (2003), and Tobler (2004) all proposed linked brushing as a method of visually communicating the thematic connection between the conventional map and the cartogram. Another mouse-hover effect is an infotip that appears as a

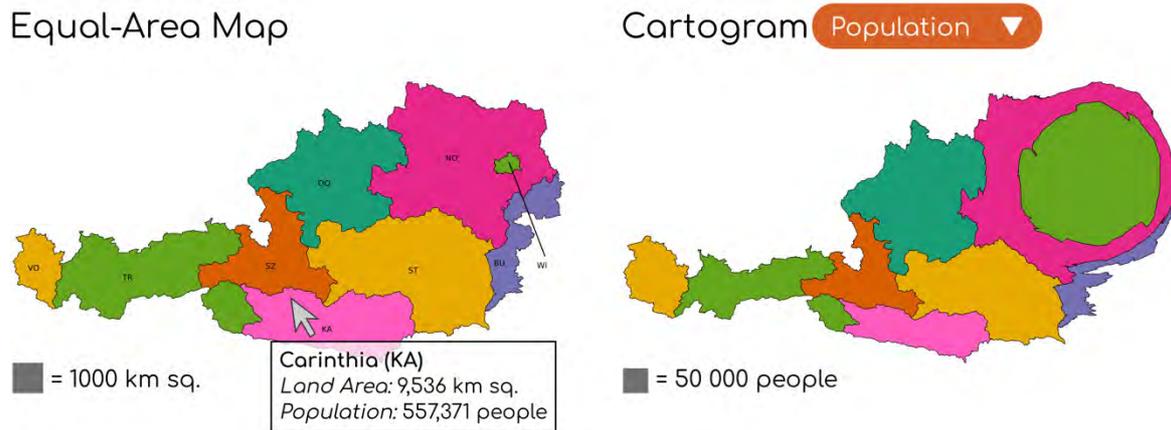


Figure 2. Screenshot of the *go-cart.io* user interface. A conventional equal-area map of Austria (left) and a population cartogram (right) are shown alongside each other.

pop-up with data about the region under the mouse pointer (Figure 2). Nusrat et al. (2018) proposed infotips as a way to reveal the exact value of the numeric data represented by the region's area. Infotips have been implemented in cartogram software such as GeoViz Toolkit (Hardisty and Robinson, 2011) and MAPresso (Herzog, 2005). However, these software tools are no longer up to date. The cartogram feature of GeoViz Toolkit has been reported to be broken<sup>1</sup>, and MAPresso is no longer supported by contemporary web browsers because it is a Java Applet.

## GO-CART.IO

We have developed the web application *go-cart.io* (Gastner, 2020) as a free alternative to existing cartogram software that takes advantage of state-of-the-art web technology. It aims to provide an intuitive interface to create cartograms supported by backend computer code that outputs the desired cartograms within seconds (Gastner et al., 2018; Tingsheng et al., 2019). By design, *go-cart.io* neither requires technical knowledge about programming nor access to geographic information system software so that even non-experts can create cartograms from their own data. To generate a new cartogram with *go-cart.io*, users first select a desired input map (e.g., a map of Austria). By default, the website displays a conventional equal-area projection of the chosen map region alongside a population cartogram (Figure 2). Users can fill in their own numeric data for each administrative region either by typing directly in the browser or by uploading a CSV spreadsheet. The website then visualizes the input as a pie chart and as a cartogram. By selecting different data sets from a drop-down menu, users can compare different cartograms (Figure 3). Users can explore the maps with interactive features—animations, linked brushing, and infotips—implemented with the D3.js library. With a simple mouse click, users can download the maps in GeoJSON or SVG vector graphics format. A tutorial with an explanation of the cartogram generation process is available on *go-cart.io*.

At this point in time, the development of *go-cart.io* is still work in progress. While working on the software, we had to make many design decisions that, in our opinion, set an example for the appropriate use of cartograms. The purpose of this paper is to summarize our design decisions as guidelines that we regard as essential if cartograms are to become an effective form of data visualization.

<sup>1</sup> <https://code.google.com/archive/p/geoviz/issues/39>, accessed on 2020-24-05.

## RECOMMENDED PRACTICES

### Interpretable Total

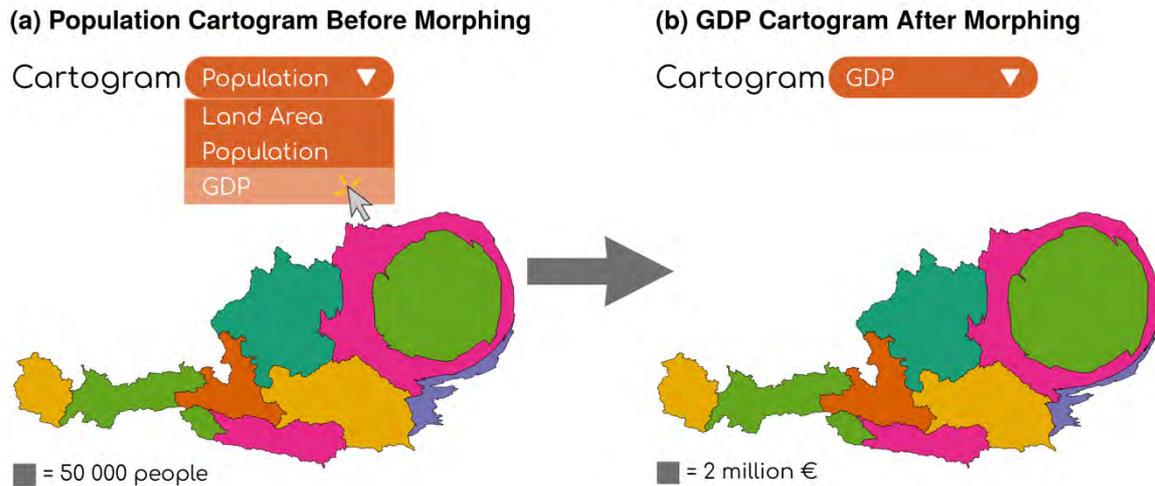


Figure 3. Users can select a cartogram from a drop-down menu. In this example, the user previously uploaded GDP data. Upon selecting “GDP”, the cartogram continuously morphs from a cartogram where areas are proportional to population to a new cartogram where areas are proportional to GDP.

The main purpose of a cartogram is to show the share of a region’s importance in the context of a larger geographic entity. For instance, we may want to show the proportion of Austria’s GDP that originates in each federal state (Bundesland). We can visualize these numbers on a cartogram where each Austrian state has an area in proportion to its GDP (data from Wikipedia, 2020b). On such a cartogram, the states’ GDPs add up to an interpretable total: Austria’s national GDP. Unfortunately, many cartograms have been presented in the literature where cartogram regions are proportional to non-additive statistics. The most common mistake is the use of per-capita statistics for the regions’ areas. For example, it is not appropriate to make a cartogram of Austria where each state has an area in proportion to the state GDP *per capita*. The states’ per-capita GDPs do not add up to an interpretable total, so such a per-capita cartogram would not reveal the contribution of a state to the federal GDP. Examples of cartograms incorrectly based on non-additive statistics can be found in Rittschof et al. (1996; books read per capita), Sui and Holt (2008; mortality rate instead of number of fatalities), and Pleger et al. (2014; citations per publication instead of total citations), to name only a few.

To understand why non-additive statistics are unsuitable for cartograms, it helps to draw an analogy with a more common form of data visualization: pie charts. The numbers associated with the slices of the pie must add up to a number that we can attribute to the whole pie. For example, if each slice represents the GDP of one state, the entire pie represents the national GDP—a meaningful quantity that we can show as a label on top of the pie chart. If instead we were to make slices proportional to GDP *per capita*, we would not be able to describe the sum of these numbers with a simple label. The analogy between cartograms and pie charts was first made explicit by the Worldmapper team (Dorling et al., 2007). We find this analogy intuitive and easy to communicate to non-experts. We have, therefore, decided to integrate the pie chart analogy into *go-cart.io*’s cartogram generation process.

Before a cartogram is shown to the user, we first present the input data as a pie chart (Figure 4). Above the pie chart, we state the sum of the input numbers and pose the question: “Is this a meaningful quantity?” The cartogram is only computed after the user confirms that the total number is interpretable. We hope that the pie chart and the accompanying text nudge users to think about whether their data are suitable and, if not, to amend their input. Figure 4a shows an example where the input numbers add up to a meaningful total, namely the total GDP of Austria. The example in Figure 4b illustrates what happens if the input is unsuitable (GDP per capita): the total of 384,300 € is clearly too small to be the total GDP of Austria and too large to be the nationwide GDP per capita.

## Color Scheme

While Dent (1975) already advised to show conventional map and cartogram alongside each other, he gave no rule how to choose colors on the two maps. Most cartograms are univariate maps: they represent only one variable (e.g., population in Figure 3a or GDP in Figure 3b), and the area is the only visual stimulus that represents this variable. In univariate cartograms, we are free to choose the colors for each region so that regions are easy to identify. We color the regions such that no neighboring regions share the same color, but corresponding regions on the juxtaposed conventional map and cartogram have the same color (see Figure 2 for an example).

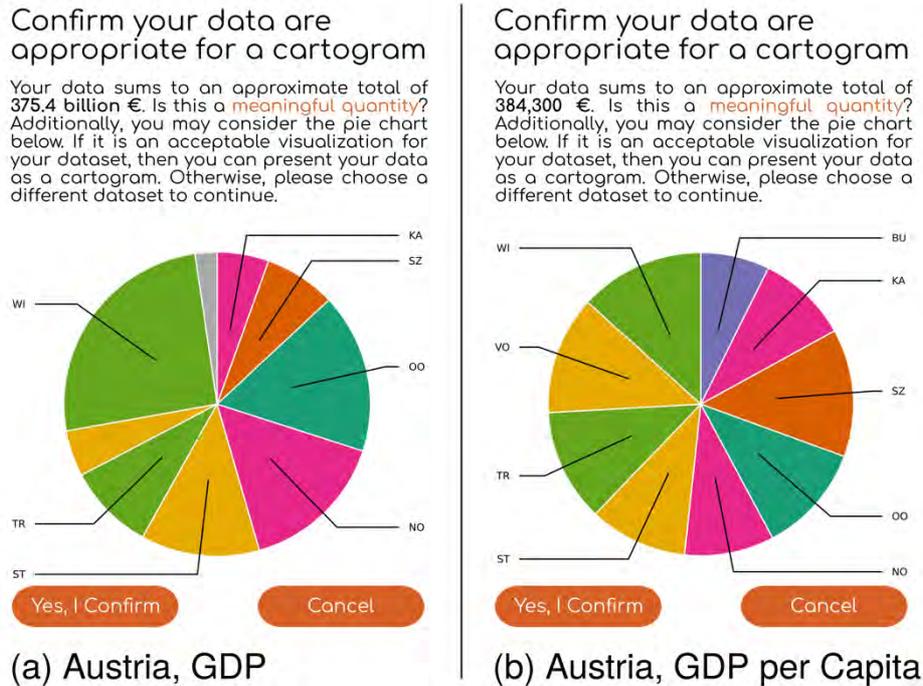


Figure 4. Examples of pie charts shown by go-cart.io during the cartogram generation process.

By default, *go-cart.io* uses the six-class Dark2 palette from ColorBrewer (Brewer, 2002; Figure 5), which is designed to work well on liquid-crystal displays. Although we believe that the default colors work well in most cases, we allow users to input other color choices, either as Hex codes or with a web-based color picker. The freedom to choose colors may in fact be necessary when representing bivariate data on a cartogram. The website ensures that corresponding regions of the conventional map and the cartogram still share the same color.

## Handling of Missing Data

Real-world geospatial data sometimes contain missing entries for some regions. Conventional thematic maps usually reserve a special color to indicate missing values. We apply the same method in *go-cart.io*. In the default color scheme, we choose light gray for missing data because it clearly stands apart from all other colors in the palette (Figure 5).

Besides setting a special color, we must also specify how large the area of a region with missing data should be on a cartogram. At first glance, it might appear natural to set the area equal to zero. In practice, however, this choice would be a bad solution. If a region's area is equal to zero, it completely disappears from the cartogram, which makes it difficult to compare the cartogram to a conventional map. An area of zero would also incorrectly imply that the statistical variable is known to be zero. A more appropriate choice is to symbolize the absence of knowledge on the cartogram by keeping the region's area the same as on the conventional reference map.

In Figure 6, we illustrate with an example how to represent missing data on a cartogram. On the left, we show a conventional equal-area map of Austria as a reference. On the right, we show a cartogram where the states' areas are proportional to the number of workers in day nurseries. The number for Vienna (WI) is unknown according to the data available from Statistik Austria (2020) We indicate the missing data with a gray fill color. We also keep the area of Vienna in the cartogram the same as Vienna's area in the equal-area map on the left.

## Value-to-Area Legend

Without any additional labels or legends, a cartogram shows the importance of the administrative units only in relative terms. For example, the viewer can judge from the areas of the Austrian states in Figure 1b that Vienna's population is approximately one fifth of Austria's total population. This knowledge is valuable, but users can gain even more insight if they know what magnitude each area represents in absolute terms. Therefore, we regard it as good practice to include a value-to-area legend in every cartogram.



Figure 5. Six-class color scheme used for cartograms in *go-cart.io*. The text strings are the Hex codes of each color. Gray is reserved for missing values.

Dent (1975) recommends a square as the legend symbol with an “anchor stimulus” (i.e., area in the square) “at the low end of the value range”. Unfortunately, he does not give an explanation how to obtain the area of the square key for a given data set. In his paper, he shows a sample cartogram of the northeastern United States, where the key represents approximately 1.1% of the total population (1.5 million inhabitants out of a total of 132.0 million). We have chosen slightly smaller keys, ranging from 0.5% for the GDP cartogram in Figure 3 to 0.9% for the day-nursery-personnel cartogram in Figure 6b. On a computer screen, the square is approximately 30×30 pixels. The exact percentage that is represented by the key depends on the aspect ratio of the cartogram. We restrict the keys to be “nice numbers” (sensu Wilkinson, 2013; i.e., powers of 10 multiplied by 1, 2, or 5). If users provide a unit as part of their input data, *go-cart.io* inserts the unit as part of the legend string (e.g. € in Figure 3).

In our current implementation, the legend is always placed below the map. The color of the legend is dark gray (Hex code #707070) to avoid confusion with any of the six colors in the Dark2 color scheme and the light gray used for missing data (Figure 5). In future versions, we may allow users to interactively change the legend color and position.

## Interactive Graphics

We integrate three interactive features into *go-cart.io* to render more readable and understandable cartograms. These interactive features are cartogram-switching animations, linked brushing, and infotips.

- **Cartogram-switching animations:** Users can choose between different data sets from a drop-down menu on the screen, as shown in Figure 3. When the user selects a data set, the previously displayed cartogram morphs into a new cartogram that visualizes the selected data. In *go-cart.io*, the transition from one cartogram to another is implemented as a smooth shift of the polygon vertices from start to end position during a one-second time interval. Figure 3 shows the start and end point of the animation when the user chooses to view the GDP cartogram whereas the original cartogram displayed is the population cartogram.
- **Linked brushing:** The cartogram is always displayed alongside a conventional map in *go-cart.io*. As the user hovers the mouse over an administrative region on one of these two maps, the corresponding region is simultaneously highlighted on the other map. In our current implementation, we highlight the region by increasing the brightness of its fill color. Other forms of highlighting (e.g., changing the border color or thickness) are also conceivable and may be implemented in future versions. We demonstrate linked brushing in Figure 2, where we show a population cartogram of Austria alongside a conventional equal-area map. Because the mouse is hovering over Carinthia on the equal-area map, the fill color has become a lighter shade of purple (#FF5CBD) than the default (#E7298A, see Figure 5) on both the equal-area map and the cartogram.
- **Infotips:** As the user hovers the mouse over an administrative region, a pop-up automatically appears at the position of the pointer. The text in the pop-up consists of the region's name and the data (e.g., population and GDP) represented by the areas in the juxtaposed conventional map and cartogram. An example is shown in Figure 2.

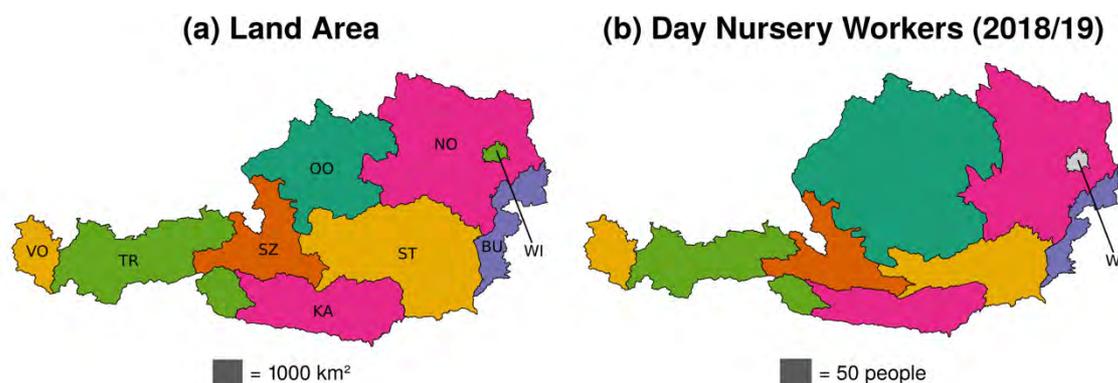


Figure 6. Maps of Austria. (a) Conventional equal-area map. (b) Cartogram where the areas of the states are proportional to the number of day nursery workers. The number for Vienna (WI) is unknown. We symbolize the missing data with a gray fill color (Figure 5) and with an area that is equal on both maps.

## DISCUSSION

The effectiveness of cartograms has been under discussion for the past few decades. In previous literature, cartograms have often been characterized as confusing and difficult to read (e.g., Dent, 1975; Rittschof et al., 1996; Fotheringham et al., 2007; Woodruff, 2008). We acknowledge that cartograms are inherently distorted, but we believe that the previous criticism of cartograms has often been triggered by poor usage rather than a fundamental flaw in the concept of a cartogram. Previous experiments sometimes presented cartograms to the participants without showing a conventional map as a reference (Sun and Li, 2010; Nusrat et al., 2018), which increases the perceived difficulty of understanding cartograms. If there is no value-to-area legend, interpreting a cartogram becomes even more challenging because it is unclear to the reader how to translate the areas to concrete numbers. Moreover, cartograms in the previous literature often translated non-additive statistics into region areas (e.g., Rittschof et al., 1996; Sui and Holt, 2008; Pleger et al., 2014), which renders cartograms almost uninterpretable. However, there is evidence that cartograms have great potential if they are used appropriately. For example, when Dent (1975) tested cartograms based on additive statistics with a value-to-area legend and a conventional map as inset, users described them as “exhibiting a definite style”, “interesting”, and “innovative”.

At the time of Dent’s (1975) experiment, readers encountered maps mostly on printed paper. With the rapid development of map-making technologies, cartograms nowadays appear more often on a computer screen than in print. If presented electronically, we can convey information with interactive features that are not possible on printed paper. Three interactive features have been described in the literature: cartogram-switching animations (Ware, 1998), linked brushing (Dykes, 1997; Haining, 2003; Tobler, 2004), and infotips (Nusrat et al., 2018). While other interactive features exist in the general literature on data visualization or cartography (e.g., zooming, panning), they would not add obvious value to cartograms. We have recently completed an experiment in which we tested how these interactive features affect participants’ performance in cartogram reading tasks. Our initial results suggest that animations are especially helpful in synoptic tasks (i.e., tasks in which users must summarize large-scale information about the cartogram). For elementary tasks, participants performed well without any interactivity, but the combination of the three investigated interactive features never had any negative impact. Therefore, we recommend the full suite of features (i.e., animations, linked brushing, and infotips) to be available whenever cartograms are presented on a computer screen. All three features are automatically implemented if cartograms are generated with *go-cart.io*.

We are unaware of any experiment that has specifically tested the influence of our other guidelines (i.e., interpretable total, combining conventional map and cartogram with matching colors, indicating missing values, and value-to-area legends). To judge how well the recommended practices integrate as a whole in *go-cart.io*, we conducted a pilot study with 13 college students in Singapore. We used Brooke’s (1996) System Usability Scale, which is a widely used tool for the evaluation of user interfaces in industry. In our pilot study, *go-cart.io* received an average score of 70.45 out of 100. This score is close to the median 70.91 for a large sample of System Usability Scale scores collected by Bangor et al. (2008).

Considering that *go-cart.io* is still work in progress, this result is encouraging. Still, more work needs to be done to ensure an even more satisfactory user experience. Currently, administrative units are only labeled on the conventional map, not on the cartogram. Automatic label placement is a complex problem (Freeman, 2007). We are not aware of an existing algorithmic approach to label placement that we can easily adopt for our needs. We also acknowledge that the current version of *go-cart.io* is not ideally suited to making bivariate cartograms. Users who are interested in bivariate cartograms must currently change the regions' colors manually and add a legend with other software.

## ACKNOWLEDGMENTS

We thank Bernard Boey Khai Chen for help with implementing the algorithm to handle missing data. This work was supported by the Singapore Ministry of Education (grant R-607-000-401-114) and a Yale-NUS College start-up grant (R-607-263-043-121).

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# FROM A PRINTED ATLAS TO A WEB MAP PORTAL – REFLECTIONS ON HISTORIOGRAPHICAL WEB MAPS PREPARATION

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## **Abstract**

*The paper introduces a newly developed web map portal, representing an extension of the topics presented in the last major historical atlases issued in recent times, namely the Academic Atlas of Czech History (2014) and the Czech Historical Atlas (2019). The web map portal is meant to provide a compendium of interesting and still not fully cartographically grasped themes that have been dealt with in Czech historical sciences in the last few decades.*

*The paper brings new insights into the issue of the transfer of maps originally prepared for a printed atlas into the web environment. The basic steps of the conversion process and its problematic aspects are mentioned and developed in detail. It also outlines the basic requirements for a suitable design of the whole portal, formalization of the structure and presentation of historical information in the form of story maps and their interconnection with supplementary information.*

**Keywords:** Czech Historical Atlas, web map portal, atlas cartography, historical cartography, Story Maps, storytelling

## **INTRODUCTION**

The rich history of the Czech Lands and the wider Central European region has always been the subject of interest and scientific research by historians and the general public. Significant historical events were regularly, and with a varying degree of accuracy and precision, captured on maps and in periodical publicistic volumes of which the maps were often a part.

In the latter half of the second millennium, atlases were increasingly compiled as a means of testifying to historical events, the domain of which was mainly the twentieth century. At the end of last century, with the development of computer technology and digital methods of information recording, partially electronic means of publication began to appear. Initially, they were published on digital media as stand-alone applications, later (due to the progress of the Internet, data transfer standards, development of graphic formats and network tools leading towards cloud solutions) electronic atlases started to make full use of the Internet environment and its capabilities. Subject of this paper represents one of the outputs of an ongoing project consisting partly of a printed publication of the Czech historical science and, in its greater part, of a set of interactive web map applications. Presenting the history in the form of the atlas portal complies with the recent trend when printed atlases may be complemented with a digital content or may be completely digital. This trend is still evident and is leading to a decline in large-scale printed atlas works.

## **HISTORICAL ATLASES**

The publication of electronic atlases started in the last decade of the 20<sup>th</sup> century, and, along with the expansion and improvement of the technologies used during the 21<sup>st</sup> century, electronic atlases may become a platform for communicating knowledge of historical sciences.

In the Czech environment, one of the important works accompanying the advent of digital technologies in the preparation of atlas works has been represented by the Historic Towns Atlas series (Šedivý 2015). One of the most recent, truly comprehensive printed historical atlases published in the Czech Lands was the Academic Atlas of Czech History (Semotanová et al. 2014). It may also become one of the last comprehensive professional historical atlas publications to be published as purely printed, without accompanying electronic contents. This atlas was also discussed in Janata et al. (2014).

A partly successor project, which in printed form focuses mainly on the Czech Lands and Central Europe in the 20<sup>th</sup> century, is the Czech Historical Atlas (CHA), which was already presented by Havlíček et al. (2018). The great innovation of this

work is the electronic map portal, which brings a large number of maps originally designed for the Academic Atlas of Czech History (AACH) and converted into electronic form, along with dozens of maps completely newly created based on research by the Institute of History of the Academy of Sciences of the Czech Republic (more to the cooperation of historians and cartographers in Seemann (2016)).

Within the Academic Atlas of Czech History, following the example of other atlases (cf. e.g. the database of historical atlases presented in Bláha and Močičková (2018)), temporal verticals represent guiding lines of its structure and the basic division of atlas sections, dividing the period from prehistory to the present into classical chronological stages, such as the High Middle Ages, the Modern Age, Modern History, etc. On the other hand, the printed Czech Historical Atlas (Fig. 1) also includes horizontal topics dividing themes into sections of “Society”, “Space” and “Time” (Semotanová et al. 2019). This division has its justification in the printed medium, but for the electronic one the temporal chronological categories have been taken over again, representing a lower level of thematic division.

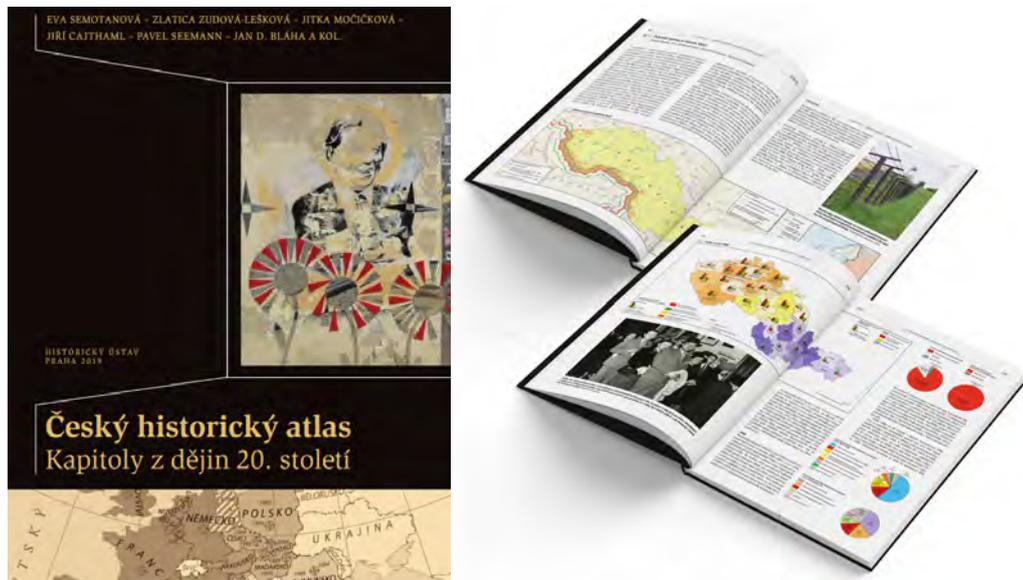


Figure 1. Czech Historical Atlas

## WEB PORTAL AND ITS STRUCTURE

As mentioned above, the content of the web map portal is based on not one topic but is composed of selected topics of the aforementioned two printed atlases (AACH and CHA). The topics and chapters were chosen carefully to provide a wider insight into the Czech history via modern cartographic and web mapping methods. The structure of the portal is designed with a view to the user-friendly interface with a simple and intuitive control to provide its accessibility to the broad public. The topics are sorted into 8 chapters, namely Borders and Territories, Borders and Regions, Czech State and Europe in the 20<sup>th</sup> Century, Populations, Religion and Faith, Historical Milestones, Periods and Consequences, War Conflicts and their Consequences, and Landscape and Humans. Each chapter consists of several subchapters, that are composed of related maps (Fig. 2). The subchapters then form separate web mapping applications. Every web map application includes a Content tab through which the user can reach any chapter or subchapter in the atlas structure. Moreover, related topics are offered and highlighted.

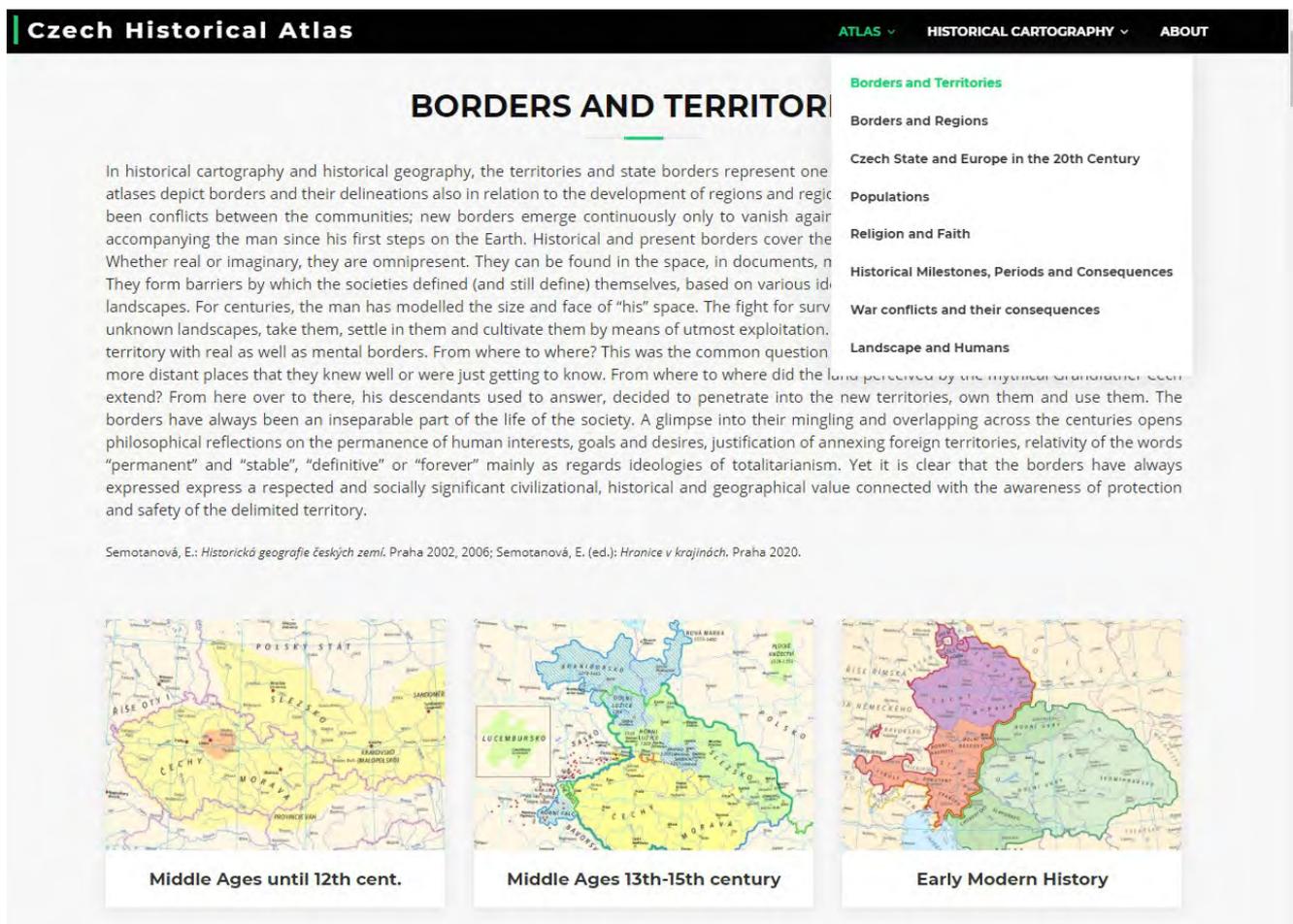


Figure 2. The web portal with chapter and subchapter selection

The web map portal is not only the signpost to single maps or topics, but it is complemented by texts giving the insight into the historical cartography as a research field, and by links to other historical cartography works, either digital or printed ones (Jílková and Cajthaml, 2019). The web map portal is based on HTML, CSS, JavaScript and PHP technologies used in the part of the web portal with included web mapping applications.

As the Esri software was mainly used for the map production for both printed atlases, the Esri platform was the first choice even for the online publication of maps for the web map portal. The Esri platform is widely used at the authors' department, has a decent support and wide functionality which is still being developed. On the other hand, it is a licensed solution, hence the utilization of open source tools was also broadly discussed and tested (Suk 2017). After careful considerations of the advantages and disadvantages of each tested technology, the Esri platform was the final choice. As a way to present the information, Esri Classic Story Maps were used, as they provide different templates for presenting various themes. Journal or Cascade templates may serve as examples of applications that are suitable for presenting temporal developments or data with apparent time consequences, such as the development of the railway network during the 19<sup>th</sup> century or the construction of dams in the 20<sup>th</sup> century. The Story Map Series template is more convenient for presenting a series of thematically related maps depicting geographically or temporally different areas. Moreover, Journal and Series templates provide a framework for embedding other Story Maps templates (e.g. Swipe or Spyglass) that enable the user a direct comparison of related maps. Some of the complex topics were extended beyond their original scope (compared to the printed version of the atlas) and supplemented with more visual material and narrative text to become more storytelling. For this purpose, specifically the Cascade template was used. With respect to the type of map or its content, some of the web map applications were modified with enhanced functionality (time slider, swipe, layer switching) to allow the user to visually compare a change in the depicted phenomena over time.

## DATA PROCESSING

As web map applications often combine maps from the AACH and CHA atlases, the initial part of preparation works on the web maps demanded compiling together not only data, but also map keys, fonts, layouts of legends, etc. The major issue was to unify the historical frontiers, as the maps may be mutually compared within a complex map application presenting the temporal development of the depicted phenomena. For this purpose, generalised datasets of frontiers related to principal periods were harmonised for the basic scale levels (2M, 5M etc.). Here, the data from CHA were used here as a reference set, where the courses of line features (rivers, frontiers) were unified within both datasets. Thematic data for each subchapter were stored in a separate geodatabase, further divided into feature datasets storing data for individual maps. To unify the visual form of all web maps, the graphic style (map symbols, colour scheme, fonts, layout) of the printed Czech Historical Atlas was adopted. The original colour model was converted from CMYK to its RGB equivalent to preserve the colour perception of the printed atlas for the web environment.

The scale series and the cartographic projection were unified to enable visual comparison of maps within one map application. In the printed atlas, the Albers equal area conic projection was originally used but with several options of the central meridian depending on the extent of the Czech Lands historical territory. There was also a necessity to transfer the originally static maps that were designed to be viewed at a single scale, to dynamic multiscale maps that would display data properly across all zoom levels, as zooming is one of the core functions of the web application (Muehlenhaus 2014). Firstly, the basic scale levels were set in order to depict the whole area of interest in a respective historical time (1:3M for Czechoslovakia, 1:2M for the Czech Republic or the Czech Lands). Other zoom levels were then derived from these basic scale levels using a given ratio of 1.5 to ensure the continuity of zooming. Secondly, the sizes of symbols and labels were set uniquely to each map scale to ensure the visual continuity across all zoom levels, as they increased in size improperly when using the default symbol scaling based on the reference scale of the original map (Fig. 3). The maximum zoom level was set specifically for each web map with regard to the level of detail and generalisation of the original data.

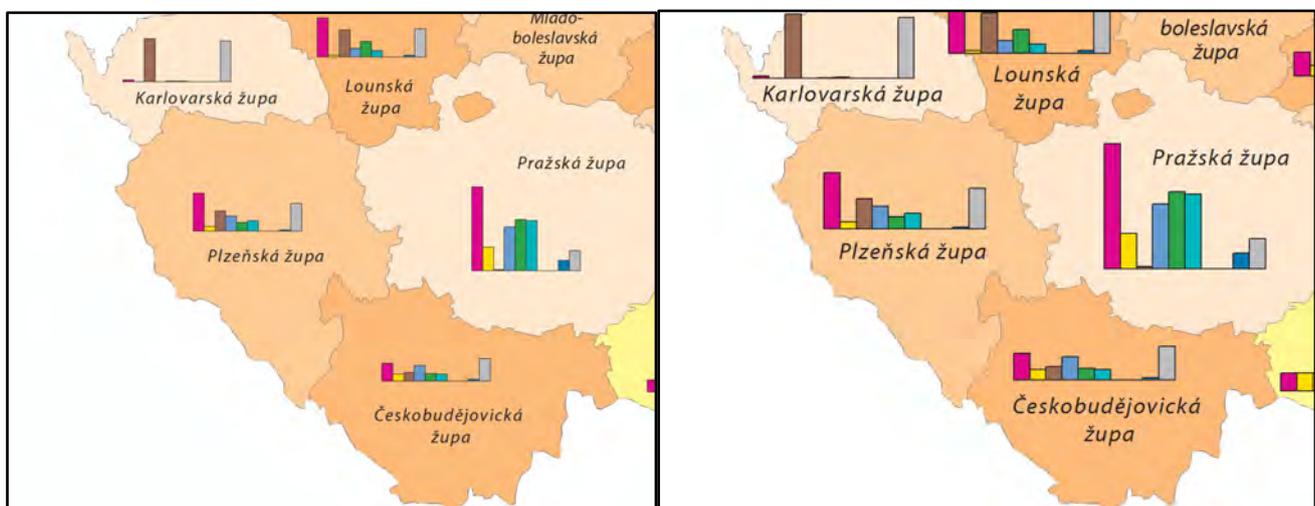


Figure 3. The size of symbols uniquely set to a given map scale (left) versus default symbol scaling based on the reference scale of the original map (right) at the maximum zoom level

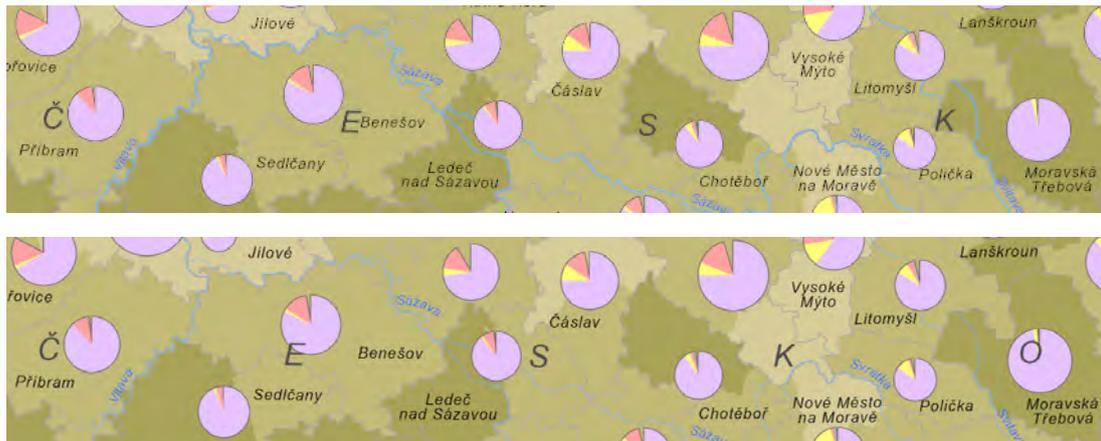
For the purpose of the publication, the map layers were sorted into two groups:

- thematic layers that can be queried by the user (active layers);
- other layers (including annotation) that form an inactive map background.

An inactive map background was published as a map service to a stand-alone ArcGIS Server to be drawn using tiles from a cache, whereas the active layers were published as a feature-access service to the ArcGIS Online cloud. The final web maps combine the aforementioned services and are enriched with configured pop-up windows that serve as a primary source of information that would otherwise be too complex or detailed to render within the cartographic method of the maps themselves.

Due to the limitations of the technology used for publishing the maps, compromise solutions had to be adopted in some cases, as certain layers or drawing techniques used for designing printed maps could not be published to the web environment properly (e.g. annotation groups or masks). For example, the variable-depth masking technique needed to be

replaced with simple text halos, or original annotation layers needed to be converted to vector layers, as they were deformed (moved out of their original place) during the publication process (Fig. 4).



*Fig. 4 Original position of the label “ČESKO” (top) versus its position in the map service when published as an annotation layer (bottom)*

## CONCLUSION

The Czech Historical Atlas portal represents an innovative approach to communicate the information on historical topics in new ways. It does not strive to replace the printed medium, but rather complements it and makes historical facts more accessible to a wider audience in an effort to facilitate an easier and deeper understanding of the context.

The authors aim to conceive the work more as a storytelling application corresponding to the trends and needs of the modern concept of interactive web content while keeping the maximum degree of cartographic conventions and historiographical accuracy of the presented content.

The general public will especially appreciate the added functionality within the web map applications (time slider, swipe) which may further improve the user interaction with the map; historians can appreciate the complex content in a uniform manner, easily accessible in one place and enabling the comparison and the overall understanding of historical events as a whole. This was previously difficult to reach. The new approach is supported in particular by the interconnection of the map portal, which is offering related topics to each web map application. The portal is accessible in English and Czech languages on the web page <http://www.czechhistoricalatlas.cz>.

## ACKNOWLEDGEMENTS

The research has been financially supported by the grant of the Ministry of Culture of the Czech Republic, NAKI II programme, project No. DG16P02H010.

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# NUTS GEO-ONTOLOGY

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## **Abstract**

*Nomenclature of Territorial Units for Statistics (NUTS) is a European standard for referencing the subdivisions of countries for statistical and data science purposes. There are three NUTS levels for each country. The lowest NUTS level (NUTS 3) is divided into Local Administrative Units (LAU; LAU 1 and LAU 2). The current NUTS classification (2016) contains 104 regions at NUTS 1, 281 regions at NUTS 2, 1 348 regions at NUTS 3 level and 99 787 LAUs. The structure of NUTS and LAU comprises the hierarchical tree structure. Therefore an ontological description of NUTS is a legitimate question for a better implementation of NUTS to any knowledge systems and bases dealing with geographic data and information. There are several pieces of data storing NUTS as RDF (Resource Description Framework) triples, which enable efficient modelling of the regular tree hierarchy. This contribution presents a proposal for a complex ontological system of NUTS. The NUTS Geo-Ontology provides not only the simple structure of NUTS, but it uses the Description Logic for modelling of mutual relations among particular NUTS classes and individuals. Just the implementation of Description Logic as the main logical background of modern ontologies is the primary goal of our research. Also, the implementation of relations is challenging. Except for traditional generalization and specialization, there are topological and mereological relations. Such defined ontology enables a more semantically detailed description of concepts as well as more efficient control of data reliability and correctness for purposes of the geographical domain, including geographical information systems and cartography. The NUTS ontology uses logical axioms also for a derivation of new relations, which are not explicitly coded in the original ontology.*

**Keywords:** *Ontology, geo-ontology, NUTS, topology, mereology.*

## **INTRODUCTION**

Nomenclature of Territorial Units for Statistics (NUTS) is a European standard for referencing the subdivisions of countries for statistical and data science purposes. There are three NUTS levels for each country. The lowest NUTS level (NUTS 3) is divided into Local Administrative Units (LAU; LAU 1 and LAU 2). The current NUTS classification (2018) contains 104 regions at NUTS 1, 281 regions at NUTS 2, 1 348 regions at NUTS 3 level and 99 787 LAUs. Eurostat designed NUTS as well as LAUs (as former NUTS 4 a NUTS 5) as a complex system of territories for providing comparable statistics. The processes of the development of NUTS started at the 1970s. Now users can work with the version 2016, but the NUTS 2021 is in progress.

The structure of NUTS and LAU comprises the hierarchical tree structure. Therefore an ontological description of NUTS is a legitimate question for a better implementation of NUTS to any knowledge systems and bases dealing with geographic data and information. The nature of NUTS emphasizes this fact. NUTS are vehicles for statistical data and information; therefore, they are crucial components of many databases and knowledge bases. Advanced ontological description of NUTS supports sharing and interconnecting of such databases and knowledge bases. It improves communication and limits misinterpretation as well.

The goal of this contribution is to present the draft of a complex ontological structure describing NUTS. The geo-ontology follows similar products – ontologies and linked data containing NUTS. These tools use RDF (Resource Description Framework) triples for NUTS data storing because they enable efficient modelling of the regular tree hierarchy. The presented geo-ontology combines traditional ontological approach based on classes, semantics attributes and linking relations with geographical approach (topology). The NUTS Geo-Ontology provides not only the simple structure of NUTS, but it uses the Description Logic for modelling of relations among particular NUTS classes and individuals. Just the implementation of Description Logic as the main logical background of modern ontologies is the primary goal of our research. Also, the implementation of relations is challenging. Except for traditional generalization and specialization, there are topological and mereological relations. Such defined ontology enables a more semantically detailed description of concepts as well as more efficient control of data reliability and correctness for purposes of the

geographical domain, including geographical information systems and cartography. The opportunity of the derivation of many non-explicitly coded properties is the main benefit of the approach based on the elaborate description with logical axioms.

The article is structured as follows. After the introduction characterizing the initial problem, the Research part describes the essential terms of the article (NUTS, ontologies). This section provides a short overview of existing data product, which use ontologies or linked data (RDF triples) for storing information about NUTS. Then short Methodology sections present a summary of methodologies for building ontologies as well. The Results part shows the detail description of proposed geo-ontology. After that, future steps and an overlapping to other knowledge bases are discussed.

## RESEARCH

The article works with specific terms (NUTS, LAU, ontology and geo-ontology), which are defined at the beginning of the Methodology section. After that remaining parts describing existing ontologies and other semantic products dealing with NUTS and a summary of methodologies for the development of geo-ontologies follow.

Nomenclature of Territorial Units for Statistics or NUTS is a geocode standard used for referencing the subdivisions of countries [1]. Eurostat developed this system primarily for statistical purposes, but the European Union’s Structural Funds and Cohesion Fund uses NUTS as delivery and locating mechanisms. The regions are divided into four levels of NUTS and two levels of LAU (Local Administrative Units; formerly known as NUTS 4 and NUTS 5). The particular countries are represented by NUTS 0. LAU 2 is the most detail feature of the NUTS system. It corresponds to municipalities. The following table (Table 1) show the NUTS levels and number of respective regions (information adopted from NUTS 2016 version effective from 1 January 2018, [2]). Territories were classified based on governing principle, but they are also limited by population (for example NUTS 1 region should have between 3 and 7 millions people). The NUTS structure covers not the area of the European Union, but also countries of EFTA and associated countries such as Turkey or Albania. Publications [3-5] provides more information about NUTS.

*Table 1. NUTS units overview.*

Level	Code example	Description	Number of areas
NUTS 0	CZ	Country	28
NUTS 1	CZ0	Major socio-economic regions	104
NUTS 2	CZ01	Basic regions for the application of regional policies	281
NUTS 3	CZ011	Small regions for specific diagnoses	1 348
LAU 1	CZ0641	Upper local administrative units	8 695
LAU 2	CZ554499	Municipality	162 386

The ontologies (in the meaning of information technologies, not as the discipline of philosophy) represents the advanced communication tools using principles of description logic and pieces of markup languages and general modelling of resources. Changes of views on ontologies are evident from the development of definitions of ontologies [6-9]. Ontologies represent compelling tools enabling the transformation of standard information to a formal and formalized structure. The understanding of ontologies is significant from the perspective of implementation of participation and involvement of various experts, stakeholders and public.

There are only a few publications focused on geo-ontologies (ontologies in spatial data and information domain, ontologies of geographical objects). Geo-ontologies can be described as an ontology dealing with “the totality of geospatial concepts, categories, relations, and processes and with their interrelations at different resolutions” [10]. Their specifics (e.g. the relation of objects to the Earth surface, a considerable share of A Box structure coming from the traditional GIS /Geographic Information System/ approach, semantics, which is implicit and evident at the instance

level, the necessity of maintaining the logical as well as spatial integrity) are mentioned in publications [11-15]. According to [16], this specific type of ontology an essential tool from the perspective of the semantics of seemingly clear and unambiguous geographic data and information. Such description using an explicit semantics improves the understanding of particular structures of the geographic world as well as the world as the whole among different subjects (cultures, languages, nations, social groups, professional groups and others). This attribute is essential from the view of geographic data and manipulation, sharing, changing and interconnecting.

The development of NUTS Geo-Ontology has to follow existing semantic products describing NUTS units. There is a lack of ontologies containing data or information about NUTS. However, NUTS are in many cases published as Linked Data. The form of linked data is very similar to ontologies because both products use RDF triples of a description of any feature. Therefore NUTS as linked data could be used as inspiration for the development of an ontology, as well as linked data, could be a content of the ontology. The following list shows the example of NUTS presented as linked data.

- Linked Open Data by Eurostat are accessible through SPARQL endpoint. It is a standard interface enabling entering the query and retrieving data. However, there is missing detail information about data and its structure. Also, the link to Base-URI for the NUTS classification is broken.
- Linked Open Data by Eurostat are interconnected with the EU Open Data Portal, which provides data about NUTS. It is possible to download data in five formats (SHP, SVG, GDB, GeoJSON and TopoJSON). However, the data is provided as traditional spatial data without any semantic information.
- NUTS RDF is the transformation of NUTS data to RDF format published on geovocab.org. There are links to various NUTS level. These links go to tables with particular objects (for example CZ). Users can download data, including geometry in various formats (GML, KML, HTML and two serializations of RDF). Data contains only codes and names of particular units. There are also topological relations and identical relations (owl:sameAs). The same relations link particular NUTS object with an equivalent object in other datasets (but during the testing the majority of links were broken).
- The Open Data Portal Germany (OPAL) project provides data in OWL format. The current version (0.3.0) contains classes for particular NUTS and LAUs levels. There are two object relations – has broader, has related match. They correspond with similar properties used in the SKOS standard. The ontology does not contain any individuals yet.
- The Ministry of Housing, Communities and Local Government of United Kingdom publishes data about NUTS without geometry and any additional attributes for the territory of the United Kingdom of Great Britain and Northern Ireland. Data is available as RDF triples (N-triples). The similar data is offered by the British Office for National Statistics (this dataset is more vibrant from the perspective of attributes). Those are examples of NUTS presentation on the national level.
- Other datasets providing NUTS as RDF triples are mentioned in [4].

## METHODOLOGY

During the last thirty years, many various methodologies for the development of ontologies were created. The article [16] mentioned eight methodologies which can be re-used for building geo-ontologies – TOVE, Enterprise Model Approach, METHONTOLOGY, Methodology published by Bernaras et al., On-To-Knowledge Methodology, DOLCE, Ontology Development 101 and UPON. The selection of this methodologies follows many research studies [17-21]. All methodologies have a one common characteristics – they deal with a participatory phase. It enables the participation of a larger group of co-creators. Co-creation process is crucial for geo-ontologies because this type of ontologies is usually cross-domain and requires the engagement of many experts from various domains. The same methodologies could be used for development geo-ontologies as well because there are not specific and intricate methodologies for the construction of geo-ontologies. The development process of NUTS Geo-Ontology uses components of methodologies mentioned-above.

The methodology used for the construction of NUTS Geo-Ontology includes the following steps. Above all, the first three items are fundamental from the perspective of design and further development of the ontology. Existing outputs of these three steps are presented in the Results section of the article.

1. Specification
2. Initial ontology development

3. Ontology refinement and structuring
4. Ontology maintenance
5. Ontology implementation
6. Ontology evaluation
7. Documentation

Ad 1. The NUTS Geo-ontology provides spatial information about NUTS regions (as the fundamental statistical unit) in Europe. The content of the ontology includes necessary identification information about NUTS (official NUTS codes) and a set of object relation interconnecting particular NUTS. These object properties describe topology and mereology (whole-part relation) semantically. The ontology will re-use existing vocabularies and other ontologies (such as GeoSPARQL) as much as possible. The purpose of the developed ontology is to serve as fundamental knowledge bases for thematic statistical application and services as well as for all tools and products dealing with NUTS. The primary value added to similar existing products (mentioned in the Research part) consists of the implementation of Description Logic for the description of NUTS. It enables automatic control of ontology consistency and correctness of information during ontology update and maintenance as well as the automatic derivation of new pieces of information which are not coded in the original ontology.

Ad 2. The initial ontology is composed of two main classes (*Country* and *StatisticalUnit*) and object relations. The *StatisticalUnit* class contains four sub-classes: *NUTS0*, *NUTS1*, *NUTS2* and *NUTS3*. The *StatisticalUnit* class is limited by the covering axiom (Stevens 2011) – *StatisticalUnit is SubClass Of NUTS0 or NUTS1 or NUTS2 or NUTS3*. All sub-classes of *StatisticalUnit* class are disjointed. The object relations are divided into three groups: *mereologicalProperty* (relations following RCC8 /Regional Connection Calculus/ approach; [22, 23], *mereologicalProperty* (*hasPart* and *isPartOf*) and *semanticProperty* (*neighbourhood*). All object properties have the same domain and range – *owl:Thing* (the root element of the ontology). The mutual relations among particular types of relations are explained in the following section of this paper. The logical rules and axioms have been tested of the sample of individuals (countries Austria, Czech Republic, Slovakia, Slovenia and Luxembourg and NUTS 1 units in these states).

Ad 3. The ontology can derive new information based on existing information and logical rules. The class *Country* and the majority of topological relations between particular individuals (NUTS units) are the explicit input of the ontology. Reasoner derives other information (for example classification of individuals or mereological relation or defined classes). The NUTS Geo-Ontology is developed in the Protégé software [24, 25], version 5.5.0. Therefore the in-built reasoners (above all FaCT++ 1.6.5) are used. The examples of logical rules and inferred information are described in the next section of this contribution.

## RESULTS

This section contains a set of logical statements, which play a crucial role in the development of NUTS Geo-Ontology. These statements have been transformed into the logical rules in the ontology. They guaranteed the consistency of the ontology as well as they enable derivation processes mentioned above in this article. The rules follow the nature of NUTS and implemented types of relations.

The logical statements are described by following symbols:

- $X$  – class (because of compression of long labels of classes, the acronyms are used:  $C$  – *Country*,  $SU$  – *StatisticalUnit*,  $N0-N3$  – *NUTS0-NUTS3*)
- $X(a)$  – instance of the class, for example  $C(AT)$
- $R(a, b)$  – relation between two instances
- $\equiv$  – equivalence
- $\sqsubseteq$  – inclusion
- $\sqcap$  – intersection (and)
- $\sqcup$  – union (or)

- $\perp$  – empty concept (without instances)

The first four axioms concern classes of the NUTS Geo-Ontology and their hierarchy.

1.  $N0 \sqsubseteq SU$  (the same relation is true for  $N1$ ,  $N2$  and  $N3$ ) – classes representing of particular NUTS level are sub-classes of the general statistical unit.
2.  $SU \sqsubseteq N0 \sqcup N1 \sqcup N2 \sqcup N3$  (closure axiom) – the general statistical unit (in the perspective of NUTS Geo-Ontology) is composed only from classes of particular NUTS levels.
3.  $N0 \sqcap N1 \sqcap N2 \sqcap N3 \sqsubseteq \perp$  (disjoint classes) – classes representing of particular NUTS level do not have any collective element (intersection). **Each NUTS unit has to be a part of exactly one NUTS level.**
4.  $N0 \equiv C$  – NUTS 0 corresponds to countries, therefore **classes *Country* and *N0* have to be identical**. After reasoning, the instances of *Country* class belong to the *N0* class.

The ontology contains object properties limited by the following characteristics. These restriction are partially based on GeoSPARQL standard [26] and mereotopology rules [27, 28].

5. The ontology contains all RCC8 relations except PO (partially overlapping). **The nature of NUTS (tree structure of disjointed areas) does not allow any overlappings between particular regions.**
6. Inverse relations –  $R(a, b) \Rightarrow Ri(b, a)$  – following couples of object relation are inverse: *hasPart* – *isPartOf*, *NTPP* (non-tangential proper part) – *NTPPi*, *TPP* (tangential proper part) – *TPPi*.
7. Symmetric relations –  $R(a, b) \Rightarrow R(b, a)$  – the ontology contains these symmetric relations: *neighbourhood*, *EC* (externally connected).
8. Functional relations –  $R(a, b) \wedge R(a, c) \Rightarrow b = c$  – the mereological relation *isPartOf* is functional. This statement ensures the basic tree structure of NUTS, because **each NUTS unit (except NUTS 0) is part of one NUTS region of the closest higher level.**

The next logical statements enable to derive object relations from existing and explicitly entered topological properties.

9.  $EC(a, b) \vee NTPP(a, b) \Rightarrow neighbourhood(a, b)$  – **External connection or non-tangential proper part mean neighbourhood.** If two NUTS entities are interconnected via *EC* or *NTPP* object properties, it is possible to name such relation as neighbourhood and classify it as semantic property. Such name is more comprehensible for users without any experience with topology. In the ontology, this statement is realized through *SuperProperty Of (Chain)* operation.
10.  $TPP(a, b) \vee NTPP(a, b) \vee EQ(a, b) \Rightarrow isPartOf(a, b)$  – Similarly to previous point it is possible to infer the mereological property *isPartOf* from topological relations. To be able to generate the essential mereological relation *isPartOf* from topological properties (in case of NUTS) it is necessary to implement a small trick. The *EQ* (equivalence) is originally the symmetric property. However, because of *isPartOf* is not symmetric relation, the equivalence has to be described by two “one-way” additional inverse relations *EQ* and *EQi*. It holds that  $EQ(a, b) \Rightarrow EQi(b, a)$ . Now it is possible to define that **if one NUTS unit is a proper-part of other NUTS unit or both units are topologically identical, they are also interconnected by mereological relations** (there are restrictions for the installation of topological relations, which limits using *TPP*, *NTPP* and *EQ* properties for NUTS classes).
11.  $EC(a, b) \wedge EQi(b, c) \Rightarrow EC(a, c)$  – **If two NUTS units are identical (from the topological view) and one of them is interconnected with any other NUTS element via *EC* relation, then this element is connected by *EC* relation with second equivalent entity.** There is the important condition (explained in following rules): *a* and *b* are instances of the next higher NUTS level than *c*, for example,  $N0(a), N0(b), N1(c)$ .
12.  $EC(a, b) \wedge TPPi(b, c) \Rightarrow EC(a, c)$  – this is the paraphrase of previous statement applied to *TPP* property.

The following restrictions define the behaviour of particular classes (NUTS levels) and their instances.

13. **Each element of NUTS 1, NUTS 2 and NUTS 3 has to be linked to just one region of the next higher NUTS level** (for example  $isPartOf(N1(a), N0(b))$ ). This fact is guaranteed by the functional character of *isPartOf* property and closure axiom [29].

14. From the previous rule there is derived other restriction – **Each element of NUTS 0, NUTS 1 and NUTS 3 has to be connected to at least one region of the next lower NUTS level.**
15. **Two elements on the same NUTS level have to be interconnected by a following mutual topological relation: *EC*, *NTPP*, *DC*** (disconnected; this relation holds for all other cases; therefore it is not modelled in the ontology).
16. Two elements on the same NUTS level must not be interconnected by a mereological property as well as by topological equivalence.

The previous logical rules are implemented in the code of the NUTS Geo-Ontology. The ontology uses the OWL 2 (Web Ontology Language; [30]). The main benefit of proposed ontology is the ration between explicitly entered information and derived information. For example, the asserted (original) ontology provides only one information about the individual *AT* (represented Austria): *AT* belongs to *Country* class. All other 37 pieces of information are derived during the reasoning process.

## DISCUSSION

The current version of the NUTS Geo-Ontology represents a prototype for further testing, optimization and improvements. For next months there are planned following steps:

- Implementation of defined classes or relations such as *BorderRegion* class.
- Completing of logical rules and restrictions for NUTS 2 and NUTS 3 regions. It is connected with the implementation of transitive relations to enable inheritance of object properties.
- Populating of the ontology – sequential adding of new instances.
- Interconnection of the ontology with other semantic tools and Linked Data resources through identity relations. This step concerns not only classes or instances but also relation. Authors of the NUTS Geo-Ontology have in mind a re-using of topological relations as they are defined in the GeoSPARQL standard [26].

The NUTS Geo-Ontology will be implemented for other solutions. There are suggestions to use the ontology as the fundamental framework for the assessment of regional attractivity. The NUTS Geo-Ontology can be used on a national level as well (for example, in the Czech Republic it can be interconnected with National Set of Spatial Objects – NaSaPO).

## CONCLUSIONS

The main goal of this contribution was to presents a proposal of NUTS Geo-Ontology. This knowledgebase store essential data about NUTS units, including topological, mereological and semantic relation. Just the amount of relations (defined as object properties) represents one of the main benefits pro introduced solution. The second advantage consists in the implementation of logical rules and restrictions. They enable to derive much new information from the original ontology. For example, the semantic property *neighbourhood* is inferred from topological relation externally connected (*EC*) and non-tangential proper-part (*NTPP*). The using of Description Logic is beneficial also from the perspective of checking the correctness and integrity of the ontology.

The introduced ontology is just a fragment of a future complex solution. The Discussion section offers several ideas and plans on how to continue in this work and extend the ontology. They consist above all in adding new types of properties (transitive relations) and populating of the ontology (addition of new instances representing particular NUTS regions).

The NUTS Geo-Ontology can be interconnected with other knowledge bases, ontologies and Linked Data resources. This extension can provide more semantics (links to semantic vocabularies), standardization (connections to standardized vocabularies) or information (relations to Linked Data providing statistical data for NUTS). The extensibility shows the main scope of the NUTS Geo-Ontology. It should be used as essential reference tools providing information about NUTS for various purposes. The main benefit of the proposed solution is the ability of automated checking integrity and consistency as well as the derivation of new information from implemented logical construction during the phase of reasoning.

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# PRELIMINARY STUDY ON ONTOLOGY CONSTRUCTION FOR HOSPITAL NAVIGATION

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## Abstract

*People spend most time in increasingly complex indoor environments. The amount of semantic information of human activities in hospitals requiring efficient data management and query process. However, the available indoor navigation system for presenting information lack semantics. In this paper, we propose a knowledge base for representing knowledge of hospital navigation in a semantically enriched and machine-readable manner. First, we constructed a preliminary framework with the semantic data for sharing and managing, which is involved in indoor space ontology, user ontology, process ontology, location ontology, interface ontology, and medical ontology. Finally, knowledge-based hospital navigation will build based on ontology and provide the potential for sharing semantic data when faced with similar services.*

## 1. INTRODUCTION

People spend more than 90% of their time in indoor spaces and have a lot of activities. And activities can be described by various semantic information such as type (e.g., work or visit), time, space, and participants. Hospital is an example of a complex environment with a great variety of services and presupposes certain urgency in the flow of patients and staff (Mollerup, 2009). It is difficult to find facilities and access information, namely, what treatment to seek, when, where, how to get to, and how to perform. The process is often rather involved in the complex sequences of tasks and needs to move independently to reach the locations where treatment is provided (Ardissono et al., 2012). Visitors who are burdened by health concerns and uncertainty and often difficult to find the right way in hospital navigation (Fixova et al., 2014).

The existing indoor navigation systems use different data structures, infrastructure, and provide different routing information (Huang et al., 2009). The knowledge base is to build the model in an indoor environment for users to search, track, and share semantic information. Some studies develop new methods for knowledge-based semantic retrieval to improve retrieval efficiency for indoor navigation (González et al., 2020; Sanya, 2018), among which services in university (Lee et al., 2016), shopping mall (Orciuoli et al., 2016; Yao et al., 2017), museum (Domingo et al., 2016), and hospital (Kim G et al., 2009; Fleiner et al., 2017). In the hospital, people have the amount of semantic information about indoor activities and may change frequently. However, there is no knowledge base and semantic standard so far in the design of hospital navigation services. Ontology-based semantic queries can facilitate the search in computing environments through better getting semantic information.

Previous studies focused on the usability of ontology techniques for indoor navigation for personalized route planning system (Anagnostopoulos et al., 2005; Dudas et al., 2009), context-aware (Kritsotakis et al., 2008), and seamless navigation in indoor and outdoor spaces (Yang & Worboys, 2011). However, the proposed ontology models are not suitable for navigation services in a hospital. In addition, with the widespread use of smartphones, the integration of

ontology and semantic techniques with location-based services needs to be considered. Thus, this study focuses on the implementation of an ontology model for hospital navigation and the integration of the model with semantic queries in hospital spaces.

In this paper, we focus on the implementation of an ontology model to construct a knowledge base to enhance quick retrieving for efficient semantic data management and queries in the hospital navigation. Ontology provides unified terms to improve the semantic interoperability of domain knowledge (Sonsilphong et al., 2016). The knowledge base can store conceptual workflows (Zhuang et al., 2018). It provides relevant information retrieval capabilities through various reasoning rules (Berners-Lee et al., 2001; McIlraith et al., 2001).

## **2. RELATED WORK**

### **2.1 Knowledge representation based on ontology**

Ontology is a set of names and descriptions of the types, properties, and interrelationships of the entities in the environment (Maedche, 2001). It can formally represent knowledge of spatial objects (Guarino, 1995). For sharing semantical information in indoor space modeling, the formalized representation of knowledge is an essential step in building a knowledge base. For machine processing, more specialized formalization of knowledge, such as Web Ontology Language (OWL) and Semantic Web Rules Language (SWRL), is needed for representing knowledge, defining rules and carrying out semantic reasoning (Xing et al., 2018).

Hospital navigation typically consists of various types of data, such as indoor space data, medical knowledge, information of users, and location databases. It is unsatisfied to query or utilize those data in navigation service because the system lacks semantic information. Users have the challenge of finding the information they need. Therefore, there is a need to discover or uncover valuable information from those data to transform such data into a knowledge base that could help in improving navigation services at the hospital (Riañoa et al., 2012). To help the organization to adopt Semantic Web, the World Wide Web Consortium (W3C) has formed the Semantic Web for Health Care and Life Sciences Interest Group (HCLSIG). And there are some medical ontologies, including Systematized Nomenclature of Medicine - Clinical Term (SNOMED CT), Medical Dictionary for Regulatory Activities (MedDRA), WordNet of Medical Events (WME), Gene Ontology (GO), and Foundational Model of Anatomy (FMA).

### **2.2 Indoor navigation ontology**

Ontology is applied to indoor navigation models such as IndoorGML (Kim et al., 2014) and BIGML (Kessel et al., 2010). Building Topology Ontology (BOT), which a minimal ontology for describing the core topological concepts of a building, was proposed by the W3C Linked Building Data Community Group. As in the case of RDF, the IFC to LBD (Linked Building Data) converter is available. For example, Farias et al. (2015) make the information contained in an IFC file useful for indoor navigation base on the ifcOWL ontology. And they all focus on the representation of indoor spaces.

With the demand for indoor navigation services is increasingly diversified, people have different needs and put forward various semantic restrictions on route planning. Traditional map navigation service provides the query function, which is more to the given starting point, ending point, and the shortest route between two points. However, in some cases, such as during the physical examination, there are many people taking blood tests, but few taking internal medicine so that people can first go to internal medicine. Therefore, the shortest path may not be the best choice to navigate due to it is not applicable for personalized preferences under multiple metrics (Zhuang et al., 2018). The ontology-based semantic model can effectively solve the problem of organing and sharing knowledge in indoor navigation.

The main goal of using ontology for indoor navigation is to provide a semantic description of the certain events occurring in an indoor environment. Anagnostopoulos et al. (2005) develop an ontology to describe the indoor environment in a detailed way named OntoNav. Khruahong et al. (2018) described a multi-level indoor navigation ontology. Dudas et al. (2009) present an ontology and an algorithm for indoor routing named ONALIN, which takes the ADA (American Disability Act) standards, among other requirements, into consideration. Sriharee (2015) proposes a prototype using symbolic information described by OWL for indoor navigation. In addition, Leea et al. (2017) focus on indoor activities in a university context using ontology-based semantic queries. Yang et al. (2011) focus on the usability of ontology for seamless navigation in indoor and outdoor spaces. Kim et al. (2009) present a knowledge model for spatiotemporal context-awareness. The knowledge-based designed to understand user goals and to guide users who perform complicated tasks at a hospital.

### 3. KNOWLEDGE-BASED HOSPITAL NAVIGATION

Knowledge-based hospital navigation adapts the ontology-based approach and provides a comprehensive knowledge to support the navigation process. A set of ontologies are needed to capture knowledge related to the problem-solving solution to build the knowledge base. Formalizing the knowledge base will assist both patients and staff in intelligent navigation services. In order to realize the capability of representing the knowledge of the hospital navigation process, the knowledge base provides a set of ontologies as follows: Indoor space ontology, User ontology, Process ontology, Location ontology, Interface ontology, and Medical ontology. These ontologies are combined to provide support for all facets of navigation, each of which plays an important role in the hospital with rich, dynamic, and flexible knowledge base.

#### 3.1 Indoor space ontology

Previous studies of indoor space modeling, the standards such as CityGML and IFC (industrial foundation classes) of building SMART, provide data models for geometric representation, attribute, and visualization of building components. However, they all lack of semantics and information representation of objects associated with indoor space. IndoorGML is a geospatial standard for the application of indoor navigation and focuses on expressing the topological relationship and simple semantic information of indoor space. As the indoor space gradually becomes larger and complex, the semantic partition of the existing data model for indoor space cannot meet the needs of the fine expression in navigation (Geraerts, 2010). Therefore, this study proposes indoor space ontology modeling. Figure 1 shows the taxonomy of indoor space ontology. The definitions of indoor space are from Yang & Worboys (2011). The container is a subclass of room, story, and subspace. Portal refers to an opening with or without a covering, affording the passage from one container to another. It has subclasses including Doorway, Exit, Entrance, and Window. The connector is a subclass of vertical passage and horizontal passage, assisting in transitioning through a barrier and connecting two objects that are separated by the barrier. The barrier is a structure or object that impedes free movement. For example, walls afford the barrier function. It can be fixed or movable.

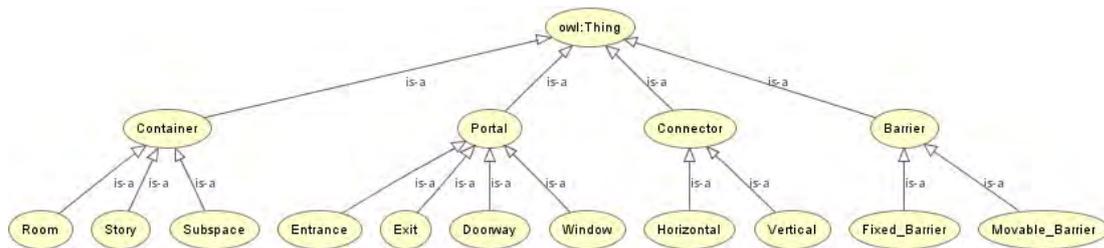


Figure 1. Indoor space ontology

#### 3.2 Process ontology

Process ontology is designed to provide users that take the number of tasks and services. It also tells the user how to do this. The model has three subclasses: Process, Service, and Task. The process consists of a flow of services. And the service can also have a sequence of the tasks that users should carry out for the service. With the process ontology, the system can recognize whether or not users are doing well with the process and can provide users with relevant guidance when they have problems.

#### 3.3 Location ontology

Location model expresses the location, distance, orientation, topology of the real-world (e.g., buildings, roads) and moving objects (e.g., pedestrians). Through the model, we can obtain the rich location semantics of the physical world and make location knowledge possible understanding. Location ontology is designed to recognize the location of users in the process. Location Ontology has two subclasses: Zone and Area. Areas are linked to Zones so that the navigation route can be described as a sequence of zones.

#### 3.4 User ontology

User ontology is divided based on different contexts in the indoor environment and significantly different, such as in children's hospital, dental hospital, general hospital, etc. The classification of indoor navigation users will be based on the educational background, the goal of navigation, and the frequency of using hospital buildings and so on. Medical

staff and patients are the primary users of the hospital building space. The identity of indoor navigation users is divided into patients and their friends and family members, medical staff, managers, logisticians.

### 3.5 Interface ontology

Tasks are used as reusable components to accomplish the composition of navigation processes. The composition requires an evaluation of the correspondence of interfaces. The knowledge base needs to include sufficient information on interfaces. An interface involves the description of operands that contain inputs and outputs, constraints that contain a precondition and result, and non-spatial parameters. The Interface class consists of the subclasses Input, Output, Parameter, Precondition, and Result.

### 3.6 Framework architecture of knowledge base

The framework architecture of the knowledge base for hospital navigation is described in this section and illustrated in Fig. 2. It shows the delineations of the definitions of ontologies and how they relate to each other.

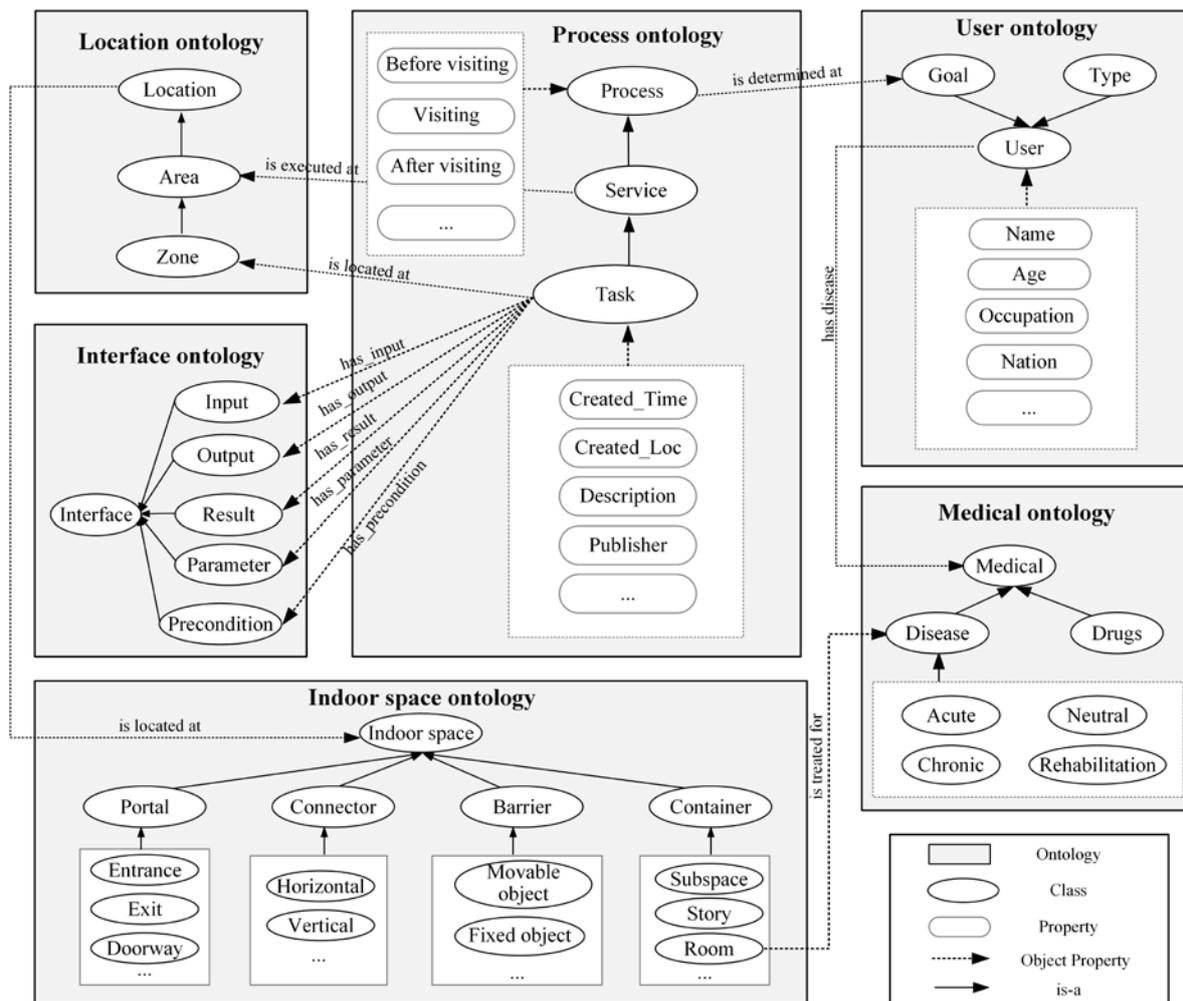


Figure 2. The relationships of ontologies in the knowledge base.

## 4. CONCLUSIONS AND FUTURE WORK

This paper proposes an ontology model of hospital navigation and abstracts semantic in indoor space that used as a reusable component for services. The knowledge base is built to sharable and reusable medical knowledge and semantic services for hospital navigation. In the knowledge base, we combine multiple ontologies (e.g., Indoor Space Ontology, Process Ontology, Location Ontology, Interface Ontology, User Ontology, and Medical Ontology) to assist in all facets of indoor navigation services. Knowledge base can give useful querying facilities to patients and staff. This study has some limitations. First, hospital processes are complex and dynamic, and they are challenging to be analyzed, quantified, and organized by the system. Second, hospital navigation was limited regarding the provision of location-

based information. Finally, there are a large number of visitors in a hospital, and there are many uncertainties. Our navigation knowledge base is a preliminary frame, and we will expand in future work.

## ACKNOWLEDGMENTS

This research was funded by National Key R&D Program of China (2016YFE0131600), National Natural Science Foundation of China awarded project (41871371).

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# EXPLORING THE OPPORTUNITIES OF OPEN SOURCE DATA USE IN CREATION 3D PROCEDURAL CITY MODELS

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## **Abstract**

*Two dimensional (2D) Geographic Information System (GIS) data structured with required attribute information can be realistically visualized in three dimension (3D) by using procedural modeling techniques. The procedural model consists of a sequence of parameterizable procedures and represents the object construction process. In this study, the usability of the open source data for creating 3D procedural city models were examined by applying the technique in two different study area located in London and Istanbul. For this purpose, 3D city models were produced using 2D vector data of OpenStreetMap, digital elevation model of “Shuttle Radar Topography Mission” (SRTM) and city landmark models provided by Google 3D Warehouse. As a result of this study, the production of a 3D city model and its results were evaluated by using open and crowd-sourced GIS data as an alternative to today's widely used and very overcosting spatial data production methods.*

**Keywords:** 3D City Model, Smart City, Digital Twin, Procedural Modeling, 3D Visualization

## **INTRODUCTION**

Although 2D and 2.5D maps have been widely used as a tool for presenting and communicating geographic information for many years, 3D modelling and visualization approaches rapidly become widespread as a result of the developing computer and geovisualisation technologies. Public institutions and private sector, especially local administrations, closely follow the concept of “smart urbanism”, which has been on the agenda of the world in recent years, and the latest studies in this field. Therefore, the need for effective use of spatial data in many areas varying from urban planning studies to urban management has increased much more than previous years (Erving et al., 2009; Moser et al. 2010; Albrecht and Moser, 2010). Several studies such as urban transformation, change detection, renewable energy source management, city skyline conservation, disaster management and noise mapping are currently carried out more accurately by the use of available 3D city models produced as “digital twins” of the physical reality (Sengul, 2010; Aliaga, 2012; Prandi et al., 2013; Prandi et al., 2014; Biljecki et al., 2016; Slade, 2018). Many potential negative situations in real life can be prevented by taking timely measures thanks to the effective use of computer graphics and simulation technologies. Similarly, large scale engineering projects can be simulated in 3D city models before construction starts. This opportunity increases the capacity of engineers to predict the impact of the planned projects on the environment and city life.

The production of 3D city models is recently one of the ongoing research topics in various universities, institutions performing cartographic and photogrammetric studies (Brenner et al., 2001; Flamanc and Jibrini, 2003; Tunc et al., 2004). However, the extensive use of 3D models are not that much common due to the high production costs of 3D models across the cities with required temporal and spatial resolution. Since all created city models have undergone a certain data production process, they always reflect the situation in the past (Fan et al., 2008). Neither photogrammetric studies, which are one of the most effective methods for measuring and modeling large areas compared to traditional measurement methods, nor measurement techniques such as LIDAR, which have become widespread in recent years, can provide realtime products without a certain processing time (Weissenberg, 2014). Despite the development of current software that automates building model production, they still need to apply time consuming manual processes for validating the final outputs as reliable data (Ennafii et al., 2019). As a conclusion, it is not possible to produce an up-to-date data in realtime by the use of current technologies (Fan et al., 2008).

Recent developments have led to the need to quickly model a whole city in 3D, using spatial data produced by different methods or already available. For this reason, some procedural modeling techniques have been developed that enable the spatial data of 2D to be quickly converted into a 3D city model.

The utilization of the procedural techniques in 3D modelling provides realistic models of the cities from 2D GIS data with required attribute information (Merrell and Manocha, 2011; Weissenberg, 2014; Dobraja, 2015; Adão et al., 2016; Biljecki et al., 2016). Since it enables the reproduction of the 3D model using the attribute data that stored in the vector geometries, it reduces the size of data stores. Therefore procedural techniques is considered more favorable than the other methods which stores a comprehensive and detailed model in a digital environment for the use of reproduction. In addition, since the model production is created with pre-coded computer algorithms, it prevents drawing and topological errors due to operator and model production (Biljecki et al., 2016). In this way, the required models can be created when needed, with the least number of polygons and the most accurate drawing technique.

The concept of open data is based on the concept of freely accessible data so that everyone can use and re-publish data without any restrictions. Because spatial data is not only an indispensable factor in many GIS projects and regional GIS studies, but it is also very costly and difficult to obtain (Strobl and Nazarkulova, 2014). Another development today is the use of crowd-sourced data sets, such as OpenStreetMap, is becoming more common. It is seen that these data can compete successfully with many official and institutional data sets (Goodchild, 2007; Ramm, 2011). Within the scope of the study, using only open source data and procedural modeling technique, a city was modeled in 3D and its photorealistic visualization was provided. The results of using only open and crowd-sourced data for creating 3D City Model, which are carried out by using very costly methods today, were also evaluated in the study.

## DATA AND METHODS

### Input Data and Study Area

The data to be used for producing 3D city model of selected study areas was provided by open sources in accordance with the aim of the study. For this purpose, OpenStreetMap (OSM) data was used as 2D GIS data. The OpenStreetMap project, which started to be developed as a map that everyone can freely access and use within the scope of a project launched in England in 2004, has become a spatial open data platform widely used by many people today (Haklay and Weber, 2008; Ünen et al., 2013). A study by Fan and Zipf (2016) showed that the 18.4 million building footprints data on OSM had a high degree of completeness and semantic accuracy in Germany. In terms of location accuracy, there is an average of about four meters offset. Regarding shape data, OSM building footprints are highly similar to those in local authority data.

Using the OSM data, 3D models of the buildings in the study area were automatically created through procedural techniques. Figure.1 presents the data provided for Istanbul and London from the online mapping platform.

Shuttle Radar Topography Mission (SRTM) data was considered as the Digital Elevation Model (DEM) for presenting the topography. The SRTM project was carried out jointly by the American National Aviation and Space Administration (NASA) and the National Spatial Intelligence Agency (NSA) in February 2000. Within the scope of this project, digital elevation data with a resolution of 1 sec (~ 30 meters) for the United States and 3 sec (~ 90 meters) for the global scale were produced (Rabus et al., 2003). The global elevation model of SRTM is currently used by several web cartography applications.

Additionally, required landmark models and satellite images were adopted from Google 3D Warehouse and ESRI respectively as presented in Table 1. The data service "World\_Imagery", which ESRI provides for free by compiling from DigitalGlobe, GeoEye, Earthstar Geographics, The National Centre for Space Studies (CNES / Airbus DS), The United States Department of Agriculture (USDA), The United States Geological Survey (USGS), AeroGRID, IGN, and GIS User Community data, is easily accessible with many geographic information system software. World Imagery provides 1 m or higher resolution satellite and aerial imagery in many parts of the world. The images offered as a service include 15 m TerraColor images (~ 1: 591M to ~ 1: 72k) and 2.5 m SPOT Images (~ 1: 288k to ~ 1: 72k) in small and medium sizes. In the United States and some parts of Western Europe, 0.5 m resolution images from Maxar are used. In addition, Maxar's data with a resolution below 1 m is used for many parts of the world. In other parts of the world, images of different resolutions provided by the GIS User Community are available. In some regions, very high resolution images (up to 0.03 m) can be used up to ~ 1: 280 scale.

Within the scope of this study, the supply of satellite images of the regions planned to be modeled in three dimensions is shown in Figure 1. Some techniques have been applied to visualize the output model in a photorealistic way as close as possible to the physical reality. Thus, a digital twin was produced for the use of smart city management and decision support studies.

Table 1. Data that used in 3D city model production.

Data Type	Data Characteristic	Source
Digital Elevation Model	3 sec (~ 90 meters) resolution	“Shuttle Radar Topography Mission” (SRTM) data conducted by the American National Aeronautics and Space Administration (NASA)
Satellite Imagery	Varies from 0.03 to 15 meters according to data source and study area	ESRI “World Imagery” compilation satellite images
GIS Data	Varies but highly similar to those in local authority data	OSM building data provided by the OpenStreetMap Foundation (OSMF)
Landmarks	Varies but highly realistic	Symbolic building models in the cities provided by Google 3D Warehouse

In this study, Istanbul and London as two great cities in Europe, was selected as the study area. Implementation focused on the historical centers of these cities. In this context, two regions covering Historical Peninsula and City of London respectively from Istanbul and London were modelled in 3D within the scope of the study (Figure 1).

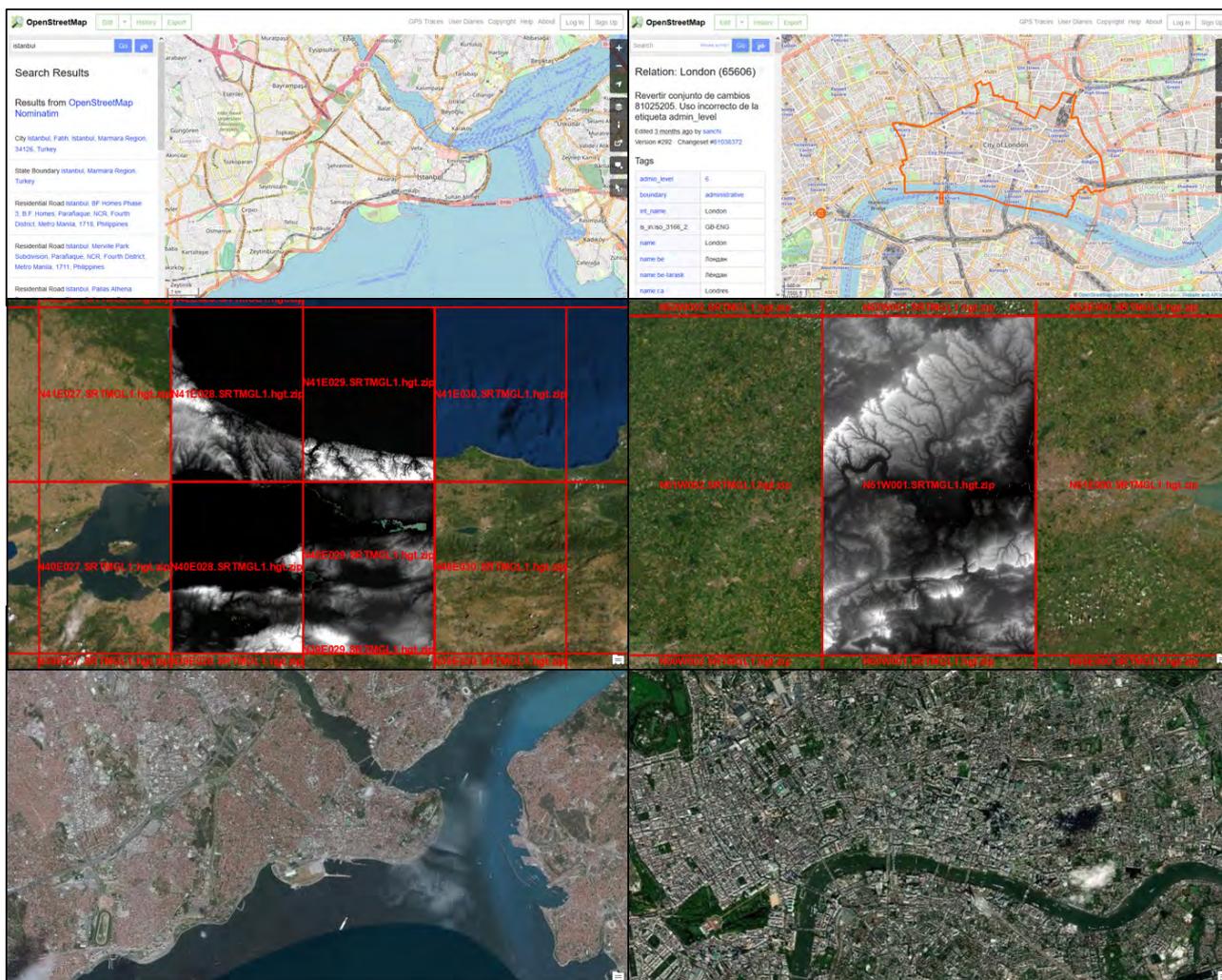


Figure 1. OpenStreetMap data for Istanbul (left top), SRTM Digital Elevation Model for Istanbul (left middle), ESRI World Imagery data service for İstanbul (left bottom), OpenStreetMap data for London (right top), SRTM Digital Elevation Model for London (right middle), ESRI World Imagery data service for London (right bottom)

## Methodology

This study uses procedural modelling technique for creating 3D city models using open source data. Procedural modeling is an umbrella term for a number of techniques in computer graphics to create 3D models and textures from sets of rules. As the main difference of the procedural modelling technique from the other modeling approaches, it generates model by setting rules to create the model instead of editing input models. By defining the generation rules the methodology basically automates the 3D model generation process. Procedural modeling techniques require longer initialization and coding studies than conventional modeling methods. Despite this, it is actually an effective modeling technique developed to produce a much faster and performance solution. After a certain planning work, the coding process is initiated, which will provide the desired modeling. Although this process seems to be longer than normal modeling at the beginning, the number of buildings to be modeled and all possible changes to be made on the design afterwards can be applied directly to the modeling. Therefore, based on the overall study, procedural techniques greatly shorten the modeling process.

The flow diagram in which the methods and procedures followed to create a 3D city model are presented as a whole are shown in Figure 2. With the step-by-step implementation of the operations, a 3D model is obtained by first generating a realistic terrain model and then building models. If available, the perception of reality is further enhanced by using models of some important structures in that region.

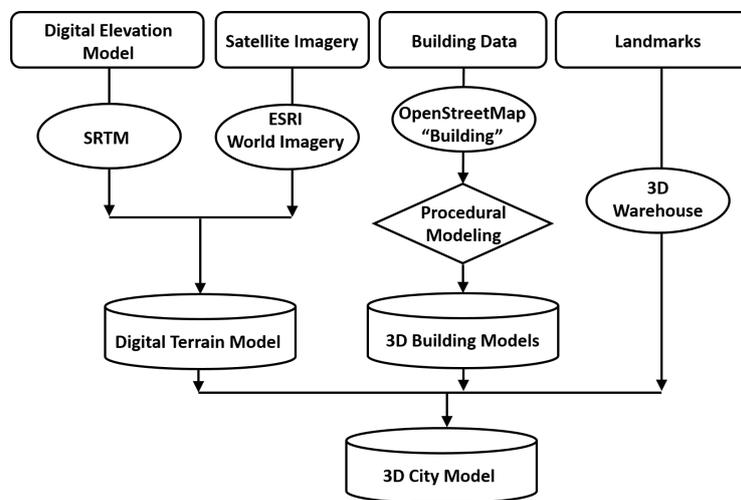


Figure 2. Workflow Chart

## CREATING A 3D CITY MODEL

In this section, all the spatial data which presented for sharing as open data will be combined and the studies for creating a 3D city model and the results of photorealistic visualization will be explained.

### 3D Design

Each pixel in the SRTM elevation model has an approximate elevation value that corresponds to the actual terrain surface at that point. Using these values, a three-dimensional surface model can be created using several GIS software. In order to create the terrain model in a digital environment, 4 frames for Istanbul and 1 frame for London were selected and downloaded from the data provider site. Additionally, a single raster mosaic height model was created by combining 4 frames in a digital environment for Istanbul. In Figure 1, digital elevation model (DEM) of the "Historical Peninsula" and "City of London" regions which were obtained from SRTM data is shown. The digital elevation model used to create a 3D terrain model was obtained by clipping the study areas from those data. In the study, the 2D data was reconstructed in 3D by using procedural modeling techniques. For this purpose, OSM "Building" data was used as the input 2D GIS data. The "Building" layer in OSM contains the footprint area of the buildings as polygon geometry. These base geometries can be transformed into three-dimensional models by procedural techniques. Using the attribute fields (See Table 2) provided with building geometries of OSM datadata, a 3D building model was created procedurally at the level of 45469 for Istanbul and 14000 for LOD2 in London (Figure 3). Computer Generated Architecture (CGA) coding language, which is a rule-based three-dimensional coding language developed by ESRI, was used in building production.

Table 2. List of attribute fields of OSM Building geometries considered in 3D city model production.

Building Attribute Data	
Definition	Attribute
Number of Floors	_ <u>getLevels</u>
Roof Height 1	_ <u>getEaveHeight</u>
Roof Height 2	_ <u>getRidgeHeight</u>
Building Type	_ <u>getBuildingForm</u>
Roof Type	_ <u>getRoofForm</u>
Floor Height	_ <u>getFloorHeight</u>
Building Color	_ <u>getBuildingColor</u>
Roof Color	_ <u>getRoofColor</u>

As an advantage of the 3D model production procedure, textures are automatically created while modelling. These textures can be the real photo of the building or are called from a symbolically prepared a texture library. In this study, random facade texturing was prepared from similar building pictures in accordance with the number of floors for all polygons created. Building models with facade texturing are shown in Figure 3.

Based on digital elevation model used to visualize topography an error may appear in precisely locating the building models on the ground due to potential inconsistency in between the accuracies of the in put datasets. OpenStreetMap “Building” data contains certain height values, but placing the created building models exactly on the terrain provides a smoother visualization. After the terrain model and building models were created, the 3D models of the city landmarks can be used to produce more realistic model in 3D. 3D models of the Istanbul and London city landmarks were adopted from Google 3D Warehouse and were used in the study for improving the visual quality of the output models.



Figure 3. The workspace in Istanbul; procedurally produced LOD2 level building models (top left), The workspace in London; procedurally produced LOD2 level building models (top right), In the Istanbul study area; LOD2 level building models which are procedurally produced with random facade texturing (left middle), In the London study area; LOD2 level building models which are procedurally produced with random facade texturing (right middle), “Historical Peninsula” region design with all data integrated (bottom left), “London” region design with all data integrated (bottom right)

Procedural modeling production was performed on a machine with 64-bit Windows 10 operating system, Intel Core i7-8700K CPU, 3.70Ghz, 64GB RAM, 2x 8GB GDDR5x Nvidia GeForce GTX 1080 graphics card configuration. Production times were presented in Table.3. Landmark models were mostly kept in their real coordinates in Google 3D Warehouse and can be easily positioned in modeling studies, depending on the professionalism levels of the users who produce them. If any desired model were produced without georeferencing, it would need to be further georeferenced. Within the scope of the study, the models downloaded from the data source was already georeferenced, so they were directly imported in to the created 3D model (Figure 3).

Table 3. Time spent to create 3D building models with procedural modeling technique.

Procedural 3D City Model Production				
	Istanbul		London	
Type	Quantity	Time (sec)	Quantity	Time (sec)
Solid Model	45469	46''	14000	8''
Textured Model	45469	53''	14000	22''

### Photorealistic 3D Visualization

Effective processing, analysis and 3D visualization of data has currently begun to emerge as one of the most important fields of study. Today, many disciplines work with three-dimensional data and are closely interested in this field. Three-dimensional applications are very important tools for the accurate understanding and modeling of complex spatial analysis and dynamic simulations (Aalbersberg et al., 2014).

The most important stages of three-dimensional visualization are the use of light, shadow and ambient absorption values. In addition, correct determination of the material settings of the objects ensures that these reflection effects are closer to the perceived reality. By using all these values correctly and in appropriate proportions, it is possible to visualize models much more realistically. Output is produced by using these effects and values in the final visualization stages of all 3D design software such as StudioMax, Maya, Blender, Cinema4D, Rhino, Houdini, or game engines such as Unity and Unreal. Although the light and environmental settings differ according to the specific menus and setting windows of the program used, these processes can be adjusted easily in all programs. There are many 3D design programs on the market for similar purposes. Although the software is designed differently from each other, environmental light, shadow and ambient absorption values can be adjusted in all. In the game engine used within the scope of the conducted study, the relevant parameters were brought to certain levels depending on the user initiative and the photorealistic 3D visualization results of the study areas in Istanbul and London were presented in Figure 4.

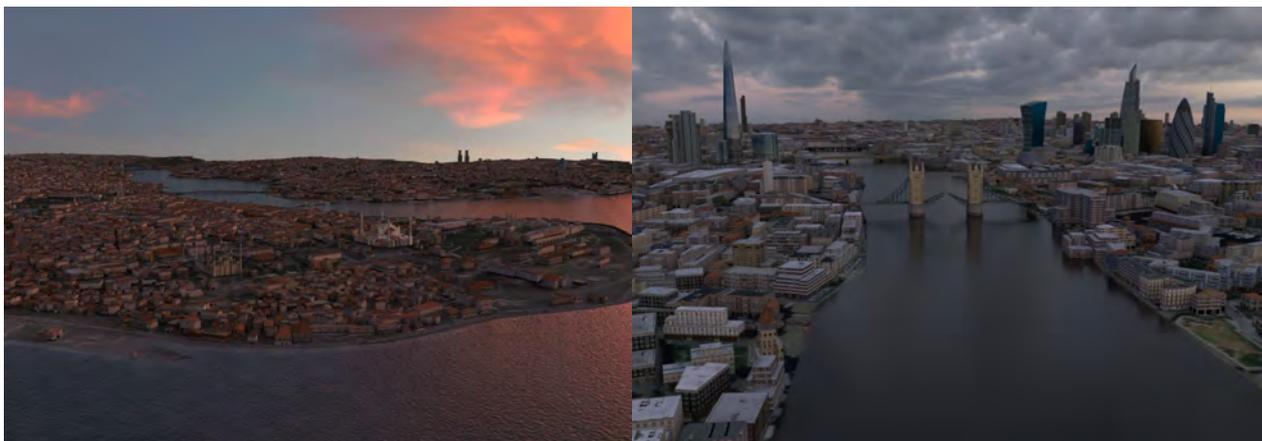


Figure 4. Photorealistic visualization of the Historical Peninsula region (left), photorealistic visualization of City of London region (right)

### CONCLUSION AND DISCUSSION

In this study; a 3D city model that can form a base for many smart city applications has been produced today using completely free data. In addition, it has been shown that it is possible to model and visualize large areas quickly and effectively in 3D using procedural modeling techniques. Combining spatial data from different sources in 3D city model production has made 3D visualization much more realistic. Also, the created digital twins are brought closer to the

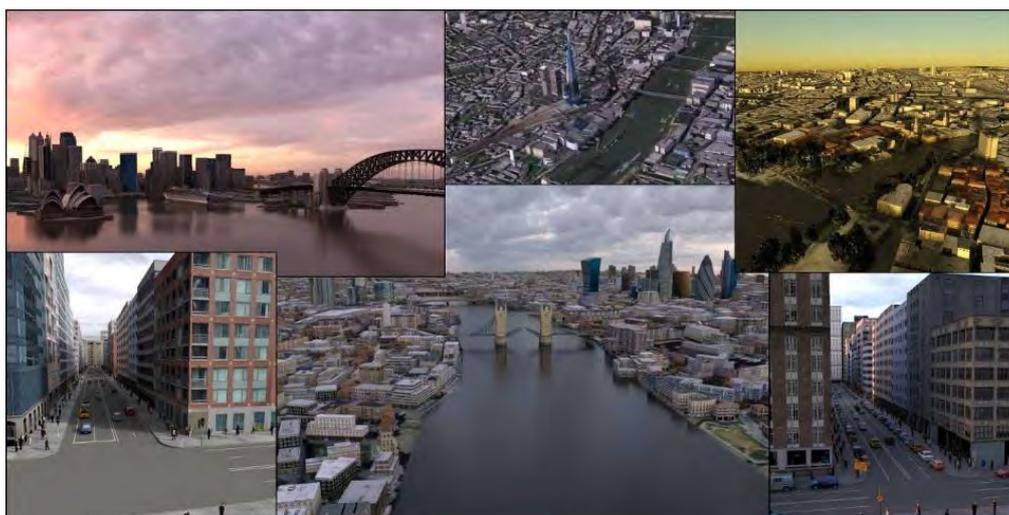
reality of photography by using other visualization techniques such as environmental light and atmosphere effects. Some other 3D photorealistic views from different parts of the cities presented in Figure 5.

One of the important implications of the study is to prove the usability of the free data in 3D urban planning and management. The study results encourage the use of open data sources for producing 3D models based on the accuracy requirements of the models instead of wasting financial sources to produce or obtain high accurate datasets of the cities. The main thing is to create awareness of smart city management in local administrations and to use the existing spatial data in an integrated and efficient way.

Open and crowd-sourced data emerge in the results of studies carried out for certain purposes. Some institutions in the world present the data as open data for academic and general use within the approach that the data produced by public resources belong to the public. The data presented as crowd-sourced are mostly shaped by individual studies. Therefore, it does not seem possible at the moment to expect perfection or completeness for open and crowd-sourced data.

Sometimes such spatial data is shared directly, sometimes it is presented to users by blending with each other. For this reason, data with the same sensitivity may not be available for every region on earth for now. However, there is plenty of data available to the general public and it grows rapidly thanks to the crowds contributing to the open data vision. In this study, two photorealistic 3D city model was produced, for many smart city studies, by combining the data obtained from different free sources. Sharing these data for public use not only extends the use of the data but it also contributes to the development and sustainability of the data.

When a similar methodology is applied using more accurate official spatial data, high accurate and complete 3D models will rapidly be available for the use of public institutions and local governments. Thus, in this study, a fast production method was presented to create 3D city models compared to many common methodologies using terrestrial and aerial data production techniques such as LIDAR, photogrammetry and remote sensing etc.



*Figure 5. Photorealistic 3D city model visualizations*

One of the most important advantages offered by 3D visualization is the absence of areas that cannot be seen by other data due to the effect of a single perspective or perspective, allowing all data to be easily viewed and evaluated in all aspects within the 3D environment. In addition, the fact that virtual reality (VR) and augmented reality (AR) imaging systems, which are becoming more and more common in use today, are being used for the visualization of spatial data will seriously affect the future and direction of geographic information systems. Thus, 3D visualization and experience of spatial data will be a frequently encountered and needed field of study in the near future.

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# RENDERING A SERIES OF 3D DYNAMIC VISUALIZATIONS IN (GEOGRAPHIC) EXPERIMENTAL TASKS

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## **Abstract**

*Real-time 3D visualization engines have evolved in both their capacity to render visual fidelity and in their openness to scripting capabilities (photorealism, programmable shaders and object properties, dynamic visualizations). This contribution is to look at the potential and limitations of such implementations with an experimental/educational scope in mind: rendering multiple 3D (cartographic) visualizations of maps/scenes in a controlled experiment-purposed application, with an emphasis on their transition from one visualization to another.*

*While 3D dynamic visualizations offer an increase in choices and customization in display and function (as opposed to traditional/2D media), this does come at a price of rising implementation costs. Both dynamicity and three-dimensionality of presented data require algorithms to process this (be it terrains, visibility models, collision models, graphics shaders, or other components). Because such algorithms require initialization time and run-time resources, their optimization is crucial. There are constraints and costs to where/how they can be used, too. Good practices of dynamic experimental scene implementation are discussed; in scene-to-scene transitions, multiple approaches are weighted against each other (multi-scene, in-scene with object transition, in-scene with user viewport transition). Techniques of static data retention and in-scene object manipulation are discussed. The conclusions are grounded in previous and current implementations of such tasks (an educational topographic map application, or ongoing research on cross-cultural differences in foreground-background visual perception).*

## **1 MOTIVATION**

This contribution discusses implementing real-time 3D engine transitions for the needs of displaying visually complex, often dynamic visualizations. There is no particular research implementation attached to the paper as *the solution* because solutions offered in the paper are multiple and should be research-design-agnostic. This goes hand in hand with ensuring that the presented solutions cover a broad palette of research implementations in real-time 3D. In other words, per good research practices, the technical implementation should be adapted (and readily adaptable) to the research design in mind, and not the other way around.

That is not to say either implementation examples or user interface & user experience (UI & UX) considerations that tie to them are omitted from the text; on the contrary, they are quite frequent, and they drive the points forward - but they should be considered for what they are: hook points in the current paradigms of computer graphics and UX, nothing more.

In previous 3D experiments of ours, users were presented with large-scale, continuous, or varying data (indoor/outdoor environments, 2D/3D maps, 3D models and text stimuli) Some portions of these experiments were dynamic - the contents of the visualization presented to users were altered through the experiment (be it by the user, an administrator, or by an event-based script). Choosing a suitable implementation to execute such alterations was necessary - in different

scenarios, we had used different solutions, as they provided more suitable than others. This is discussed later on in the *Application* chapter.

First, though, let us frame the subject by discussing what constitutes complexity in 3D/dynamic visualizations (the canvas and the visualization). This is followed by an overview of existing research (user movement in virtual environments and virtual reality (VR), users' understanding of virtual space). The *Implementation* chapter covers three approaches to implementing user/scene transitions, along with some real-time 3D engine processes to keep in mind; and lastly, existing research applications are described.

### 1.1 The canvas and the visualization

Since the beginning of the visualization discipline, humans have always been constrained by the properties of their supposed canvas, and its appropriateness to visualize what they actually wanted to be visualized (Durand, 2002; Stoops, 1966). As a simplification, one can reduce the problem into two essential variables that predetermine the viability of a visualization: the properties of a canvas (size, granularity, technology, and others), and the method of intended visualization (schematic or realistic depictions, flat or in-perspective spaces, amount of detail to convey). To put things into a contemporary context, "canvases" are meant to be LCD displays, or virtual reality head-mounted displays (VR HMDs), and the visualization methods we concern ourselves with are either 2D raster graphics or 3D geometries.

The supposed "canvases" of today are a given; and while events like new developments in VR HMDs push the technology forward, one step closer to the visual fidelity of human sight (Epstein & Rogers, 1995), we are no hardware developers ("Comparison of virtual reality headsets", 2020). So let us concern ourselves with presenting complex visualizations to the user - that is, 3D continuous/dynamic spatial data (Fig. 1).



*Figure 1 (Left) Photogrammetry 3D model of a castle ("Hrad Landštejn", 2020) - a very vertically differentiated structure, where a single viewpoint fails to provide the full understanding of the castle's spatial layout. (Right) 3D map of the surrounding terrain, which goes off to vast detail-losing distances ("Landštejn Castle - Mapy.cz", 2020).*

With visualizations of such nature, we assume the resolution of the available canvas may never be enough to convey all the needed information to its user in one instance (not without panning, zooming, switching scenes, or through other means of progressively modifying what is displayed on the canvas). Therefore, if the view to visualization is to be purposefully altered (either intentionally by a user interface (UI), or without their knowledge/contribution, as in a controlled experiment), there are ways to achieve that.

### 1.2 Existing research

There is a body of research that ties into user aspects of scene transitions, e.g., UX, UI, usability. As new user interfaces and means of moving through virtual environments are introduced (Caserman et al., 2018), these are being compared, one against other - be it in basic research (Vlahovic et al., 2018), or specific/expert tasks (Kubíček et al., 2017). Besides continuous movement, some controllers/implementations also allow for non-continuous movement - teleportation; the software-side of such implementations can also be put for evaluation (Bozgeyikli et al., 2016). User-friendly

implementations try to ensure the user retains their sense of location and spatial awareness, even after teleporting; other research designs try to deliberately challenge user's orientation in virtual space (Koltai et al., 2020).

User behavior and interface usage are measured to be analyzed and evaluated (Herman et al., 2018). Interfaces are developed to convey compelling usability metaphors (Sweeney, 2016). Etc. The scope of applicability is vast; the references mentioned here are merely scratching the surface of the subject. However, they relate to scene transitions (a technical topic not often described in detail in research papers).

## 2 IMPLEMENTATION

Our implementations were realized using the Unity 3D engine, version 2018.4 LTS. Specifically, we developed a series of Unity editor script extensions called *Toggle Toolkit* to make object/user transitions as simple as possible (Ugwitz et al., 2020). The implementation should, however, be somewhat engine-agnostic, as similar principles apply across other engines.

Moving a user inside a scene, moving other in-scene objects in relation to the user ("Transform.position"), or moving a user across different scenes ("Application.LoadLevel"), all that is simple, as far as 3D engine programming interfaces (APIs) are concerned. What is not so simple is the processing overhead that happens along with this. 3D engines generally achieve real-time performance by rendering objects, shadows, terrain, particles, and other graphic elements that are far away in lower detail or not at all (a technique generally known as Level of Detail (LoD)). For the most part, such LoD computations are taken care of by the internal algorithms of the 3D engine; engine rendering pipeline scriptability ("Scriptable Render Pipeline"), if any, allows for some customization of this; however, the algorithms keep running as the user moves, or some animated objects move in/out of user's vicinity: LoDs are determined and based on their changes, graphics detail is redrawn. The more LoDs that are recalculated (e.g., quite so by making a distant leap by teleporting a user), the more costly this is for the CPU and the hard drive (should textures be involved).

When object LoDs are suddenly "popping in" (too slow a CPU to process what is needed in real-time), when an empty surface takes time to load a texture (too slow to load real-time from the hard drive), the user witnesses unwanted glitches in the 3D visualizations that break immersion - which is something generally undesired (Ghosh et al., 2018). Thus, there are workarounds to prevent this. Furthermore, other resource-heavy components, e.g., mesh colliders ("Mesh Collider") and other geometric algorithm-based solutions, if directly accessible from within the 3D engine, may benefit from optimization as well.

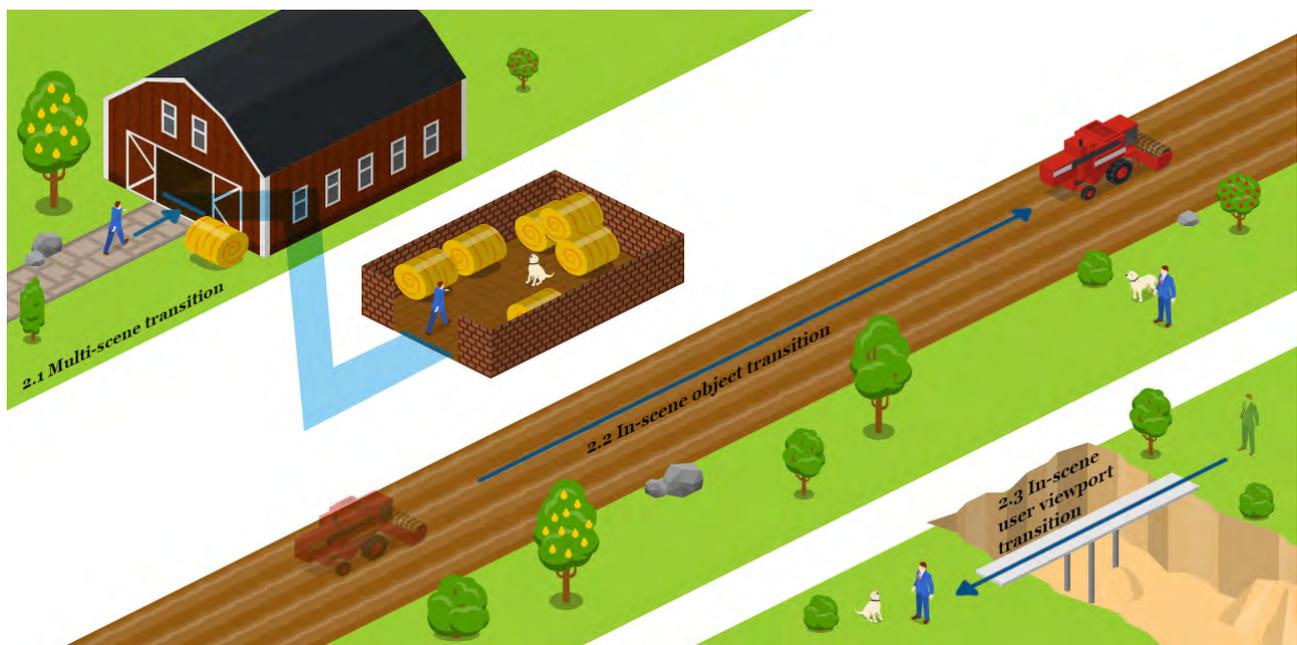


Figure 2 (Top) Multi-scene transition, where the user is transferred from one scene to a wholly different one. (Middle) In-scene with object transition, where the user remains in the same place, while portions of the 3D spaces are manipulated around them. (Bottom) In-scene with user viewport transition, where the user is teleported within the bounds of a single scene. This figure was illustrated using IcoGrams Designer.

Fig. 2 illustrates the three approaches to 3D scene transitions. We will now cover detailed technical aspects of their successful implementation.

## 2.1 Multi-scene transition

This is a simple solution where portions of an intended virtual world are separated into different scenes. Before the advent of *open-world* solutions, this was (and in some cases still is) the most common way of making the transition from one area to another: by means of arriving at one scene's end, the next one would load up.

Historically, it made sense to divide the virtual world into such chunks for several reasons. For one, 3D engine editors did not offer a feature to edit a scene collaboratively - so by creating separate scenes, editing workload could be distributed across several people (Unity still does not have a standardized collaborative editing functionality; Unreal engine has ("Multi-User Editing", 2020)). Furthermore, separating a vast virtual space into smaller chunks can make it easier to manage by the engine - lesser the amount of objects in a scene overall means less CPU time spent on LoD and other distance/zoning algorithms; a unifying visual theme in a scene (assuming a scene portrays a location with a coherent theme to it) can help with texture allocation, making most, if not all textures fit into the memory, effectively eliminating hard disk reads for loading textures.

Another advantage of a separate scene is that it is a "blank slate". It can be set up to contain the scripts, effects, lighting set-ups it needs, without the need to consider set-ups of the other portions of the virtual world (something that would be implementation-costly and error-prone in an open-world scene, as with enabling specific visual/scriptable features of one portion of the virtual world, others would have to be checked to be disabled).

The inherent disadvantage of the multi-scene approach can be its slow loading times (especially if large objects like detailed 3D meshes and textures are included). In loading a new scene, all the existing memory objects of the current scene would be destroyed, and the next scene would initialize their own. This also means that if there were crucial data attached to the user in the previous scene to be transferred into the next one, the data would have to be saved/loaded on the side of the scene transition process (e.g., by implementing an XML writing/loading script).

## 2.2 In-scene object transition

The user remains in the same worldspace coordinates, while a transition happens around them. In most cases, these are dynamic alterations to the surrounding visuals (be it continuous animations or instant events). It would make sense to structure virtual worldspace interfaces to react to the user this way (e.g., "XR Interaction Toolkit", 2020); it would make a cumbersome effort to "teleport" the user by moving the whole virtual scene around them.

## 2.3 In-scene user viewport transition

This approach is the correct way to teleport the user within the scene: their worldspace coordinates are changed to move them to a defined area of the scene. Conventionally, a teleporter, if not unknown to the user, is to visually communicate it is a teleporter (be it standardized color schemes, effects, or other visual leads), and to teleport the user upon entry, or interface usage. The teleportation function of the standard VR HTC Vive controller utilizes this principle (Van de Kerckhove, 2019).

The HTC Vive controller teleportation implementation is an example of preventing/solving some of the scene transition issues mentioned above. There is a fade-in/fade-out animation upon teleportation - something that could hide potential LoD/texturing glitches; the controller also visibly indicates the place the user will be teleported to, ensuring they retain their spatial orientation. Large-distance teleporting using the HTC Vive controller is also severely limited.

While manipulating user's worldspace coordinates is to be expected, manipulating their viewport rotation would be considered a bad practice. In cases of VR systems (Hearney, 2019), rotation is evaluated by the VR hardware and then sent to the 3D engine; and even in cases of a scene visualization portrayed on an LCD monitor, changing the user's rotation could hamper their spatial orientation - unless that is the intent of the research.

### 3. APPLICATION

The first, and possibly the most straightforward implementation of in-scene user viewport transition involved VR exploratory research, where the users were tasked to explore a vast outdoor area on their own; upon finishing, they were to be teleported to a watchtower, never mind the location in which they decided to end their exploration. The implementation involved a script that mapped a keypress to the watchtower virtual world coordinate; as the experiment administrator pressed the key, the user was teleported into the watchtower.

Another simple implementation was a multi-scene transition consisting of two VR scenes, and no movement apart from the head rotation for the user. The first scene had a control script attached to it, where the user was presented with a set of words to remember. Once all the words were shown, the user was transferred to the second scene and asked to recall the previously shown words. Since both scenes had a vastly different lighting set-up (something rather difficult to set up in Unity, with no profiling), splitting the visualization into two scenes was the right decision. More complex examples follow (Fig. 3).



Figure 3 (Left) In-scene object transition experiment (figure-background eye-tracking), where 30 scenes were shown in succession, experiment design per Čeněk et al. (2019), depiction by Fitz (2020). (Right) In-scene object transition experiment (contour lines) with virtual UI altering the visualization on the virtual table, by Šašinka et al. (2019).

There is a pending eye-tracking study on figure-background attention preferences in cross-cultural contexts, by Čeněk et al. (2019). This study was to be replicated for VR eye-tracking while preserving the original research design: i.e., to have 30 scenes presented to the user in succession. Since the users were mere observers in the experiment, their only range of motion was their head. Thirty non-demanding landscape visualizations were created, all within one scene, all placed onto the same coordinates. The scenes were intentionally deactivated (visually hidden). Once the experiment started, a switching timer script proceeded to show the scenes to the user, displaying each for four seconds. The user was situated in the same vantage point all the time, making this an object transition experiment. Due to this being an eye-tracking experiment, i.e., something that requires accurate timing of the presented stimuli with no delays or graphics artifacts, all the 3D models and textures present in the 30 subsequent visualizations were purposefully preloaded before their presentation to the user ("Resources.LoadAll"). We ensured the preloaded visuals were small enough to fit the experimental PC's memory (e.g., 16GB RAM, 8GB VRAM).

The most technologically sound implementation of ours is described by Šašinka et al. (2019) - a solution intended for collaborative education (in this case, the subject is contour lines). Not only does the implementation involve an intertwined virtual UI which allows for a variety of 2D/3D visualization adjustments of the subject presented on the table, but there is a network layer to it, too - while all collaborating users technically each run their instance of the visualization on their PC, the network layer ensures that if a user alters the look of their instance, this propagates to other users' instances as well. From the perspective of scene transitions, this is again an in-scene object transition experiment; the fact that the majority of the user's surroundings is a virtual room that remains unchanged (the only dynamic elements being the visualization on the table, and the potential networked co-users) ensures the user stays grounded in the virtual space they occupy. This implementation did offer a dynamic, animated transition where the 3D visualization of the terrain would be switched to 2D or vice versa; during this one-second transition, the highly detailed 3D terrain would gradually flatten into 2D; because the terrain would offer interactivity in terms of the ability to place items onto it, including a mesh collider component was crucial; during the transition animation, the mesh collider would, however, be forced to recalculate each rendered frame, hogging down the CPU and the framerate of the

application. Therefore, for optimization purposes, the mesh collider terrain component was scripted to disable during the animated 3D/2D terrain transition and re-enable once the animation finishes.

## CONCLUSION

This contribution raised the issue of working around 3D visualizations that are too complex in shape or dynamically changing in time - which then leads to the need to adjust the content of one's viewport so that most of the information present in the visualization is conveyed (Fig. 1). Whether the user has a full or limited range of motion and UI usage to achieve that is not relevant, as defining that belongs to a research design based around such issue. We have presented the most common scene transition issues and offered three approaches to object/user transition in a 3D visualization (Fig. 2). These were then discussed in detail regarding their shortcomings, advantages, and possibilities; lastly, some of our previous research designs utilizing these approaches were described, including the specifics of their implementation. We hope that such insight into the technical side of 3D/VR experiment creation can aid future experiment creation.

## ACKNOWLEDGMENT

This publication was supported by the Czech Science Foundation (GC19-09265J: The influence of socio-cultural factors and writing system on perception and cognition of complex visual stimuli).

Preparation of related experiments was made available by the research infrastructure of Virtual Geographic Environments Lab, Department of Geography, Faculty of Science, Masaryk University, and HUME Lab Experimental Humanities Laboratory, Faculty of Arts, Masaryk University.

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# DOES 3D GIS PROVIDE A DIFFERENT INSIGHT THAN 2D?

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## **Abstract**

*The third dimension in GIS is popping up everywhere nowadays. When somebody sees a perspective (or even full 3D visualization) of 3D geographical data, his or her first reaction is usually very positive. However, after a second look or a longer work with the 3D GIS, the user sometimes realizes no or minimal added value, accompanied by unsolicited complexity caused by the need to handle 3D data on a 2D screen (or on some 3D portraying device in general).*

*The contribution aims to present outputs from a deployed online questionnaire, which dealt with comparison of solving tasks based 2D or 3D visualization of data. Based on such outputs we provide several best practices examples consisting of workshops and tutorials, how to work with 3D geographic data, followed by examples of projects' outputs dealing with 3D geographical data. The pros and cons of such use cases are then discussed. We focused on cases where the use of the third coordinate adds value comparing to two-dimensional geographic data, their analysis, and visualization.*

**Keywords:** 3D GIS, use cases, 3D and 2D comparison, hs layers ng, openlayers, cesium

## **1. INTRODUCTION**

A discussion about using 2D or 3D GIS and 2D and 3D maps for different purposes is live and still ongoing these days because an advantage of handling data in three dimensions can be used in various important topics such as urban planning (Popelka (2018), Ying et al. (2012)), 3D cadastre (Ying et al. (2012), van Oosterom (2013), FIG (2018), Janečka & Bobíková (2018)) or Building Information Management (Biljecki et al. (2014, 2015)).

A general overview of 3D GIS regarding data collecting, data modeling, data storing, data structures, and data usage within 3D GIS is described extensively in Jedlička (2018). An overview of virtual 3D maps, their definitions, their creation workflow, and their cartographic principles was depicted in Hájek et al. (2016). A methodology and description of experiments for evaluation of such cartographic principles were incorporated in Hájek et al. (2018). Particular geospatial tasks regarding the usability of 2D and/or 3D maps for their successful solving were conducted by an online questionnaire depicted in Hájek et al. (2018), while some particular general results from such a questionnaire are depicted further in this paper. Based on such experiences, we finally describe and shortly evaluate best practices examples, which we have experience with for the last several years.

## **2. EXPERIMENTAL COMPARISON OF 2D AND 3D MAP REPRESENTATION**

There already exist related works dealing with research on 3D representations or comparing 2D/3D representations of geographical features in a field of cartography using respondents. Each of them is somehow dealing with particular tasks for the respondents, where questions for respondents are asked and answers are responded on a base of the displayed situation. Each of the studies deals with a particular topic of research. For example, Bleisch & Dykes (2015) handled tasks dealing with quantitative data and its location and altitude-related situations on a base of 2D or perspective representation of such data. Popelka & Doležalová (2016) were dealing with an influence of 2D/3D environment on a size determination of objects. Liu et al. (2017) dealt with an influence of a 3D representation of objects regarding perceiving their size, shape and color. Petrovič & Mašera (2006) were examining the usability of digital 2D maps and different perspective-view based representations for recognition of point/linear/polygon-type objects, together with obtaining numeric data from such kind of maps, such as distance, direction or height differences. Herman & Stachoň (2016) worked on a comparison of user performance in tasks' solving using interactive or static 3D visualization. Nevertheless of each study focus, the conclusion is seldom straightforward. More often a reader can find a statement explaining that the advantage of using 3D depends on a particular usage.

The study described in this paper focuses on experiments for evaluation of cartographic principles described thoroughly in Hájek & Čada (2018). Particular examples mentioned further were designed to cover some tasks, which could be

solved using either 2D or 3D representation of reality in maps. Such experiments were dealing with solving thematically related tasks such as “finding a particular type of building”, “object size (area) estimating”, “finding an object which is higher/lower than another one”, or “comparing of 2D and 3D point/line/polygon representation of objects and their recognition by a user”. The experiments were deployed using an online questionnaire, where six thematic experiments were incorporated for both 2D and 3D variants of a task.

As a particular example of such a task, see figure 1. The task portrayed there deals with a question “Which combination of buildings has direct visibility, respectively between their peaks defined by yellow dots?” The upper part is showing the 2D variant of the task, the lower part is showing the 3D variant of the experiment.



Figure 1. An example of a 2D and 3D version of an experiment dealing with visibility.

Each of the conducted tasks was statistically evaluated using a nonparametric test of equality of parameters of two alternative distributions (a.k.a chi-squared test, also written as  $\chi^2$  test) and the significance level  $\alpha$  was determined to be 5% (i.e. 0.05) for all of the tests. The zero hypothesis stated as “There is no difference between 2D and 3D versions of a given experiment, both variants of the experiment are solved equally correctly”.

The results for the statistical evaluation of the mentioned task is depicted in figure 2 below. The left side of the figure 2 depicts frequencies of correct answers (green column) and false answers (red column) for both 2D and 3D variant of the task - in this example the null hypothesis of the agreement of the percentage frequencies of correct answers in favor of the alternative hypothesis at the level of significance of 5% was rejected. *This means that the respondents were statistically significantly more successful in solving the 3D variant of the experiment than in its 2D variant.* The right side of the figure 2 shows boxplot visualization of time and correctness of all answers of this task - in this example any answer provided within 2D variant of the task took significantly longer than any answer within 3D variant of the task (for the incorrect answers the time is even statistically longer).

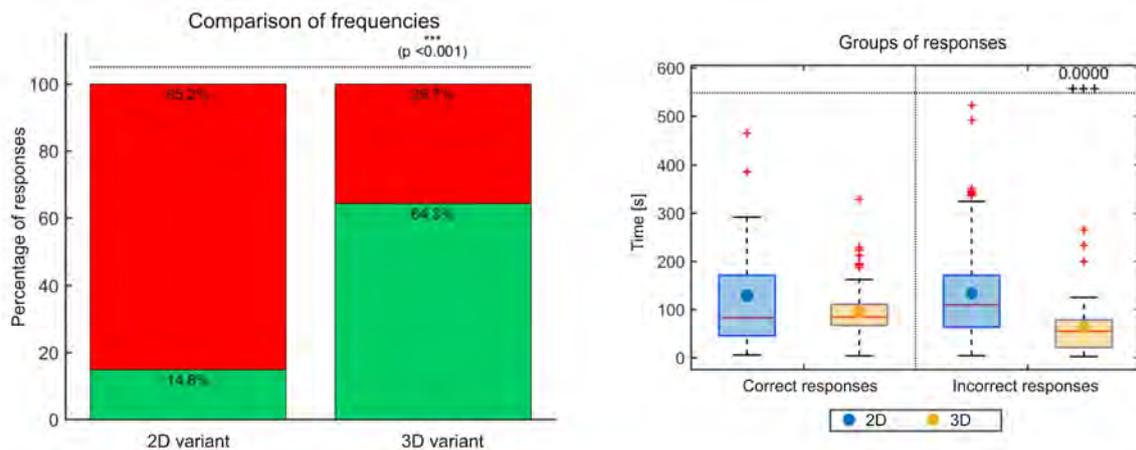


Figure 2. Results for statistical evaluation of a visibility decision task.

After a thorough evaluation of all the questions in the conducted questionnaire (see details in Hájek & Čada (2018)), the finding can be synthesized in the following bullets:

- The purpose of the map and the choice of an appropriate form of its representation is key for proper communication between the map and the reader;
- The cartographic representation of objects in the map plays a key role in their recognition by the map reader;
- There are tasks that can be solved more successfully by the map reader on a 2D variant of the map (e.g. determining the area in 2D), as well as there are tasks that can be solved by the map reader more successfully on a 3D variant of the map (e.g. direct visibility);
- However, there are tasks that do not depend on the selected 2D or 3D variant (e.g. find buildings of a selected category) and it is necessary to add semantic information about the object to the map;
- In virtual 3D maps, the 3D representation of real objects around us is more natural for human perception than their abstract form;
- For virtual 3Ds, 3D display of abstract phenomena (e.g. statistical data) is less suitable, in this case, a 2D variant of the map is a more suitable basis for displaying such information. However, it is possible to find a 3D representation of abstract phenomena that is suitable for virtual 3D maps and is beneficial (e.g. spatial propagation of noise, fumes, etc.).

In general, we can say that, it was proved by the questionnaire mentioned above, that the 3D map visualization as a part of a 3D GIS solution has its own added values.

The next chapter describes our experiences with the 3D GIS and 3D visualization of objects and features by describing particular examples of workshops, tutorials and projects, in which authors of this paper were involved. And these examples are followed by our explanation, why we find 3D representation of data useful for the particular example.

### 3. BEST PRACTICES EXAMPLES

This chapter deals with authors' experiences with 3D data, 3D GIS and 3D or perspective visualization (on a monitor screen). There is a section of workshops and tutorials followed by a section about the projects, in which we were involved.

For each workshop or project (let's call them activities in general), there is a brief overview of its topic, followed by a representative figure for getting an idea, how the outcome of the workshop or project looks like. Nevertheless, there is also to the activity's web page, in order to provide more comprehensive information to the reader of this contribution and possibly a link for a short movie showing a 3D visualization of data, where available. Each activity is concluded by a summary of used technologies, Described project are then also provided with pros and cons of the used technology, approach and/or a way of visualization, depending the particular activity described.

It is also worth to note that a majority of the following examples (and much more) is also referenced at following URL's: <http://kgm.zcu.cz/3dgis>, respectively <http://kgm.zcu.cz/3dgis/examples>

#### 3.1. Workshops and tutorials

This is a list of workshops and tutorials focused on various topics related to three dimensional GIS. These workshops were presented on various occasions, such as conferences or invited lectures at extraneous universities.

##### *Multi LOD 3D visualization in the Web Environment*

Workshop participants get a short introduction about the 3D visualization techniques for big data applicable in the web environment and then participants learn how to create their own 3D scene with a 3D cube using multiple levels of details principle from CityGML standard and embedded in a web page. A visualization of a 3D cube using level of details principle is described in figure 3.

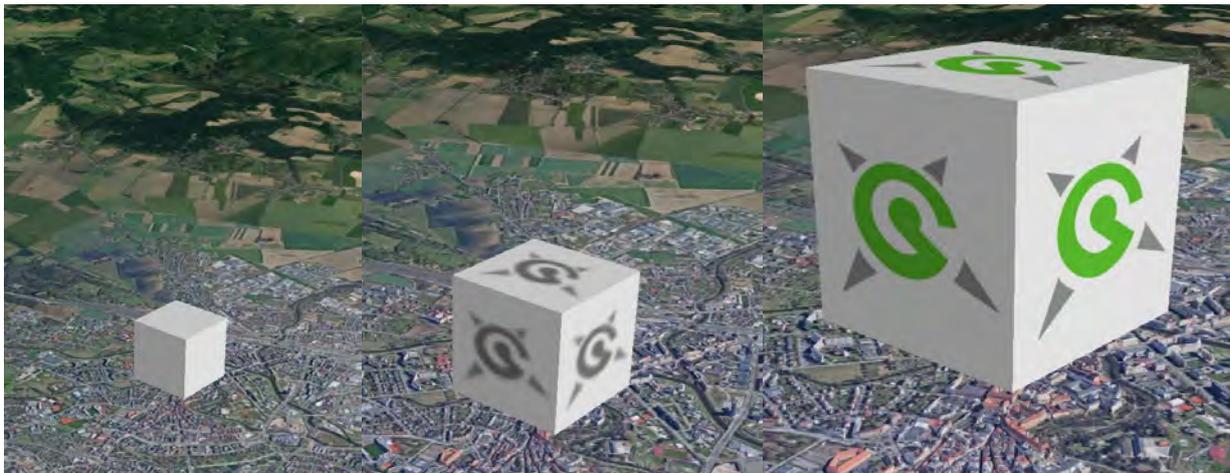


Figure 3. An example of 3D visualization using level of details principle.

Workshop link: <http://old.gis.zcu.cz/projekty/3DGIS/MultiLOD/>

Technologies used:

- Text editor for editing addressed languages such as HTML, KML and WebGL,
- Web browser for visualization 3D data in WebGL
- Google Earth Plug-in for web browser or Google Earth Desktop for visualization 3D data in KML

Goal: Demonstration of the difference of level of detail concept in 3D and in 3D. Providing easy, step by step guide for getting started with a multi LOD 3D visualization in the Web Environment, using simple tools and general web browser.

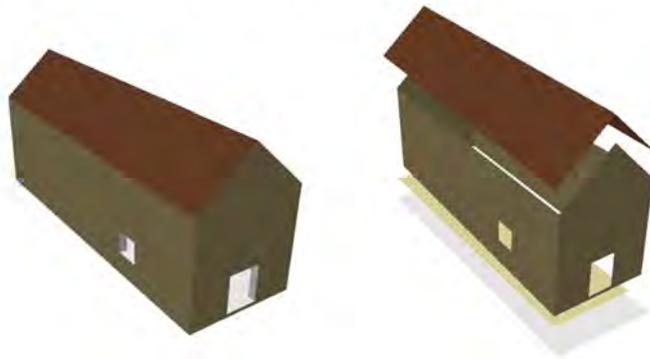
### ***Export of semantically rich models from SketchUp to CityGML***

This workshop stressed the importance of semantically rich 3D models. The participants of the workshop get the theory needed and then follows a tutorial to create a 3D model of a simple building in popular 3D software SketchUp. Then they tag each part of the building model by prescribed attributes of CityGML (roof, wall, ground, inner wall, ceiling, floor) using a SketchUp Extension. Finally they convert the data in ArcGIS geodatabase - a suitable GIS representation. See result in figure 4.

Workshop video can be found at [https://bit.ly/SketchUp2GIS\\_video](https://bit.ly/SketchUp2GIS_video), the presentation here <https://bit.ly/SketchUp2GIS>.

## **City GML -> ArcGIS**

Comparison of uncategorized model export and CityGML categorized model



*Figure 4. Comparison of uncategorized (left) and categorized (right) model*

Technologies used:

- SketchUp for 3D model creation
- City GML Export Plugin to create CityGML file of a building/bridge/tunnel from an appropriately categorized SketchUp model. ([https://github.com/smrcek/SU\\_CityGML\\_ExportPlugin/wiki](https://github.com/smrcek/SU_CityGML_ExportPlugin/wiki))
- Data Interoperability for ArcGIS - to convert citygml to Esri Geodatabase
- ArcGIS - to browse the final result

Goal: demonstration of creation of semantically rich models and their import into GIS

### ***Analysis in 3D***

This workshop presents 3D analytical techniques in ArcGIS and describes a way, how the data has to be prepared to enable the analysis. Only techniques working with 3D geometry are presented, namely Visibility, SkyLine, SkyLine Barrier, SkyLine Graph, Inside 3D (see fig X.), Is Closed 3D, Enclose MultiPatch, Inside 3D, Buffer 3D, Intersect 3D, Difference 3D, Sun Shadow Volume and Near 3D. The important difference between 2D and 3D analysis can be spotted at <https://bit.ly/3DVisibilityatJunction>. It shows driver's visibility conditions using 3D analysis. Red point shows a car entering a junction. Green areas shows the driver's view. It is clearly visible that vertical obstacles play a crucial role in the visibility analysis – see fig. 6.

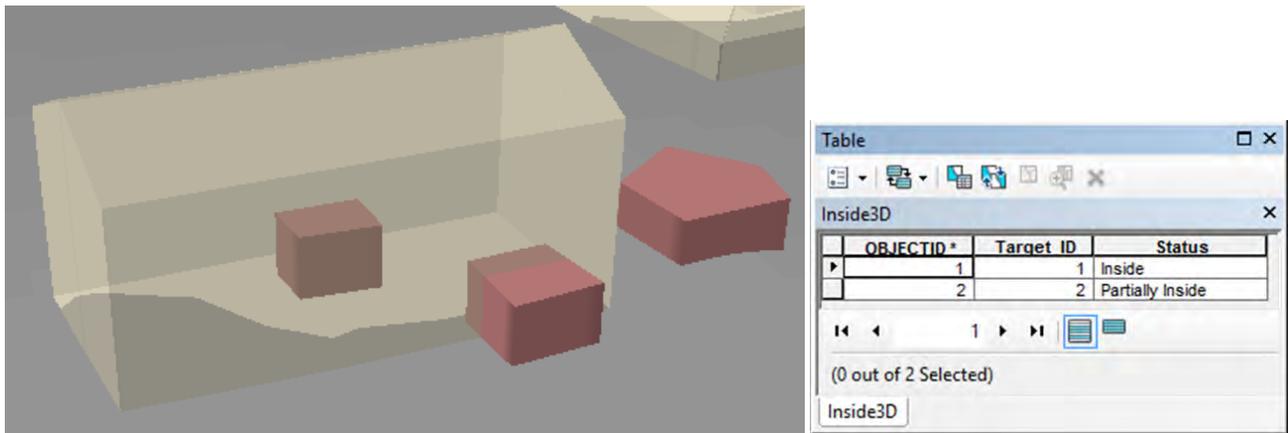


Figure 5. Results of the Inside 3D operation

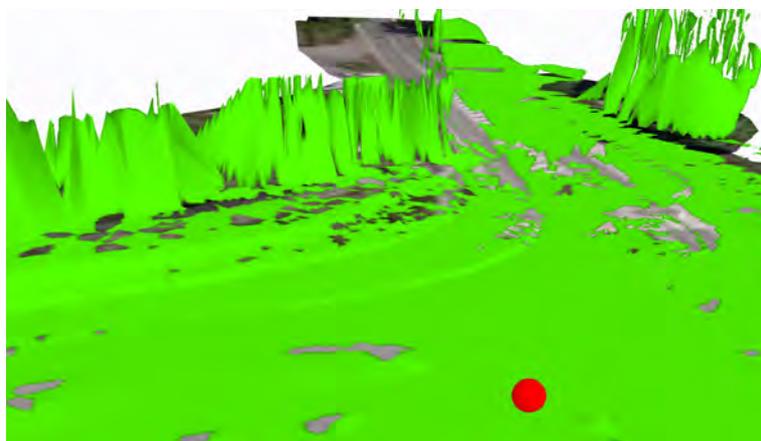


Figure 5. Driver's (red point) visibility conditions using 3D analysis

A video from the workshop can be found at <https://bit.ly/AnalzyVe3D>. Technologies used: ArcGIS with 3D Analyst extension Goal: demonstration of 3D analytical functionality of GIS

### 3.2. Projects

#### *Spatially oriented register of Cultural Heritage - Castle Kozel Case Study*

Kozel Chateau is a digital playground and a very first 3D project (<http://old.gis.zcu.cz/projekty/Kozel/>) of our 3D GIS team. The 3D model (<https://bit.ly/KozelExteriors>) consists of visualization of chateau exteriors, in particular it portrays detailed terrain, land use, buildings with windows, doors and facade relief, forests and freestanding trees, bushes, etc, see fig. S. Buildings models were created by 3D editing tools in SketchUp and converted to Geodatabase using CityGML SketchUp plugin and ArcGIS Data Interoperability Extension. The chateau chapel is modelled including interior (CityGML LOD4), according to techniques described Export of semantically rich models from SketchUp to CityGML chapter. Elements of the chapel model contains unique identifiers in order to be connectable to the Czech spatial database of immovable heritage maintained by National Heritage Institute. Moreover each tree portrayed in the model is connected to MyTrees database (<https://www.treeworks.co.uk/our-technology/mytrees-tree-management-database/>).

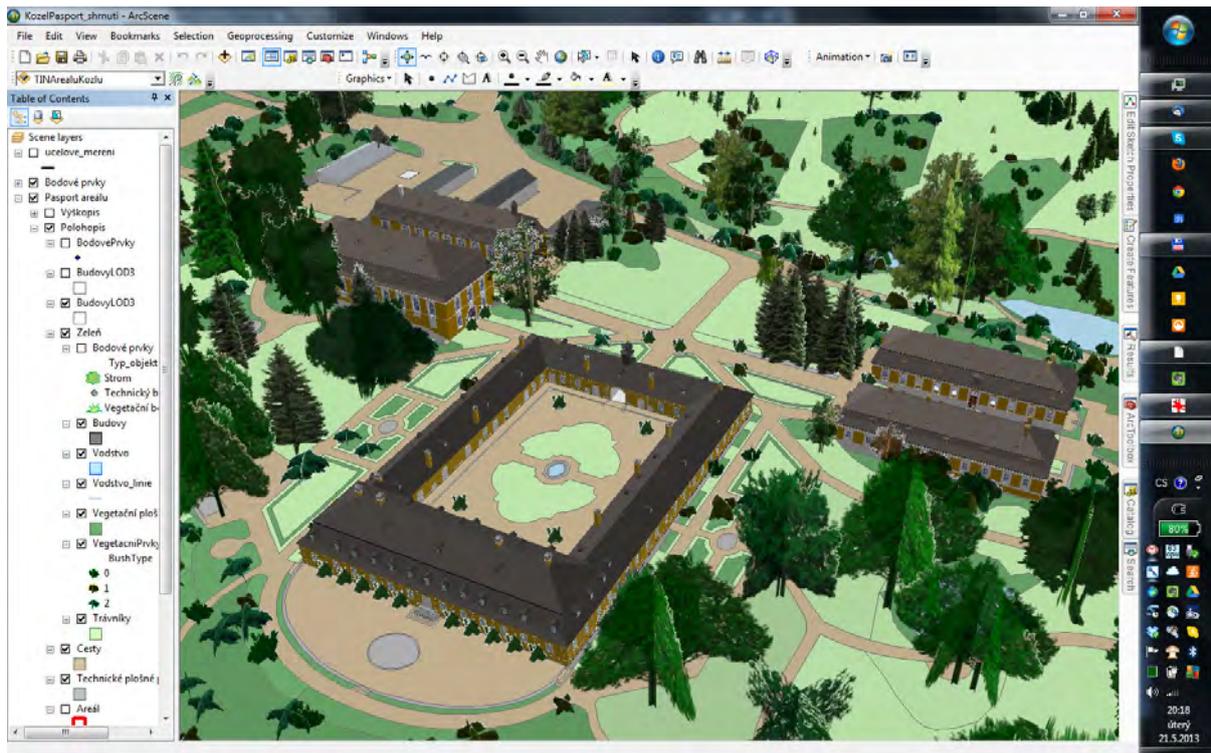


Figure 7. Visualization of Chateau Kozel exteriors

Technologies used:

- Creation of 3D models - SketchUp by Trimble Inc.
- Visualization of 3D models - ArcGIS and ArcGIS Online.

Pros:

- 3D representation of object of interest are interesting to the general public from the point of view of attractiveness of such objects,
- and they serve as a reference for Content Management System in order to retrieve interesting information about the chosen object.

Cons:

- Loading of the virtual 3D scene via internet can take longer time due to the size of the 3D models visualized, while at the moment the model is visualized as whole.

Further reading in Jedlička et al. (2013).

### ***Memorial Landscapes Dresden and Terezín as places to remember the Shoah***

The project “Landscape of memory. Dresden and Terezín as places of memories on Shoah” had the main goal to develop and populate a data model suitable for 3D visualization of large-volume spatial data (the whole area of the Terezín town in the state of art of 1944) together with related descriptive data. An overview of the Main Fortress of Terezín visualized by Cesium.js is depicted in figure 8.



Figure 8. 3D visualization of the Main Fortress of Terezín.

Links: Video (<https://www.youtube.com/watch?v=JhgmwNDW45s>), project [www.gepam.eu](http://www.gepam.eu)

Technologies used:

- Creation of 3D models - SketchUp by Trimble Inc.
- Visualization of 3D models / data format used
  - originally Google Earth plug-in for Web browsers using Keyhole Markup Language (KML) data format of 3D models with active Level of Details (LoD) principle for visualization (the plugin's API expired at the end of 2016),
  - at the moment Cesium.js JavaScript library using GL Transmission Format (glTF) data format of 3D models displaying just the most detailed models' LoD.

Pros:

- 3D representation of object of interest are interesting to the general public from the point of view of attractivity of such objects,
- they also serve as a presentation of the historical resemblance of the objects of interest, while some of them exist anymore,
- and they serve as a reference for Content Management System in order to retrieve interesting information about the chosen object.

Cons:

- Loading of the virtual 3D scene via internet can take longer time due to the size of the 3D models visualized, while at the moment the model is visualized as whole (previous version of the model was related on Level of Detail principle in order to speed up the loading of models, but the technology of the platform had changed and so the visualization of the model had to be changed).

For further information about the project itself, see Hájek et al. (2013), Hájek et al. (2015)

### ***Peregrinus Silva Bohemica (Pavel)***

In project “Peregrinus Silva Bohemica – Multimedia and digital tourist guidance for cross border historic routes in the Bavarian-Bohemian forest”, there was a multimedia digital travel guide created, in order to make the historical-cultural landscape more attractive for tourists not only through virtual 3D maps but also through 3D printed models of objects of interest. It contains cultural heritage sites important for tourists and especially for pilgrims on a part of pilgrim ways between Bavaria and Bohemia. An example visualization of a virtual 3D map using Cesium.js for visualization is showing particular historical buildings of Church of the Immaculate Conception of Virgin Mary and St. Ignatius and Jesuit College in Klatovy, Czechia in figure 9.

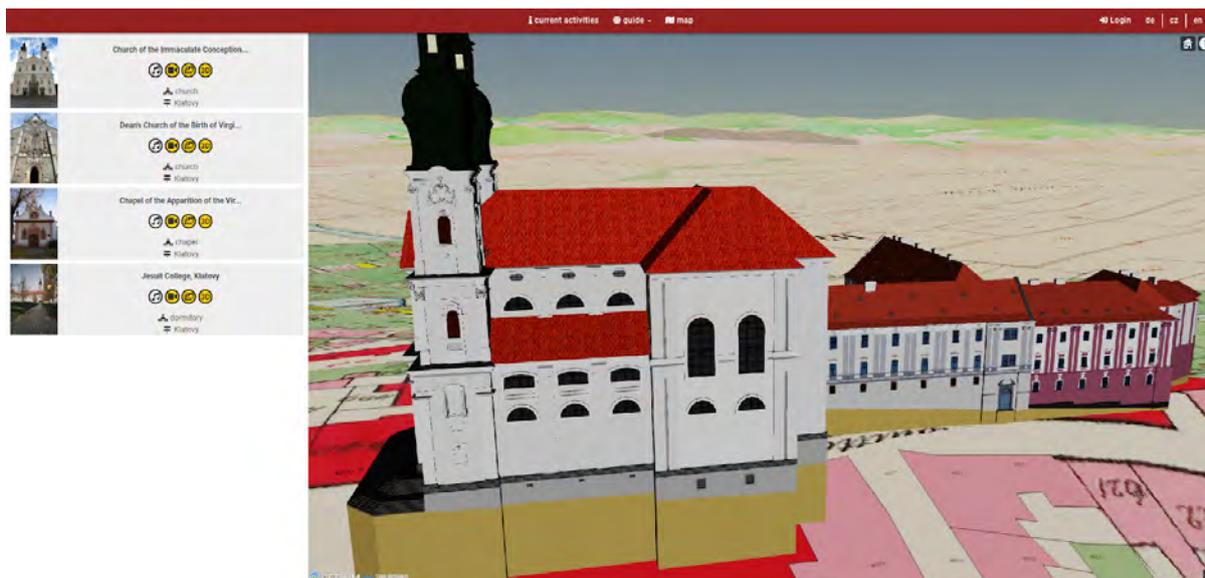


Figure 9: 3D visualization of important historical buildings in Klatovy.

Links: project <https://peregrinus.online/>

Technologies used:

- Creation of 3D models - SketchUp by Trimble Inc., Blender by Blender Foundation
- Visualization of 3D models / data format used - Cesium.js JavaScript library using GL Transmission Format (glTF) data format of 3D models.

Pros:

- 3D representation of object of interest are interesting to the general public from the point of view of attractivity of such objects,
- they also serve as a preservation of the historical resemblance of the objects of interest,
- and they serve as a reference for Content Management System in order to retrieve interesting information about the chosen object.

Cons:

- Loading of the virtual 3D scene via internet can take longer time due to the size of the 3D models visualized.

For further information about the project itself, see Kepka Vichrová et al. (2017), Kepka Vichrová et al. (2020).

### ***Perspective visualization of Big Data on top of terrain***

Three large datasets: Open Land Use (OLU), Smart Points of Interest (SPOI) and Open Transport Map (OTM) have been integrated into one web application (<https://app.hslayers.org/3d-olu/>) in order to test visualization of Big Data on terrain in a Perspective visualization. Check <https://www.plan4all.eu/open-data/> for details about the data. The visualization portrays a web map service (WMS) of OLU segmented by regions - where only the regions in the field of vision are loaded. SPOI (described in Vohnout et al. 2014) and OTM (more about in Jedlička et al. 2016) follow the same “field of vision” principle, but these datasets are not optimized. Thus a user can compare the reaction time (also can be checked at this presentation video: [https://bit.ly/3D\\_OLU](https://bit.ly/3D_OLU)). Figure 10. shows the application with OLU and OTM visible.

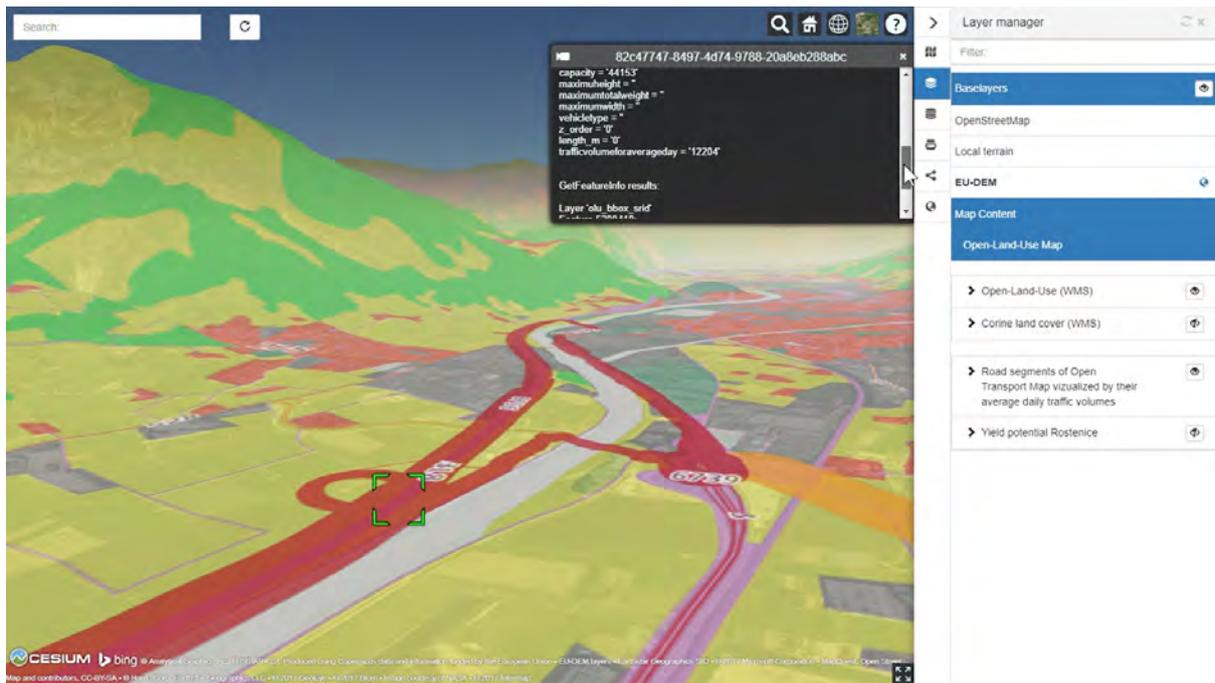


Figure 10. A web application showing visualization of OLU and OTM.

Technologies used:

- Library HS Layers NG (<https://ng.hslayers.org/>), a customized version of Open Layers library <https://openlayers.org/>.

Pros:

- a proof of concept that visualization of Big Data is possible in 3D and via internet.

Cons:

- Loading of the virtual 3D scene via internet can take longer time due to the size of the data visualized.

For further information about the project see Jedlička & Charvát (2018) or CHarvát et al. (2018).

### **3D Map of Šumava Mountains**

Physical 3D model of the Šumava Mountains and Bavarian Forest of size 12 x 5 meters. See first tiles milled in hardboard in figure 11. This project is ongoing, the physical 3D model is not ready yet. But it should contain a 3D representation of the crossborder mountains of Czech and Bavaria with a topography represented as colorful layers overlying the terrain itself. On top of that, there should be little off-scale 3D models of important places of interest such as watchtowers or churches placed on the terrain.



*Figure 11. Prototype 1x1 meter tiles milled into hardboard*

Technologies used:

- Creation of the terrain model - Quantum GIS (QGIS) for downloading EU-DEM terrain data, CATIA and Siemens NX for data preparation to be turned into 1 x 1 meters blocks using CNC technology
- Topography data - QGIS and OpenStreetMap data

Pros:

- Physical 3D model of the area enabling users/visitors to have a good impression about the area of interest

Cons:

- Physical, but not touchable 3D model of the area

#### **4. DISCUSSION AND CONCLUSION**

This paper deals with a question “Does 3D GIS provide a different insight than 2D?” The paper firstly described fundamental outcomes from a deployed questionnaire regarding solving geospatial tasks using 2D or 3D representation of objects. It concludes, that 3D representation of data is handful, where the third dimension comes with an added value for “reading a map”, but is not that beneficial, where the third dimension of data restricts obtaining information from a map or 3D visualization.

Next, this paper described experiences of the authors by showing and evaluating best practices examples, where using 3D data handling, 3D GIS and 3D visualization comes handy. The best practices examples were divided into two main groups, workshops run by the authors of this contribution and projects, where the authors were involved.

This paper tent to show, that 3D GIS in general can be helpful not only for visualization of objects and features, but also for serving as a database for data retrieving or for making geodata more attractive for general public.

#### **5. ACKNOWLEDGEMENTS**

The work on Traffic Modeller and the authorship of this contribution was supported by Ministry of Education, Youth and Sports of the Czech Republic, project PUNTIS (LO1506) under the program NPU I.

## 6. BIOGRAPHY



Karel Jedlička: The theoretical background of Karel's research lies in modeling, analysis, and even simulation using multidimensional (geographic) data structures. In particular, Karel actively researches on 3D and 4D aspects of Geographical Information Systems. Karel focuses on influence on transport to the city life, by designing and developing interactive traffic models for Digital twins of Smart cities. Karel has been leveraging his skills in various EU projects since 2007. Karel usually acts as a leader of small research or technical team in the project.



Pavel Hájek is a researcher and a lecturer at the Department of Geomatics. He participated in several EU projects such as OpenTransportNet, GEPAM, Peregrinus Silva Bohemica or EUXDAT. His focus was mainly on data modelling, assembling and gathering. Research activities: Geographic Information Systems (GIS), multidimensional data modelling – especially 3D data handling, cartography and visualisation, 3D GIS/CAD/BIM.

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# AN ALTERNATIVE APPROACH FOR CREATING 3D CITY MODEL USING PROCEDURAL MODELING

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## **Abstract**

*Two-dimensional (2D) maps, which have been used extensively for many years, are now being replaced by increasingly widespread three-dimensional (3D) applications on these days. Recent developments have led to the need for rapid production of an entire city in three dimensions using spatial data produced by different methods or already available. Due to data production time, up-to-date data requirements and relatively high costs, it is not easy to produce the required 3D data at the whole city scale. The data obtained after many studies are rapidly becoming out of date. Some procedural modeling techniques have also been developed that enable the rapid transformation of 2D spatial data into 3D urban models. By using procedural modeling techniques, it is possible to realistically visualize the 2D geographic information system (GIS) data that contains the required attribute information. The biggest advantage of procedural modeling technique is; using attribute data which is stored in vector data to reproduce the model as needed. The aim of this study is to present the contributions provided by the use of procedural modelling technique in 3D city modelling. Based on the study, 3D building models, which are the most basic component of 3D city models, are produced by using a new database schema and procedural techniques developed for this purpose. In addition, examples of how building models can be produced at different levels of detail are presented, and the advantages and disadvantages of using procedural modeling techniques as an alternative to aerial surveying methods are discussed.*

**Keywords:** 3D City Model, Procedural Modeling, LOD, 3D Visualization, Digital Twin

## **INTRODUCTION**

Digital maps with 2 and 2.5 dimensions have been effectively used in the field of cartography since the computer aided design technology came in to use. The use of those digital mapping technologies certainly contributed to fully developed traditional theory and practice of cartography. However, emerging visualization and modelling technologies extend cartographic vision by providing new challenges together with the great opportunities of latest developments on 3D modelling and visualization. Many sectors, in particular public and local administrations, require using digital maps as a base in many new applications in the field of smart city planning. As a result, the need for effective use of spatial data is increasing day by day in many studies such as urban planning and city management (Kemec et al., 2007; Erving et al., 2009; Albrecht and Moser, 2010; Moser et al., 2010;; Silva et al., 2018).

As the processing capacities of computer technologies increase, demand for the fast production of up-to-date 3D models increase. This situation triggers the use of high-tech measurement devices such as satellite or aerial camera, which are primarily used for relatively fast measurement of the data in large extends, for producing the data to be used for 3D modelling. However, even high-tech devices are used for this purposes, it is not always possible to produce up-to-date three-dimensional data at the required temporal and spatial resolution. Particularly producing 3D spatial data of a large city as a whole, the complete process is still time consuming. The data obtained due to such production process are never up-to-date since they practicaly reflect a physical reality frozen at one certain time point (Fan et al., 2008). As an example, although the use of measurement techniques as light detection and ranging (LiDAR) has steadily increased, it still takes a certain time to process the data collected across the city in a comprehensive manner (Weissenberg, 2014; Yastikli et al., 2017). Despite the development of new software that automates some stages of production process, human intervention may still be needed for the regulation and control of the resulting products. These regulation and control studies are also processes taking a certain period of time (Ennafii et al., 2019).

Although many methods can be used in digital data production including the latest technologies, all of the data obtained is rapidly aging (Han et al., 2008). For this reason, with some studies carried out in recent years, procedural modeling technique, which enables the production of a three-dimensional city model from existing two-dimensional spatial data, has also emerged.

Detailed three-dimensional models can be produced with procedural methods from two-dimensional spatial data containing required attribute data (Merrell & Manocha, 2011; Weissenberg, 2014; Dobraja, 2015; Adão et al., 2016; Biljecki et al., 2016;). With the help of procedural modeling, three-dimensional model production can be performed dynamically using the attribute information in the vectorial data held in digital environment. In this way, instead of storing the whole model in a digital environment, only one polygon and a procedure for how the entire model can be produced from that polygon are stored. Thus, the data size decreases and performance is increased. In addition, as the three-dimensional model production is carried out with procedural algorithms, many drawing errors that may arise from the operator are prevented (Biljecki et al., 2016). With procedural modeling, the most ideal three-dimensional model can be produced when needed, using a minimum number of polygons.

Currently, researches on 3D city modeling are mostly performed by institutions and universities working in the fields of photogrammetry, remote sensing and cartography (Brenner et al., 2001; Flamanc and Jibrini, 2003; Tunc et al., 2004). Several studies including urban transformation, change detection, renewable energy source management, city skyline conservation, disaster management and noise mapping are currently carried out more accurately by the use of available 3D city models (Sengul, 2010; Aliaga, 2012; Prandi et al., 2013; Prandi et al., 2014; Biljecki et al., 2016; Padikli et al., 2017; Slade, 2018). Thus, many studies planned to be carried out in the city can be tested by computer simulations and possible results can be predicted. The effects of the large structures planned to be built on the environment can be calculated and different measures can be taken to prevent unwanted situations that may occur before they occur. In the smart city management approach, these and similar decision support systems can be realized using 3D city models.

## DATA AND METHODS

### 3D Data Standards

There are certain levels of detail (LOD) that are widely used in 3D city model production studies and have been accepted as standard by Open Geospatial Consortium (OGC) in the world. Building models can be defined and stored at different levels of detail using these LOD levels, which are also shown in Figure 1. In this way, it is possible to use the model at the level of detail that is more suitable for the purpose of that study in different studies.

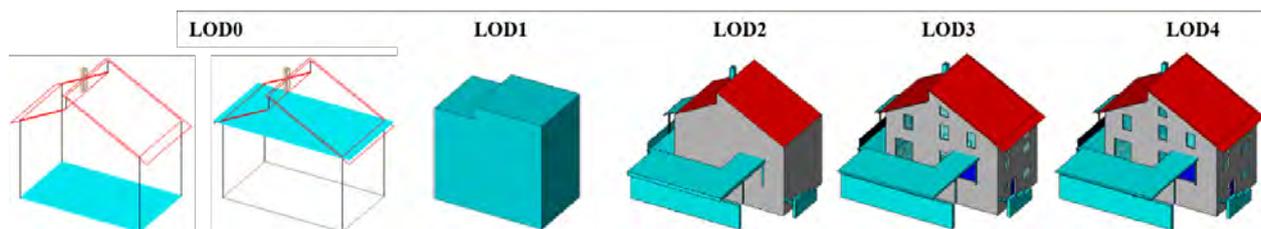


Figure 1. LOD levels defined in OGC City Geography Markup Language (CityGML) Encoding Standard (OGC 12-019) project document (source: Karlsruhe Institute of Technology (KIT), courtesy of Franz-Josef Kaiser)

All data obtained by remote sensing technologies such as satellite images, aerial photogrammetry and aerial LiDAR are mainly based on the principle of determining the roof edge line of the building. Three-dimensional building models are created by reflecting the three-dimensional roof model data obtained in this way to the surface of the land. While building the building model from the data obtained from the air due to the production logic, the distances between the roof and the facade are ignored as the roof edge lines are often taken as basis. This problem can be solved to a certain extent by using a higher number of high-overlap oblique images, lowering the GSD value and additional terrestrial measurements in the required areas. However, these methods cause both production costs and production time to increase significantly. For this reason, in LOD2 level building models which is produced from the data obtained from the airborne systems, there is generally no “Roof Overhanging Parts” produce.

However, there are two important parameters for LOD2 building model level in the OGC City Geography Markup Language (CityGML) Encoding Standard (OGC 12-019) project document (Gröger et al., 2012). The first is the value of "> 4 \* 4m / 2m" specified in the "Generalization" clause. It states that details smaller than this value can be generalized and not shown in the model. As a result, data larger than this value can be stored at the LOD2 detail level if they are available. The second is the description of “Yes, (if known)” in “Roof Overhanging Parts”. Similarly, if the

distance between Roof and Facade can be determined by the measurement method used, LOD2 can be stored in the level of detail. These are very important details that must be known to create a 3D building model that complies with OGC standards.

## Method

When using the procedural modeling technique, firstly it is necessary to identify procedures and a partially long coding process. Considering the classical three-dimensional modeling studies, this period may seem unnecessary and excessive at the beginning. However, after the procedures are determined and coding works are completed, it takes seconds to produce a comprehensive model. Afterwards, any number of buildings can be modeled, changes desired to be made on the design can be reflected on the models and updated in seconds. This makes procedural modeling a faster and more convenient solution for modeling studies in large areas.

In this study, first of all, the required attribute data is determined for the realization of the procedural production. At this stage, the *Building Database*, where the graphic objects are stored, is created using the attributes determined. Then, with the developed code, 3D building models with LOD0, LOD1 and LOD2 detail levels are produced from these data. The process of the 3D city model used in the study carried out and the stages followed are shown in Figure 2.

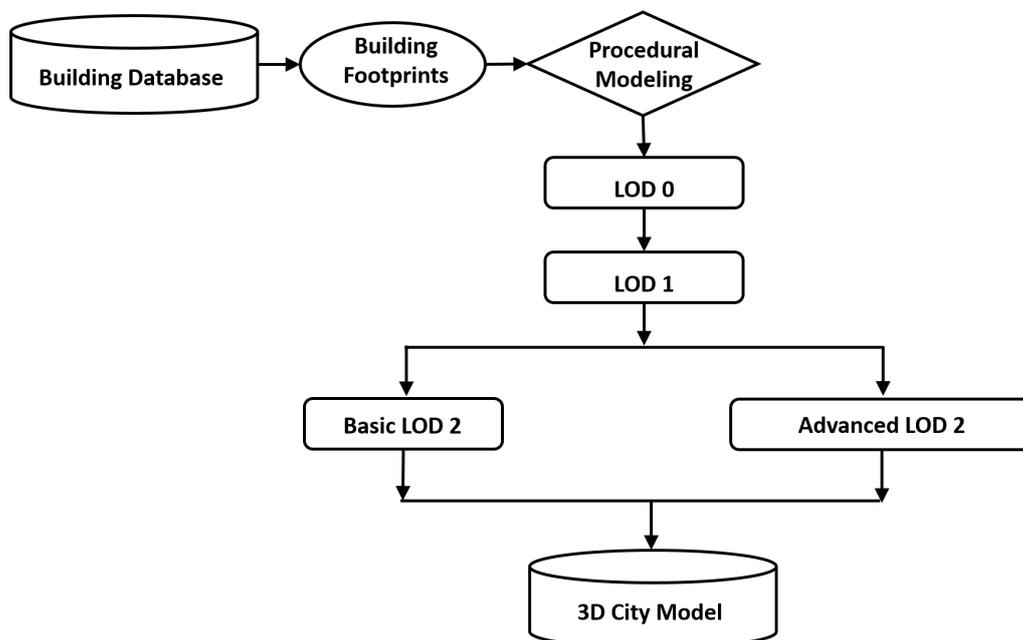


Figure 2. Work Flow Chart

## IMPLEMENTATION

As the implementation of this study *Building Database* schema was designed based on the requirements of procedural modelling technique. Afterwards, a 3D city model of Istanbul Historical Peninsula region was produced by using this database and procedural modeling method using coding developed within the scope of the study. Procedural modeling algorithm was developed using the *Computer Generated Architecture (CGA)* programming language provided by ESRI (Zupan et al., 2018).

### Building Database Schema Design

First of all, the required attribute data was determined for the realization of 3D architectural model production. At this stage, the design of the "*Building Database*" was also provided. Attribute fields to be considered in 3D modelling were also determined for ensuring the multiple production with different levels of details as "*Basic*" and "*Advanced*".

It is possible to produce LOD2 models with a level equivalent to 3D models obtained from techniques such as aerial photogrammetry and aerial LiDAR using Building Footprint data and attributes specified as "*Basic*" in the database. By using the attributes determined as "*Basic*", it was aimed to create only a simple mass model of the building. By using additional attribute data called "*Advanced*", the parts of roofs and facades can be produced in three dimensions in a

more detailed and closer way as possible as they actually are. Moreover, the models produced in this way were both produced in more detail and created in accordance with current LOD2 standards. *Basic* and *Advanced* attribute information was given in Table 1.

Table 1. Attribute data used in the production of procedural 3D city model.

Building Attribute Data	
Basic Attributes	Advanced Attributes
Building Height	Building Entrance Floor Height
Building Color	Roof Overhanging Parts
Roof Height	Front Facade Extrude
Roof Color	Back Facade Extrude
Roof Type	Right Facade Extrude
Roof Front Slope Angle	Left Facade Extrude
Roof Back Slope Angle	
Roof Right Slope Angle	
Roof Left Slope Angle	

### Creating Basic 3D Building Model

After the *Building Database* schema was created by determining the required attributes for procedural modeling, it was ensured that 3D building models with LOD0, LOD1 and LOD2 detail levels were produced using this database. LOD0 building data can be stored as either a building floor area or a roof border as standard. In the study carried out, LOD0 was used as the Building Footprint area as it is more commonly known. LOD1 data was produced procedurally using the building height value from the Building Footprint data. The basic roof models were produced which are widely used in Turkey, using "*Building Height, Building Color, Roof Height, Roof Color, Roof Type, Roof Front Slope Angle, Roof Back Slope Angle, Roof Right Slope Angle, Roof Left Slope Angle*" values. Thus, a data equivalent to LOD2 data obtained from airborne measurement techniques was produced procedurally.

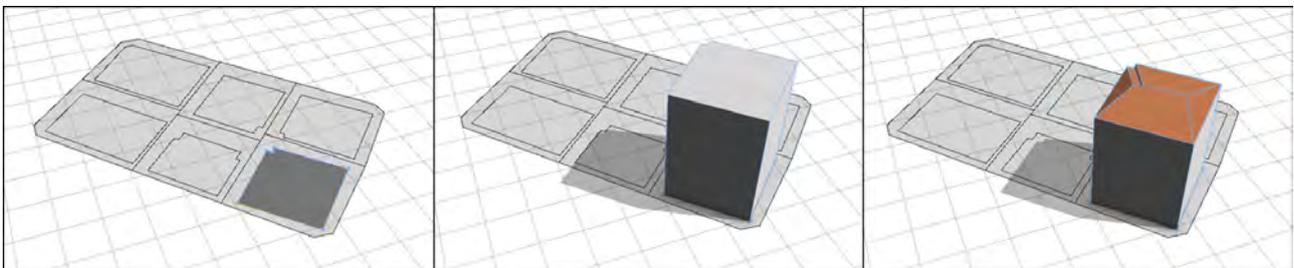


Figure 3. Basic LOD0, LOD1 and LOD2 building models produced similar to models obtained by remote sensing methods using procedural techniques

### Creating Advanced 3D Building Model

It is possible to produce more detailed 3D models in accordance with the generally known LOD2 standards by using the attributes stored in the *Building Database* and designated as "*Advanced*". In Turkey, while the buildings are designed, according to the architectural plans, some facades can extend to certain direction after the first floor. This situation, which is carried out in accordance with the "*Zoning Law*" and other regulations, is made for the purpose of obtaining more usage areas on the floors after the first floor and is applied widely in most buildings. Since it is not possible to measure and model these sections in the data obtained from the air with remote sensing and photogrammetric methods, such details on the building facade, such as roof length details, are also ignored when building the LOD2 building model.

However, if the details of these sections in the buildings are stored as attributes in the graphic data, it is possible to be produced by the procedural modeling method. The basic roof models were produced which are widely used in Turkey, using "*Building Entrance Floor Height, Roof Overhanging Parts, Front Facade Extrude, Back Facade Extrude, Right*

*FacadeExtrude*, *Left Facade Extrude*" values. In this way, a much more detailed building model than LOD2 data was obtained from airborne measurement techniques can be produced purely procedurally.

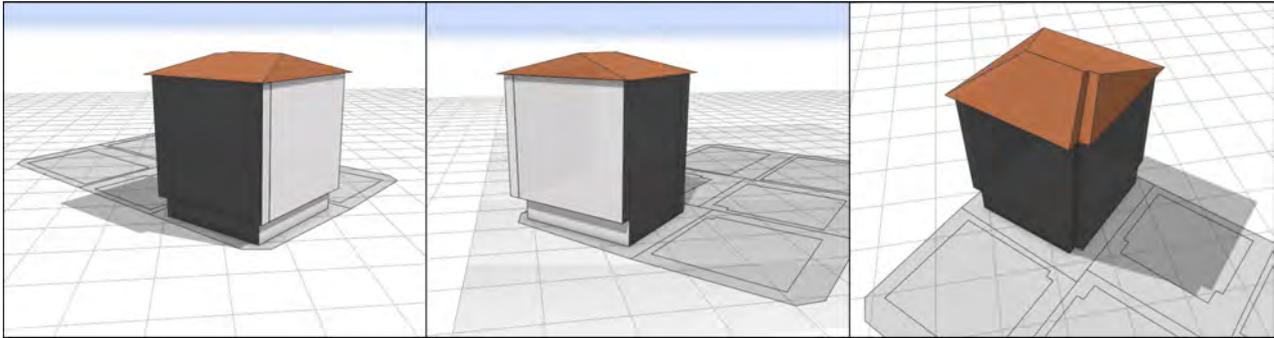


Figure 4. Advanced LOD2 building model produced using procedural techniques

## Test Study

At this stage, 3D city model production was tested using the procedural modeling method using the *Building Database* schema designed within the scope of the study. For this purpose, OpenStreetMap (OSM) data was used as 2D GIS data. The OpenStreetMap project, which started to be developed as a map that everyone can freely access and use within the scope of a project launched in England in 2004, has become a spatial open data platform widely used by many people today (Haklay and Weber, 2008; Ünen, Yılmaz and Güngör, 2013). After building footprints data was obtained from OpenStreetMap in this way, all existing attribute information in it was deleted. After that, the lean building footprints data obtained was transferred to the *Building Database* schema designed within the scope of the study. Naturally, that vector data do not contain any attribute information yet. A representative city data was obtained by randomly filling the empty attribute values with the possible values to be used in the test study.

The test study was carried out in two stages. In the first stage, the LOD2 city model, which is widely used, was produced by using the attribute data defined as *Basic*. In the second stage, the feature data determined as *Advanced*, which were determined within the scope of the study, were used. With these data and procedural modeling method, a more detailed 3D city model has been produced in accordance with LOD2 standards. The results of two different productions were presented in Figure 5.



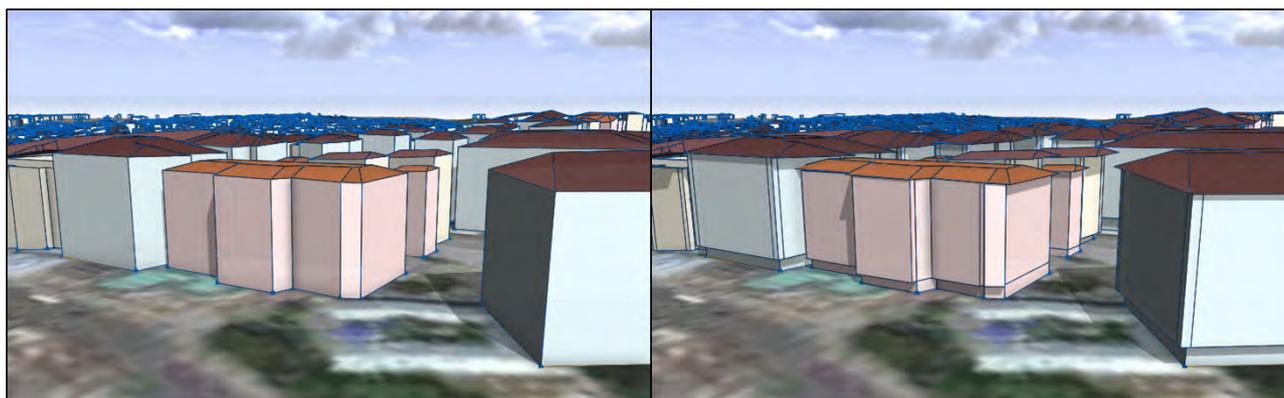
Figure 5. Procedural modeling (left) at basic LOD2 level, advanced LOD2 procedural modeling (right) including roof and facade details.

Procedural model production was performed on a machine with 64-bit Windows 10 operating system, Intel Core i7-8700K CPU, 3.70Ghz, 64GB RAM, 2x 8GB GDDR5x Nvidia GeForce GTX 1080 graphics card configuration. 3D building models with LOD0, LOD1 and LOD2 detail levels were produced by using the Building Database containing the required attributes for procedural modeling and footprint data of 45457 buildings. Production times are presented in Table.2.

*Table 2. Time spent to create 3D building models with procedural modeling technique.*

Type	Quantity	LOD0 (sec)	LOD1 (sec)	LOD2 (sec)
Basic Solid Model	45457	0''	8''	16''
Advanced Solid Model	45457	-	-	26''

An advantage of the 3D model production procedure is that the building color values can be assigned automatically to the created models. Since building color and roof color values can be stored in the database schema designed within the scope of the study, the building models produced can be visualized much closer to the reality. All buildings created in this study were assigned random color values within the scope of the test study. Building models with roof and facade coloring were shown in Figure 5 and Figure 6.



*Figure 6. Procedural modeling (left) at basic LOD2 level, advanced LOD2 procedural modeling (right) including roof and facade details.*

## CONCLUSION AND DISCUSSION

Within the scope of this study, 3D city model of Istanbul Historical Peninsula region was produced in two different ways by using 2D spatial data and procedural modeling technique. Thus, it has been shown that it is possible to quickly and easily produce the 3D models of cities at the desired level of detail by storing the building footprint data and some attribute information of the buildings.

In the first stage, the basic level LOD2 models were obtained by using procedural modeling method. Nowadays, the basic level LOD2 models are generally produced costly and time consuming remote sensing methods. However, within the scope of the study, equivalent models could be produced procedurally using the building database schema. In the second stage, a more detailed LOD2 level modeling, which is much more difficult to obtain by remote sensing methods, was realized. Fully procedural techniques were used in the production of both models.

With this work; a very fast and low cost production method, which can be used as an alternative to existing 3D modelling techniques based on overcosting data acquisition and processing operations, was presented. In addition, this study demonstrated the efficiency of procedural modelling on producing LOD2 3D models with the same and even higher level produced by traditional methods. Today, 3D visualization and analysis of data has emerged as a new field of study. Many complex situations can be modeled using advanced spatial analysis and dynamic simulations (Aalbersberg et al., 2014). Many disciplines have been working in this field in recent years and are closely interested in 3D data. With the widespread use of virtual reality (VR) and augmented reality (AR) technologies, the visualization and experience of spatial data in geographic information systems in three dimensions will be a frequently encountered and needed field of study in the near future.

Using the prepared digital twin, it can be carry out many planning, design, analysis and simulation studies at a city scale. In this study, the test data adapted from free and open sources were used through the new designed database schema. The study presented the usability of data from open sources in 3D modelling with in the constraints of required accuracy. When the described method is applied with official and more sensitive spatial data held by public institutions and local governments, higher precision results will be obtained. The priority is to create smart city awareness in local and central governments. Than, it will be possible to obtain a much higher efficiency with much lower costs by re-evaluating the spatial data available to public institutions and by developing data storage systems.

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# 3D HISTORICAL RECONSTRUCTION WITH INTERACTIVE WEB-BASED APPLICATION

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## **Abstract**

*The cartography does not stop its progress – it becomes more attractive, more innovative and more applicable in different fields of life. Using 3D and interactive maps is almost daily routine. There are big amounts of all kind of geospatial data and almost every place in the world is mapped. But what about if a map of a place that does not exist anymore should be created?*

*The paper presents combination of 2D and 3D historical reconstruction of a residential district in Sofia city, Bulgaria. The maps present the area during the period 1927-1944 where nowadays there is nothing preserved from that time. The cartographic products are made using data from old cadastral maps, an old aerial photo, old photos, manual sketches, and live memories of people who still remember the place.*

*The final cartographic products are integrated in interactive application which is developed based on web languages HTML, CSS and JavaScript and it runs in kiosk mode using Google Chrome background.*

**Keywords:** 3D modeling, 3D map, GIS, Landscape simulation, Web-based application, Interactive maps

## **INTRODUCTION**

Three-dimensional (3D) modeling and visualization allow recreating the environment through dynamic models or generation of photorealistic images using a wide range of geodata: geographical, geological, architectural, botanical, etc., which are available or can be acquired through direct or remote measurements.

Over the last decade, researchers discuss and offer cartographic standards, principles of design and visualization techniques to further increase efficiency and expressiveness of 3D modeling and production of 3D maps. The most basic term "3D map" as defined by Haeberling (2002, 2005) as a computer-generated perspective view (presentation) of a three-dimensional integrated model to map content, i.e. according to a cartographic symbol system and requirements for generalization. A significant number of studies have been performed in connection with the principles of cartographic design, acquisition and realistic visualization of 3D geodata, interactive communication and user-oriented maps (Bandrova et al., 2012, Dinkov, 2016, 2018, Pegg, 2016). Currently, 3D modeling and mapping are key components for the growing number of different applications and have a diverse range of users in areas such as urban planning, landscape monitoring, service and transport management, tourist maps and 3D cartographic services. Various studies have demonstrated the need for and benefits of 3D modeling and restorations of buildings and sites of historical importance. A similar project was presented by Hájek et al. (2014) for the Terežín Memorial in the period of the Second World War, as well as "Rebuilding Kinsale: 1601" - Historical re-creation by Cherba (2001).

The current study aims to present a historical reconstruction of Izgrev district, Sofia for the period 1927-1944 together with an interactive web-based application based on cartographic products, historical documents and multimedia files. The final goal of the application is to illustrate the exact vision and historical information about Izgrev district, Sofia for the period of settlement and activity of the Master Peter Dunov and his followers in the neighborhood (then Boucher area on the outskirts of Sofia). The following cartographic products have been developed for the implementation in the application:

- A map of the region for the period 1927-1944

- Thematic map of the land cover for the period 1927-1944
- Three-dimensional panoramic map of Izgrev district, based on a real 3D model of the relief, land cover and infrastructure, using historical data and materials for the studied period.

Historical documents and photos from the archives of the White Brotherhood, multimedia archival materials, as well as consultations with contemporaries from the considered historical period were used.

## DATA AND METHODOLOGY

During the development of a three-dimensional project for a certain territory, initial selection and processing of source data is done and also compilation of geoinformation layers, generation of terrain and the process is completed with an interactive application based on photorealistic visualization of the entire model or selected scenes.

### Initial selection and processing of input data

The input data for the project are collected from archival sources in the State Geodetic, Cartographic and Cadastral Fund (GeocartFund) - orthophotos from 1940 and 1950 (Fig. 1/a) plan for street and yard regulation from 1947 (Fig. 1/b), Topographic map in scale 1: 5000 from 1954 (Fig. 1/c) and last but not least the approximate plan of the district for the considered period, compiled by Eng. Vasil Stanev<sup>1</sup> (Fig. 1/d).

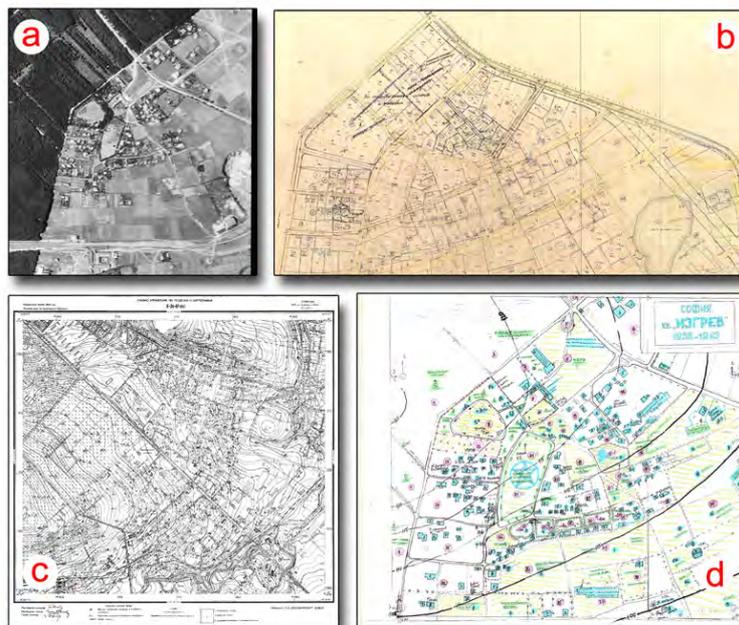


Figure 1. Raster geodata sources

All raster data sources are combined and transformed into a single coordinate system WGS84 (UTM) Zone 34N. The development of digital database is accomplished with specialized software for GIS - ESRI ArcGIS after vectorization of raster data (maps, plans, orthophoto images). A GIS project with information layers containing all vector and raster data for Izgrev district, Sofia (1927-1944) has been developed.

### Organization of data in geoinformation layers:

- Relief data
- Land cover data
- Road infrastructure data
- Hydrography data

<sup>1</sup> Eng. Vasil Stanev - a longtime teacher of cartography in Sofia High School of Civil Engineering, Architecture and Geodesy "Hristo Botev" and one of the last contemporaries who lived in the Izgrev district from the historical period

- Data on buildings and facilities

In GIS, all data is in digital form and has a geographical component, i.e. the final data (vector and raster layers) must be georeferenced and have attribute information about their qualitative characteristics.

For the development of a three-dimensional model of Izgrev district, Sofia (1927-1944) the vector data were initially processed in ArcGIS-shape format and the necessary information was filled in the attribute tables.

### ***Creating the 3D Digital Terrain Model (DTM)***

The main component in the 3D model is the digital terrain model (DTM). DTM is made from vector terrain data (contour lines, elevation points, structural lines). DTM could be TIN (Triangulated Irregular Network), where the terrain is presented as a set of points with known coordinates and heights, based on which a network of non-overlapping triangles is formed, or DEM (Digital Elevation Model where the terrain is represented by a regular grid of identical squares or rectangles. An irregular digital terrain model (TIN) for the area of the current project was generated in the ArcGIS software.

### ***Preparation of land cover data for the needs of three-dimensional modeling***

Raster georeferenced images are used for texturing or making thematic images of the land cover, which are applied in the process of three-dimensional modeling. For the preparation of the three-dimensional map of Izgrev district, Sofia, a thematic georeferenced raster image of the area has been created, which combines several information layers of GIS data with a qualitative component - the type of land cover (Figure 2).

Table 1 presents classified the main elements of land cover with their corresponding RGB color values, which will be used in the software for three-dimensional modeling through thematic georeferenced image.



Figure 2. Georeferenced raster image with classification of the land cover of Izgrev district, Sofia (1927-1944)

Table 1. Color classification of land cover

Land cover	Color	R	G	B
VEGETABLE GARDEN		0	132	168
ORCHARD		197	135	243
YARDS		246	197	103
VINEYARDS		255	115	223
FLOWERS (GARDENS)		226	58	63
COMMON PASTURE		85	255	0
CONIFEROUS FORESTS		38	115	0
DECIDUOUS FORESTS		38	115	0

EXCAVATION FOR CLAY		170	110	0
FIELDS		244	199	148
SWAMP, WATER		0	112	255
ROAD NETWORK		204	204	204

## Methodology

Specialized software products and applications are used for creating the interactive application and 3D models.

The software product VNS (Visual Nature Studio) (3D Nature, LLC, 2008) was used for creating the three-dimensional map of the Izgrev district (1927-1944). VNS is a 3D GIS for creating maps based on spatial data by providing realistic visual simulation.

SketchUp software was used for creating the 3D geometry of the buildings from the Izgrev district (1927-1944). SketchUp is easy, intuitive and fast to use. The standard tasks of creating geometry take much less time than with traditional CAD software. Its rich features for import and export in various formats and intuitive modeling tools contribute to the choice of SketchUp for three-dimensional modeling of buildings in the Izgrev district, Sofia (1927-1944).

For developing the interactive application, web programming languages are used - HTML, CSS and JavaScript, as well as some jQuery plugins.

## THREE-DIMENSIONAL MODELING IN VNS (VISUAL NATURE STUDIO)

VNS allows users to create realistic landscapes and simulate "flight" on the generated surface using the integrated animation system. Software can represent real-world objects and environment caused by human activity. Real 3D objects from the environment, such as trees, plants, buildings, etc., can be situated on the surface of the terrain. VNS also contains specialized modules that support simulation of various objects in the world around us: sky, water, atmosphere, clouds, sun, moon, stars, etc.

Figure 3. shows the main structural elements for 3D modeling and visualization of the land cover in VNS as follows:

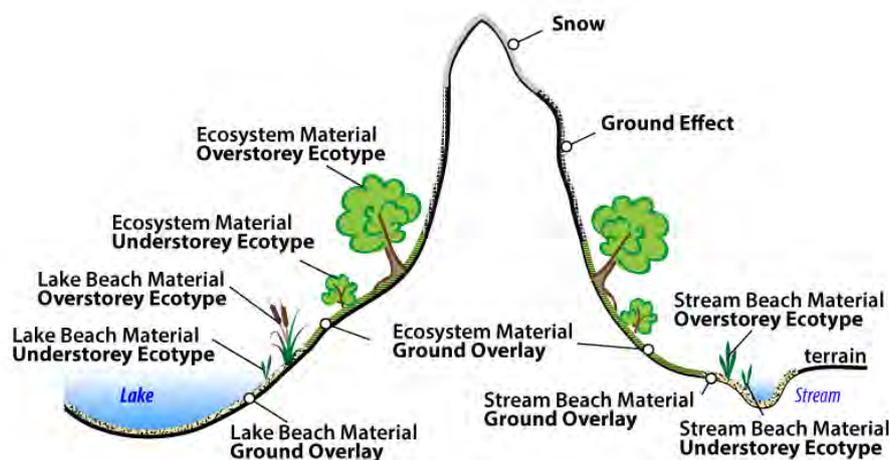


Figure 3. Main structural elements for 3D modeling and visualization in VNS (Visual Nature Studio) (modified, Source: 3D Nature, 2008)

The land cover is managed by vector polygons or thematic color maps. To make the terrain look natural, tools are used to simulate the real-world effect. Then by applying tools such as Ground Effects, Ecosystems and Environments we get a realistic reproduction of the environment.

For the three-dimensional modeling of Izgrev district, Sofia (1927-1944) the terrain model made in the ArcGIS software was used, which was imported into VNS using Arc Grid format - cell size (X, Y) 1m / 1m.

The developed local database, consisting of vector and thematic raster layers, is used to adjust the characteristics and to model different categories of 3D objects for the Izgrev district (1927-1944).

### THREE-DIMENSIONAL MODELING OF BUILDINGS AND FACILITIES

In this study the buildings have a special weight due to the need to achieve authenticity in their vision for the specific historical period. Sources of data on the appearance and construction of all buildings are archival photographs (Figure 4/a), as well as manual sketches of Eng. Vasil Stanev (Figure 4/b).

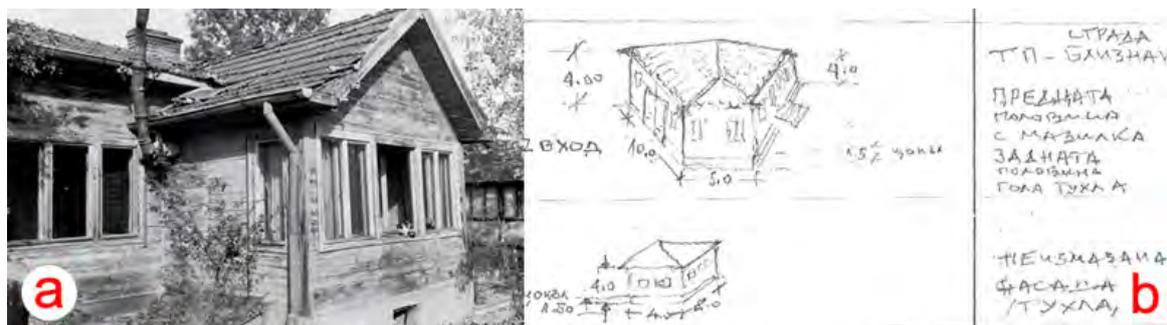


Figure 4. Archival data for buildings:  
a) photo of a house in Izgrev district (1927-1944); б) manual sketches of Eng. Vasil Stanev

Apart from the authentic appearance of the houses, the other main task is the exact geographical location of the buildings in the district. In order to construct correctly the three-dimensional model of the buildings, the compiled digital database was used - an information layer "buildings" obtained from the digitization of the plan for street and yard regulation from 1947 (Fig. 5). Especially valuable to the plan from 1947 is that the contour of most buildings includes the year of their construction, which contributed to the correct identification of sites and compliance with the historical period of development.



Figure 5. Part of Plan for the street and yard regulation of Stalin locality (Izgrev district), Sofia Scale 1:1000, 1947.

In the process of modeling in SketchUp the following main steps are performed (Fig. 6):

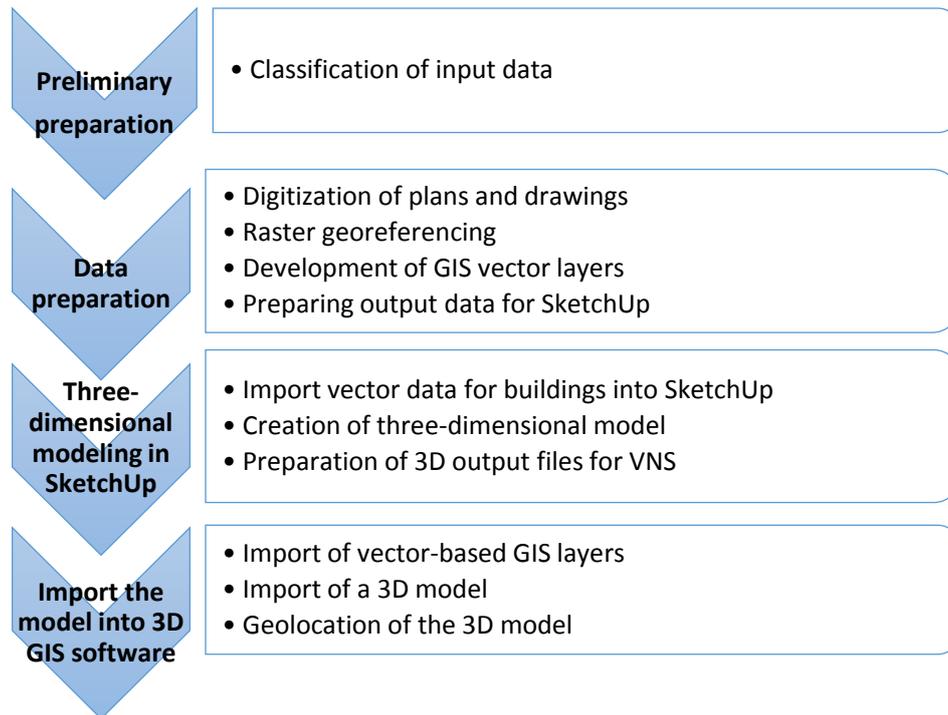


Figure 6. Workflow diagram for three-dimensional modeling of buildings

The vector footprints of the buildings in Izgrev district, the available photos and additional sketches for the constructions were used for three-dimensional modeling in the SketchUp software.

### ***Importing vector data for buildings from GIS layers into SketchUp***

To import vector data (ESRI shape format) in the SketchUp software, various applications have been developed as plugins for both SketchUp and ArcGIS. An example of such application is *spirix\_shapefile\_importer* for import into SketchUp.

In this project, the ArcGIS extension - Google SketchUp 6 GIS Plugin was used to export data from a GIS environment to a SketchUp file.

### ***Development of three-dimensional models of buildings and facilities***

After importing the necessary vector data in the SketchUp software, three-dimensional models of the objects are made. The specifications from dimensional sketches, the photos of the buildings and the vector data for the correct construction of the geometric model are used. The facades of the buildings are textured with relevant materials and colors. Figure 7 / a) shows the initial stage of the models with input data from GIS layers, and in Figure 7 / b) - the final result of the modeling.



Figure 7. Three-dimensional modeling in the environment of SketchUp

### ***Integration of buildings and facilities in the 3D model of Izgrev district, Sofia (1927-1944)***

Created 3D models in SketchUp are saved in \*.obj format, grouped by neighborhoods.

In the 3D GIS - VNS models are imported to their exact location, using GIS-vector data with the footprints of buildings for georeferencing.

## **PREPARATION OF RASTER MAPS FOR INTEGRATION INTO THE INTERACTIVE APPLICATION**

### **2D Map of Izgrev district, Sofia (1927-1944)**

Based on the processed information layers in the GIS environment and their attribute information about the buildings and the occupants for the considered historical period, a 2D map in scale 1:1000 of Izgrev district, Sofia (1927-1944) was created. There are specific zones in the territory, through which the individual buildings are indexed (for example for zone №20 - the buildings are indexed with 20\*1; 20\*2, etc.). The 2D map created in this way represents a digital basis for a 2D map module in the interactive application.

### **3D map for historical reconstruction of Izgrev district, Sofia (1927-1944)**

The three-dimensional map is a rendering of the real three-dimensional model, which is made after combining all the components in one project: terrain, land cover, buildings and facilities. Rendering is the final process for obtaining the photorealistic image.

The final three-dimensional visualization of Izgrev district, Sofia (1927-1944) has a resolution of 3800 x 2636 px and is saved in JPG file format, which is used for the interactive application.

## **INTERACTIVE WEB-BASED APPLICATION**

The purpose of the application is to collect all the historical information about this area including produced maps, text, photos, audio and video files and to present it easily to users, similar to a website. The difference is that the application should also run local-hosted without need for Internet connection. The main goal is to make the raster maps interactive for users.

The application is developed using web languages HTML, CSS and JavaScript which gives a lot of advantages. Firstly, programming with these languages makes the developing process independently of using a special software, it is totally free of cost and gives unlimited functionality – everything that is need it could be coded. Second very important advantage is that these languages could be run on any kind of operating system and they are used especially in web programming so the applications can be hosted on server and visualized on any web browser connected to the Internet. The good thing is that the files can be hosted locally and visualized in a web browser for a background engine, so the Internet connection is not mandatory.

### **Application Structure and Interface**

In general, the application structure contains three major parts: introduction, home screen and main pages.

The content is divided to six main pages: Historical facts; 2D interactive map; 3D interactive map; Video library; Music library; Photo gallery.

The major interface contains a header with a navigation menu to the main pages, content area and a footer area. The header and footer are visualized constantly, and the content area visualized the current page content.

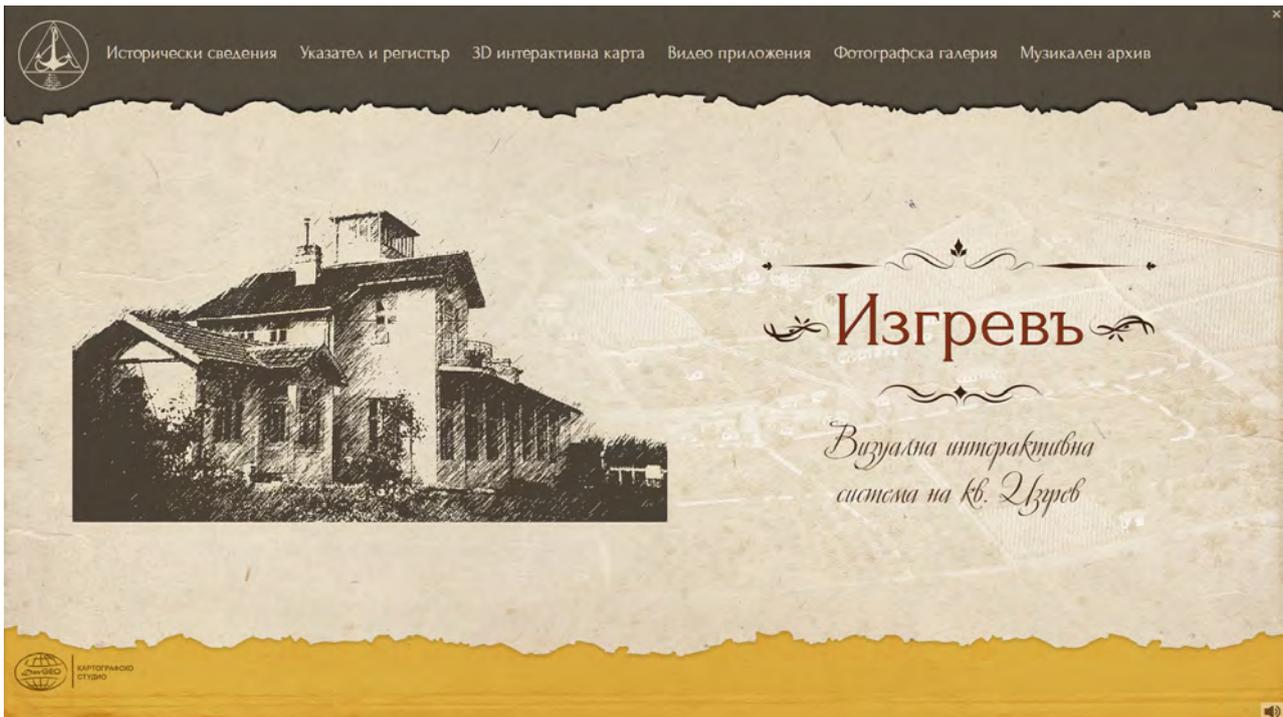


Figure 8. Main application interface

## Developing

Unlike most websites, where the different pages are separate HTML files and users switch them with the navigation menu, in the current project all the content is created in just one HTML file which could be interpreted as a executable file of the app. The using of one file achieves smooth fade-in-out transition between different “pages”.

The HTML document is developed regarding official web standards of the language and uses semantically definition of all HTML elements: header, footer, headings, divides, paragraphs and so on.

The styling of the app is controlled by the CSS (Cascading Style Sheets) file. Just like in a regular website, the CSS file defines all the positions, colors, fonts, background images and all the other styling.

The interactivity is achieved through JavaScript and jQuery library.

## Interactive maps

In the recent years the interactive maps became more popular on the Internet. Most of them use a web server for display and querying of raster, vector, and database formats. The current project describes a simple technology for creating interactive maps based on a raster image of produced and completed maps. The interactive application integrates a 2D map and a map based on 3D model of the Izgrev district which can also be used for printed maps. They are completed raster map products. Since the application will be used without a need of Internet connection, there is no need of a web server. The main purpose of the application is to turn the static raster images into interactive maps. In the current project the interactivity is achieved through integrating a several jQuery plugins and simple JS code.

The 2D map presents a register of the buildings, their ID's, purpose of the building and information about people who lived there. There are tooltip information balloons, pictures, additional pop-up information windows and a search filed for searching objects into the register (Fig. 9).



Figure 9. 2D interactive map

The 3D map gives additional options available for the significant buildings. There is a menu available for the building giving options for 3D panorama of the exterior and interior of the building and links to multimedia content available for the current place such as photo galleries, video or audio.



Figure 10. 3D interactive map. An additional menu for object is open

As usual, both maps also contain a legend, scale bar and an overview map.

## Main application functions

### *Pan function*

Almost each web map has pan function. It is useful to show large image in smaller container.

The dimensions of final raster images are 3550 x 3942 px for the 2D map and 3800 x 2636 px for the 3D map. These dimensions allow enough visibility of all the details, but a Full HD screen is just 1920 x 1080 px. This requires the need of using an interactive pan function.

The integration of “jQuery image panning” plugin allows smooth movement of the raster image depending the mouse cursor position and no drag-and-drop clicks are required. The raster image moves in proportion to the cursor coordinates into the visualization container until the edges of the image equal to edges of the container. The image outside the container is hidden and the user sees only the content inside. Using this interaction, the user can easily and quickly observe all the map content without clicking and needing of zoom in and zoom out. A small overview map in the right bottom corner shows the current visible position of the map.

### *Interpreting parts of the raster as vector objects*

Since the map is just a raster image, the objects such as buildings and others polygon objects are not defined in any way (no vector data available, no databases). The objects should be recognized through HTML so the user can interact with them – highlight on mouseover, click on them for information or find objects with searching. This could be possible with HTML elements `<map>` and `<area>`. The `<map>` tag defines an image-map. An image-map is an image with clickable areas. A clickable area is defined using an `<area>` element with coordinates for each vertex in pairs, one for the x-axis and one for the y-axis, measured in pixels. For example, the coordinates 270, 350 is located 270 pixels from the left margin and 350 pixels from the top of the image.

Creating all the `<area>` elements with their coordinates is done with exporting the vector layer with all building contours from Adobe Illustrator.



```
<map name="wbmap">  
    <area shape="poly" id="4-1" class="tooltip" coords="2587,643, 2664,679, 2645,718,  
2568,682, 2587,643, 2587,643" title="4*1 Сем. Христови, деца Стефанка и Здравко - ученици"  
name="4*1 Сем. Христови">
```

Figure 11. Definition of an `<area>` element and coordinates for a rectangle polygon

### *Highlight on mouse hover*

It is important for interactive maps to get reaction between mouse and objects. Even with `<area>` elements, the objects are not visible or clickable. There is a need of JavaScript to bring them into visible vector polygons. For that purpose, a useful jQuery plugin named “Maphilight” is used. The plugin applies to images with a 'usemap' attribute, and outlines the areas defined in their `<map>` element on mouseover. There are several options to set border thickness, border color, fill color, transparency, shadow and others. The plugin is also used for highlighting the objects which are selected by searching.

### *Searching objects*

Searching the objects is realized with simple jQuery code which finds equality between the value of chosen option from a dropdown list and the “name” attribute of the `<area>` elements. If those values are equal, then a several events are happened. Firstly, the coordinates of the map pan function are set to values which make the searched object visible on the screen. Then the highlight function of the `<area>` element is set to active and the object is highlighted in red. At the same time, the tooltip for that object is also activated so the information for it is visible.

### *Tooltips*

It is common the usage of pop-up tooltips in almost every interactive map on the Internet. Thanks to them the user receives quickly more information about the objects on mouseover. In the current project, the tooltips are used to display short information and even historical pictures of important objects. Information include building ID, names of

the people living there, purpose of the building or some historical fact for it. Some buildings are more significant and there is more information for them, therefore an option for click is available and an addition pop-up information window appears.

The tooltip functionality is realized with the help of jQuery plugin “Tooltipster”. This very powerful plugin includes a lot of functions and settings. The plugin activates tooltips on mouseover for elements with class=“tooltip” which in the case of the map are all <area> elements. The text which is displayed in the tooltip comes from the “title” attribute of <area> element so no additional <div> elements are needed for the text. All <area> elements are organized beforehand in a simple Excel table like a database where the columns are all the attribute of the <area> element such as id, class, coords, title, name and others. Thereby it is easy to work with more than 200 objects and to organize the information for them and after that to export the text needed for the HTML document.

### ***3D panoramas***

Since the 3D map is not actually 3D but it is a raster image based on rendering of a 3D model, there are options available for certain buildings to explore them with 360° panoramas of the exterior or interior. The illusion is that the 360° panoramas are also not a real 3D object. They are a bunch of frames rendered in advance. The result is fast visualization without need of real-time rendering. For that purpose, “3dEye.js” plugin is used. It creates 360-degree 3D panoramic view and works in all major browsers and mobile devices.

3D panoramas of the exterior are created in Visual Nature Studio (VNS) where the camera path is set around certain building and the animation of camera moving is exported to separate frames.

The exterior of the main building is created in SketchUp where the animation of camera is set inside the building. Again, a bunch of images is exported.

“3dEye.js” needs a path to the folder with all the frames and creates the 360° panoramas based on them. 3D view is controlled by mouse dragging – forward and backward for exploring the panorama in both directions.

### ***Running the app in kiosk mode***

As it was mentioned before, the HTML file runs as a standalone local-hosted application. The final app contains one HTML file as an executive file and all the addition folders with JS libraries, Styles, Fonts, Images, Audio and Video files. All these files need a web browser to read their content and to render it. For that purpose, a Google Chrome browser is used as a background engine which is run in kiosk mode. Kiosk mode disables some regular browser functions such as menus, options, mouse events (right click, text select etc.) and visualize only the HTML content in full screen. The user does not see it as a usual web browser, only the app content is available. It is suitable for using this function for information kiosks used in public places.

A shortcut to the Google Chrome EXE file must be added on the computer desktop so the app can be started in the same way as all other application icons on the desktop. This shortcut is important because the kiosk option is set in its target field. Some additional options are also added to the shortcut target such as path to the HTML file, enabling full screen mode and enabling sounds auto start.

## **DISCUSSION AND CONCLUSION**

The current paper presents cartographic and web-based applications for organizing geospatial and multimedia data, 3D modeling and rendering in the case of representing historical places and events. Using a combination of different software products and technics for data processing, a digital geographical and multimedia archive is created – historical reconstruction of Izgrev district, Sofia, during the period 1927-1944.

Various technologies for structuring geospatial data, 3D modeling and rendering are used for achieving realistic and accurate re-construction of the study area.

The results and practical experience are based on application of leading practices and trends in modern geographic information systems, three-dimensional modeling and visualization and WEB-technologies for developing the final product for presenting all cartographic, multimedia and archival materials.

The presented technology for web-based application is affordable, user-friendly and easily applicable for different purposes. The application can be integrated online on websites and mobile devices or can be run local hosted without need for an internet connection.

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## BIOGRAPHY

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# AUGMENTED REALITY NAVIGATION MAP OF MOUNTAIN AREA

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## **Abstract**

*During the recent years, mapping of mountain areas has become one of the most discussed topics in cartography. People are increasingly oriented towards a healthy lifestyle and a direct connection to nature. The desire to conquer peaks in mountain areas, mountaineering and tourism is increasing. A large number of tourists use mountain markings, indicated by specialized teams, to help them navigate. The tourist marking provides accessibility to the existing natural landmarks and nature protected areas. In the high parts of the mountains and where the summer and winter paths do not coincide, summer and winter markings should be made. The Augmented Reality (AR) is the inclusion of virtual elements in the vision of the real physical environment for real-time mixed reality creation. The presented content may include 2D or 3D images and models, video and sounds, among others. The virtual objects can be used to display additional information about the real world that are not directly perceived. This paper describes the technology and the steps which a cartographer has to go through for creating AR map of mountain area. The additional information is in form of a 3D model of the area of Vihren peak, navigation dots on the landscape showing the optimal route from the hut to the peak and identification signs of Vihren hut and of Vihren peak (2914 m) which are one of the most popular tourist destinations in Pirin Mountain. The aim of the project is to provide mountaineers with additional information about the navigation to key points and tourist routes using this kind of new technology.*

**Keywords:** 3d model, Augmented reality, 3d map, mountain areas, mountain navigation

## **INTRODUCTION**

Mountains are one of the most important natural resource of every country. Their ecological and tourist meaning stimulates the development of the new management plans, containing steps for preservation of the natural resources and maximum usage of their potential. A part of the management of these territories is the process of collecting and managing cartographic data and mountain mapping for different purposes - scientific or tourist.

Very often the mountain territories are not friendly for unprepared tourist. An acquaintance with the specific characteristics of a tourist route like difficulty, obstacles, landmarks or help centers, is important part of the preparation for everyone who is going to spend time in the mountain. Orientation involves complex of abilities like estimating slope and passability, calculating time of travel (Savova, Bandrova, 2014).

Mapping of mountain areas is attended by a set of studies by specialists (cartographers, scientists), which can be divided into the following stages:

- Description of the location/area;
- Source data and materials;
- Mapping methods;
- Results and conclusions.

Mountain maps in traditional paper form are very usable and will still be used for several years in the future. But, technology development like multimedia and interactivity give a chance to find new cartographic representation of mountain regions which would become a very usable products in the future (Petrovic, 2001).

Visualization of planned areas has been developed by classical, static, modern, flexible, presenting methods, which are increasingly more than 3D and 4D visualization (Buckley et al, 2004). In the near future people will use more interactive and dynamic visualization of mountain processes and environments. Topics such as interactivity, virtual reality, augmented reality, GIS and database availability, applying logic in cartographic communication and geographic visualization, dominate current research approaches.

The following chapters describe the study area, one of the magnificent peaks in the Pirin Mountains, the created 3D map with specialized software, with data provided by the Directorate of "Pirin National Park" and augmented reality as a method and additional tool for mapping mountain areas and navigation.

## OBJECT DESCRIPTION

Pirin National Park (Figure 1) is located in the Pirin Mountain, Southwestern Bulgaria. It's a territory, lying between the "Predel" and "Todorova polyana" territories. It covers 40356 ha and it includes two reserves - "Bayuvi dupki - Dzhindzhiritsa" and "Ulen". The altitude ranges from 1000 m up to 2900 m. More than 50 granite and marble peaks rise with altitude over 2500 m and among them is the highest - Vihren - 2914 m above sea level. Pirin National Park is known for its 35 circuses in which lie about 170 glacial lakes. It was included in the Convention for the Protection of World Cultural and Natural Heritage of UNESCO in 1983.



Figure 1. Pirin National Park (<https://naturalworldheritagesites.org/sites/pirin-national-park>)

Vihren peak (Figure 2) is the highest in the Pirin Mountains. With its 2914 m, it is the second highest peak in Bulgaria and the Balkans' third, after Musala and Mytikas. It is located in the northern part of Pirin on the main ridge between Kutelo peak (northwest) and Hvoynati peak (southeast). The saddles Premkata (2610 m) to the north and Kabata (2535 m) to the south connect it with these two peaks. Until 1942, the peak was called Eltepe (peak of storms). Nowadays, this name bears a small shelter at the foot of Vihren. The Eltepe shelter is located next to a permanent snowfield, along the study of which the shelter itself was built. Viewed from Bansko city, Vihren looks like a truncated pyramid, and from the south - a four-walled pyramid. It is characteristic of this peak that it looks very different from different directions. The rocks that make up Vihren are marbles that do not retain water, which is why there are no rivers or lakes in the entire area of the peak. The nearest lakes are the Vlachs in the southwest. The vegetation on the slopes of Vihren is poor - grass and lichens, while the fauna is richer - there are birds, small rodents, but mostly wild goats that inhabit the Kazan at the foot of the peak. The edelweiss flower is abundant on the rocky edge of Jamdzhievi rocks.



Figure 2. Vihren Peak – 2914 m ([https://commons.wikimedia.org/wiki/File:Pirin\\_-\\_Vihren\\_peak.JPG](https://commons.wikimedia.org/wiki/File:Pirin_-_Vihren_peak.JPG))

### 3D MAP OF THE AREA OF VIHREN PEAK

In the last decades 3D maps became a very useful tool of cartography. They give cartographers more possibilities to represent thematic and special information in a way that is understandable to map users (Bandrova & Bonchev, 2010). 3D modeling can be defined as creation of a spatial model using special computer software. The built-in 3D model can be viewed from all sides and also be located in one or another environment. There are several steps in processing the information to reach the original 3D model: collecting primary data, preparation in points, polylines, or polygons, and finally creating a 3D model, typically consisting of triangulated network. A data source is any source of information that can be used on the map.

For the creating of the 3D map of the area of Vihren peak the Directorate of “Pirin National Park” provided the following data: contours in vector form (vectorized in 50 m, with sufficient precision for the next steps of working); peak with altitude; rivers; tourist paths and hiking trails (Figure 3). Data processing is a complex process. It requires reconciliation of different types of information presented in its formats.

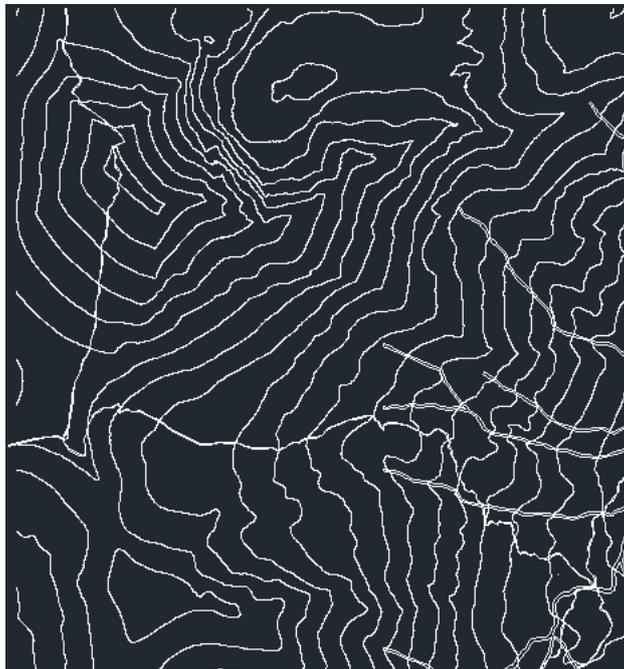


Figure 3. Input data from the Directorate of “Pirin National Park”

A 3D map of the area of Vihren peak was created (Figure 4). The basic map represents: terrain relief; hydrography; tourist routes; chalet. The additional content of the map depicts: annotation for the north and scale. The chalet Vihren is located in the research area. Designing a chalet as a virtual object, it is intended to be close to the real object. It was made with measurements, using electronic roulette. Volume scaling is used, which is a simultaneous increase or

decrease of object dimensions on the three axes of a local rectangular coordinate system. One scale section corresponds to 20 m. A north-arrow sign is placed on the northwest side of the map.

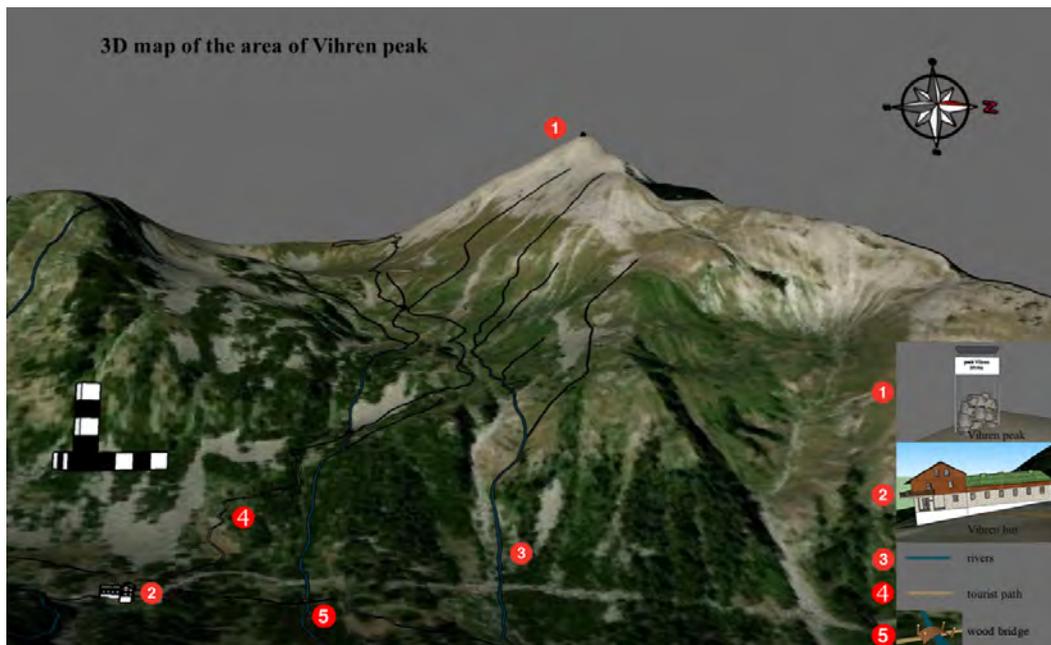


Figure 4. 3D map of the area of Vihren peak

The purpose of the map is to help users practicing mountaineering and hiking with the introduction of areas and choosing the optimal tourist paths. There The 3D dimension of the map makes orientation easily in the research area.

There are several tourist paths which lead to Vihren peak (Figure 5). Most of the tourists start their ascend from Vihren hut - a mountain hut built at altitude of 1950 metres in the valley of the Banderitsa river, several kilometres away from the town. Once you get to the hut, there is marked trail (white-red-white) that starts from the cark park and leads to the eastern slope of peak Vihren. The ascend from this side of the mountain is not technically difficult thought the cumulative gain is more than one thousand metres and the last section of the trail crosses many loose rocks while climbing the steep marble slope before the top. If one keep a good steady pace, taking the distance from the hut to the highest point of the mountain usually takes 3-4 hours or so. For the research area is used the optimal tourist path which start from Vihren hut.

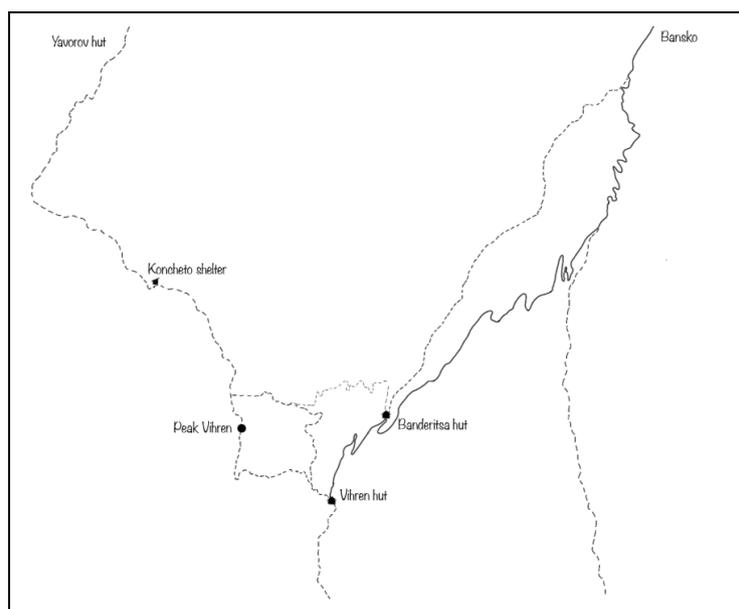


Figure 5. Tourists paths, which lead to Vihren peak (<http://gowhere.bg/en/places/mountains/vihren-peak/>)

## AUGMENTED REALITY

### Definitions

Augmented Reality (AR) is a technology that augments reality with either two or three-dimensional computer generated imagery (CGI), objects and/or information, and allows users to interact with them (Azuma 1997; Carmigniani et al. 2011).

AR can be interpreted “as a view of a physical, real world environment whose elements are integrated with computer-generated sensory input” (Freina & Ott, 2015). The objective is to “see and experience the real world mixed with various virtual objects, without losing the sense of reality” (Persefoni & Tsinakos, 2015).

In 1994, Paul Milgram and Fumio Kishino defined the continuum of Augmented Reality (AR) and Virtual Reality (VR) (Figure 6).

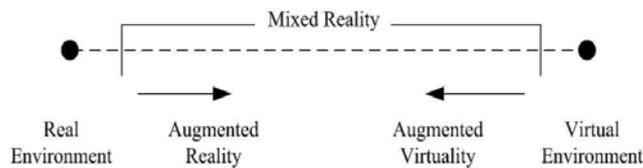


Figure 6: Milgram's Augmented Reality Continuum, (Azuma, 2001)

AR lies between the real and virtual environment and the state within the two environments is called "mixed reality". A mixed reality integrates digital information into the real environment. According to Azuma (1997), AR merges both types of objects either in 2D or 3D, leading to an interaction in real time which reflects the mixed reality in Milgram's AR continuum. Users will begin to experience a virtual surround environment as the point moves to the right leading to the virtual environment. Real objects are added to the virtual ones within the virtual environment to complement the background. Unlike the point on the left side, AR offers a range of digital objects such as audios, videos, haptic touch, and/or images; which can be overlaid onto a real environment.

### Types of Augmented Reality

#### Marker-based AR (Image recognition)

It requires a special visual object like a printed Quick Response (QR) code or any other special signs and images. Marker based applications use a camera on the device to distinguish a marker from any other real world object and it overlays information on top of this marker (Figure 7). Simple patterns (such as a QR code) are used as the markers, because they can be easily recognized and do not require a lot of processing power to read. The AR device also calculates the position and orientation of a marker to position the content.



Figure 7: Marker-based AR

### ***Location-based (Markerless AR)***

It uses the mobile device's GPS, compass, gyroscope, and accelerometer to provide data based on user's location. This data then determines what AR content you find or get in a certain area (Figure 8). The wide availability of smartphones and location detection features they provide is in essential significance for the markerless augmented reality technology. It is most commonly used for mapping directions, finding nearby info, and other location-centric mobile applications.



Figure 8: Location-based AR

### ***Projection-based AR***

It works by projecting artificial light onto real world surfaces. Projection based augmented reality applications allows human interaction by sending light onto a surface from the real world and then sensing the human interaction of that projected light. Detecting the user's interaction is done by dissociating between an expected projection and the altered projection caused by the user's interaction. An example of this is The AR Sandbox. This real-time integrated augmented reality system can physically create topography models by shaping real "kinetic" sand (Bandrova, 2015). The relief in the sandbox is recalculating according to the depth data, sensed by the camera and processed by the software in every moment (Figure 9). After that it is rendered from the data projector over the sandbox, depicting perfectly matched virtual relief over the sand landscape (Figure 10) (Savova, 2016).

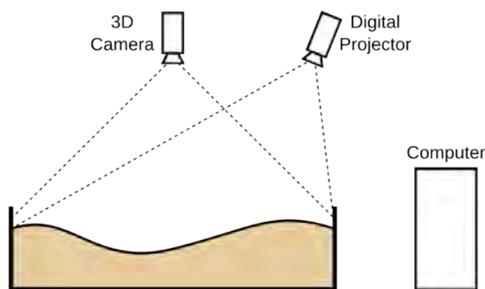


Figure 9. The AR Sandbox system construction, (Savova, 2016)

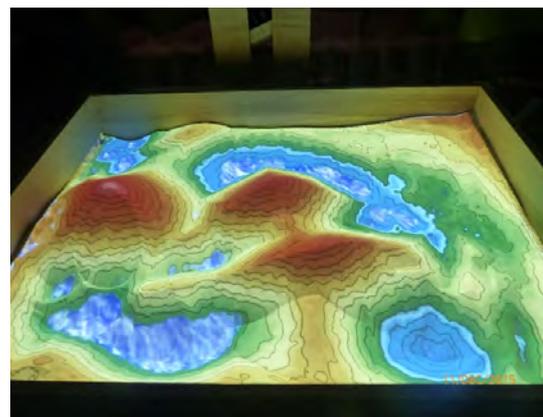


Figure 10. Virtual topography projected directly over the sand, (Savova, 2016)

### ***Superimposition-based AR***

It partially or fully replaces the original view of an object with a newly augmented view of that same object. In superimposition-based augmented reality, object recognition plays a vital role because the application cannot replace the original view with an augmented one if it cannot determine what the object is. An example of this AR is the IKEA

augmented reality furniture catalogue. By downloading their app and scanning selected pages in their catalogue, users can place virtual IKEA furniture in their own home with the help of AR.

### **Technology of creating and adding Augmented Reality**

The steps which a cartographer has to go through and that we went through to create and add Augmented Reality are summarized and presented in Figure 11.

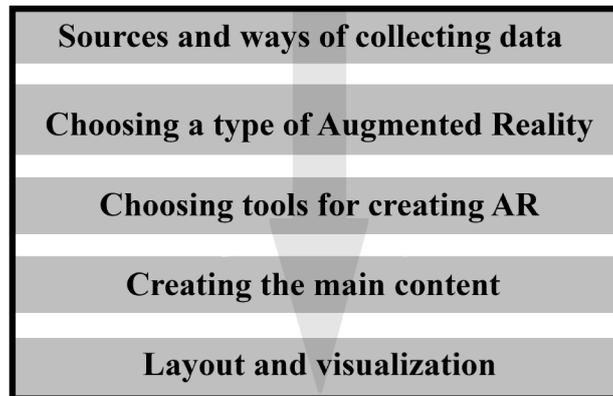


Figure 11. Creating and adding Augmented Reality technology

#### ***Sources and ways of collecting data***

There are unlimited sources for creating an AR like topographic maps, raster images, videos, 3D models, coordinates from geodetic field measurements and more. A 3D model of the area of Vihren peak is created and used as the additional information that is displayed with the AR app (Figure 12).

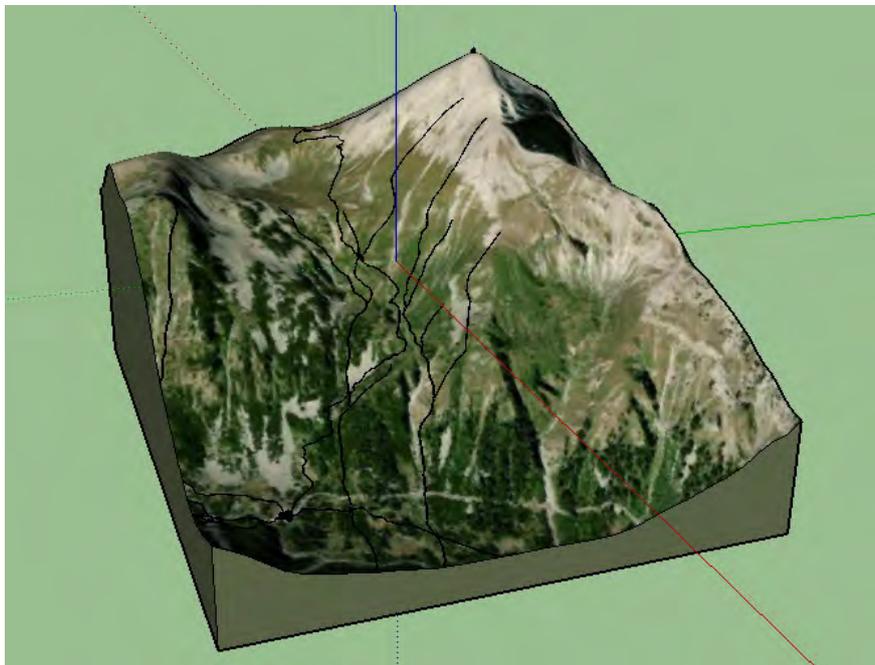


Figure 12. 3D model of the area of Vihren peak

#### ***Choosing a type of Augmented Reality***

Location-based AR is the most suitable type of AR for mountain navigation. As mentioned above this type of AR is based on the camera, GPS, accelerometers and other sensors to define the location of the user on the go and all surrounding objects and to display additional information on certain location.

## Choosing tools for creating AR

According to Dodero (2017) AR tools can be classified into three categories.

1. **Low-level libraries** - these tools provide only integration with computer vision algorithms, so require strong programming skills to be able to use them.
2. **High-level programming environments** - these tools simplify the development process by providing a supporting environment for building applications.
3. **Graphical user interfaces (GUI) based development tools** - they are in the reach of non-programmers.

GUI-based development tools are very appropriate because they do not require previous knowledge of programming and are generally easier to use and they allow showing 2D, 3D models, photos and videos. But for more elaborate 3D models, animations and simulations in the augmented reality most convenient are Low-level libraries.

## Creating the main content

The main content is the overlay information. In this project is used a combination of Marker-based AR and Location-based AR to create a mobile app in help of the mountaineers to provide them with additional information about the navigation to key points and tourist routes. As mentioned above Marker-based AR use image recognition capabilities to recognize images and overlay information on top of this image. Markers are labels that contain a colored or black and white pattern that is recognized by the AR application through the camera of the device. In this project the created 3D map is used as marker to display the created 3D models as additional information (Figure 13).

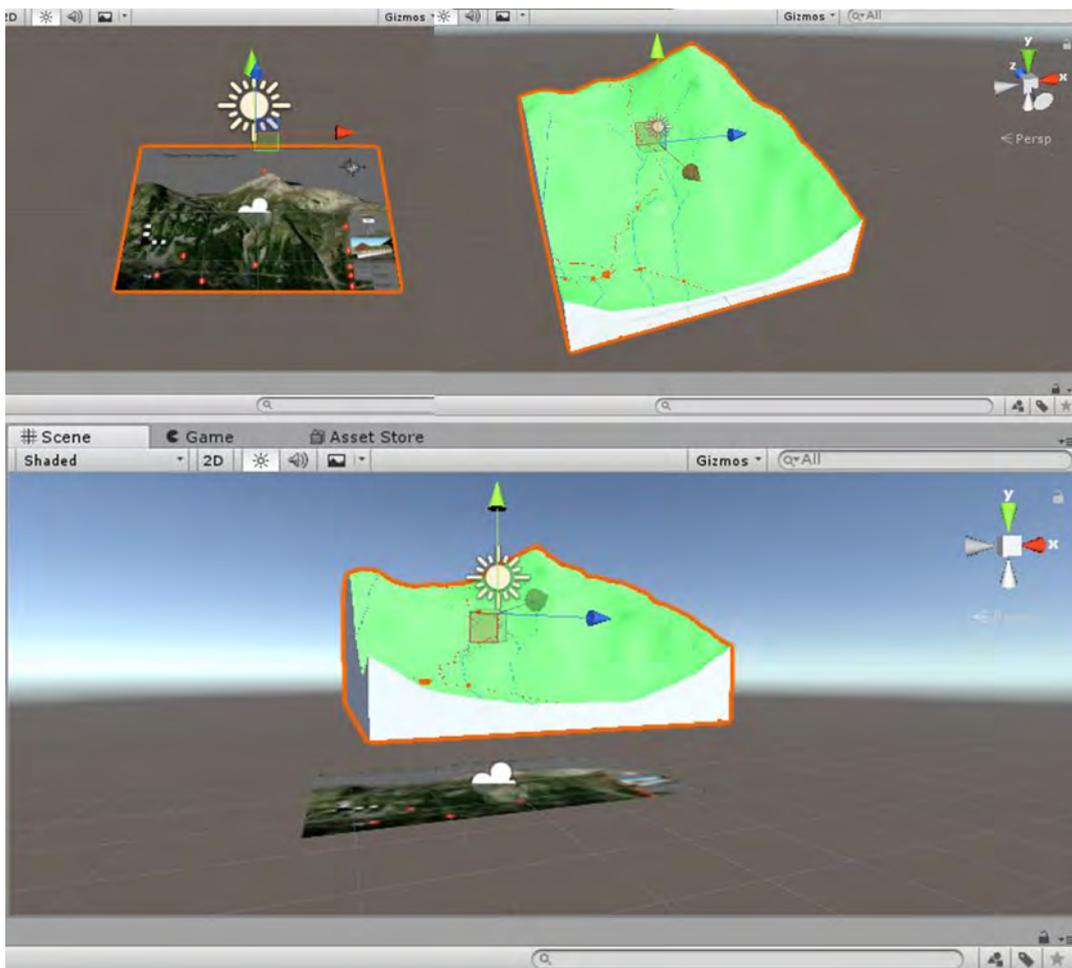


Figure 13. Creating the marker-based AR content

The vector data provided from the Directorate of “Pirin National Park” and the detailed 3D model are used to determine the exact location of each dot of the optimal route from the hut to the Vihren peak. These navigation dots and identification signs of Vihren hut and of Vihren peak are the main content of the location-based AR. The dots are displayed on the landscape through the whole route and the identification signs are displayed above the hut and the peak, with the exact elevation and the distance to each of them measured in walking time (Figure 14 and Figure 15).

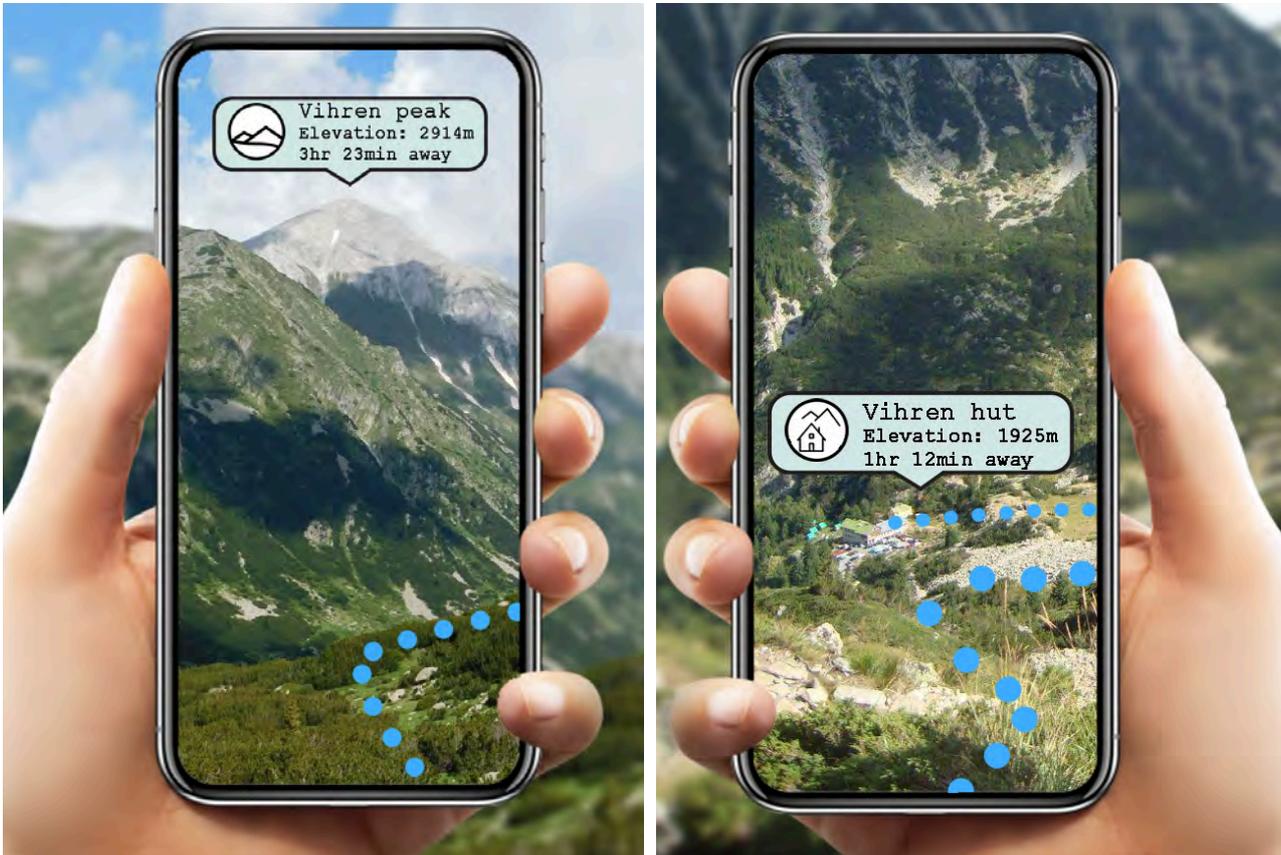


Figure 14 and Figure 15. Displaying the location-based AR information – navigation dots and identification signs of the Vihren hut and Vihren peak (concept)

### **Layout and visualization**

- Matching all elements
- Selection of projection, scale, scene and range
- Additional effects and animations
- Rendering
- **Final product – AR mobile app**

In this project the navigation app is created using Unity3D in combination with Vuforia for the Marker-based AR and in combination with AR+GPS Location for the Location-based AR part of the app.

### **FUTURE WORK**

In near future a research with volunteers mountaineers and with students from University of Architecture, Civil Engineering and Geodesy in Sofia will be conducted to explore the perception of the new technology. During a period of a week, several analyses will be made and different tasks will be solved by the students with the help of non-wearable devices – smartphones and tablets. Several variables such as the time to reach the final destination, easier orienteering and perceiving will be measured. The specific focus will be the potential use of AR for mountain navigation.

## CONCLUSIONS

Making an AR app is an extremely complex and labour-intensive process. AR has a rich application and can be of benefit to many different users. The challenges of creating and adding Augmented Reality App for mountain navigation are still not only gathering data, modelling, design and visualization but to use AR in more useful way, to become a strong tool for navigation. With this work we proposed a method of using AR as a kind of new technology in cartography and show a way how we can provide mountaineers with additional information about the navigation to key points and tourist routes.

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## BIOGRAPHY



**Dipl. Eng. Nikola Yonov** is PhD Student in University of Architecture, Civil Engineering and Geodesy, Sofia. In 2017 he graduated from university with an excellent grade on his thesis “3D mapping for the needs of sport”. During his student years, he joined an internships in “Here Maps”, with contribution of updating data base. In June, 2018, he presented an article “3D MAPS – cartographical aspects” with prof. dr. eng. Temenoujka Bandrova in 7th International Conference on Cartography and GIS in Sozopol, Bulgaria. In July, 2019, he presented an article “School atlas with Augmented reality” in 29th International Cartographic Conference in Tokyo, Japan and was awarded with two scholarships for his work.



**Dobrin Veselinov Petkov** is graduated student at University of Architecture, Civil Engineering and Geodesy, Sofia with major Geodesy, specialization Cartography. In January, 2018, he presented his master thesis with topic “Cartographic modelling of avalanches”, which is one of his science interests. Currently, he works as geodetic engineer in company “GeoMobile” Ltd. and have previous experience at company “Geo Engineering” Ltd. and “Agency of Geodesy, Cartography and Cadastre”. During his student years, he joined an internships in “Here Maps”, with contribution of updating data base. In June, 2018, he presented an article “Cartographic modeling and visualization of snow avalanche areas” with prof. dr. eng. Temenoujka Bandrova and dr. eng. Silvia Marinova in 7th International Conference on Cartography and GIS in Sozopol, Bulgaria.

In 2019 he started his PhD program in Cartography at University of Architecture, Civil Engineering and Geodesy.

# CHANGE DETECTION ANALYSIS OF LAND COVER BEFORE AND WITHIN THE SYRIAN CRISES USING REMOTE SENSING AND GEOSPATIAL TECHNIQUES CASE STUDY OF AL-SALAMIYAH DISTRICT, SYRIA

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## **Abstract**

*Since 2011, Syria has suffered from one of the longest armed conflicts in the world which have presented significant consequences including the changes within the spatial patterns of the environment including the land cover. This research used the remote sensing data and geospatial techniques to study the land cover changes in Al-Salamiyah District using Landsat images at the end of the dry season in three selective years: 1989, 2004 and 2019. The results show that the actually cultivated lands were decreasing from 115 thousand hectares in 1989 to 97 thousand hectares in 2019 and the rate of change is higher in the period (2004-2019) which includes 9 years of the Syrian conflict comparing with the first one. The results shed the light on the current situation of the land cover and raising questions on the environment-related challenges resulted from the Syrian conflict and the urgent need to maintain and preserve the productive agricultural lands in this region.*

**Keywords:** Remote Sensing, Cartography, Land Cover, Syrian Crises, Al-Salamiyah District

## **INTRODUCTION**

Land-cover change has numerous ecological, physical, and socioeconomic consequences (Pellikka et al., 2013) and the biophysical and human forcing factors that result in changes in land cover and land use are manifested through different phenomena (Gutman et al., 2004). Warfare and armed conflict can impact land systems in major ways, but these effects are diverse and not unidirectional (Baumann et al., 2016).

The Syrian conflict is ongoing for 10 years and despite this overwhelmingly devastating crisis, the state of the environment is often left out of the discussion (Creighton, 2017), and since the outbreak of the crises in 2011 the environment was one of the biggest parts to be affected.

Most of the cultivable lands turned to be inaccessible because of the armed conflict and some of the cities received a massive number of people which were internally displaced, over-cutting of forest trees which turned to be used as fuel for heating in winter (Hammad et al., 2018) and taking into consideration that Syria has also been exposed to one of the worst long-term droughts waves which also put pressure on local resources which were already vulnerable.

Providing an initial mapping of ongoing land use and land cover changing before and during the conflict which will help in better understanding the changing mechanisms of the land-cover and land use in Syria based on natural and human-made changes.

## **Study area**

The study area is represented by the administrative boundaries of Al-Salamiyah District, which is part of Hama Governorate (Fig. 1). Al-Salamiyah District contains the main city and 202 villages with a total population of 351,437 (Civil Registration Office, 2011). It covers more than 5,000 sq km which makes up 60% of total Hama governorate area and it is located within two climatic zones (arid and semi-arid) (Mousa and Harba, 1985).

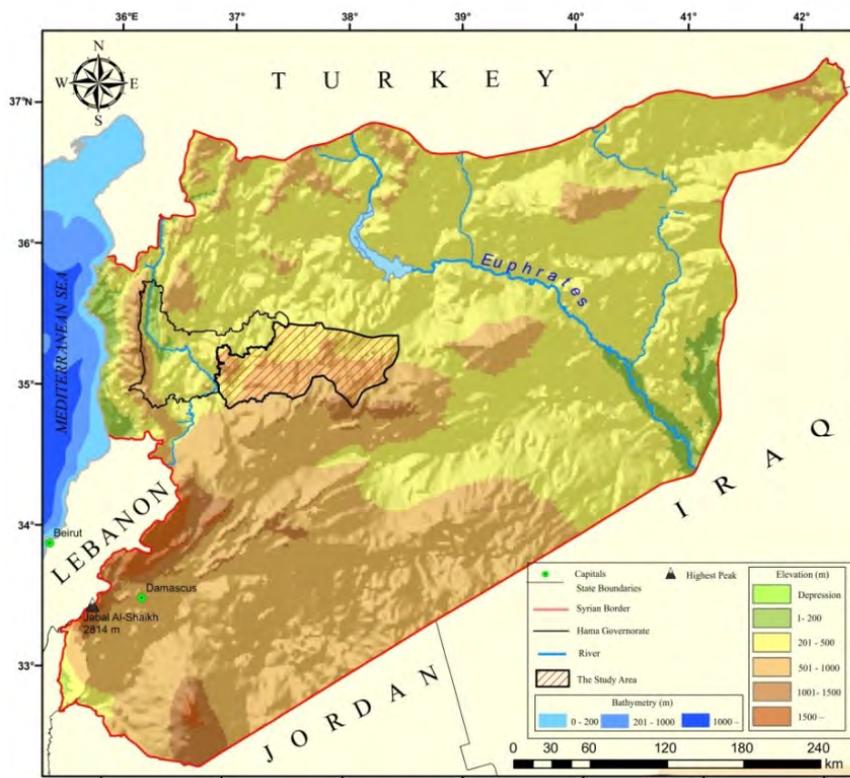


Figure 1. The location of the study area in Syria

The elevation is ranging from 300m to 1195m (Fig. 2). One of the distinguished mountain there is (Jabal Al –Bala’as, 1017m) and this area is considered as one of legislated protected areas in Syria (12000 hectares for Pistacia Atlantica plant) (GEF, 2002).

The majority of the district’s arable land base is rain-fed agriculture, but a small amount (8%) utilises limited groundwater for its irrigation needs and close to half of the arable land base in Al-Salamiyah district is barren steppe land (Kassam et al., 2011).

(Fig. 2) also shows the equal rainfall lines map compiled based on 19 recorded rainfall stations for 2005-2006 rainfall year (from September 2005 to August 2006) (AKF,2017) and which through we can have a general idea on the main locations of rain-fed agriculture (Western parts of the district).

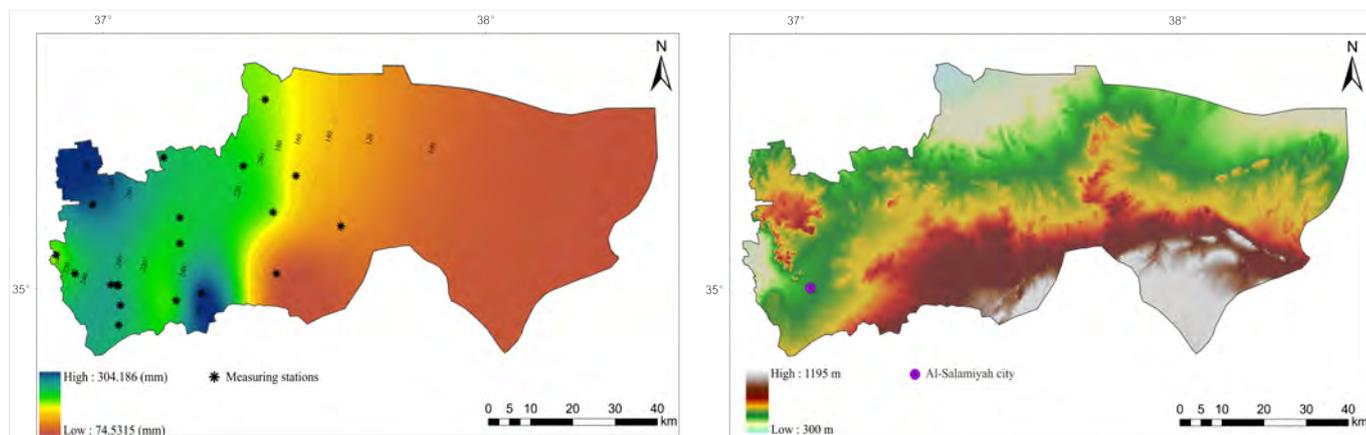


Figure 2. The equal rainfall lines map (on the left) and the elevation map of the Al-Salamiyah district

## METHODOLOGY

The remote sensing data and different GIS and cartographic techniques are the used tools in this research and we choose two different periods (1989-2004) and the second is (2004-2019) including the Syrian conflict which has started in 2011 and the detection month is August to have a better view of the surface with a clear sky and as summer progresses and most of the landscape dries out, different classes can be better distinguished.

The satellite images used in this study are Landsat-5 TM images for the year 1989 and 2004 and Landsat8 OLI/TIRS images for the year 2019 (USGS,2020) as described in (Table 1), radiometric corrections were applied and we used supervised classification method (maximum likelihood) to classify the images.

Table 1. The Landsat images used in this study

Image Acquisition Date	Sensor	Bands	Resolution
August 1989	Landsat 5 TM	1,2,3,4,5	30m
August 2004	Landsat 5 TM	1,2,3,4,5	30m
August 2019	Landsat8 OLI/TIRS	1,2,3,4,5	30m

In order to better understanding the land cover within the study area we used different approaches including the geological map of Syria and ICARDA (International Center for Agricultural Research In the Dry Areas) land use classification for Syria base year 1989 (ICARDA, 2004) and we had the corresponding map which shows the main surface features (Fig. 3). Irrigated lands were indicated during the classification process using the false-color composite of the satellite images.

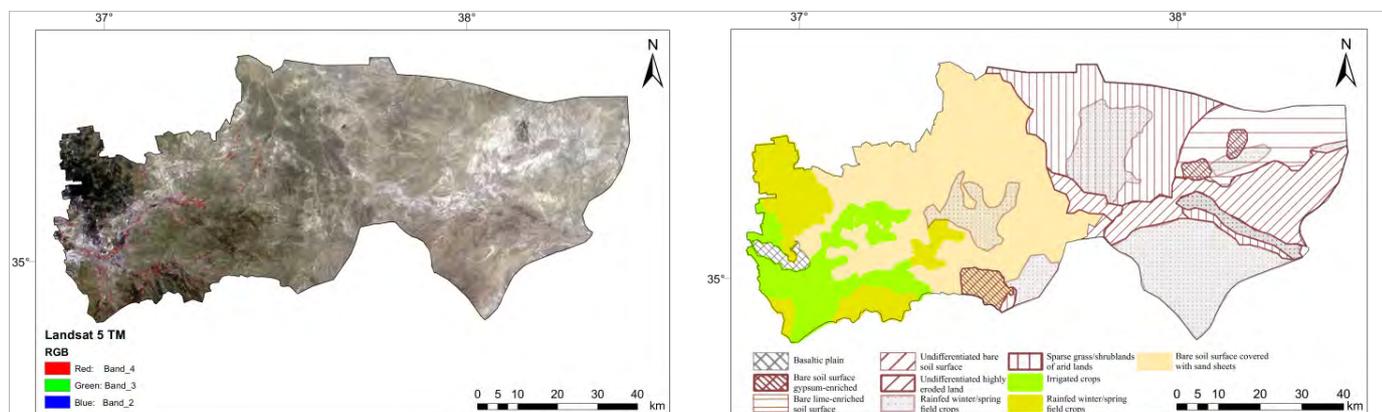


Figure 3. 1989 satellite image in false color (on the left) and the correspond map showing main surface components

The images were classified into six different classes and the accuracy assessment was done to the classification images by comparing 180 sample points to ICARDA maps, historical and highly resolution google earth imageries for the same detection time.

## RESULTS

The three classification images for the years 1989, 2004, and 2019 are shown in (Fig. 4). The land cover maps show that both barren and pastures lands are the dominant types of land cover within Al-Salamiyah district in the studied period and the area of the actual planted lands (rain-fed and irrigated lands) were decreasing during the mentioned time.

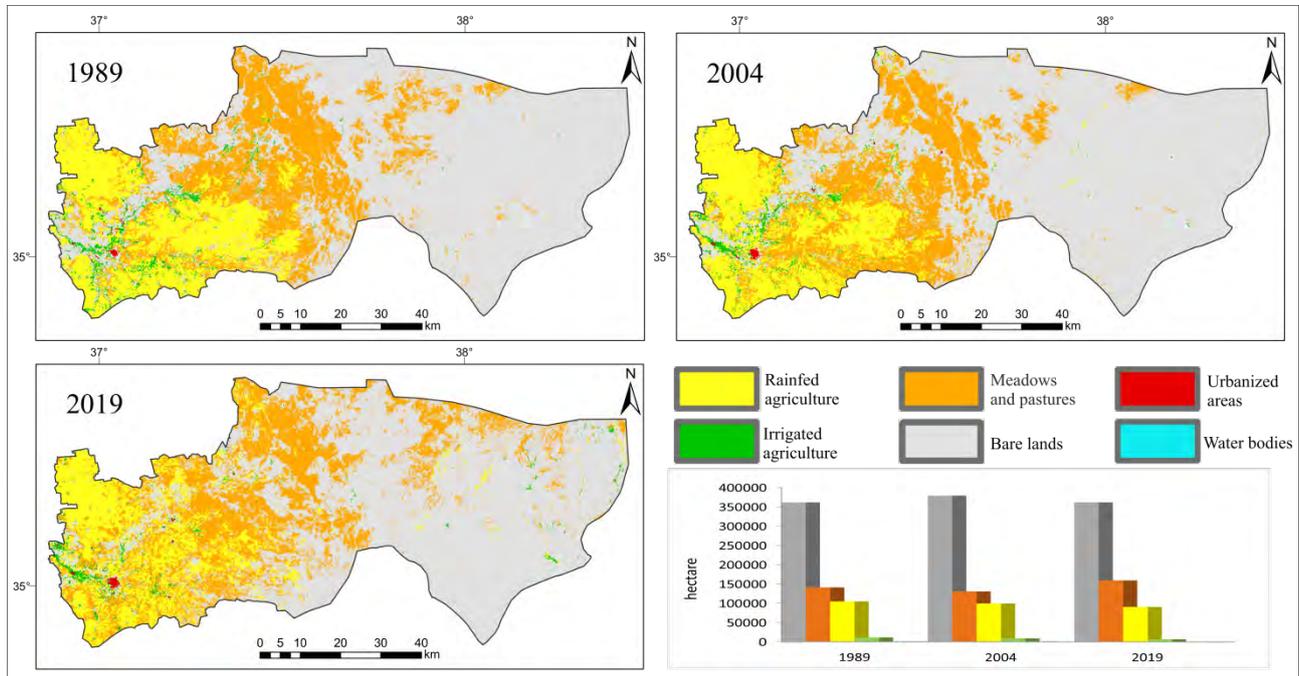


Figure 4. Land cover maps for 1989, 2004 and 2019 and the total area for each class

The results show that the rain-fed agriculture has decreased from almost 104 thousand hectares in 1989 to almost 90 thousand hectares in 2019 with a total loss of 14 thousand hectares in 30 years (62% of the total decline occurred between 2004 and 2019) (Table 2).

Similarly the total area covered with irrigated agriculture has decreased from almost 11 thousand hectares in 1989 to almost 6,500 thousand hectares in 2019 with a total loss of 4,500 hectares in 30 years (51% of the total decline occurred between 2004 and 2019).

The water bodies class which is mainly water reservoirs created by small dams and covers 16 hectares in 1989 and reaches 10 hectares area in 2019.

The urbanized areas which are represented in the classification images by the main city of Al-Salamiyah get increased by time from 657 hectares in 1989 to 858 hectares in 2019.

Although in most of the places it was hard to separate meadows and pastures class from barren surface class because of most of the study area in summer covered with low-density rangeland, what can be important to find here that the area which is covered with meadows and pastures get increased in the second period 2011 -2019 and this is a general trend in Syria regarding the meadows and pastures class which it tended to increase in through 1968 and reach 8,188 thousand hectares in 2017 (knoema, 2020).

Table 2. Land cover change statistics (in hectare)

Class	1989	2004	2004-1989 change	2019	2019-2004 change
Rain-fed agriculture	104578	99268	-5310	90580	-8688
Irrigated agriculture	11175	8920	-2255	6615	-2305
Water bodies	16	14	-2	10	-4
Meadows and pastures	140974	130791	-10183	159226	28435
Bare lands	361618	379217	17599	361675	-17542
Urbanized areas	657	806	149	858	52

According to the classification results both rain-fed and irrigated lands make up less than 25% of the total land cover in the study area (Table 3).

Table 3. The percentage of the actually planted lands in this study area

Class	1989	2004	2019
Rain-fed lands	%17	%16	%15
Irrigated lands	%2	%1	%1
Other classes	%81	%83	%84

Almost similar results can be found if we compare the classification results to governmental agricultural statistics for Al-Salamiyah district which shown in (Fig. 5), the figure also indicates the general land use percentage of Hama governorate as well (Central Bureau of Statistics,2009).

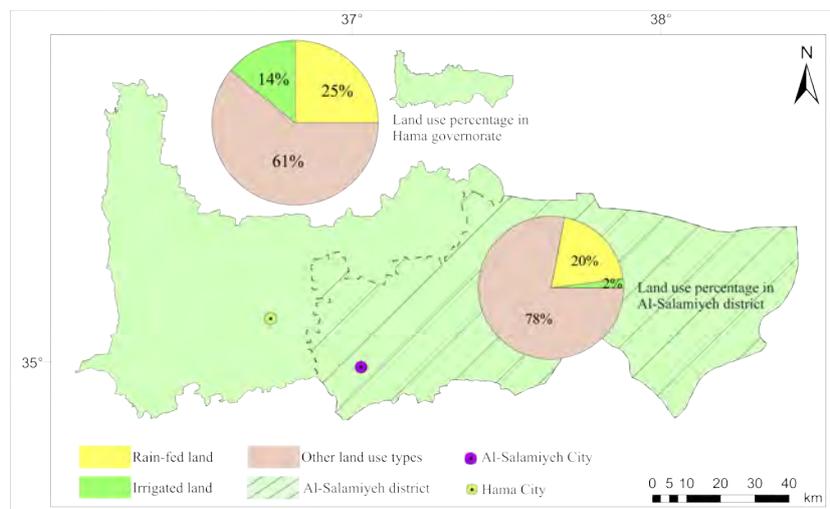


Figure 5. Actually planted lands percentage according to governmental statistics

To assess the accuracy of the classification images we generated random 180 random points (60 points for each classification image and 10 points for each class) and the overall accuracy of the three land cover maps 1989 ,2004 and 2019 equal 85%, 81.6% and 90% (Table 4).

Table 4. Accuracy assessment-error matrix for the three classified images

Class Name	1989	1	2	3	4	5	6	Total (user)	2004	1	2	3	4	5	6	Total (user)	2019	1	2	3	4	5	6	Total (user)
Rain-fed lands	1	6	0	0	4	0	0	10	1	9	0	0	1	0	0	10	1	9	0	0	1	0	0	10
Irrigated lands	2	0	7	0	3	0	0	10	2	3	6	1	0	0	0	10	2	0	8	1	1	0	0	10
Water bodies	3	0	0	10	0	0	0	10	3	0	0	10	0	0	0	10	3	0	0	10	0	0	0	10
Meadows & pastures	4	0	0	0	9	1	0	10	4	1	0	0	7	2	0	10	4	0	0	0	8	2	0	10
Bare lands	5	0	0	0	0	10	0	10	5	0	0	0	1	9	0	10	5	0	0	0	1	9	0	10
Urbanized areas	6	0	0	0	0	1	9	10	6	0	0	0	0	2	8	10	6	0	0	0	0	0	10	10
	<b>Total (producer)</b>	6	7	10	16	12	9	<b>60</b>	<b>Total (producer)</b>	13	6	11	9	13	8	<b>60</b>	<b>Total (producer)</b>	9	8	11	11	11	10	<b>60</b>

## DISCUSSION

The rate of change in both rain-fed and irrigated lands (the actually planted lands) are higher in the period from 2004 to 2019 than the rate of change in the first period (1989-2004) (Fig. 6).

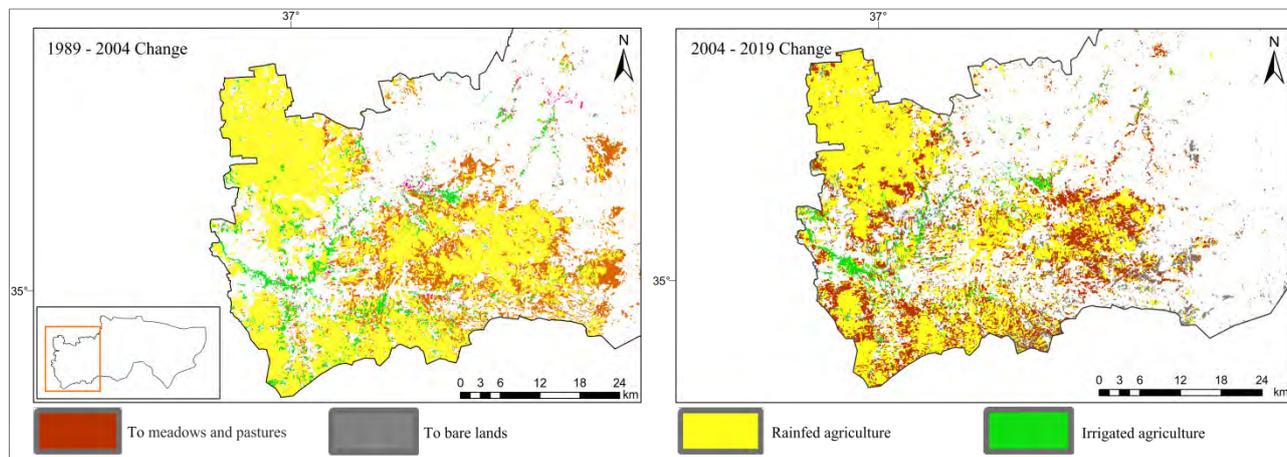


Figure 6. The areas that have changed to meadows and barren surface classes

The higher transformation pattern is to meadow and pastures class with 16.59% of the change in the first period and 26.47% in the second period (armed conflict period) and similarly the rate of change to bare lands class which was 6.35% and increased to 14.03% in the conflict time (Table 5).

Table 5. Actually Planted Lands change percentage within the study area

Patterns of change from Actually Planted Lands (Rain-fed & Irrigated lands) to other classes	% of the total area of the (Actually Planted Lands) class (1989-2004)	% of the total area of the (Actually Planted Lands) class (2004-2019)
Actually Planted Lands to water bodies	0	0
Actually Planted Lands to meadows and pastures	16.59	26.47
Actually Planted Lands to Bare lands	6.35	14.03
Actually Planted Lands to Urbanized areas	0.3	0.34
No change	76.73	59.12

The general decrease of the actual planted lands within the study area in the two periods can be explained in term of climate conditions, as this area has suffered from the drought waves for a long time but the higher rate of change between 2004 and 2019 can be linked to the direct and indirect effects of the armed conflict in Syria.

Most of the cultivated lands in the study area turned to be inaccessible during the conflict because of security reasons and the kidnapping cause total halt of daily movement for normal people and during the conflict, this area became a crossing point between the north and the south which made the armed groups always attempts to have control over it.

The lack of energy and water resources were the main challenges, trees turned to be firewood (fuel for heating in winter), and this area also received a huge number of internally displaced people who were forced to flee their homes due to the current conflict.

Between the period of 2017-2020, Al-Salamiyah district and according to the international humanitarian agencies (ACLED, 2020) recorded 2224 violent events (explosions/remote violence, battles and violence against civilians), 88 % of these events occurred in the year 2017 alone (Fig. 7) is showing the recorded locations where the violent events took place and we can see that the approaching 2020 the security situation turned to be better than before (the map of 2020 in (Fig. 7) is showing the recorded events till April 2020).

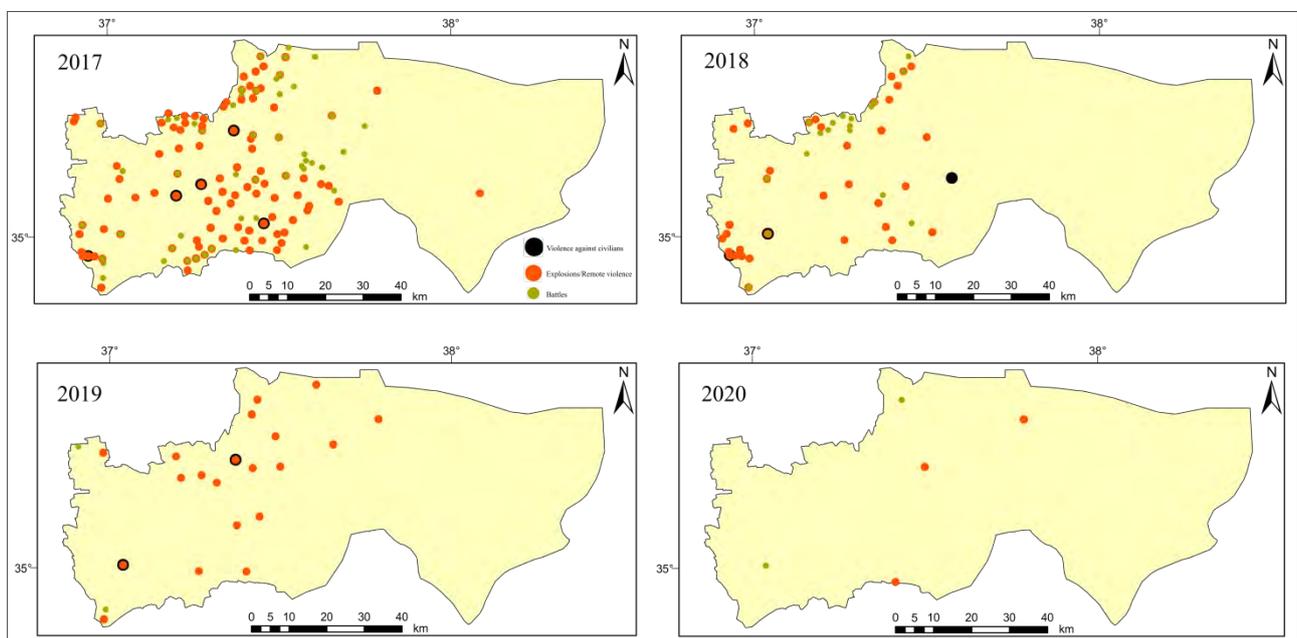


Figure 7. Recorded locations where the violent events within Al-Salamiyah district

In 2019, Al-Salamiyah district has witnessed huge fires that broke up in the agricultural lands and engulfed the crops in the flames, over 200 fires broke out and thousands of dunums of agricultural lands in this area get burnt (Asharq Alawsat, 2019).

Another aspect of the negative effects of human actions on land use in the study area is the decision of growing the wrong crops which not suitable for dryland agriculture.

The irrigated farmland had an area of 40,000 hectares in 1960 (Kassam et al., 2011). but then 77% of the irrigated area were lost and the greatest declines occurred due to a previous legacy of a national cotton policy (water-intensive crop production) which had unforeseen consequences. In conjunction with increased frequency of drought and groundwater had been dwindling (of the approximate 5,000 groundwater wells identified in 2003, almost 3,500 were dry) (AKDN, 2020).

The classification results show that the irrigated lands continue to decline and if we have a look on the changes within the actual planted areas (from irrigated agricultural to rain-fed) we found that 30.32% of the total area of the irrigated lands changed to rain-fed in the period from 1989 to 2004 and 32.73% from 2011 to 2019 (changes within the actually planted lands).

One of the main suggested solutions to preserve agriculture in this area is to drag water from the Euphrates river to Al-Salamiyah district, unfortunately these plans never saw the light of day.

## CONCLUSION

This study used Remote Sensing data (Landsat images) and geospatial techniques to assess 30 years of land cover changes in a Al-Salamiyah district in Syria and compare two different periods, the first is from 1989 to 2004 and the second between from 2004 to 2019 (included the effect of the Syrian crises).

The results show that both areas of rain-fed and irrigated lands get decreased by time and the rate of decrease was higher in the second period than the first one.

Many factors contributed in the mentioned decrease which can be linked to the direct and indirect effects of the Syrian conflict as the results show that the higher decrease of the actually planted lands happened during the 2004-2019 period which not only reflects the climate conditions of the study area, but also the long term violent events in this area representing mainly by security threats, abandoned farmlands, burned agricultural lands (intentionally and accidentally), lack of water and energy resources, poverty and poor agriculture and natural resource management in the study area.

The results also raise questions regarding the urgent need to revive agriculture especially in the abandoned farmlands and the need to move toward an agricultural system in this area which is more environmentally, economically, and socially sustainable once Syria starts approaching post-conflict reconstruction phase.

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## BIOGRAPHY



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# SUSTAINABLE MONITORING OF SEA-VESSELS OVER BOSPORUS WITH USE OF GOOGLE EARTH ENGINE PLATFORM

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## **Abstract**

*Bosporus is an important strait which connects Black Sea to the Mediterranean along Marmara Sea, and very strategic marine transportation line for commercial sea-vessels which carry economic good. Traditionally the statistics of vessels are under responsibility of Turkish coastline security Department. In this study, we develop a sustainable vessel monitoring system which allows user to monitor the sea vessels from the specific date which SAR satellite data are available. The system is based in Google Earth Engine Platform. Sentinel 2 images have been used to create water mask. Sentinel SAR image has been used to detect the vessels. The image has been preprocessed for angle correction to ensure the image all pixels to the same pixel size. Then, the median value of SAR pixel values of all image collection in Google Earth engine is calculated to allow the detection of any object on the sea, which shifts the pixel value from the median value. The method is implemented in Google Earth Platform and the user can select any date to monitor the vessels over Bosporus including the information of number of total vessels.*

**Keywords:** Ship detection, RADAR, Google Earth Engine

## **INTRODUCTION**

The position and behavior information of the ships is important in particular for safety, environment, and border control of maritime (Kanjir et al., 2018; Mátyus, 2013). Large scale geospatial datasets which include SAR and optical images are significant for maritime monitoring (Bi et al., 2017; Kanjir et al., 2018),.

In the last decade, research studies on ship detection from SAR images have been significantly increased. Liu et al. (2019) separated these studies into four groups. These are constant false-alarm rate (CFAR), the generalized-likelihood ratio test (GLRT), the saliency-based methods and the deep learning-based methods.

There are also existing online ship monitoring systems. For example, Shipping Explorer (Web1) uses AIS data (automatic identification system) to identify locations and provide detailed information about ships. Based on AIS, the system creates a map of ship movements in real time on the seas and oceans, allowing monitoring the positioning of ships and ports. In this system, there are additional layers in the application that contain information about air, wave and wind. The program allows searching of ships according to various criteria (ships, MMSI, IMO, type, registration information, destination, etc.). For example, it allows you to monitor all cruise ships go to some specific location. There are flexible configuration systems for notifications via SMS and email to track ship positions in real time. For example, you can be informed when your ship enters a certain area, changes its speed or course.

Another service is The MarineTraffic website (Web2) is a community-oriented project based on research collaboration between academics and developed by existing Information and Communication Technology (ICT). The main purposes of the service are; maritime telecommunications, simulation of ship movements to secure navigation and cope with critical events, interactive information systems design, design of databases that provide real-time information, statistical

processing of ports traffic with their applications in operational research, pollution identification studies, Design of effective algorithms for maritime assessment, estimation of estimated time of ship arrivals, weather forecast and maritime operations. The system provides free real-time information to the public via its website, along with the positions and movements of the ships, as well as other relevant information (e.g. traffic on the ports, travel details), especially on the coastline of many countries around the world.

The Find Ship (Web3) is a software which produced by Marine Toolbox. It is mostly for the amateur users. It is a program followed by users with sailors, yachts, sailboats and small boats. It is not as successful as other applications due to its high content and error margin.

There are several ship monitoring technologies. Automatic Identification System is one of them (Web4), and it is an obligatory to set up and use for commercial ships bigger than 300 Gros Tonalito according to the World Maritime Organization. AIS uses audio frequencies but cannot be perceived and understood as sound. AIS receiver and transmitter are required to read the broadcast. The AIS system maintains ship anchor status, destination and ETA next port (estimated arrival time) movement, name, port, speed, call sign, position (coordinates) of the ship, ship size, number of personnel and regularly sends this information to land stations. This information can be followed by any person. The transmission of this information is expressed as a maximum of 20 nautical miles in good weather conditions. On the other hand, Long Range Tracking and Identification (LRIT) is an international tracking and identification system established by IMO to provide a comprehensive monitoring system for ships around the world under the SOLAS agreement.

Apart from these tracking services and technologies remotely sensed images are other alternative to track and count the ships according to the image acquisition temporal resolution. In this study, we used Google Earth Engine Platform to detect the ships on the Bosphorus, Istanbul-Turkey from an imperially selected date. The methodology is based on Wong et al. (2019)'s study with modifications in thresholding and integration of optical imagery to improve the quality of the results.

## MATERIAL AND METHODS

### Material

Google Earth Engine Platform(Web5) has been used to derive and process the datasets and visualization of the results. The platform is operated by JavaScript programming language in Google Servers as Cloud Computing platform and free of charge for the research purposes. There is a large geospatial data catalog that the user can call and process the respective datasets for different type of operations and research studies. The catalog includes satellite imagery datasets (Landsat, Sentinel etc.) in global scale, and some high resolution datasets in regional areas. The catalog also includes vector and atmospheric datasets to combine with any other assets provided by the users.

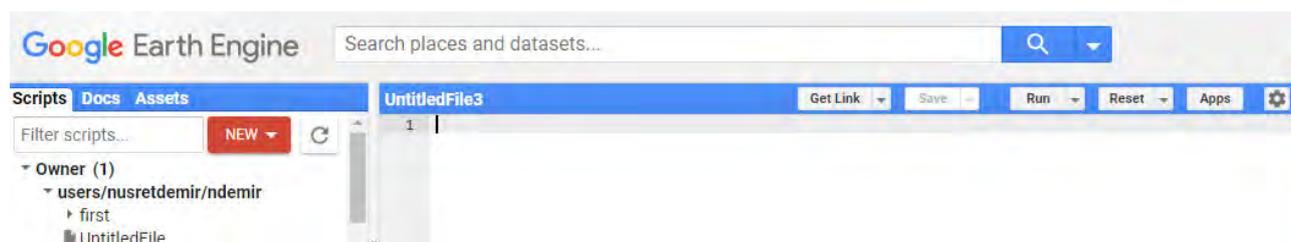


Figure 1. Google Earth Engine code editor

Three types of datasets have been used in this study, which are

- Sentinel 1 SAR Image
- Sentinel 2 Multispectral Image

Sentinel 1 SAR images have been used for the ship detection purpose. The properties of Sentinel 1 data are shown in Table 1.

Table 1. Specifications of Radar Image

<b>Sensor</b>	Sentinel 1
<b>Image type</b>	Synthetic Aperture Radar
<b>Ground Sample Distance</b>	10 m.
<b>Data type</b>	Ground Range Detected
<b>Acquisition Date</b>	2018-07-20

Sentinel 2 multispectral images have been used to create water area mask to process only the regions where have potential to have ships. Normalized Difference Water Index has been calculated with use the median values of the satellite images from the specific date range. The use of a single image will not be sufficient to calculate the NDWI value since the water pixels may be covered by other objects including ships. Therefore analysis of all pixels among a large data range would allow picking the consistent water pixel value with calculating the median value. The properties of Sentinel 2 data are shown in Table 2.

Table 2. Specifications of Optical Image

<b>Sensor</b>	Sentinel 1
<b>Image type</b>	Optical
<b>Ground Sample Distance</b>	15 m.
<b>Acquisition Date Range</b>	'2018-01-01', '2019-06-30'
<b>Cloud Pixel Ratio</b>	Max 5%

## Method

The overall method has been compiled in Google Earth Engine Platform including use of open datasets and visualization. The general workflow is shown in Figure 2.

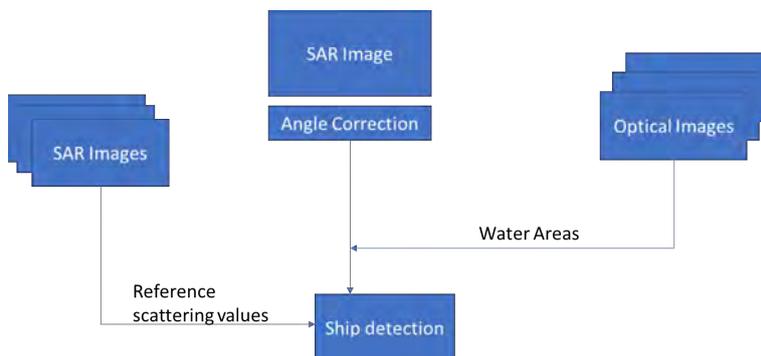


Figure 2. Methodology for ship detection

The method starts with loading Sentinel 1 SAR data from the specific date. The datasets are loaded with selecting respective polarization, filtered by acquisition date. Here, we have picked the date of 2018-07-20 imperially. The radar pixel values are needed to be corrected due to the radar imaging geometry. The pixel values closer to the sensor have less ground sample distance compared to the farthest part of the image. Angle correction makes the pixel size regular with same size in x and y direction. This is useful to process radar images for any further analysis (Wong et. al, 2019).

The presence of any ship cause brighter pixel compare to the other water surfaces. But the consistent radar pixel value for the water surfaces has to be calculated. This is done with calculating median value of the all available of radar imagery in Google Earth Engine data catalog. The median value allows detecting the consistent pixel value with excluding any object on the scene. This calculated image is called as Radar Reference Image. As expected that the ships stand on the water surface, multispectral satellite images have been used to detect the water surfaces to use as the regions to clip. The image contains median values of the selected image series is subtracted from the image which is specific date, to determine the objects, mainly ships. To identify the water surface, a mask has been created with use of Sentinel 2 multispectral image from a series of images between the dates of '2018-01-01', '2019-06-30' which are selected imperially . The median values of each pixel along the series have also been used to calculate the Normalized Difference Water Index.

The water index is calculated as following;

$$NDWI=NIR-GREEN/NIR+GREEN (1)$$

NWDI value bigger than 0 indicates the water surface, so the areas where meet this condition are selected. Apart from the water surfaces from NDWI. The identified area is overlaid with the input SAR image.

For detection of the ships, the selected input SAR image have been subtracted from the Radar Reference Image. The values which are greater than zero have been selected as ship objects. Then, morphological dilation is applied to merge the segments which are very close to each other, and possible to belong to the same ship.

## RESULTS

### Test Area

Test area is the Bosphorus strait in Istanbul-Turkey (Figure 3). The region is selected as region of interest and the corresponding images from the specific dates are called through Google Earth Engine Platform.



Figure 3. Test area, The Bosphorus Strait

The used Sentinel 1 SAR image and its angle corrected version is shown in Figure 4.



Figure 4. The used SAR image after applying angle correction.

The generated mask from NDWI and reference image which was calculated with median of all available images, are shown in Figure 5.

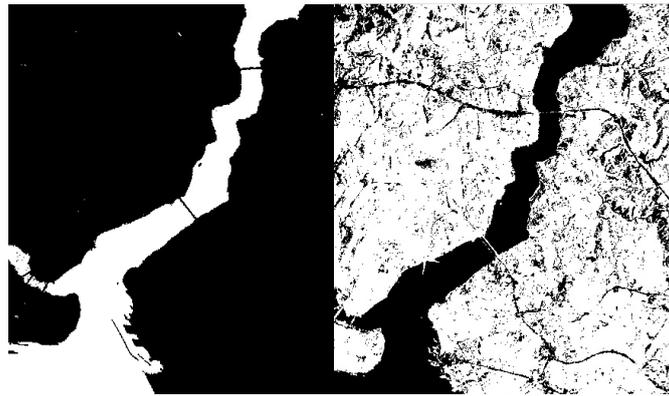


Figure 5. Mask derived from NDWI and SRTM(Left), Reference SAR image (Right)

The subtraction from radar reference image from the selected radar image is used to derive the ships. The pixels which have values bigger than 0 are selected as ships. Morphological opening has been applied on the results to overcome the over segmentation. The detected ship polygons can be found in Figure 6.



Figure 6. Detected ships overlaid with Google Maps

The final detected objects are converted to the vector features, and the number of vector features indicates the total number of ships is calculated as 64 on the area of interest which is the Bosphorus strait in our study. For assessment of the study, the ships are manually counted as 72 on the radar image along the strait with human interpretation.

## CONCLUSIONS

Radar images have a big potential to detect ships since the backscattering from ships compare to the water surfaces is remarkable, thus the ships are easy to identify. The monitoring of ships and other sea vessels is important for management purposes, and there are already existing monitoring services available.

In this study, we have aimed to detect the ships with use of remote sensing by cloud computing platform. Because satellite images are good source for monitoring of the ships, but with limitation of the sensor temporal resolution. But the advantage of the use of remote sensing , any ship can be detected regardless the AIS is switched on or not.

Radar images are useful for detection of the ships, which is already discussed in previous literature; we have used open source Sentinel 1 dataset. But the processing of radar image needs high performance computing environments. Therefore we have used Google Earth Engine Cloud Computing platform to eliminate the need of data download and process in the software packages. The whole processing has been performed in the cloud including data loading, integration with other datasets, processing and visualization. We have followed the suggestions of Wong et al.(2019) and extended the approach with inclusion of optical datasets to improve the detection results. The study will be extended to improve the detection accuracy with testing on different test sites.

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# SUSTAINABLE MANAGEMENT OF WATER BODIES BASED ON MULTITEMPORAL SATELLITE IMAGES

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## Abstract

*In this paper, the authors present a robust methodology for multitemporal analyses of 'Ogosta' reservoir near Montana in Bulgaria, based on the processing of satellite images only with open-source data and software solutions. The 'Ogosta' reservoir was chosen as it is one of the largest man-made water body in the country and its wall is situated less than 600m away from the nearest neighbourhoods and the free water level of the reservoir is higher than the level of the city of Montana. Reservoir poses an enormous danger for the population of the region, especially after heavy snow melting. Thus, the authors decided to analyse the multitemporal development of the water surface. We chose open-source optical data from Sentinel-2. The extraction method was by computing the normalized difference water index and binarizing the images. Every binary image was later vectorized in order to create polygons with surface water data and calculate their area. The results were compared with a surface polygon of the reservoir.*

**Keywords:** Copernicus, sentinel, NDWI, water bodies

## INTRODUCTION

Monitoring of water bodies such as dams and reservoirs plays an important role in the National Security of the state. Dams are built to provide with fresh water which is vital for humans or for agricultural irrigation purposes. In either way, the key to the sustainable management of water bodies is to keep track of the spatial and temporal variability of the water. Elevation of surface water, water areas and volumes are just a few of the hydraulic variables that are daily measured by engineers. One of the numerous Remote Sensing tasks is mapping open water bodies accurately. Remotely sensed data provide with technology on how to effectively observe land cover and especially surface water bodies. According to a review article (Huang et al., 2018) based on the number of scientific publications since 2000, satellite images have become widely used in monitoring surface water. By 2019, the publications have doubled. Surface water bodies are rivers, lakes, dams, reservoirs, etc. They are crucial water resources for both fresh-water supply and irrigation. Thus, it is of paramount importance that we keep track of their development. Water bodies are dynamic. Especially artificial water bodies such as dams and reservoirs. They shrink after the summer and expand after the snow melting. Therefore, multitemporal monitoring is strongly advisable to be used in managing man-made water bodies.

For our study, optical image data from Sentinel-2 was used. Sentinel-2 mission is part of the Copernicus programme conducted by the European Space Agency and the European Union. Sentinel-2 are two twin satellites: Sentinel-2A and Sentinel-2B launched in 2015 and 2017 (European Space Agency, 2020b). The mission provides with high-resolution optical imagery which is fully open-source and available the Copernicus Open Access Hub website (European Space Agency, 2020a). The platform uses a push-broom sensor which records multispectral images alongside a 290 km swath. The satellites provide optical image data in 13 bands with spatial resolution varying from 10m to 60m. The temporal resolution of Sentinel-2 is 5 days. The visible bands have the following parameters: blue (490nm), green (560nm), red (665) and have a spectral resolution of 10m. Some of the main purposes of Sentinel-2 are spatial planning, agro-environmental monitoring, water monitor, vegetation monitoring, etc.

There are several methods for extracting surface water from satellite data: image classification (supervised or unsupervised) applied in some scientific studies (Kaplan and Avdan, 2017), Random Forest Classification (Acharya,

Subedi and Lee, 2019) and water indices. In this paper, we present the simplest method for surface water extraction – by using a water index, namely, the Normalized Difference Water Index. Multitemporal data can map the decreasing trends in case of droughts and leakage or increasing – when snow melting. The study focuses on the usage of open-source data and software solutions.

## STUDY AREA

The focus of this paper is on the water reservoir Ogosta near the city of Montana, Bulgaria (43.38°, 23.18°). It is the fourth largest by area and second-largest by volume artificial reservoir in the country. The water body is situated 600m away and 60 m above the city. Ogosta captures the waters of the rivers Ogosta, Barzia and Zlatica. The construction was finalized in 1986 and its main purpose was for irrigation of large arable areas. Unfortunately, only half of the irrigation pipelines were built.

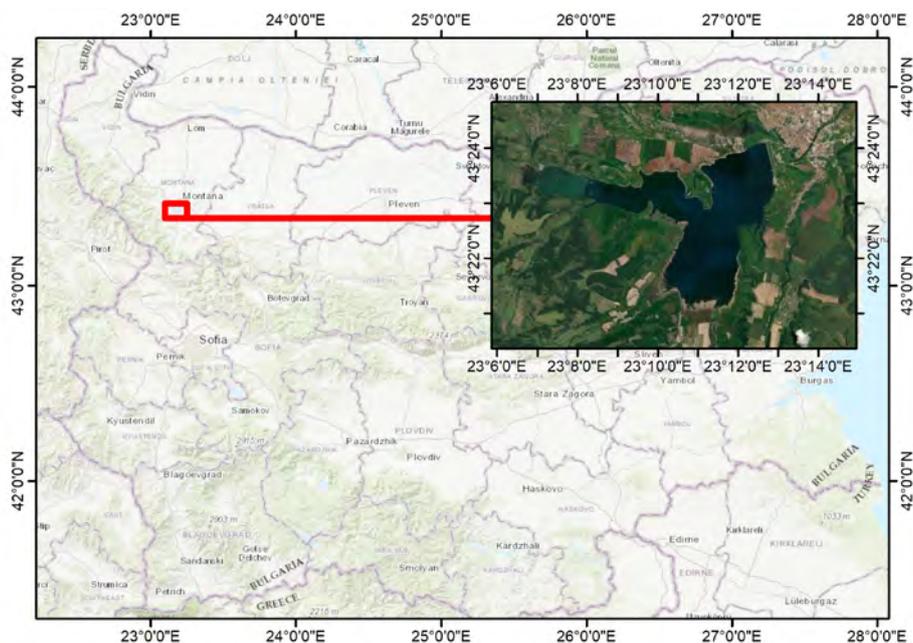


Figure 1. The geographical position of Ogosta reservoir. CS: WGS '84

Given the fact that only half of the irrigation installations are constructed, that leads to the Ogosta reservoir not being used at its full capacity. Moreover, the quality of the water is bad and that it is not used as intended. Instead of irrigation purposes, today's purpose of the reservoir is producing electricity by two water power plants. The parameters of the reservoir are stated in Table 1.

Table 1. Parameters of the Ogosta reservoir

Length	Width	Catchment basin area	Area	Average water mass per year	Volume
6.3 km	2.6 km	948 m <sup>2</sup>	23.6 km <sup>2</sup>	384 mil. m <sup>3</sup>	506 mil. m <sup>3</sup>

The dam wall of the Ogosta reservoir is probably the most notoriously discussed in Bulgaria. It is claimed that the wall is unstable, a probable landslide is discussed. The fact that the water level is 60 m above the town of Montana makes it a potential peril to the near and further settlements. The main reason we chose to analyse this reservoir is the publicity on how the water 'disappears' during the summer which is an index of dry seasons (vesti.bg, 2020), (Za vodata, 2014), (Wikipedia, 2020). Moreover, there is an active petition sent to the European Parliament for immediate actions on state of the dam wall (European Parliament, 2020).

## CURRENT STAGE OF THE PROBLEM

In Bulgaria, dam and river waters are managed by the Ministry of Ecology and Water (MEW), however, hydro-engineering constructions and riverbeds are managed by the Ministry of Regional Development and Public Works (MRDPW). As per MEW, Bulgarian territory is divided water-wise into four large groups, water-wise: East Aegean River Basin Directorate, West Aegean River Basin Directorate, Black Sea Basin Directorate and Danube River Basin Directorate (Tuntova, no date). The Ogosta reservoir is under the management of the Danube River Basin Directorate which is part of the Ministry of ecology and water. There are two important geographical information systems whose purpose is to monitor different object entities in Bulgaria and, of course, water bodies. The first one is the GIS of the Ministry of Regional Development and Public Works (see Figure 2) and the second one is by the Ministry of Ecology and Water (see Figure 3). The second GIS is more detailed as far as waters are concerned. It consists of vector data of the water bodies, as well as water catchments and control points. However, both GIS do not include multitemporal data of the water bodies.

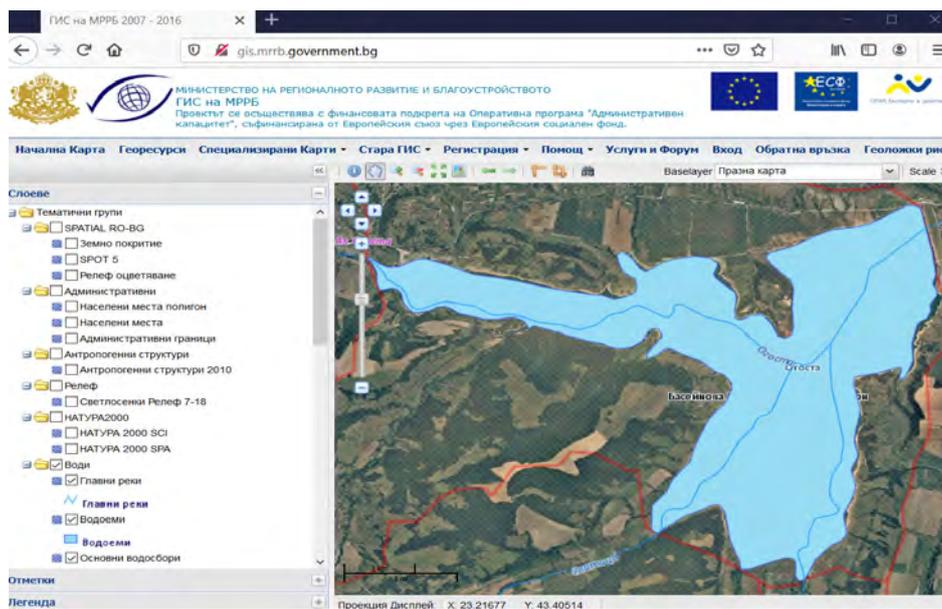


Figure 2. GIS of the Ministry of Regional Development and Public Works. The platform is available at <http://gis.mrrb.government.bg/>

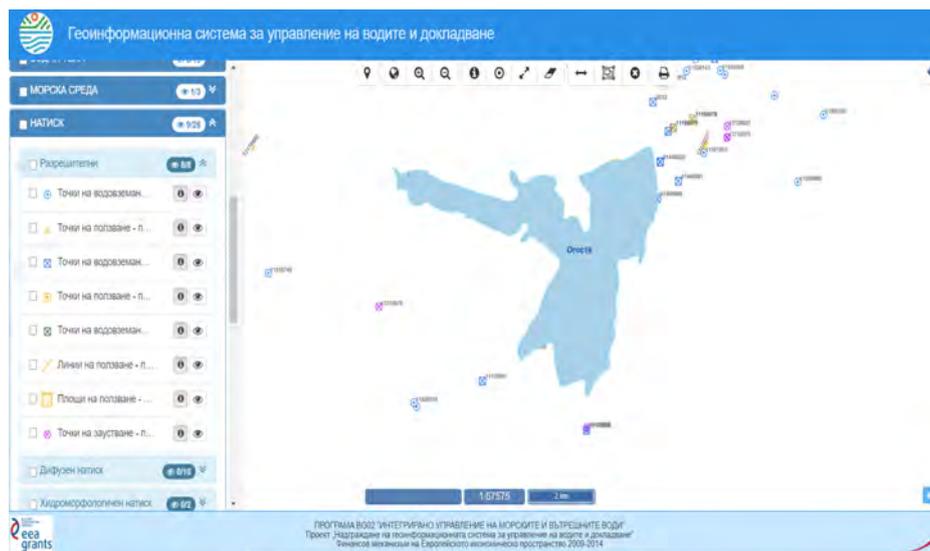


Figure 3. Geoinformation system for water management and reporting of the Ministry of Ecology and Water. The platform is available at <http://gwms.eea.government.bg/giswmr/>

## PROPOSED METHODOLOGY

In this paper, we aim at proposing a simple processing methodology for multitemporal observing of water bodies. For this purpose, we use fully open data by the Copernicus programme.

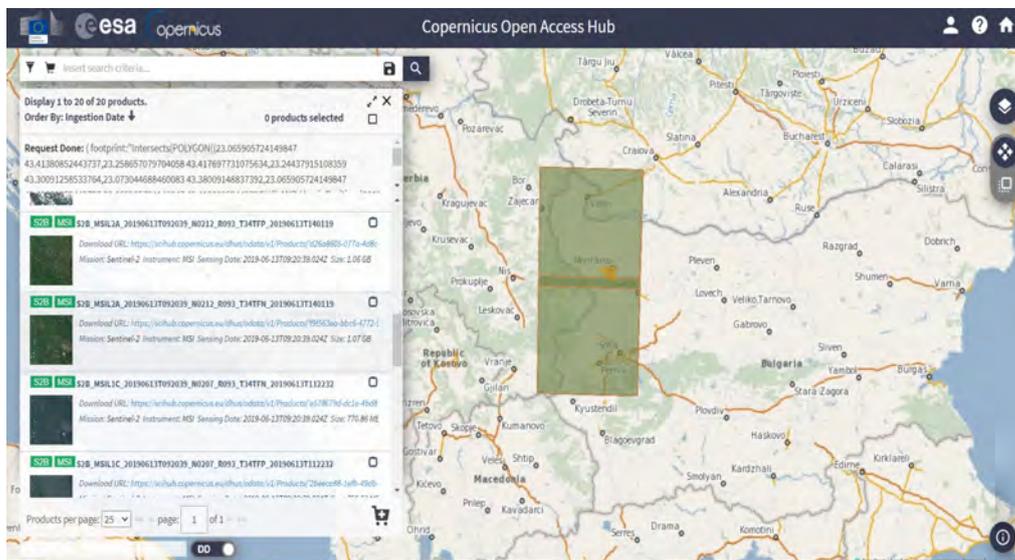


Figure 4. Copernicus Open Access Hub available at <https://scihub.copernicus.eu/dhus/#/home>. Satellite imagery is fully accessible after registration.

We opted for optical data by the twin satellites Sentinel-2. We used data from 2019. We worked with imagery after the snow melting, during the summer and imagery from the autumn (see Table 2).

Table 2. Tables should be produced directly within the text. Captions 10 pt., *Italic, Center, above the table*

Multitemporal Imagery	Scene 1	Scene 2	Scene 3	Scene 4	Scene 5
date	25 <sup>th</sup> March	8 <sup>th</sup> June	18 <sup>th</sup> July	7 <sup>th</sup> August	8 <sup>th</sup> September

Before creating a workflow, we decided to test different color composites in order to choose the methodology where water is seen as contrast as possible. We used four different approaches – true-color composite, false-color, NDWI and mNDWI. When working with Sentinel-2 data, the band order must be followed:

- RGB – or true-color composite [B4, B3, B2]
- False-color composite - [B8, B4, B3]
- NDWI – normalized difference water index –  $(B3-B8)/(B3+B8)$
- mNDWI mean normalized difference water index –  $(B3-B11)/(B3+B11)$

In true-color composite, the water does not have good contrast and could be unrecognizable. However, in the false-color composite water appears dark and vegetation reddish. When having NDWI or mNDWI water appears white and vegetation dark. Based on this analysis we concluded to work our methodology by computing the NDWI as a way of surface water extraction.

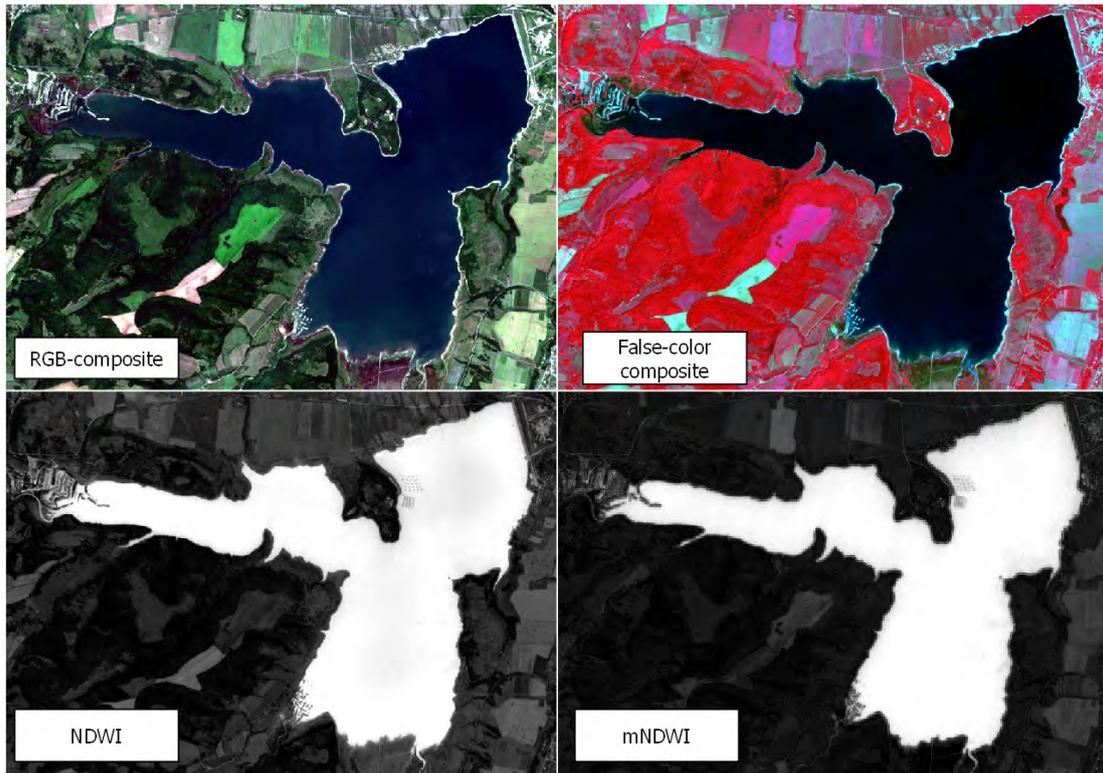


Figure 5. State of the Ogosta reservoir on 8th June seen in true-color composite, false-color composite and NDWI and mNDWI.

The postprocessing was conducted in the Sentinel native open-source software – ESA SNAP (*SNAP Tutorials / STEP*, no date). The processing workflow is shown in Figure 7. The downloaded scenes are zipped with an approximate size of 1GB. The zipped file (a.k.a. product) was imported into SNAP. We created a workflow graph to automatized the processing the multitemporal images. The graph is shown in Figure 6. The workflow was applied to all scenes. Given the fact that the spatial resolution of the channels is different, the processing step is to conduct a resampling of the bands from 10 m to 60 m. The bands with a 10m-resolution are red, green, blue and near infra-red. We chose to resample all bands to have a spatial resolution of 10m. Then we conducted a geospatial subset with predefined coordinates of the Ogosta area.

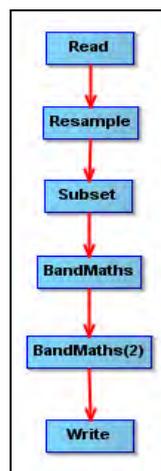


Figure 6. Automatical satellite image processing in SNAP using a graph builder

When subsetting the area of interest, one could save valued time and computer memory when applying further calculations. Thus, we calculated the Normalized Difference Water Index as per formula

$$NDWI = (B3 - B8)/(B3+B8), (1)$$

Where B3 is the green band and B8 is the near infra-red band. The green electromagnetic light has a high reflectance and the NIR band to the contrary has low reflectance. The NDWI values from a mathematical point of view belong to the interval [-1; +1].

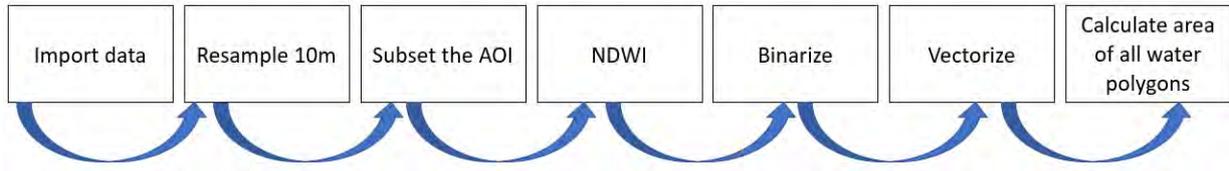


Figure 7. The workflow of the proposed methodology

After calculating the NDWI index we set a threshold to the values in order to binarize the image. The threshold was set according to Formula (2):

$$\text{if } NDWI > 0 \text{ then } 1 \text{ else } 0, (2)$$

This formula gives us a binary image where the water pixels get a value 1 and the non-water pixels – 0. The work continued in the open-source software QGIS (QGIS community, 2020). The binary images were imported and vectorize in order to get a polygon or a few polygons which contain surface water. Then we calculated the area of each water polygon and the total area of all polygons. This metadata was saved in the attribute table of every dataset.

The results from the postprocessing were compared to the surface polygon of the Ogosta reservoir is available from the European Environmental Agency. The total area of the surface polygon is 17.23 km<sup>2</sup>.

## RESULTS

The results of the analyses are monthly maps comparing the water surface status with the original water boundary. The areas are computed for each month that was observed. Given the fact that we used a predefined computation workflow, thanks to the graph builder in SNAP, the computation of 5-month worth of data was less than 3 hours.

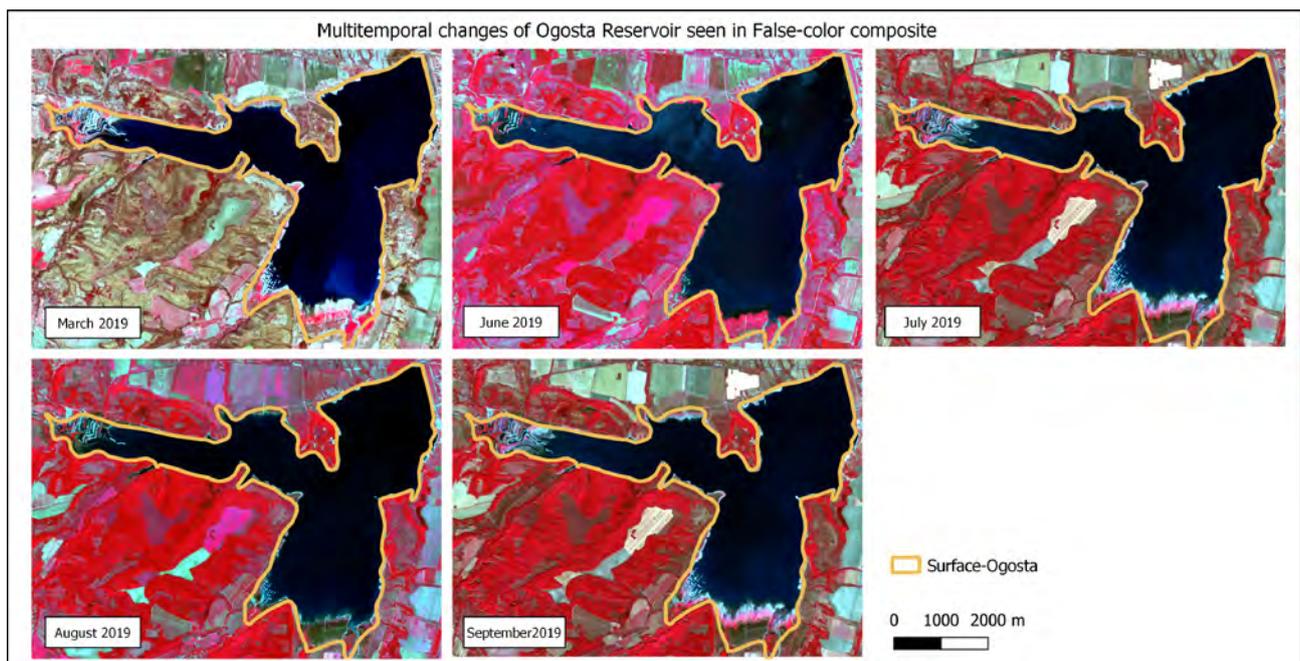


Figure 8. State of the Ogosta reservoir as per 8th June seen in true-color composite, false-color composite and NDWI and mNDWI.

The first maps in Figure 8. are false-color composites which show the exact state of the surface water. Nonetheless, the area calculations were based on vectorized binary images. The results of the surface water computations are shown in Figure 9.

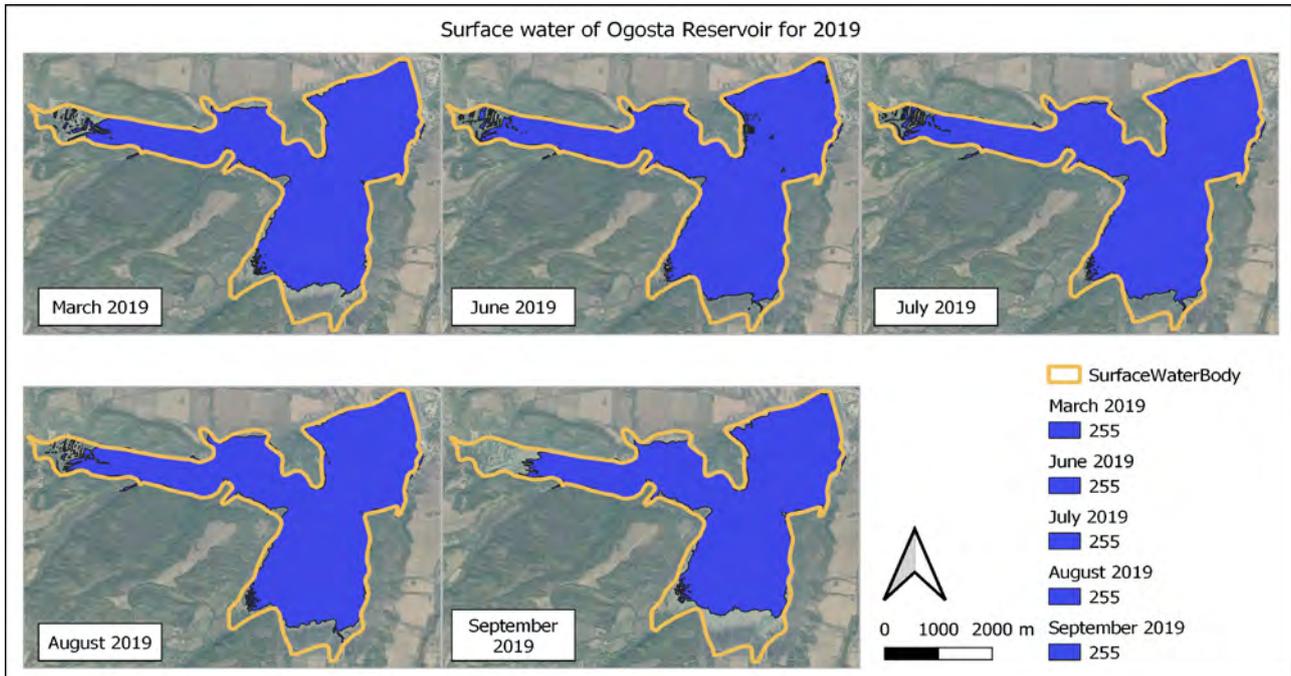


Figure 9. Multitemporal analyses of the surface water of Ogosta reservoir in 2019

The monthly calculations of the water surface area are shown in Table 3. alongside with the official area of the reservoir and the area boundary presented by the European Environmental Agency. The results show that after the snow melting, the surface area increases to 15-16 km<sup>2</sup>. The biggest area value is observed in August which is an index that 2019 was not a dry year. Judging by the results in August 2019 water was started to be released from the reservoir in the Ogosta river. This is a classical operation to prepare the reservoir area for the following autumn and winter season.

Table 3. Surface water area of Ogosta reservoir

Area [km <sup>2</sup> ]	EEA [km <sup>2</sup> ]	March [km <sup>2</sup> ]	June [km <sup>2</sup> ]	July [km <sup>2</sup> ]	August [km <sup>2</sup> ]	September [km <sup>2</sup> ]
<b>Official</b>						
<b>26.60</b>	<b>17.28</b>	14.19	15.16	15.43	15.96	13.27

We also compared the results to two area values available from official information and the data from the EEA. It is noticeable that there is a big difference between the official area value 23.6 km<sup>2</sup> and the calculated ones from 2019. This could mean that the reservoir is not being filled on purpose due to the instability of the dam wall. Another reason could be that this surface was never filled with water and this area value is a project value from the '80s.

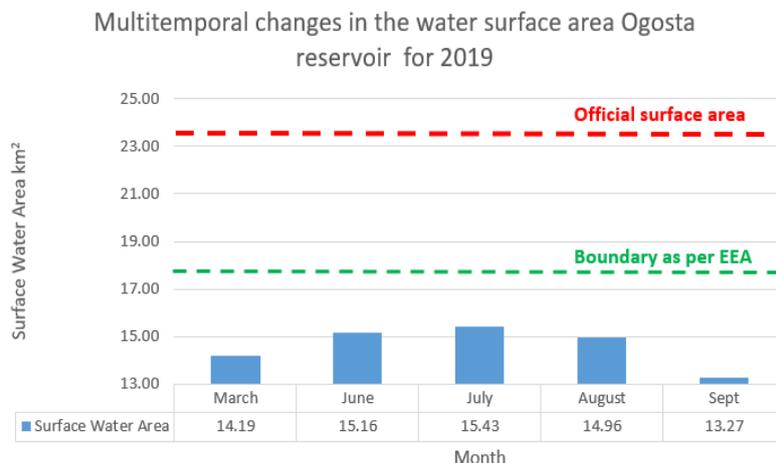


Figure 10. Comparison graph of the surface water area from 2019. Official surface water is stated to be 23.6 km<sup>2</sup>. The polygon area provided by the European Environmental Agency is 17.28 km<sup>2</sup>.

## CONCLUSION

The purpose of this study paper was to show the necessity of a multitemporal observation of large water bodies. A robust and simple methodology for multitemporal surface water analyses was presented. The data used was open-source Sentinel-2 optical satellite data. Sentinel-2 is part of the Copernicus programme by the European Space Agency and the European Union. Image processing was conducted in the native open-source software from ESA – SNAP. The workflow consisted of a graph builder for automatic computation of multitemporal data: band resampling, geographical data subset, normalized difference water index computation, computing of binary images and exporting. The rest of the processing was done in QGIS which is another open-source software GIS analyses. All binary images were vectorized in QGIS which resulted in a few water polygons. The areas of the water polygons were computed and stored in the attribute table of each dataset. The total area was then computed, and a comparison table was created – see Table 3. and Figure 10.

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# FLOOD EXTENT DETERMINATION IN AGRICULTURAL FIELDS USING SENTINEL-2 DATA AND RANDOM FOREST CLASSIFICATION

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## **Abstract**

*This study mainly aims to determine the extent of the flash flood that occurred in the Seyhan River Basin located in the Mediterranean Part of Turkey. In this region, flash floods primarily affect the agricultural fields. For the study, 20/12/2019 and 27/12/2019 dated freely available Sentinel-2 (Level-2) multispectral data were used to generate flood inundation extents of the selected test region. Object-based random forest classification was applied to determine dry and wet regions in the study area. Pre-flood maps were used to delineate the permanent water surface. The accuracy assessment of each scene was performed using randomly selected validation points. The overall accuracy of flood inundation mapping was found above 90% for both images. The results show that flash floods affect mainly agricultural fields in the region.*

**Keywords:** Flood mapping, Flood monitoring, OBIA, Random forest, Sentinel-2

## **INTRODUCTION**

Among all natural hazards, floods are the most frequent, widespread, and devastating across the world (Mallinis et al., 2011; Tsyganskaya et al., 2019). Flood damage can be classified into direct and indirect losses (Messner and Meyer, 2006). Direct losses are all kinds of detrimental effects due to physical contact with floodwaters, such as loss of life, injuries, damages to agricultural soils, livestock, and cultural heritages, harmful impact on the ecosystem, destruction of infrastructure and superstructure systems and properties (Nicholls et al., 2015). Some of the indirect effects are public service disruptions outside the flooded area, financial losses of those who have economic relations with the disaster area, the effects of the post-flood recovery process, post-disaster trauma disorders, and even loss of confidence in management and managers (Nicholls et al., 2015). Thus, floods influence human life in many aspects and lead to serious economic and also ecological damages.

Flooding occurs irregularly around the world, and it is a difficult task to measure hydraulic variables and determine flood inundated areas during the flood period whereas it is necessary for effective flood management (Balasch et al., 2019; Agnihotri et al., 2019). In this case, remote sensing provides certain advantages for flood mapping and monitoring. For instance, easy accessibility, low cost, and wide coverage of large archive optical data, and the robustness and efficiency of image processing techniques are some of these advantages (Gianinetto et al., 2006; Delen et al., 2019).

The remarkable progress of object-based image analysis (OBIA) over the past two decades has overcome the restraints of the traditional pixel-based image analysis, such as low accuracy, sub-pixel problems and the speckle noise effect, and thus enabled to produce and analyze image objects for reliable and accurate flood mapping (Dao and Liou, 2015). Although OBIA has generally used with high spatial resolution images, it has been used with medium spatial resolution images as well for flood mapping. For instance, Mallinis et al. (2015) conduct a research using Landsat Thematic Mapper (TM) and ENVISAT/ASAR images with OBIA approach to map flood extent. They concluded that the adopted approach provided satisfactory overall accuracy results. Besides, it was stated that the OBIA approach can be more integrated with ease into and political decision-making and social understanding. In another study, Dao and Liou (2015) aimed to map flood inundation areas using Landsat-8 images and estimate affected rice fields using MODIS vegetation index products based on OBIA. It was reported that an overall accuracy of higher than 95% was achieved for flood mapping.

Apart from medium-resolution data such as Landsat, the Sentinel-2 mission has contributed significantly to these researches since 2016. Sentinel-2 mission provided a great opportunity for researchers and decision-makers with high spatial resolution and high temporal frequency.

The main purpose of this research is to determine the flash flood extent caused by heavy rain that occurred in the Seyhan River Basin in December 2019, using freely available Sentinel-2 Multispectral Instrument (MSI) images. To extract the flood inundation areas from pre-flood and post-flood images, an object-based random forest (RF) classifier is adopted in the research.

## **STUDY AREA AND DATA**

### **Study Area**

Seyhan River Basin is located in the Mediterranean region of Turkey. Seyhan River is one of the most important rivers in the basin, which is one of the biggest rivers pouring into the Mediterranean Sea in Turkey. The Mediterranean climate is dominant in the selected region (Figure 1a), where winters are warm and rainy, and summers are hot and dry. Agriculture is an important economic sector with both open agricultural fields and greenhouse activities. The flood generally occurs in December-May in the region due to the rain and melting of snow. Moreover, the floods mainly affect the agricultural fields and greenhouses in the region, and it causes serious economic losses especially for the local farmers and rural communities.

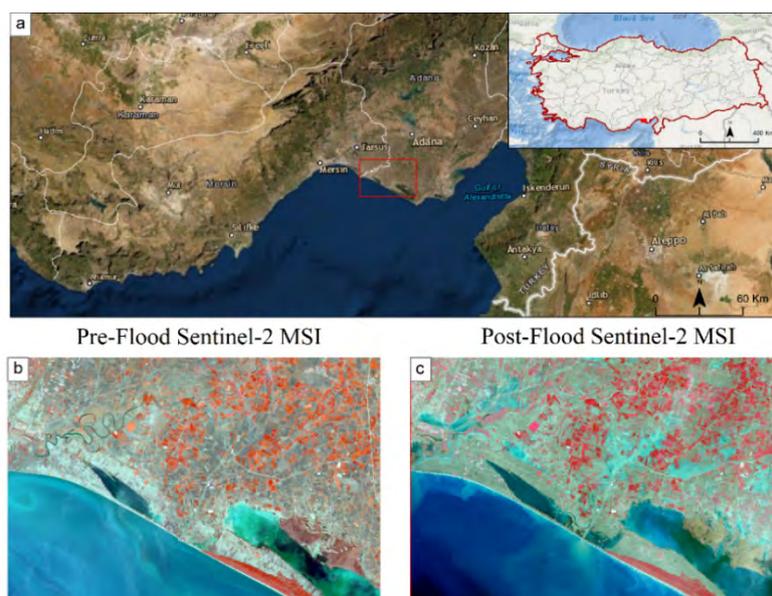


Figure 1. a) Location of the selected study area, and b) pre-flood and c) post-flood Sentinel-2 MSI images in false-color composition.

## Data

Freely available Sentinel-2 MSI data corresponding to pre-flood (2019-12-20) and post-flood (2019-12-27) periods were used for the analysis (Figure 1b and 1c). Sentinel-2 MSI has a swath width of 290 km with high revisit time. It includes 13 spectral channels with a ranging spatial resolution of 10 m to 60 m in the visible, near infrared (NIR), and short-wave infrared (SWIR) regions of the electromagnetic spectrum. In this research, blue, green, red and NIR bands were used for the analysis as these bands have a spatial resolution of 10 m. The specifications of the used bands were presented in Table 1.

Table 1. Corresponding band specifications.

Bands	Central Wavelength (nm)	Bandwidth (nm)	Spatial Resolution (m)
Blue – Band 2	490	65	10
Green – Band 3	560	30	10
Red – Band 4	665	30	10
NIR – Band 8	842	115	10

## METHODOLOGY

The adopted methodology of the research was given in Figure 2. The first step of the study is segmentation of the pre-flood and post-flood Sentinel-2 MSI data. The second part is the feature extraction using different statistics and indices. The third step is the object-based classification using RF classifier, and classification accuracy assessment is the last stage of the study.

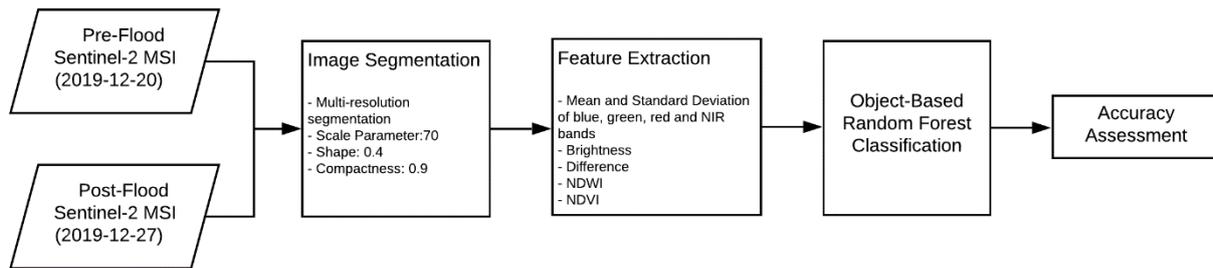


Figure 2. Work flow of the research.

The first step of the OBIA is image segmentation. The segmentation stage of the Sentinel-2 MSI images was conducted using multi-resolution segmentation (MRS) algorithm. MRS is a bottom-up region merging method based on the intended objects to be segmented (Baatz and Schape, 2010; Tian and Chen, 2007). There are three key parameters determined the outcome of the MRS; scale parameter, shape and compactness. These parameters were determined with the systematic trial and error approach by visual interpretation. It should be noted that OBIA was conducted using eCognition Developer 9.0 software (eCognition Developer 9.0.1 Reference Book, 2014)

After the image segmentation stage, basic spectral information (mean and standard deviation of R, G, B, and NIR bands, brightness and difference), and remote sensing indices which are normalized difference water index (NDWI) and normalized difference vegetation index (NDVI) were extracted for each image objects. NDWI was proposed by Mcfeeters (1996) to determine open water features. This index utilizes the reflectance of the water in the green band and NIR band. In NDWI, vegetation and soil usually have zero or negative values, while water features have positive values. The formulation of NDWI is given in Equation 1.

$$NDWI = \frac{Green - NIR}{Green + NIR} \quad (1)$$

NDVI is one of the most frequently used remote sensing indices, mainly for vegetation researches. NDVI proposed by Rouse et al. (1976) is defined as the difference between reflection in red and NIR bands divided by their sum (Equation 2). NDVI can be used for the distinction of vegetation and other land covers such as soil and water due to their reflectance values. Thus, this index is adopted since the agricultural fields are the dominant land cover in the selected region.

$$NDVI = \frac{NIR - Red}{NIR + Red} \quad (2)$$

The third step of the study is object-based image classification, which is conducted using RF classifier. In RF, which is based on a machine-learning algorithm, the training data set and a set of variables were trained by sampling individually via bagging or bootstrap aggregating. There are two main parameters of RF; the number of active variables in the random subset at each node and the number of trees in the forest (Breiman et al., 1984). In this research, the number of trees was fixed to 200, and the number of active variables was set to the square root of the features numbers based on literature research.

The last stage of the research is accuracy assessment. The classified pre-flood and post-flood maps of the region were evaluated by creating an error matrix with validation samples. Kappa coefficient and overall accuracies (OA) were assessed to evaluate the accuracy of the images.

## RESULTS

Image segmentation, which is the first phase of the study, was conducted using MRS. According to the trial-and-error approach, scale parameter, shape and compactness were determined as 70, 0.4 and 0.9, respectively. Additionally, since the reflectance of water in NIR band is lower than other bands, the weight of the bands was specified as 1, 1, 1 and 2 for R, G, B and NIR bands respectively to improve segmentation. Figure 3 shows the sample region for segmented pre-flood and post-flood Sentinel-2 MSI images.

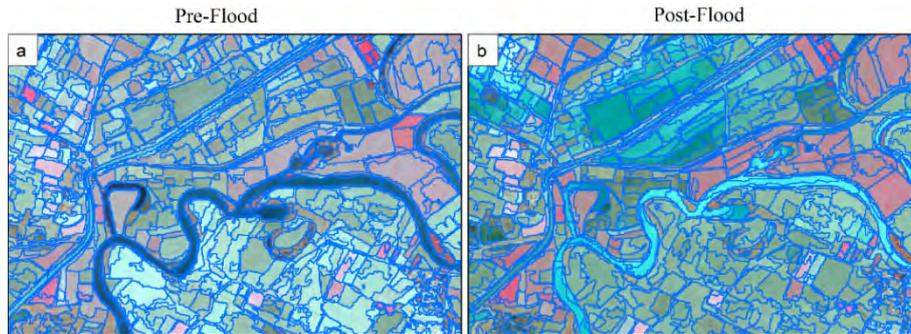


Figure 3. Image segmentation results of sample region for (a) pre-flood and (b) post-flood Sentinel-2 MSI images.

Within the context of research, pre-flood and post-flood Sentinel-2 MSI images were classified using the object-based RF algorithm. Training samples and selected features (basic spectral information, which are mean and standard deviation of blue, green, red and NIR bands, brightness and difference, and remote sensing indices which are NDWI and NDVI) were used to train the algorithm. A total of 490 objects for pre-flood and 469 objects for the post-flood image were used as training samples. Detailed information on training and validation samples were given in Table 2. Classified pre-flood and post-flood maps were presented in Figure 4a and 4b. Additionally, change from pre-flood to post-flood maps were determined both visually and statically. In Figure 4c, change from non-water to water were given and three selected sub region were visualized on high-resolution imagery. According to the statistical analysis, it has been found that 7391.73 ha area has been flooded in the selected test region.

Table 2. Detailed information on training and validation samples.

		Training Samples		Validation Points
		Number of objects	Number of pixels	
Pre-flood	Water	117	201548	68
	Non-water	373	191799	162
Post-flood	Water	149	293023	106
	Non-water	320	156755	124

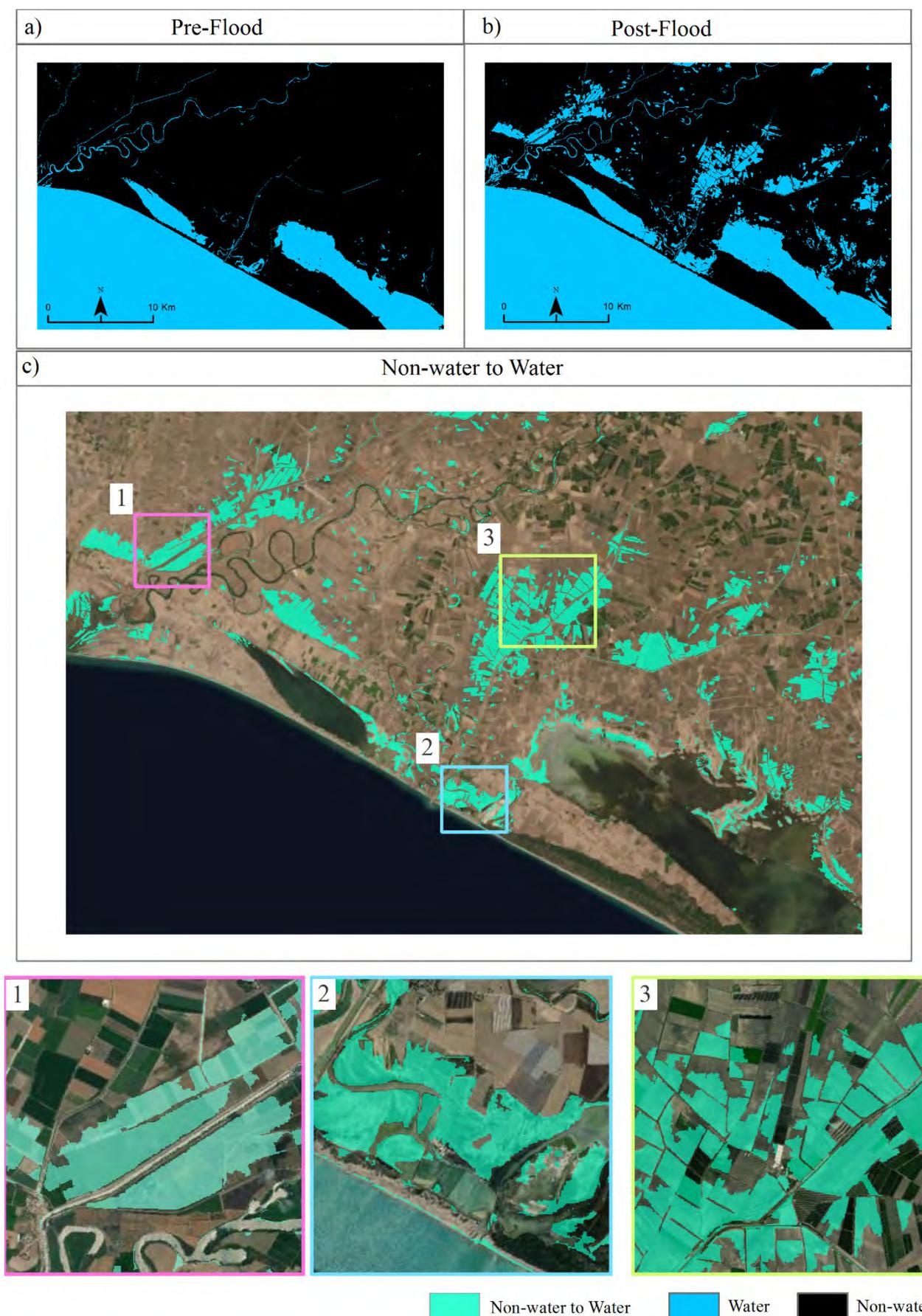


Figure 4. Classification results of (a) pre-flood and (b) post-flood Sentinel-2 MSI images and (c) change from non-water to water.

In order to evaluate the accuracy of the produced maps, a total of 230 validation samples were used for both pre-flood and post-flood Sentinel-2 images. Error matrices were constructed and OA and Kappa statistics were calculated. According to the accuracy assessment results (Table 3), OA of 96.09 % and 95.65 % were achieved for pre-flood and post-flood maps, respectively. The main reason for the misclassified water pixels in the pre-flood image is the classification of some small rivers and canals as non-water due to the spatial resolution of the image. A similar situation was seen in the post-flood image as well.

*Table 3. Accuracy assessment results of the pre-flood and post-flood classified Sentinel-2 MSI images.*

	OA (%)	Kappa
Pre-flood	96.09	0.903
Post-flood	95.65	0.912

## CONCLUSION

The usability of Sentinel-2 MSI data for flood mapping was investigated using an object-based random forest classifier in this research. The results showed that applied methodology was very successful for flood mapping with over 0.9 Kappa statistics. Machine-learning based algorithms such as random forest are quite promising for flood mapping along with object-based image analysis. Flood events are the most frequent and widespread natural hazards worldwide, and they can have hugely devastating economic, social, and environmental impacts. In the selected test site, which is located in the Mediterranean region of Turkey, flooding is a catastrophic natural disaster, especially for greenhouses and farmlands. With freely available satellite images like Sentinel-2 and advanced image processing algorithms, it provides a great advantage for monitoring this phenomenon. Moreover, rapid, accurate and timely information on the extent of flooding is very essential for decision-makers, crisis management authorities, relief organizations and insurance companies.

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## BIOGRAPHY



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# ANALYSING FLOOD AFFECTED REGION IN MERİÇ RIVER BASIN USING SENTINEL-1 AND SENTINEL-2 DATA

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## **Abstract**

*This study mainly has two significant aims; (1) investigating the efficiency of using freely available Sentinel-1 and Sentinel-2 data to analyze flood events in Meriç River Basin and (2) determining the flood extent occurred in January, 2019. Flood events in Meriç River Basin are caused by both the overflow of Meriç River and heavy rain. Sentinel-1 (C band) data acquired in interferometric wide swath (IW) mode and Sentinel 2 MSI images were used for the analysis. Firstly, Sentinel-1 scenes were preprocessed. Then, normalized difference water index was derived from Sentinel-2 MSI images. The thresholding technique has been performed for mapping flood inundation areas. The results yield that microwave remote sensing data with the support of optical data have a great potential for flood inundation mapping and monitoring for decision-makers and effective disaster management strategies.*

**Keywords:** Flood extent, Flood inundation mapping, SAR, Sentinel-1, Sentinel-2

## **INTRODUCTION**

Flood-related damages affected more than two billion people between 1998 and 2017 (WHO, 2020) and currently cause an economic loss of USD 40 billion every year (OECD, 2016). Moreover, the number of floods has increased over time. For instance, while the number of floods in European river basins was 11 between 1950-1959, this number rose to 64 between 1990-1999 (Barredo, 2006). In addition, various studies have revealed that human-induced climate change is one of the factors that cause floods (Kundzewicz et al., 2013; Arnell and Gosling, 2014; IPCC, 2014). That is, since climate change is very likely to be a significant threat in the future, it can be deduced that the number and damage of floods will increasingly continue.

The facts that the number of floods tends to rise and that they will lead to serious losses reveal the importance of being informed of the issue. Indeed, in order to develop effective responses and mitigate the consequences, several individuals and organizations such as national and local governments, decision-makers, disaster managers, and the local community

should have precise, accurate, and timely information regarding the extent of the floods (Mallinis et al., 2011; Tsyganskaya et al., 2019). In this sense, remote sensing technology and implications are one of the most efficient and cost-effective ways to generate accurate and fast flood mapping that can be used for assessments of flood damage, flood hazard, flood risk and flood vulnerability (Mallinis et al., 2011; Dao and Liou, 2015; Delen et al., 2019).

For flood mapping, both optical and passive remote sensing sensors have been used in different studies. The water surfaces can be extracted directly and reliably with the help of water indices like normalized difference water index (NDWI) from optical remote sensing data. However, optical observations are limited by clouds and unclear weather conditions (Shen et al., 2019).

In particular, microwave remote sensing becomes even more important since it is, unlike passive systems, capable of monitoring day and night in all weather conditions. Since it can detect the flooded area on a large scale and independent of borders without being affected by illumination and different weather conditions, Satellite Synthetic Aperture Radar (SAR) is considered very effective and useful for flood mapping (Tsyganskaya et al., 2019). As of October 2014, the Sentinel-1 satellite constellation has been providing continuous imagery at C-band SAR data with relatively short repetition interval (Tsyganskaya et al., 2019). By making SAR data available through the Sentinel-1 C-band SAR mission, the European Space Agency (ESA) provided great convenience for flood mapping activities (Uddin et al., 2019), which is essential for an effective flood emergency response.

Various approaches have been developed to extract water surface from SAR images with the presence of increasing temporal and spatial resolution data. One of these approaches is backscatter histogram thresholding, which is widely preferred in flood mapping studies as it is computationally less-time consuming (Liang and Liu, 2020).

The main objective of this research is to investigate the efficiency of freely available Sentinel-1 SAR and Sentinel-2 Multispectral Instrument (MSI) images for flood mapping in the selected test site of Meriç River Basin. For this purpose, backscattering responses of pre-flood and post-flood SAR images were analyzed. Moreover, NDWI was derived from pre-flood and post-flood Sentinel-2 MSI images in the selected region.

## STUDY AREA AND DATA

### Study Area

Meriç River Basin is located in the southwest part of the Sub Thrace Region of Turkey, in Edirne province. The area is a transboundary zone since Meriç River forms a border between the riparian countries. Turkey Part of the Meriç River Basin is listed as one of the Nationally Important Wetlands of Turkey. It comprises coastal lagoons, freshwater lakes, reed beds, and extensive agricultural fields that are mostly paddy fields. Besides, it was listed as an Important Bird and Biodiversity Area, Natural Conservation Area, and Protected Site since 1991. The area is mostly exposed to floods due to the overflow of the Meriç River or heavy rain. Floods occurring in the basin affect not only the living conditions of people but also the economy of the region since agriculture is the main source of income. The location of the study area was given in Figure 1.

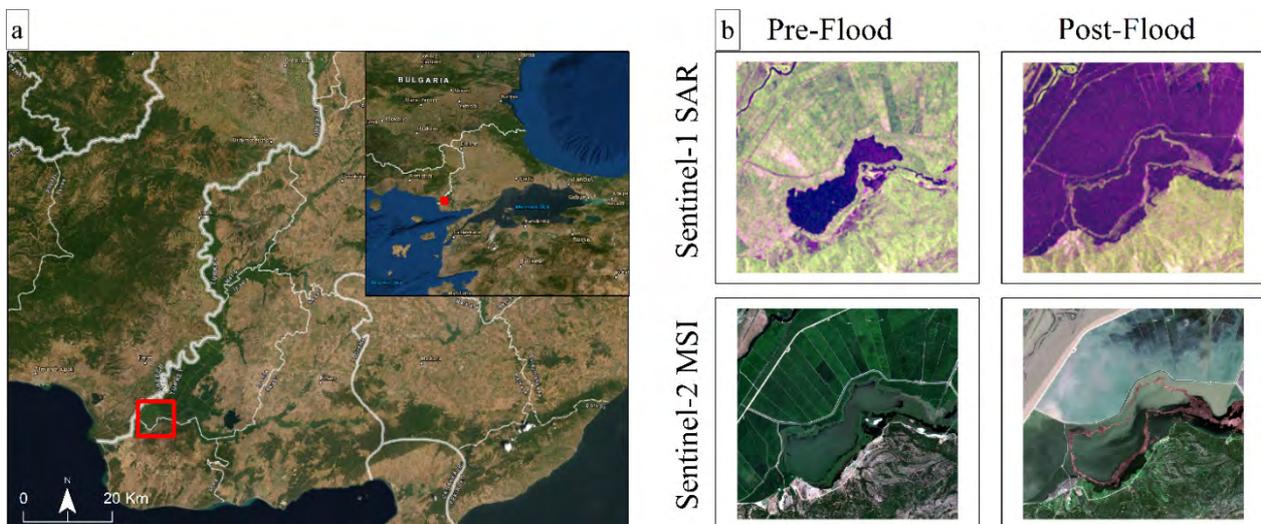


Figure 1. (a) Location of the study area and (b) pre-flood and post-flood images of Sentinel-1 (R:VV, G:VH, B: VV/VH) and Sentinel-2 MSI (true color).

## Data

New generation freely available Sentinel-1 SAR and Sentinel-2 MSI images were used in the research. Sentinel-1 C-band SAR and Sentinel-2 MSI Level 2A (surface reflectance) scenes corresponding to pre-flood and post-flood were downloaded from the Sentinel Scientific Data Hub (<https://scihub.copernicus.eu/>). Sentinel-1 SAR scenes which are acquired in the Interferometric Wide swath (IW) Ground Range Detected in High resolution (GRD) mode used for the analysis. GRD products include focused SAR data that are detected, multi-looked and projected to ground range using an Earth ellipsoid model. Additionally, Sentinel-1 acquires images in both like-polarized (vertical transmit and vertical receive (VV)) and cross-polarized (vertical transmit and horizontal receive (VH)). It has a swath width of 250 km at 5 m (ground range) by 20 m (azimuth) spatial resolution and 10 m x 10 m (range x azimuth) pixel spacing. On the other hand, Sentinel-2 MSI has a swath width of 290 and acquires images in 13 spectral bands with different spatial resolutions ranging from 10 m to 60 m. In this research, visible (R, G, B) and near-infrared (NIR) bands that have a 10 m resolution were used. The specifications of used data were given in Table 1.

Table 1. Specifications of the Sentinel-1 and Sentinel-2 data used in the research.

Sensor	Specifications			
Sentinel-2 MSI (Level 2A)	Date	Pre-flood - 2017.08.11	Post-flood - 2018.04.03	
	Used Bands	Band Name	Central Wavelength ( nm)	Bandwidth
		Blue	490	65
		Green	560	30
		Red	665	30
NIR	842	115		
Sentinel-1 SAR (C-Band)	Date	Pre Flood - 2017.08.11	Post Flood - 2018.04.02	
	Orbit	Ascending		
	Product Level	Level-1 GRD		
	Acquisition mode	IW mode		

## METHODOLOGY

The conducted methodology in the study was presented in Figure 2. It includes four major sections; (i) preprocessing of the pre-flood and post-flood Sentinel-1 data, (ii) calculation of NDWI from Sentinel-2 data, (iii) mapping flood inundation areas using thresholding technique and (iv) accuracy assessment.

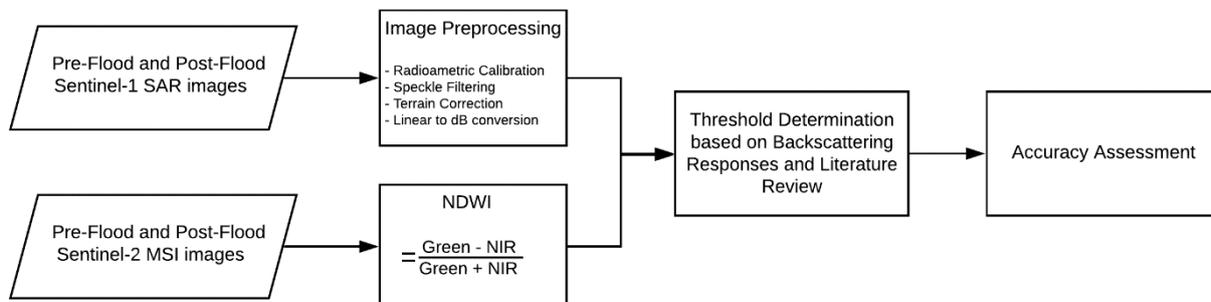


Figure 2. The conducted methodological flow of the research.

The preprocessing of the Sentinel-1 SAR image was conducted in SNAP software, and the following steps were applied. First, the Sentinel-1 GRD IW image was applied to the orbit files and radiometrically calibrated to the radar backscatter sigma0. Then, the noise speckles, which decrease the quality of the image, were reduced using a  $7 \times 7$  Lee Sigma Filter. The geometry of SAR images was corrected by applying terrain correction with a 3 sec SRTM (Shuttle Radar Topography Mission) digital elevation model. Lastly, linear to dB conversion was applied to VH band.

The water pixels were extracted from the Sentinel-1 VH polarization image and NDWI derived from the Sentinel-2 MSI image using the thresholding technique. Since the water pixels have low backscattering due to the specular nature of water against microwave signals, water surfaces appear in darker tones (Agnihotri et al. 2019). The backscattering responses of water surfaces, flooded areas and other surrounding land covers were analyzed in the Sentinel-1 VH and VV images. According to the analysis of the flooded areas in the pre-flood and post-flood images of VV and VH polarizations, it was decided to work with VH polarizations due to the low backscattering responses of agricultural areas in VV polarization images. The threshold values for pre-flood and post-flood images were determined based on the analysis of backscattering coefficients and histograms of the images. Apart from that, NDWI images were derived from the Sentinel-2 MSI images. NDWI is a remote sensing index which is developed to determine open water surfaces. NDWI, which is proposed by Mcfeeters (1996), takes advantage of the water reflectance in the green and NIR band. The pixel values of NDWI ranges between -1 to +1. Positive values show the water features, while negative values represent the other land features. The following equation shows the formulation of NDWI.

$$NDWI = \frac{Green - NIR}{Green + NIR} \quad (1)$$

As the last step, the accuracy of the produced pre-flood and post-flood maps was evaluated by the construction of error matrices. Kappa coefficients (K) and overall accuracies (OA) were calculated to assess the accuracy.

## RESULTS

Within the context of the study, firstly, SAR images were preprocessed, and then flood maps were generated from Sentinel-1 SAR and Sentinel-2 MSI images. In accordance with the methodological flow of the research, the threshold for the extraction of water features from NDWI was determined as zero based on literature research. Moreover, the threshold for VH band of Sentinel-1 SAR was determined as -23 dB for pre-flood and -25 dB for post-flood images according to the backscattering histogram analysis of the images. Histogram of the VH bands corresponding to the pre-flood and post-flood images were given in Figure 3.

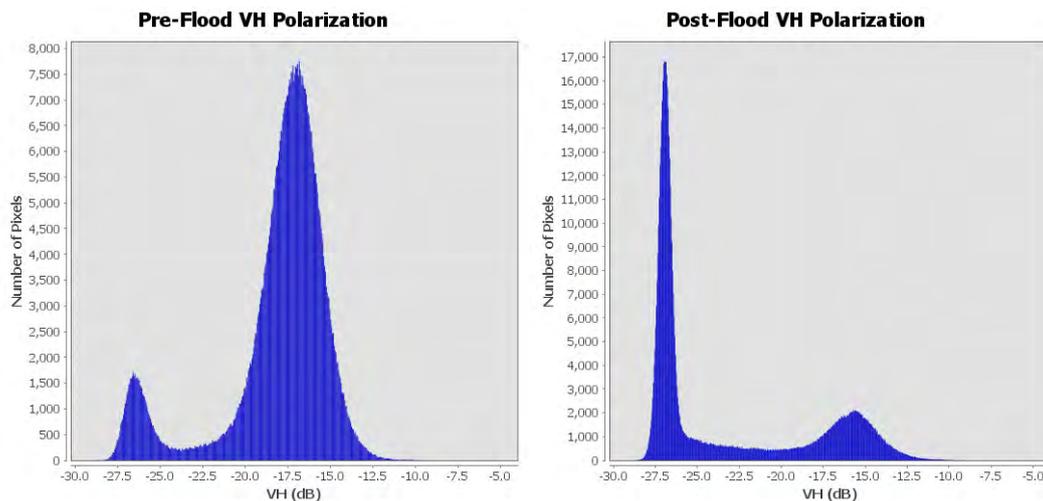


Figure 4. Histograms of Sentinel-1 SAR VH bands.

Flood maps were produced as water and non-water classes. The original Sentinel-1 SAR VH band image, NDWI derived from Sentinel-2 MSI, and produced pre-flood and post-flood maps were presented in Figure 4.

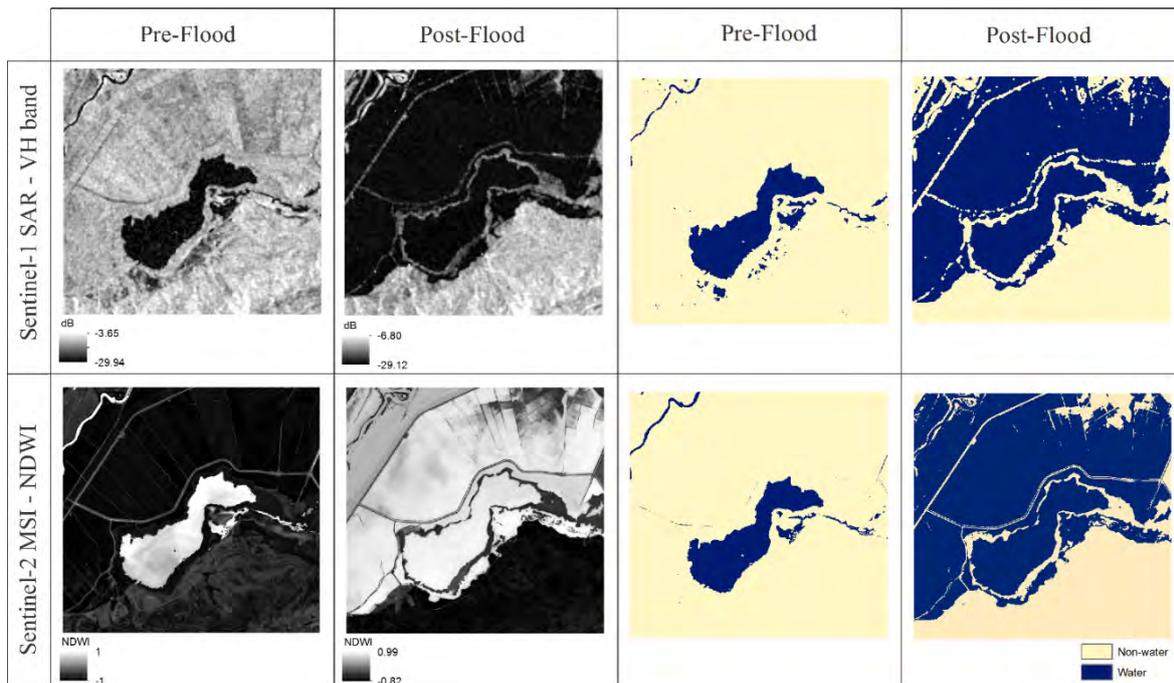


Figure 4. Sentinel-1 SAR VH and NDWI derived from Sentinel-2 MSI for pre-flood and post-flood period, and produced pre-flood and post-flood maps results.

Based on the produced pre-flood and post-flood maps from images, classification accuracy has been evaluated by the construction of a confusion matrix for the class ‘water’ and ‘non-water as listed in Table 2. The results yield that Sentinel-1 SAR and NDWI derived from Sentinel-2 MSI reached over 90% of OA and 0.88 of Kappa values. In detail, Sentinel-2 MSI has reached higher accuracy than Sentinel-1 SAR for both pre-flood and post-flood maps. On behalf of the results, 51.1% and 53.6% of the region has been flooded with Sentinel-1 SAR and Sentinel-2 MSI images, respectively.

Table 2. Accuracy assessment results of the pre-flood and post-flood classified images.

	Sentinel-1 SAR VH Band		Sentinel-2 MSI - NDWI	
	OA (%)	Kappa	OA (%)	Kappa
Pre-flood	93.0	0.89	97.0	0.94
Post-flood	91.0	0.88	99.0	0.97

## CONCLUSION

In this study, the usability of Sentinel-1 SAR and Sentinel-2 MSI data for flood mapping was analyzed in the Meriç River Basin, Turkey. The results showed that both data are very successful for flood mapping yielding over 90% overall accuracy using thresholding, which is a rapid method. Pre-flood and post-flood maps obtained with Sentinel-2 MSI were reached higher OA and Kappa values than Sentinel-1 SAR images. On the one hand, every method and data has its advantages and disadvantages for flood mapping. On the other hand, it should not be overlooked that Sentinel-1 SAR data has a great advantage in flood mapping, especially rainy weather, which is a common fact in flood events. However, it should be noted that Sentinel-1 data should be subjected to more preprocessing steps and that each of these steps has an impact on the output bands. In this study, only one method was tested for only one test area. Different classification methods, such as object-based image classification and different test areas with different land cover, should be examined in the following studies.

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## BIOGRAPHY



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# APPLICATION OF NDVI INDICES IN STUDYING FORESTS AFFECTED BY BIOTIC FACTORS USING UAV DATA

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## **Abstract**

*Deforestation is a problem that is in the focus of current research in Bulgaria and many other countries. In recent years, Bulgarian forests have experienced various phytosanitary problems. The national forest information system SYSYTEM.IAG.BG registers forest stands' damages of different types and levels. Conducting analysis of the state of forests and assessing tree health require accurate and current data. In this publication, we propose the use of data from unmanned aerial vehicles (UAV). Photogrammetry and remote sensing provide the necessary methods for mapping damaged forest stands and assessing their state. The aim of this study is to extract accurate data about forests affected by biotic factors using NDVI indices from processing of multispectral images. The specialized software ERDAS provides methods for automated analysis and mapping of problematic forests. The results of using up-to-date and high-resolution UAV images provide timely operational information on the current state of forest areas. The obtained spatial data allow a complex analysis of the biotic and abiotic causes of forest areas damages. The results of the analysis can enable adequate decision-making regarding the protection and conservation of forest areas.*

**Keywords:** remote sensing, unsupervised classification, thematic mapping, UAV

## **INTRODUCTION**

The study of forest health status has economic and social importance. Scientific research in this area can help protect the economic, ecological, and protective functions of the forest and can help ensure the forest resilience in the face of current and future climate change impacts. The general state of forest areas in Bulgaria is good: according to the data of the Executive Forest Agency (EFA) diseases and pests significantly affect only 1% of the overall forest surface. Reports from the last seven years from the respective institutions in Bulgaria show that damages by insects (bark beetle) at the coniferous forest of Scots pine (*Pinus sylvestris L.*) and damages by pathogens at the plantations of Austrian pine (*Pinus nigra*) have had the biggest impact on forest health [7], [8].

Desiccation of *Pinus nigra* plantations due to fitopathogen fungi appeared in Bulgaria in the last six-seven years. The desiccation process has had various intensities and was observed mainly in plantations growing at 700m altitude and 20-60 years old.

Immediately after discovering the first cases in the Plovdiv District, experts from different institutions (EFA, Forest Research Institute – Bulgarian Academy of Science, and University of Forestry) performed forest pathological examinations of the affected areas. As a result, urgent administrative and organizational measures have been taken to limit the spread of the disease. Despite these activities, the health problems of the pine plantations have intensified: the desiccated territories increase every year and now cover various parts of Bulgaria [9].

With the advances in remote-observation sensors technology, experts can now receive current and more accurate high-quality data, allowing for: rapid detection of newly damaged areas; successful resolution of phytosanitary forest problems; selection of activities that counter diseases and pests and ameliorates damages. With all these improvements, the forest activities on the field should be more timely and reduce the volume of the damages and economic losses.

We performed remote extraction of precise data on the health status of pine (*Pinus nigra*) plantations affected by pathogens. We used NDVI indices and automatic processing of color and multispectral images from UAV. We took advantage of specialized software (ERDAS, Pix4D) to provide us with automatic analysis and mapping of affected areas as well as assessment of the damage level.

## METHODOLOGY

### Spectral Indices for vegetation analysis

Spectral indices of the vegetation have a wide range of applications in vegetation analysis and status assessment (Table. 1). Besides the most popular NDVI (Normalized Difference Vegetation Index), a number of other known indices are used in the determination of quantitative indicators and for the reduction of soil, atmosphere, and topography influences.

Every index is expressed by a formula for mathematical operation that involves data (from various spectral channels such as water content, chlorophyll, pigment, etc.) which contain two or more different wavelengths. That data reveals specific quantitative characteristics of vegetation. When the operation uses data from multi-temporal images from the same channel, the index helps track changes in vegetation and the dynamic of its development. Some of the other vegetation indices are DVI (Difference Vegetation Index), Simple Ratio (SR), Ratio Vegetation Index (RVI), and Perpendicular Vegetation Index (PVI). NDVI is in a different group with the indices that make up for the influence of atmosphere, cloud, soil, and topography. The NDVI formulas include different combinations of data from the Red, NIR (near infrared), and occasionally Red-Edge and Green channels. Chlorophyll in plants absorbs highly in the visible zone (Red channel), whereas the cellular structure of leaves strongly reflects in the NIR zone. When plants become desiccated, sick, or affected by pests or other kinds of stress, they absorb more in the NIR zone instead of reflecting it. Observing the changes in NIR (0.70-1.10  $\mu\text{m}$ ) compared to the Red zone (0.58-0.68  $\mu\text{m}$ ) gives an accurate indication of the presence of chlorophyll, which correlates with the health of the vegetation. The use of Red Edge in NDVI indices helps to assess the stress state of vegetation.

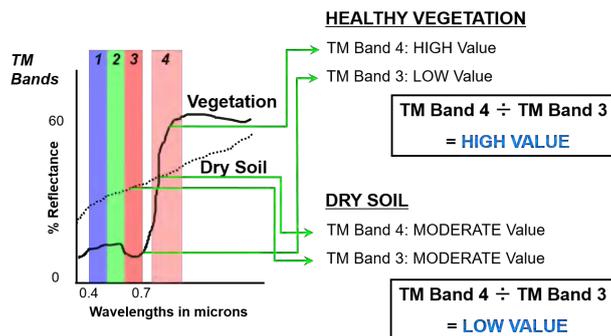


Figure 1. Surface reflectance at the thematic bands Red (Band 3) and NIR (Band 4) [12]

When conducting automated vegetation analysis using spectral indices, we have to choose values that are in the same spectral range for the respective channel, regardless of the type of sensor used. SAVI is a vegetation index for minimizing the influence of soil. The ARVI index is adapted to account for atmospheric factors (such as water vapor and aerosols) and to be sensitive to topographic elements. The improved EVI index is intended for the simultaneous correction of NDVI for the influence of atmospheric factors and soils in forest areas. This index's values for healthy vegetation range from 0.2 to 0.8 [4]. The GCL index is used to assess the content of leaf chlorophyll in vegetation. Stressed plants show decreased levels of chlorophyll; therefore the index can help assess the health of vegetation. However, the better assessment of the amount of chlorophyll is achieved by GCI using sensors with near infrared zone (NIR) and green visible zone (Green) [10]. The SIPI index is suitable for analyzing vegetation with variable canopy structure. It evaluates the ratio of carotenoids to chlorophyll. Large values of SIPI (increased carotenoids and decreased chlorophyll) are often an indicator of plant disease, which is associated with the loss of chlorophyll. The index is useful for monitoring the health of vegetation in regions with high variability in the canopy structure or leaf area index (LAI), for early detection of plant diseases or other causes of plant stress. The NBR index expresses the normalized ratio of values in the near and middle infrared zone (NIR and SWIR). It is suitable for studying areas affected by fires. Healthy vegetation shows high reflectivity in the NIR zone, while recently burned plant areas reflect strongly in the SWIR zone. The NBR index has become very important in recent years because extreme weather conditions significantly increase forest fires and destroy plant biomass [2].

Table 1. Review of vegetation Indices

Name/Reference	Formula [10], [1], [11], [5]
<b>Difference Vegetation Index</b>	
Difference Vegetation Index	$DVI = NIR - Red$
<b>RatioVegetation Indices (Band Ratios)</b>	
Greenness Index Le Maire et al. 2004	$GI = Green / Red$
Simple Ratio (SR) 800/550 Le Maire et al. 2004	$SR = NIR / Green$
Simple ratio (SRB1) 800/550 Pigment specific Blackburn 1998	$SRB1 = NIR / Red$
RatioVegetation Index (RVI)	$RVI = NIR / Red$
Datt 2 Datt 1999	$DATT\ 2 = NIR / Red\_edge$
<b>Perpendicular Vegetation Index</b>	
PVI (Perpendicular Vegetation Index)	$PVI = 1 / \sqrt{(a^2 + 1) * (NIR - a * NIR + b)}$
<b>Normalised Difference Vegetation Index</b>	
NDVI John Rouse 1973 Tucker 1979	$NDVI = (NIR - Red) / (NIR + Red)$
Green NDVI Gitelson, Merzlyak 1997	$NDVI = (NIR - Green) / (NIR + Green)$
Red-edge Index (NDRE) Barnes et al. 2000	$NDRE = (NIR - Red\_edge) / (NIR + Red\_edge)$
Red-edge Green NDVI Buschmann, Nagel 1993	$NDVI = (Red\_edge - Green) / (Red\_edge + Green)$
Red-edge NDVI Ortiz et al. 2013	$NDVI = (Red\_edge - Red) / (Red\_edge + Red)$
ARI2Anthocyanin reflectance index 2Gitelsin 2002	$ARI2 = NIR * ((1 / Green) - (1 / Red\_edge))$
NDVI Huete et al. 1997, Goward et al. 1985	$NDRI(i) = NDVI * (R_{800} / R_{680})(i) 680\ nm$
SAVI Huete	$SAVI = ((NIR - Red) / (NIR + Red + L)) * (1 + L)$
ARVI Kaufman и Tanré	$ARVI = (NIR - (2 * Red) + Blue) / (NIR + (2 * Red) + Blue)$
EVI Huete et al. 1997	$EVI = 2,5 * ((NIR - RED) / ((NIR) + (C1 * Red) - (C2 * Blue) + L))$
ERVI (i) Goward et al. 1985	$ERVI(i) = EVI * (R_{800} / R_{680})(i)$
GCI Green Chlorophyll Index	$GCI = (NIR) / (Green) - 1$
SIPI Structure Insensitive Pigment Index	$SIPI = (NIR - Blue) / (NIR - Red)$
NBR Normalized Burn Ratio Keeley, 2009	$NBR = (NIR - SWIR) / (NIR + SWIR)$

### Vegetation Indices in ERDAS IMAGINE 2020

The index models that can be applied via ERDAS IMAGINE environment are pre-configured and editable. Vegetation index formulas, recorded in the ERDAS IMAGINE modules include - DVI, MCARI2, MSAVI2, MSR705 MTVI2, NDVI, NDVI705, RDVI, RVI, SARVI, SAVI, TNDVI, VOG1, WV-VI, Wolf 2010 [10].

### Automated image processing with ERDAS IMAGINE

There are two main approaches for multispectral image classification: fully automated unsupervised and supervised. Unsupervised classification entails analysis of pixel brightness and pixel assignment to spectral classes (naturally forming groups of pixels with similar spectral qualities - clusters in the space of measurements). The individual classes must be well separated. Their identity is initially uncertain, so the interpreter must compare the results of the classification with existing data for the study area and perform a field check to determine the information classes (or interpretation classes) [3].

### STUDY SITE AND EXISTUNG DATA

The survey was conducted over a part of the forest territory of the State Forestry Enterprise (SFE) "Elin Pelin" (Sofia district, Bulgaria). The study selected a site covering forest stands affected by the action of biotic factors. The SFE team signaled the problem in April 2019 at the National Information System SYSTEM.IAG.BG [6] and the Forestry Protection Station (Sofia) performed field inspections.

The areas with desiccated forests and deteriorated phytosanitary condition are located in 6 settlements (Eleshnitsa, Potop, Gorna Malina, Sarantsi, Chekanchevo and Osoitsa) in a total of 27 forest stands (subcompartments) with an area of 203.4 ha. Pure and mixed plantations of Austrian pine (*Pinus nigra*) aged 35-85 years, relative stock 0.7-0.9, stand height 13-23 m, located at an altitude of 600-850 m are affected. The land of the village of Sarantsi, where the forest stands are most intensively affected by pathogens (*Dothistroma septosporum* and *Laphodermella*), was chosen as study site. The studied site covers 12 subcompartments with an area of 72.7 ha (Figure 2).

The study used existing vector, raster, and attribute data for the selected site (Figure 2). The vector and attribute data for the forest stands are extracted from the forest management plan (FMP) of SFE "Elin Pelin", effective since 2012. Data

for the forest areas affected by biotic factors are extracted from the information system SYSTEM.IAG.BG. Raster data from the Google Earth Pro platform was used for preliminary analysis and planning of the image-shooting activities.



Figure 2. Study site - affected forest stands according to data from SYSTEM.IAG.BG

## TECHNICAL EQUIPMENT

To achieve the aim of the research, digital images with an unmanned aerial vehicle system (UAV) have been specially made. The shooting of the selected area (Figure 2) was performed in May 2019 with two types of cameras - a standard high-resolution camera and a multispectral camera with an infrared channel.

### Unmanned aerial vehicle system

The study site was surveyed with the Swiss Unmanned Aerial Vehicle System WingtraOne with vertical takeoff and landing (VTOL), allowing the implementation of missions in hilly and forest areas. WingtraOne allows working with professional cameras. In February 2018, the WingtraOne PPK system was launched - a combination of VTOL with a Sony RX1RII 42 MP camera and PPC (Post-Processed Kinematics) - a Septentrio module, which achieves high accuracy and a new standard for photogrammetric processing of drone data with 1 cm absolute accuracy. The flight setting time is less than 5 minutes, and no additional GCP points are required for orthorectification. A Lenovo Thinkstation B30 K1 Pro professional workstation with 128 GB RAM was used for data processing.

### Sensors

Due to the specifics of the subsequent computer spectral analysis, the examination was performed with two different cameras in two consecutive flights (Figure 3):

- Sony RX1RII 42 MP color camera with high resolution and range. The obtained images allow the generation of a detailed 3D model and orthomosaics of the entire captured area;
- MicaSense RedEdge M multispectral camera with a range in five spectral zones, including the near infrared zone. The images are suitable for studying vegetation and extracting accurate geometric and qualitative information about the vitality and health of forests.

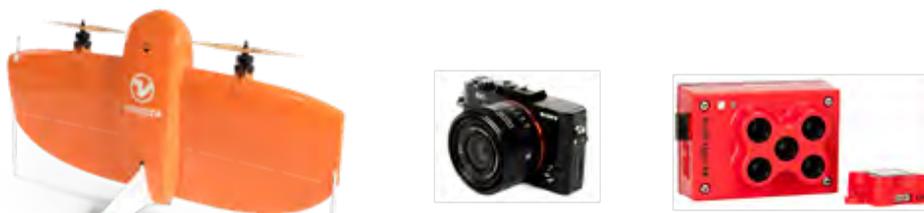


Figure 3. Technical equipment - WingtraOne, Sony RX1RII 42 MP u MicaSense RedEdge M

The multispectral camera used has five spectral channels (Table 2) - Blue, Green, Red, Red Edge, Near IR, with a resolution of Ground Sample Distance 8.2 cm / pixel (per band), altitude 120 m (400 ft), max shooting speed 1 capture per second (all bands), with 12-bit RAW Spectral Bands.

Table 2. Characteristics of the spectral channels of MicaSense RedEdge M

№	Band Name	Center Wavelength (nm)	Bandwidth FWHM (nm)	Band Range (nm)
1	Blue	475	20	465 - 485
2	Green	560	20	550 - 570
3	Red	668	10	663 - 673
4	Near IR	840	40	820 - 860
5	Red Edge	717	10	712 - 722

### Flight plan and Image Data from UAVs technology

Wingtra Pilot software was used for the planning of both flights, through which the calibration of the cameras and the planning of the air flight were performed. The studied object is defined based on a KML file under the existing vector data about the object (Figure 2). According to the flight plan, the shooting on both flights has a flight altitude of 120 m, covered area of 120 ha and duration of 48 minutes, 814 out of 964 images calibrated (84%), 5 blocks.

### Software

Initially, information about the presence of forest plantations affected by desiccation was extracted from signal sheets submitted by SFE "Elin Pelin" in the information system SYSTEM.IAG.BG. Vector and raster data in Google Earth Pro environment were used for visualization and preliminary study of the studied site (Figure 2). The flight plan was compiled and implemented using the Wingtra Pilot software. The primary processing of the obtained images from both fields was performed with the software products Pix4D Mapper and Pix4D Fields. The automated image classification is made by the ERDAS IMAGINE and Pix4D modules.

## RESULTS AND DISCUSSION

### Primary image processing

The images obtained from the Sony RX1RII 42 MP were processed into orthomosaics using Pix4D Mapper. As a result of the processing, color images with high spatial resolution in natural colors of the affected areas from pathogens diseases were obtained.

### Visual analysis of color images

Forest standards have been developed to decipher the level of damage by color images, using 5 levels - unaffected, 1/ low, 2/ medium, 3/ high affected (depending on the change in color, size of crowns and manner of distribution), and 4/ completely damaged (the crowns are of small diameter, the branches oppose each other, and are gray in color).

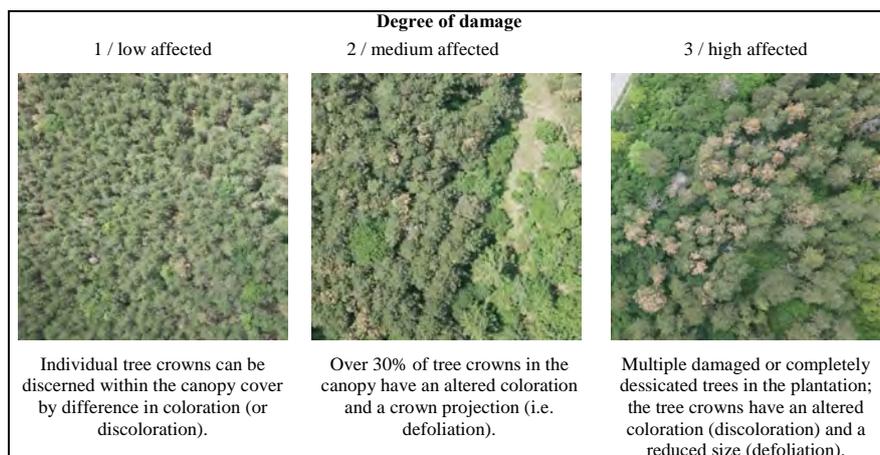


Figure 4. Degree of damage assessment by color images

## Automated analysis of the obtained raster data via Pix4D Fields

After processing the raw data, a 3D image of the captured area, high-quality TIF orthoimages with an accuracy of 1 cm, a KML file for Google Earth Pro and a digital terrain model were generated.

Multispectral analysis of the images obtained with MicaSense RedEdge via a portable computer system with Pix4D Fields installed was performed on the field immediately after the flight and the shooting of the studied object. The result and the specialized map are ready for use about 30 minutes after the drone lands.

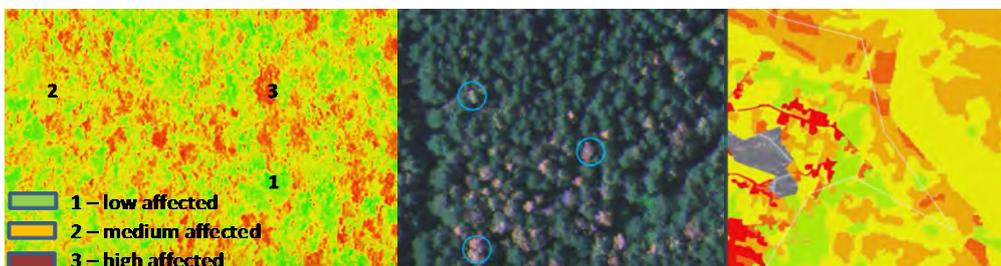


Figure 5. Result of multispectral analysis by NDRE index and assessment of the degree of damage, thematic map on the phytosanitary condition of the site

A comparison was made between the result obtained from the automated multispectral analysis of three classes and the preliminary visual interpretation of the color images (Figure 4) and the determination of the degree of damage. A thematic map of the phytosanitary condition by level of damage has been compiled.

## Image processing using ERDAS IMAGINE 2020

### Analysis of the input orthoimage

For the visualization of the study site a color composition of channels 3, 2, 1 was used (Table 3) (Figure 6 and 7) by ERDAS IMAGINE. A combination of 4, 3, 2 with the NIR infrared channel in false colors is also made, necessary for automated analysis (Figure 6 and 7). Image quality is good for interpretation purposes. The histogram has a normal distribution of the function and is suitable for the next process of automated analysis forest plantations status.

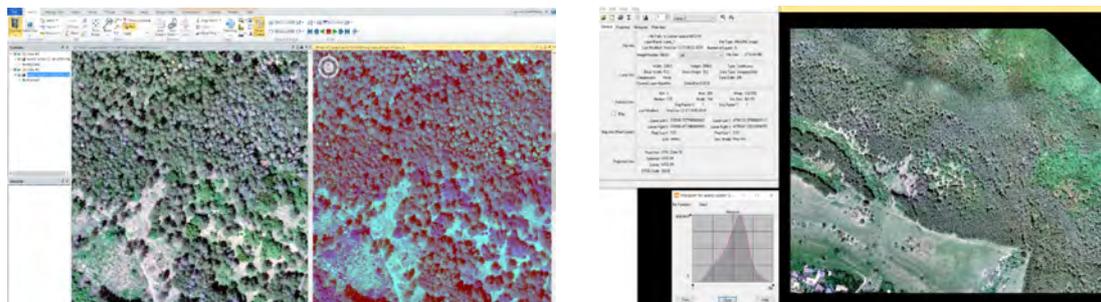


Figure 6. Color compositions and image metadata

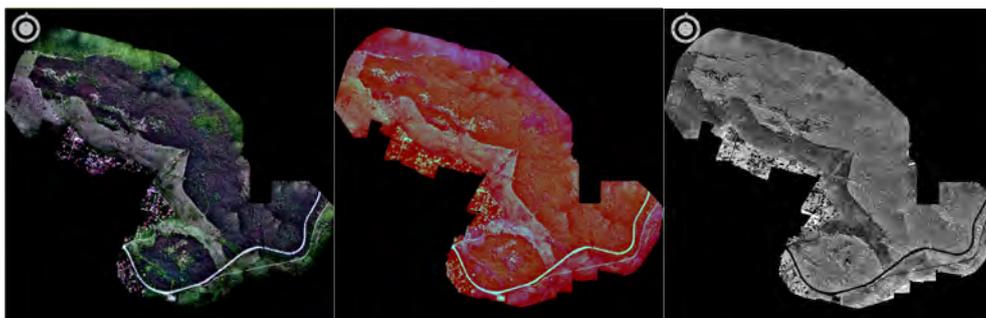


Figure 7. Visualization of orthoimage for the study area in natural colors (3, 2, 1), false colors (4, 3, 2), NDVI

### Vegetation analysis by NDVI

For the purpose of the research, we use an NDVI algorithm in the ERDAS system (Figure 8), and a factory-set sensor type with bands similar to the multispectral camera bands (Table 3). In this case, QuickBird-2 TM sensor type was chosen (<https://directory.eoportal.org/web/eoportal/satellite-missions/q/quickbird-2>).

Table 3. Compliance of the spectral range of bands

Sensor	Blue	Green	Red	Near IR
QuickBird-2 Multispectral	450 - 520	520 - 600	630 - 690	760 - 900
MicaSense RedEdge M	465 - 485	550 - 570	663 - 673	820 - 860

The obtained result clearly highlights the required forest stands affected by pathogens, visualized in black color and expressed as separate structural elements (Figure 9).

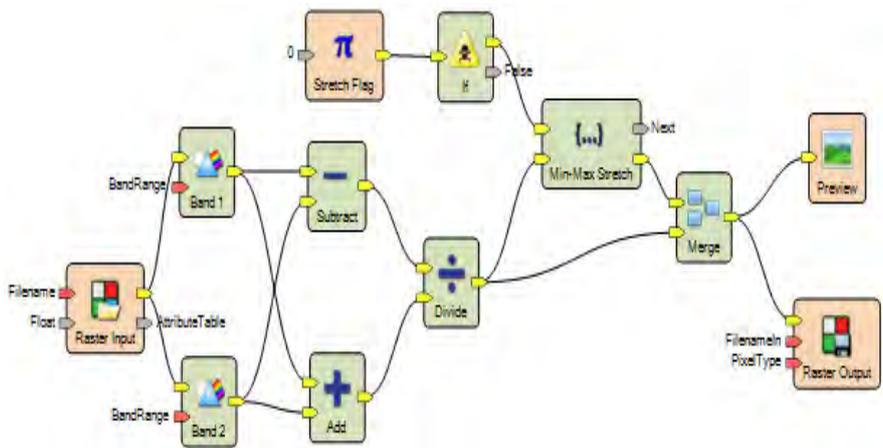


Figure 8. Vegetation index model and result after applying of NDVI

### Other Indexes (DVI, GNDVI, RVI)

Different vegetation indices were applied as follow - NDVI, GNDVI, DVI and RVI (Table 1). The three of them achieved the positive results (Figure 9). They demonstrate sharpening at the affected tree crowns. NDVI, DVI and RVI are used for the following classification.

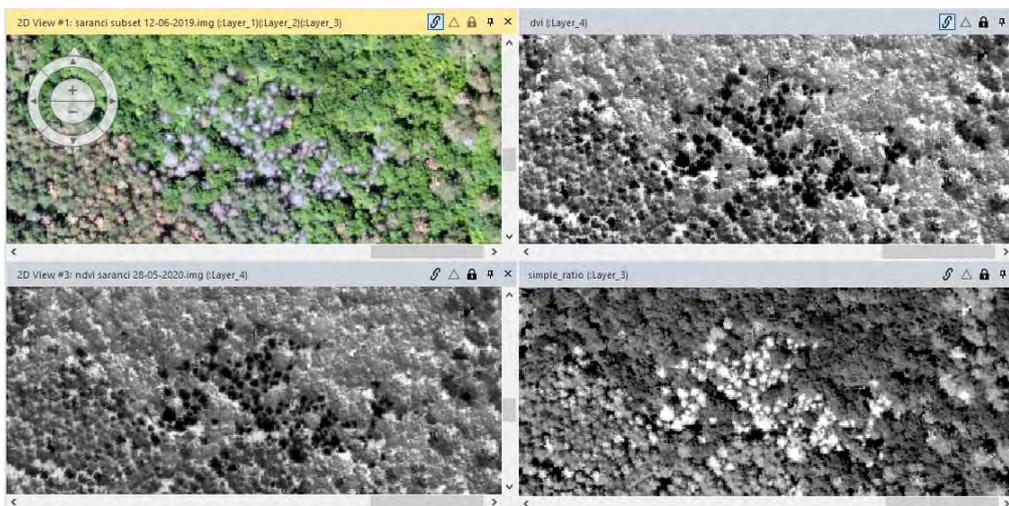


Figure 9. Results of applied indices (NDVI, DVI, RVI) with a positive results and color image

## Unsupervised classification with function K-means and ISODATA

The result after applying the NDVI (Figure 8 and 9) is a subject of processing under the two main methods – automated unsupervised classification and supervised classification.

Unsupervised Classification includes analysis of the brightness of the pixels in the image and their assignment to a certain number of spectral classes (naturally occurring groups of pixels with similar spectral qualities - clusters in the measurement space). The individual classes must be well separated. Their identity is initially uncertain, so the interpreter must compare the results of the classification with the existing data for the study area and perform a field check to determine the information classes (also called interpretation classes). In the unsupervised classification, two algorithms were applied in the analysis - cluster analysis (K-means) 3, 10, 36 classes (Figure 10), and ISODATA 10 classes (Iterative Self-Organizing Data Analysis Technique). Unsupervised classification is a preliminary step in determining the number and location of spectral classes in the measurement space required to apply the supervised classification method [3].

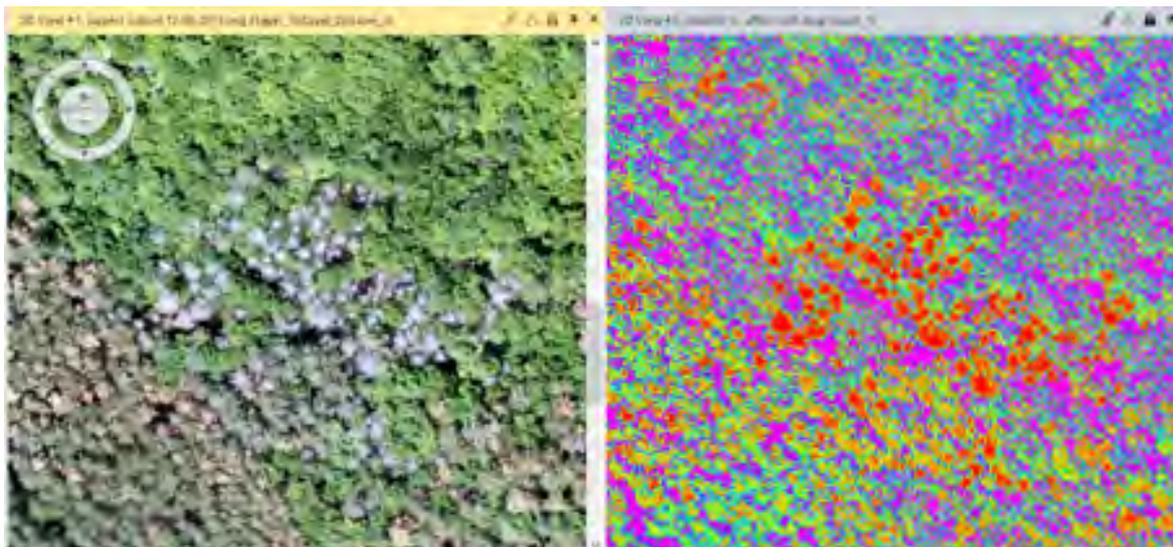


Figure 10. Unsupervised classification K-means with 36 classes, based on DVI index

## CONCLUSIONS

The dessication of the forest stands of Austrian pine (*Pinus nigra*) is a fairly recent problem in Bulgaria. The current study presents a fast and effective remote method for discovery and analysis of forests, damaged by fitopathogenic fungi.

We propose a combined method for decoding and computer interpretation of color and multispectral images from UAV. We make use of a variety of platforms suitable for mapping the problematic forest areas and assessment of the level of damage.

The usage of various NDVI spectral indices of vegetation provides us selecting the best basis for automated classification of images and extraction of accurate data on the health of forest stands.

When executing the algorithm of NDVI, it is crucial to match the spectral range of the multispectral camera to the factory settings for channels of the sensors in ERDAS IMAGINE. Specifically, the exact match must be established between MicaSense RedEdge M and QuickBird-2 TM.

After the experiments with different indices and algorithms, we can offer optimization of the sequence of procedures. The main factor for this is the extraction of spectral signatures for the spectral classes after the applied K-means algorithm and direct usage of those signatures in the process of supervised classification and production of a thematic map.

The suggested technology assures the easy of discovery of individual trees or parts of the forest stands affected by fitopathogenic fungi. The technology facilitates the assessment of the damage on a 5-level scale and the mapping of the tree health state of the forest.

## ACKNOWLEDGEMENT

This work was supported through Project B1006/2019 funded by the Scientific and Research sector of the University of Forestry. We would like to thank SFE “Elin Pelin”, GEOVARA Ltd for offering their professional expertise and for the beneficial collaboration.

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# THE DYNAMICS ANALYSIS OF ARAL SEA IN ARID AREAS OF CENTRAL ASIA

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## **Abstract**

*The distribution of lakes in space and its change over time are closely related to many agricultural, environmental and ecological issues, and are important factors that must be considered in human socio-economic development. In this study, Aral Sea (the first dry-up of the eastern coast of the Aral Sea in early 600 years) was selected in the Fuxing District of Central Asia, to explore the relationship between lake changes and regional climate change. The study shows the entire Aral Sea is in a state of obvious shrinkage from 2000 to 2015. The whole lake and the eastern and western basins of the South Aral Sea show a decreasing trend from April to October, while the North Aral Sea shows an increasing trend every month, which probably results from the reduction of snow-melting as well as increasingly human activities.*

**Keywords:** Aral Sea, water dynamics, Central Asia

## **INTRODUCTION**

Lakes, as essential components of the hydrological and biogeochemical water cycles, influence many aspects of ecology, economy, and human welfare[1, 2]. In the past several decades, dramatic ecological, morphological, and areal changes of water bodies have occurred in many lakes in the world[3]. It is critical to understand the spatial-temporal patterns of areal changes as its changes can lead to flooding or drought, and water shortages, thus imposing significant consequences to human life, agricultural systems, global water, and food security[4, 5].

Qinghai-Tibet plateau is the world's highest and largest plateau which is surrounded by massive mountain ranges. There are plenty of lakes and glaciers covering this area, and the variation of lake area is closely related to the regional and global climate changes. Due to the Qinghai-Tibet plateau's remoteness, high altitude, thin atmosphere, and harsh weather conditions, the quantitative lake water extents and their changes are still poorly known. Using satellite remote sensing, there have been numerous studies related to dramatic areal changes of lakes on different spatial-temporal resolutions. However, the water dynamics analysis at monthly or higher temporal resolution tend to using MODIS images of 500m and 1km resolution, which makes it incapable to precisely analyze the dynamics for small bodies. For example, Sun et al. mapped water surface changes over 629 lakes in China using 8-day MODIS images (500m)[6-7]. The analysis of lake dynamics for Central-Asia area at higher resolution such as 30m resolution or even better, primarily focused on one or multiple typical lakes (Aral Sea, Siling Co, Nam-co, Ulan ul et al) over the inconsecutive period, leading to some pseudo change [9-12]. Therefore, it is rare for lakes dynamics at high spatial and temporal resolution for Qinghai-Tibet plateau, which is the objective of this study analyzing monthly pattern of lakes dynamics for this area at 30m spatial resolution.

## **STUDY AREA**

The Aral Sea is located in the middle of the arid region of Central Asia, at the junction of Kazakhstan and Uzbekistan (43° 24'~46° 56'N, 43° 24'~46° 56'E). The average annual temperature in the lake area is about 9.4°C, and the annual rainfall is about 100 ~ 140 mm. The Aral Sea is a closed lake with no rivers flowing out of it. Its water loss is mainly evaporation, and its supplies are mainly supplied by the Amu Darya River in the south and the Syr Darya River

in the northeast. The Amu Darya River originates from the Pamir Mountains and flows through the Karakum Desert into the Aral Sea. In the 1960s, the annual runoff of Amu Darya River was about  $79 \text{ km}^3$ , and the average annual inflow into the lake was about  $40 \text{ km}^3$ . Lake Sire originates from the Central Tianshan Mountains on the north side of Pamirs and is mainly supplied by mountain precipitation and snow melt water. In the 1960s, the average annual runoff was about  $37 \text{ km}^3$  and the average annual runoff into the lake was  $15 \text{ km}^3$ [12]. Before the 1960s, the Aral Sea had a small fluctuation in area and remained the world's fourth largest lake with a lake area of about  $6.8 \times 10^4 \text{ km}^2$ , with a water level of about 53 m above sea level. After 1960, large-scale agricultural irrigation and domestic water use in the basin led to a sharp decline in water level and lake surface. In 1989, the Aral Sea was divided into the North Aral Sea and the South Aral Sea. The water body in the South Aral Sea fluctuated violently and the water level and area in the North Aral Sea were relatively stable[13]. As the Aral Sea drought intensifies, the ecological environment in the region is getting worse and worse.

## METHODOLOGY

### Water detection

A seed set expansion approach is explored to derive lake extent and its unique label, which is required to analyze time-series areal change spectral indices, MODIS water data and topographic data, the C5.0 decision tree is built to extract water separately on each scene of Landsat images with hierarchical weighted sampling space. Subsequently, based on multiple observations and acquisition times on pixel scale, monthly water extents are derived by time series interpolation. A complete exploration of Monthly water extents derivation is beyond the scope of this article, but more details can be found in [14].

### Lakes identification

A seed set expansion approach is explored to derive lake extent and its unique label, which is required to analyze time-series areal change of each lake. The approach used HydroLAKES database as seed set. The HydroLAKES database was created by compiling, correcting, and unifying several near-global and regional datasets[15]. The resulting map scale is estimated to be between 1:100,000 and 1:250,000 for most lakes globally, with some coarser ones at 1:1 million, which includes the lakes with surface area more than  $0.1 \text{ km}^2$ . Lake polygons were rasterized in according to the unique ID of each lake. The seed set is able to provide the location of each lake, thus facilitating the decrease of misclassified water. In addition, some lakes are observed on several adjacent images, so the seed set guarantee that the image-crossed water bodies are labelled to one lake. The seed set expansion process is as followed:

(1) The polygons of seed dataset were aggregated to the projection of monthly water result and then rasterized to pixel footprints of 90m resolution of water extent for comparison to minimize the error caused by re-projection and data format.

(2) The pixels belonging to the same lake were identified and labelled, which were regarded as initial lake pixel sets.

(3) There likely to be some separated water bodies for one lake, and because of water dynamics, some lakes probably merge or separate. In order to guarantee a unique ID for these lakes, these parts or merged lakes were assigned an ID from the lakes with larger water area. Therefore, the pixel set of each lake is sorted, and the expansion started from the pixel set of largest lakes.

The pixel was popped from initial lake pixels set of one lake in sequence. This pixel was labelled as the lake pixel and given a traversal state if the pixel is classified as water and in un-traversal state. In the meantime, the un-traversal pixels within  $3 \times 3$  moving window centered on this labelled pixel were pushed into the initial lake pixels set.

(4) The step (4) was repeated until there were no water pixels in initial lake pixels set. The lake extent was comprised of all the labelled pixels.

(5) By repeating step (4-5) with its initial water pixels for each lake, the extent of all lakes were determined.

### Change analysis

Considering the lower accuracy of water detection in colder months[16], the change analysis of lakes over Central Asia area were made for four months from June to September from 2000 to 2015. The approach to change analysis was predicated on using a linear trend (Ordinary Least Square, OLS) to smooth the monthly and annual time series of data when determining areal and numeral change of lakes [17]. It is called Change Speed (Cs) with the unit of  $\text{km}^2$  per year or per month. We further imposed the objective constraint of statistical significance of the trend to define change of lakes using the T-test model[18]. If the T-test was not statistically significant ( $p \geq 0.05$ ), we defined there was not a linear trend of lake change and vice versa. To make different size of lakes comparable, Change Velocity (Cv) was calculated with CS divided by the mean area of the lake from 2000 to 2015.

## RESULTS AND DICCUSSION

### Yearly dynamics

Figure 1 shows the spatial distribution of the changes in the lake surface area of the Aral Sea from 2000 to 2015. It can be seen that the lake surface of the North Aral Sea is the most stable, while the eastern coast of the western basin of the South Aral Sea changes greatly, and the eastern basin of the South Aral Sea changes most obviously.

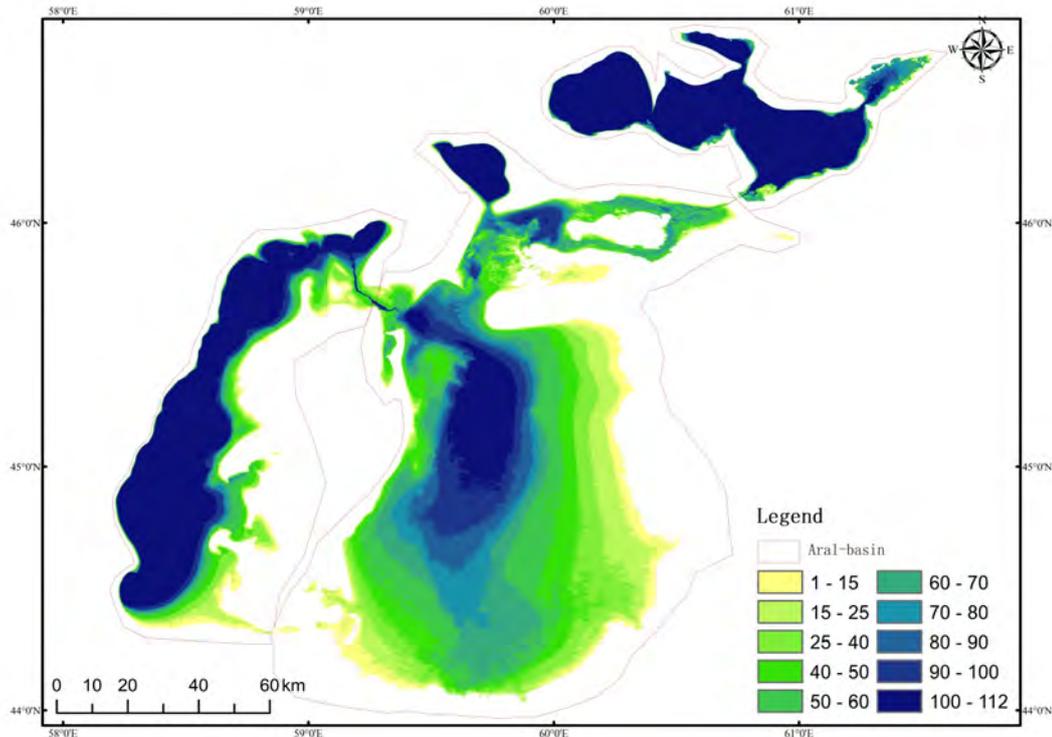


Figure 1. The extent change of Aral Sea for 2000 to 2015

Figure 2 shows the changes in the area of the Aral Sea from 2000 to 2015. The entire Aral Sea is in a state of obvious shrinkage. In 2000, the area of the lake surface was the largest, 250,000.49km<sup>2</sup>. In 2010, the area of the lake surface was significantly expanded. In 2014, the area of the lake surface was the smallest, only 7,837.15km<sup>2</sup>, which was 3% of the area of the lake in 2000. In that year, most riverbeds in the eastern basin of the Aral Sea disappeared. This may be the first time in modern history that the Aral Sea completely dried up. The shrinkage rate of the Aral Sea in 16 years may reach 1129 km<sup>2</sup>. According to this reduction rate simulation, the Aral Sea will probably disappear completely in 2020, and the simulation results are consistent with the prediction results[19].

Both basins of the South Aral Sea are shrinking. The linear decrease trend of the western basin area is the most obvious (R<sup>2</sup> is about 0.97). However, the lake area is stable in the year. In 2000, the lake area was the largest, about 6,048.13km<sup>2</sup>, while in 2015, the area was the smallest, about 3,185.35km<sup>2</sup>, with a linear decrease rate of 186.39 km<sup>2</sup>/year. Different from the fluctuation of the lake area in the eastern basin, there was no obvious increase in the lake area in 2010. The relative stability of the lake area in the western basin is mainly due to its steep coastline [20].

The lake area in the east fluctuates most violently in both years and years, mainly due to the shallower lake basin[21]. In 2000, the lake area was the largest, about 16,040.58km<sup>2</sup>. The lake area shrank to 1,022.56km<sup>2</sup> by 2014, about 6% of the lake area in 2000. The south coast of the eastern river basin almost completely disappeared. In 2015, the water body in the eastern river basin began to increase again, with an overall reduction rate of 981.1 km<sup>2</sup>/year. In particular, from 2006 to 2009, the area of this part of the lake was extremely small. On the one hand, the regional average temperature increased by 1-3 °C due to the high temperature in this period, while the evaporation of the lake increased due to drying[22]. On the other hand, the amount of runoff flowing into the Aral Sea from 2006 to 2009 was very small and almost zero[23]. In 2010, the discharge of Amu Darya River into Aral Sea increased abnormally[23-24]. In addition, the increase of temperature in the drainage area reduces the snow cover time and increases snow melting in the Amu Darya drainage area [25-26]. Therefore, the lake area in the eastern part of the South Aral Sea or the entire Aral Sea showed the most obvious increase in 2010.

On the contrary, the area of the North Aral Sea shows a relatively stable growth trend. Except for an obvious increase in lake area in 2006, the other years show a slight increase. The area was the smallest in 2000, about 2911.77 km<sup>2</sup>, and the largest in 2010 (3416.76 km<sup>2</sup>), with a growth rate of about 38.43 km<sup>2</sup>/ year. The growth trend of the North Aral Sea is due to the construction of a dam between the North and South Aral Sea in Kazakhstan in 2005. The water flowing from the Xier River into the desert basin now only flows into the North Aral Sea. From 2005 to 2006, the water level of the North Aral Sea rebounded significantly (Figure 5-2(b)), and the increase in lake level was consistent with that of the North Aral Sea (Figure 5-3(a)). Except for the North Aral Sea, obviously, the lake area in the western basin and the lake area in the eastern part of the South Aral Sea are consistent with the corresponding changes in lake water level.

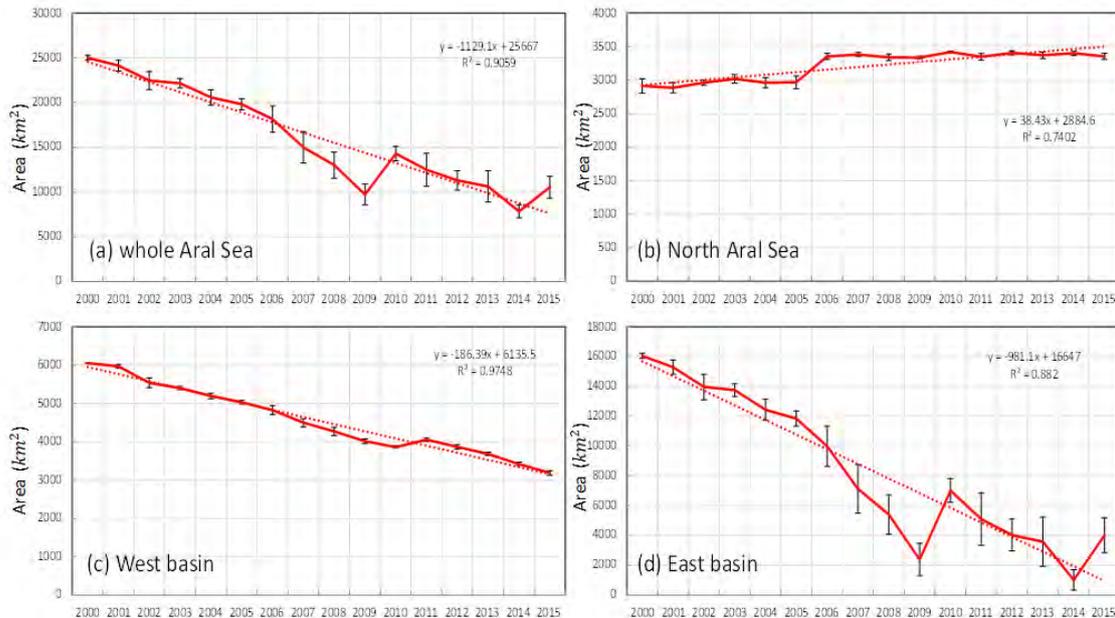


Figure 2. The yearly change trend of the area for Aral Sea from 2000 to 2015

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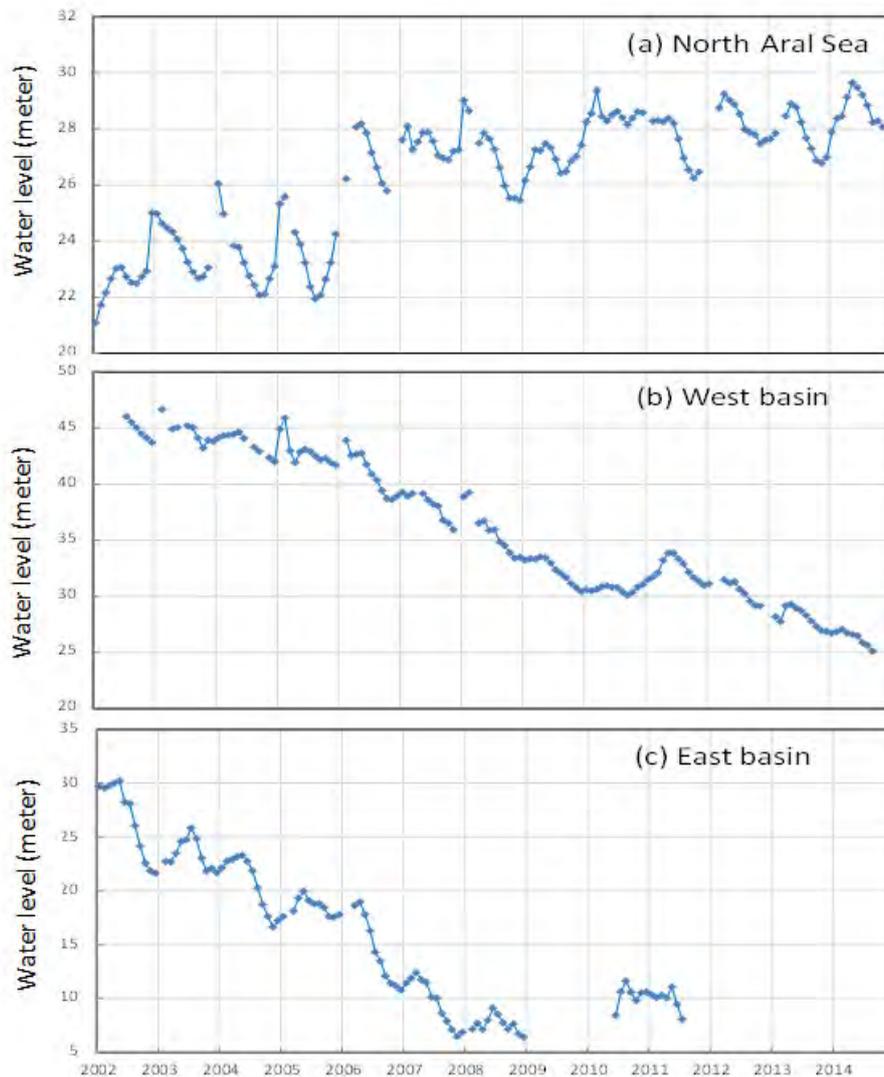


Figure 3 The water level change of North and South Aral Sea (Singh, et al., 2012)

### Monthly dynamics

Figure 4 shows the distribution of rose changes in the Aral Sea. The Aral Sea has a large area in April and May. Glacier melt water is the source of surface runoff in Central Asia. Glaciers melt in April and May and supply Aral Sea through Amu Darya River and Syr Darya lake. From July to October, the increase in temperature caused a sharp increase in evapotranspiration. Although precipitation increased, it was difficult to make up for the gap in runoff, resulting in a decrease in river runoff, which in turn led to a decrease in the amount of water entering the lake and a decrease in the lake's water surface[34]. In addition, due to human water use in summer, for example, a large number of immigrants from the upper reach of the Amu Darya and Xier Darya rivers, especially in the middle reach, reclaimed land for agricultural production such as cotton and rice. These crops will have melted snow and ice from high mountains in the coming spring of winter. However, due to the new dry climate in the mainland in summer, the irrigation of crops will make the lake area relatively small from July to October.

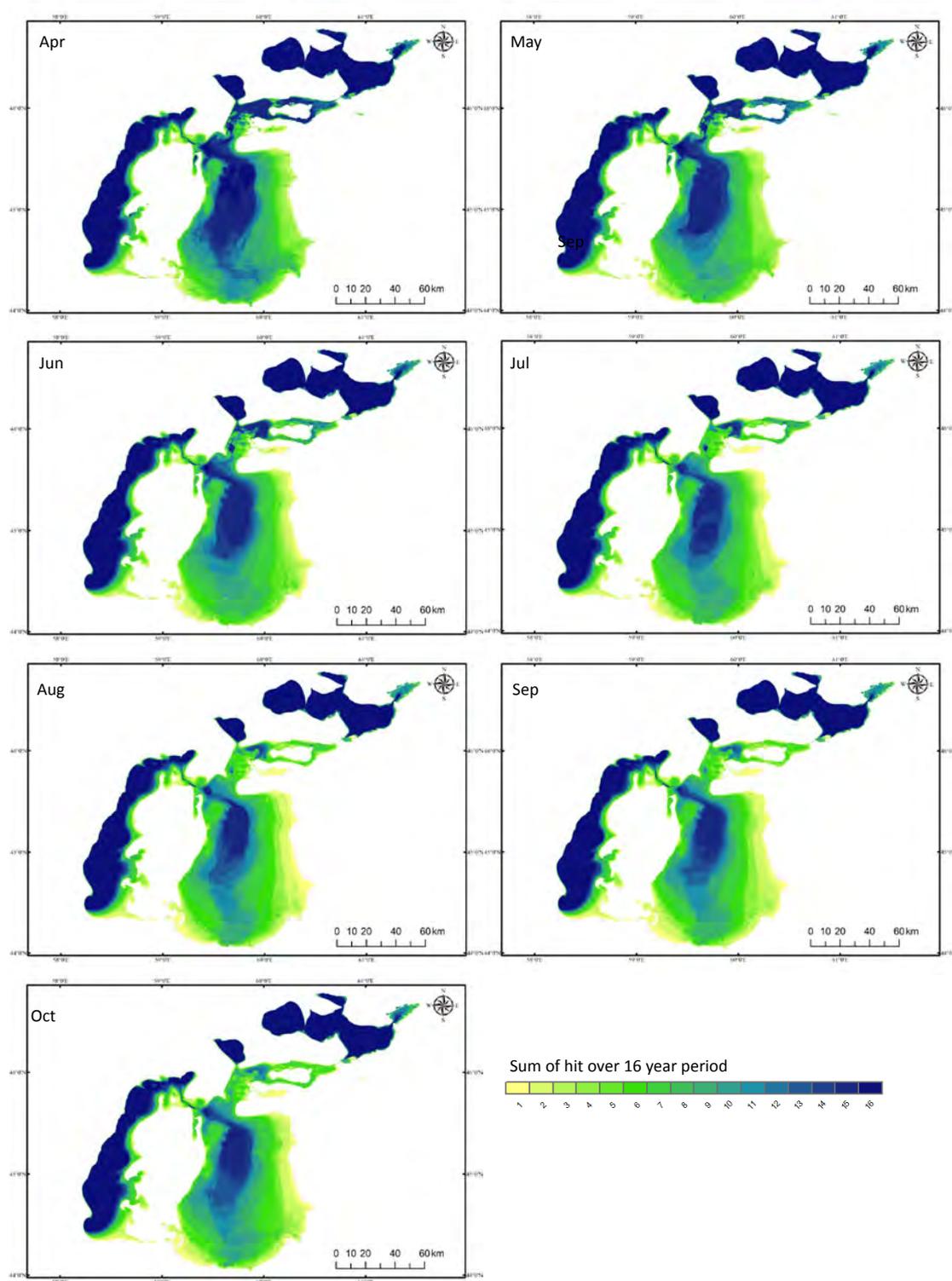


Figure 4. The monthly extent change of Aral Sea

Figure 5 shows the monthly change trend of the lake surface in each basin of the Aral Sea. The whole lake and the eastern and western basins of the South Aral Sea show a decreasing trend from April to October, while the North Aral Sea shows an increasing trend every month. The lake level of the North Aral Sea fluctuated greatly in July, and the increase in June-September was more obvious than that in other months. This was due to the increasing trend of rainfall in the Aral Sea basin [35], and the changes in the lake level of the North Aral Sea were significantly affected by rainfall. In April and May, the lake area in the western basin of the South Aral Sea decreased significantly from 2000 to 2014, mainly due to the decrease of melt water in early spring and the decrease of lake recharge due to glacier retreat [36]. The western part of the South Aral Sea is less affected by human activities, while the eastern lakes are most seriously

affected by human activities, especially in summer. The large-scale production of grain and cotton and the life of immigrants, as well as the exploration and exploitation of oil and natural gas in the dry riverbed area of the Aral Sea, have drastically reduced the lakes in the region.

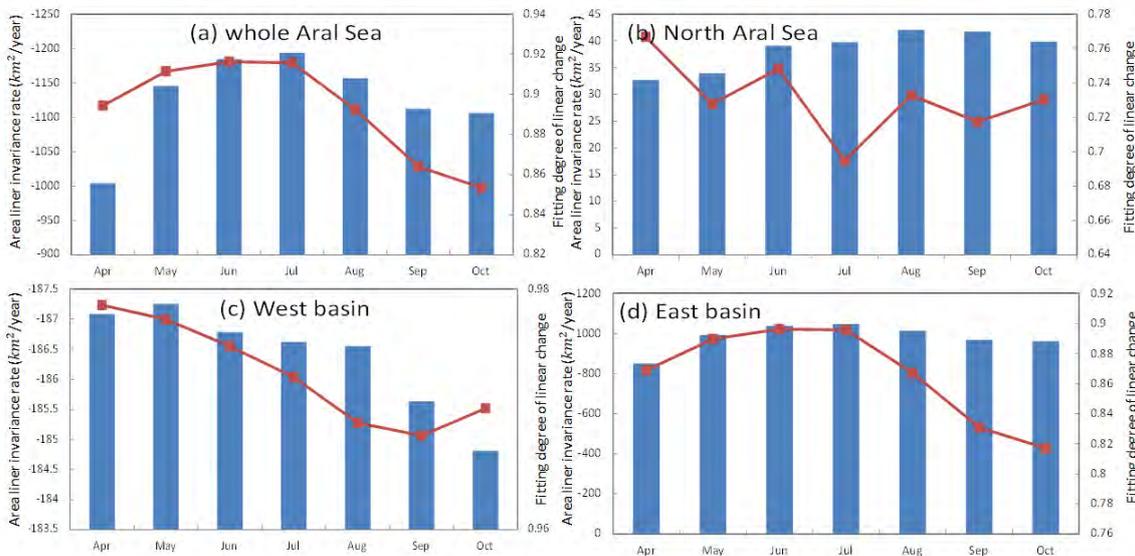


Figure 5 The monthly change trend of Aral Sea

The Aral Sea was born in the "Pliocene" period and has a history of more than 5 million years. Before 1960, the Aral Sea had good water quality and high transparency. As there are about 1,500 islands in the lake, the Aral Sea is also known as the "Sea of Islands" with a total area of over 66,000 square kilometers. Now, the Aral Sea area has been greatly reduced. Compared with 1960, the lake area has disappeared the size of "4 Beijing". The water level has dropped and the salinity of the lake water has increased. A large area of lake bottom has emerged to form salt desert and caused a large-scale "white storm" (salt dust storm) (Figure 5-6) [37]. The coastline of the lakes in the eastern part of the South Aral Sea has formed a salt shell of 2-10 meters [38]. There are also other ecological problems, such as oasis desertification, regional climate deterioration, worsening water and air pollution, endangering residents' health and salinization of the lake water, which have made the economic sources of wetland resources, fishery resources and other surrounding residents' livelihood disappear [12]. The disappearance of the Aral Sea is not only the result of climate change, but also the important impact of human activities. It is urgent to improve the ecological environment of the Aral Sea.



Figure.6. The ecological problems of Aral Sea

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# USE OF REMOTELY SENSED DATA TO MONITOR ENVIRONMENTAL CHANGES IN THE REGION OF NORTH-WEST BOHEMIA (CZECHIA)

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## **Abstract**

*At the Faculty of Environment UJEP, we focus on landscape change detection and environmental monitoring using the methods of geoinformatics the past 20 years. This paper aims to present the methods of remotely (contactless) sensed data used for this purpose. The high-resolution aerial imagery (using the Hasselblad 100MPix camera) is regularly used for monitoring the open-pit mining activity, water-dam lowstands, and in combination with multispectral imagery (satellite and air-born) to monitor and evaluate the health of the forests. The large water dams in this region are on a regular base surveyed with bathymetric mapping allowing evaluation of morphological changes in the water-dam bottoms. The newly acquired laser-scanning device Riegl VUX1-LR is a great tool for modeling the landscape under the trees.*

**Keywords:** *landscape change, analysis, remote sensing, photogrammetry, bathymetry, LiDAR.*

## **INTRODUCTION**

The region of North-West Bohemia (Czechia) was during the past hundred years affected by many types of anthropogenic activities. The heavy industrialization (including open-pit mining, large dam constructions, city enlargement) has affected the landscape structure and settlement distribution. The political situation before and after World War 2 has affected the settlement (de-population) of the Ore Mountains resulting in a dramatic change of land-use in this mountainous region. The chemical and power-production industry has affected the Ore Mountains in 1980' with massive air pollution and the acid rains and currently are forests in this region struggling from the bark-beetle and Gemmamyces Piceae calamity.

The Faculty of Environment at J. E. Purkyne University in Ústí nad Labem is focused on studying the environmental changes from different points of view. The geoinformatics tools have been used for landscape change and development analysis in the past 20 years. The fast development of GIS tools in the past decade has allowed using high-end technologies in our research. The main aim of this paper is to present the contactless methods for collecting the environmental data and the possibilities of their analysis mostly carried out by our students.

An important part of the environmental change analysis is the usage of archival data. Here we mostly use old maps and archival aerial photographs as they preserve the state of the landscape at the time of their acquisition (Brůna et al., 2014; Pacina et al., 2012; Skaloš et al., 2011; Vuorela et al., 2002). If we focus on the georelief change (bond i.e. to mining activity) than the archival data with elevation information is required – old maps with contour lines or archival aerial images with sufficient overlap (Hughes et al., 2006; Lane et al., 2003; Pulighe and Fava, 2013; Pacina et al., 2012; Sevara et al., 2017). Into the same group of archival remotely sensed data, we may put the satellite imagery. The USGS offers the Landsat imagery back to 1972 and the European satellite system Sentinel offers the data back to 2015.

The acquisition of contemporary data is important as the data available from national surveys are not updated as frequently as required and with limited spatial resolution. The remotely piloted drones are widely used for landscape observation (Rusnak et al., 2019) and as well as the small aircraft (Pacina et al., 2020). Many studies have proven that the results of processing images taken with digital cameras and processed by Structure from Motion (SfM) technology (orthophoto, digital surface model) are comparable to the results of photogrammetric cameras (Cardenala et al., 2004; Chandler et al., 2005; Quan, 2010). The LiDAR survey is an excellent tool for mapping the surface of areas that are covered with vegetation and for other types of surfaces (empty reservoirs bottoms, river beds, mining sites) as well (Allouis et al., 2010; Heritage et al., 2009; Marcus, 2012; Yeu, 2018). The landscape changes happening at the bottom of water reservoirs may be studied with shipborne sonar sensors (Bangen et al., 2014; Popielarczyk et al., 2015; Theberge and Dierssen, 2014).

## DATA AND METHODS

### Study area

Our research is focused mostly on the region of North-West Bohemia - the Ore Mountains (the bordering mountains in-between Czechia and Germany), Central Bohemian Highlands, and the brown-coal basin (see Figure 1). Within the Ore Mountains and the Central Bohemian Highlands, we focus on the landscape change connected with the different land-use caused by the depopulation after WW2 and the effects of the former air-pollution. In the brown coal basin is the landscape significantly affected by the open-pit mining and by the heavy industry. The bathymetric survey is bound to water reservoirs mostly built for the requirements of the heavy industry (electricity production, chemical industry).

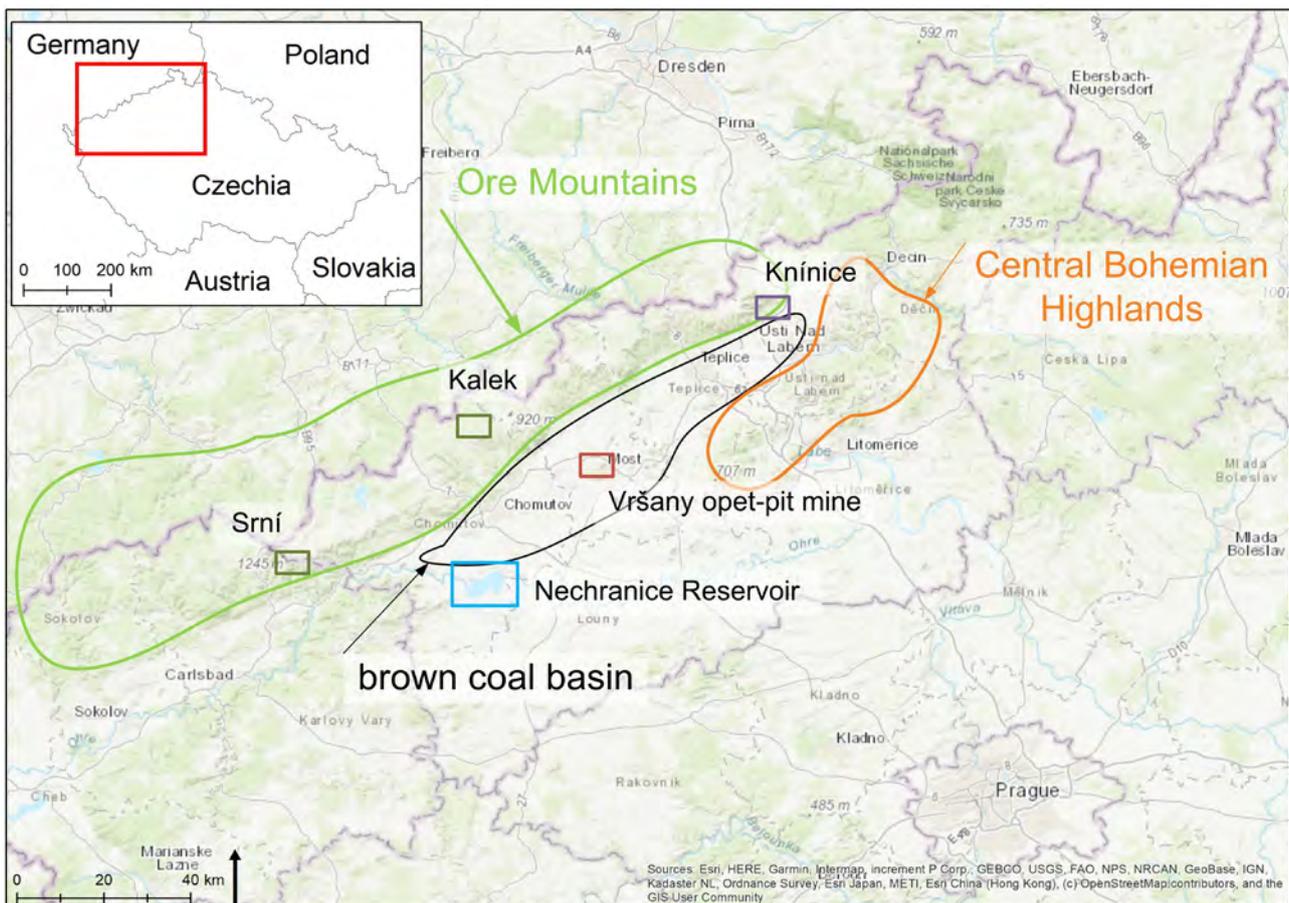


Figure 1 Region of interest with marked sites introduced in case studies

### Aerial survey

Within our research, we work both with archival and contemporary aerial imagery. In Czechia, the archival aerial images may be obtained from the national archives managed by the Military Geographical and Hydro-meteorological Institute in Dobruška (VGHMÚř) or the Czech Office for Surveying and Cadaster (ČÚZK).

The archival aerial imageries are purchased as high-quality digital copies of the original analog aerial images. The archival aerial images are processed with the SfM software Agisoft Metashape (Pacina and Popelka, 2017) and the orthophoto and digital surface model (DSM) are derived. The important part of the archival aerial image processing is the cautious identification and selection of the ground control points (GCP). The catalogs of the GCPs defined and used during the original photogrammetric survey are unfortunately not available in the VHMÚř and ČÚZK archives. The GCPs have to be thus manually identified on already processed data. The contemporary orthophoto or archival orthophoto from the 1950' available for the whole Czechia at <http://kontaminace.cenia.cz> is commonly used. The GCP identification is problematic in areas with large landscape change (i.e. the open-pit mines and the connected reclamations). The irregularly distributed GCP may affect the accuracy of the resulting DSM (Pacina et al., 2020).

In 2013, the UAVs were used for the landscape observations at our faculty for the first time. During the ongoing years, it became obvious that the UAVs won't cover properly the large areas requested for our survey. The small aircraft (see Figure 2) was for the first time used in spring 2014 and since then it represents a stable part of our research. Currently, it is equipped with Hasselblad A6D 100C camera (100 MPix) and multispectral camera Tetracam ADC Lite. The images are processed with Agisoft Metashape software. The common flight altitude for the Hasselblad A6D camera is 600 m AGL and the spatial resolution of the processed orthophoto is ca 5 cm/pixel. The images are taken every 1 second (overlap 80%) and the side-overlap is ca. 40%. The camera is not equipped with the Inertial Measurement Unit (IMU) thus the GCP has to be signalized and GNSS surveyed in advance.

The Tetracam camera has an IMU and standard GPS receiver thus the accuracy of the resulting orthophoto has the accuracy of several meters (if the precisely measured GPCs are not used). The processed multispectral images, obtained from flight altitude 800 m AGL have spatial resolution ca 40 cm/pixel.

The newest sensor for the aircraft is currently the Riegl VUX 1-LR airborne laser scanner. The most common flight altitude is 300 m AGL with the following settings: overlap of the scan-stripes 50%, flight axes distance of 200 m, scanner FOV of 80°, the pulse repetition rate of 400 kHz, and a scan rate of 48 lps. The resulting point density is about 20 points/m<sup>2</sup>.



Figure 2 Plattform used for bathymetric survey and small aircraft used for photogrammetrical and LiDAR survey

### Bathymetric survey

The bathymetric survey is carried out with the use of Humminbird Helix 7 CHIRP DI GPS G2 equipped with a standard GPS receiver. A small inflatable boat or a floating platform (see Figure 2) based on paddleboards is used to carry the sonar. A small electric drive is equipped because the use of petrol engines is most of the reservoirs in Czechia forbidden. The sonar records data as relative depths [easting, northing, depth], and the surveyed points are further processed in GIS. The survey pattern has the form of lines that are sufficiently covering the surveyed phenomena. The survey density varies with respect to the size of the reservoir and the purpose of the survey from several meters up to 100 m (in the so-far biggest surveyed Nechanice Reservoir). The actual water level prior to the survey measured with RTK GNSS in order to transform the relative depths to altitudes. Such data can be further compared with other data surveyed with other methods or processed pre-dam topography (Pacina et al., 2020).

## RESULTS

The landscape change in the region of North-West Bohemia has been analyzed with the use of GIS technologies at our faculty since 2000. The intensive use of remotely sensed data is dated back to 2013 when the faculty was equipped with the first UAVs. A lot of projects using different methods and data collection techniques were completed in this period (NAKI, kniha) but this paper has limited length – thus only several case studies representing the significant methods will be presented.

### Land-cover change in the Ore Mountains

The Ore Mountains were settled since the medieval period when the first miners started to mine silver and ore. Since then the bordering mountains between Czechia and Germany were densely inhabited and the people took care of their land. Shortly after the Second World War, the German-speaking inhabitants were deported to Germany and the Czech side of the Ore Mountains was never settled as before the war. In the 1970' and 1980' the forests at the Ore Mountains suffered from the acid rains followed by the bark-beetle and *Gemmamyces Piceae* calamity in recent years. This has led to a dramatic landscape (land-use) change.

This phenomenon is ideal to be studied with the use of archival aerial imagery, satellite imagery, and own photogrammetric survey. As mentioned earlier, the Hasselblad camera is not equipped with an IMU, thus the GCP signalization and GNSS measurements are required prior to the aerial survey. The survey areas are situated mostly in remote areas with limited access, thus the pre-survey GCP stabilization and GNSS measurements are problematic. In (Klimešová, 2017) was tested the accuracy of GCP selection using publicly available spatial data sets. The contemporary orthophoto provided by ČÚZK as a WMS is used for the identification of [X, Y] coordinates. The LiDAR data called the Digital Terrain Model of the Czech Republic of the 5th Generation (DTM 5G), are available for the whole Czech Republic as an irregular set of points, with a 1 point/m<sup>2</sup> average density. The Root Mean Square Error of the elevation information is 18 cm in open areas and 30 cm in areas covered by vegetation. The points represent the bare ground (ČÚZK, 2020). The DTM 5G is used to obtain the Z coordinate for the GCPs.

In Figure 3 and Figure 4 are presented results of land-cover change analysis in the area of Srní municipality (see Figure 1). The archival aerial imagery from 1953 was processed in Agisoft Metashape into orthophoto and the land-cover was digitized. The contemporary data were surveyed with our own survey. The aerial images were processed in Agisoft Metashape. It is clearly visible, that the former fields were transformed into pastures/grasslands and large area were overtaken by forests.

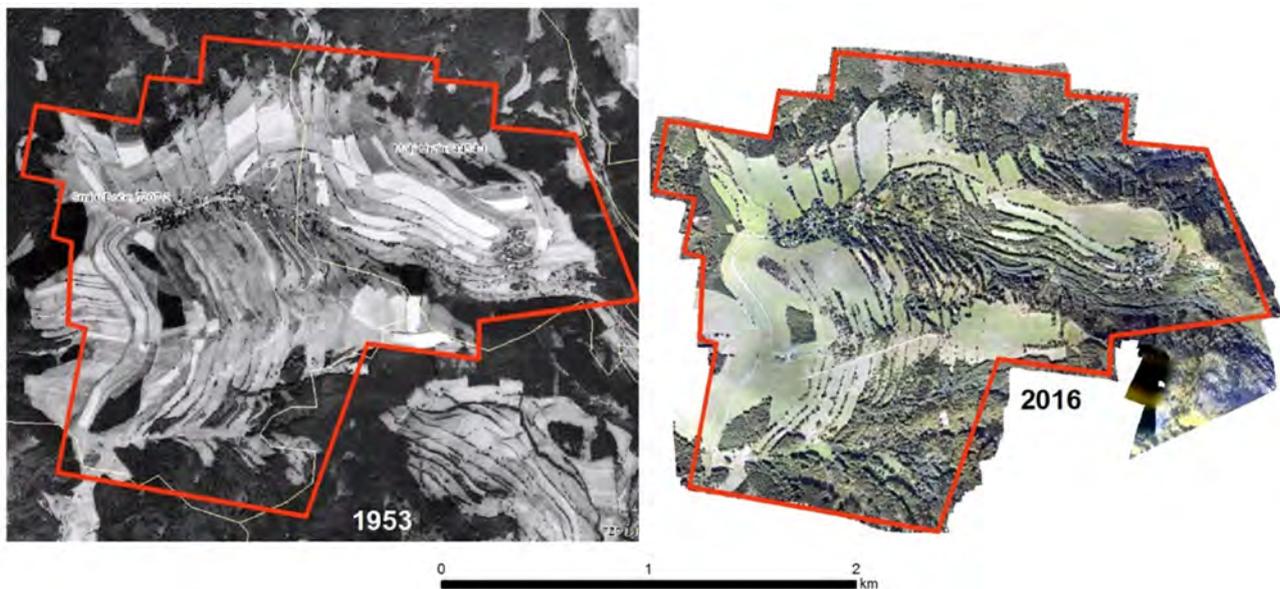


Figure 3 Land use change at Srní locality. The archival orthophoto from 1953 and our own photogrammetric survey from 2016 (right).

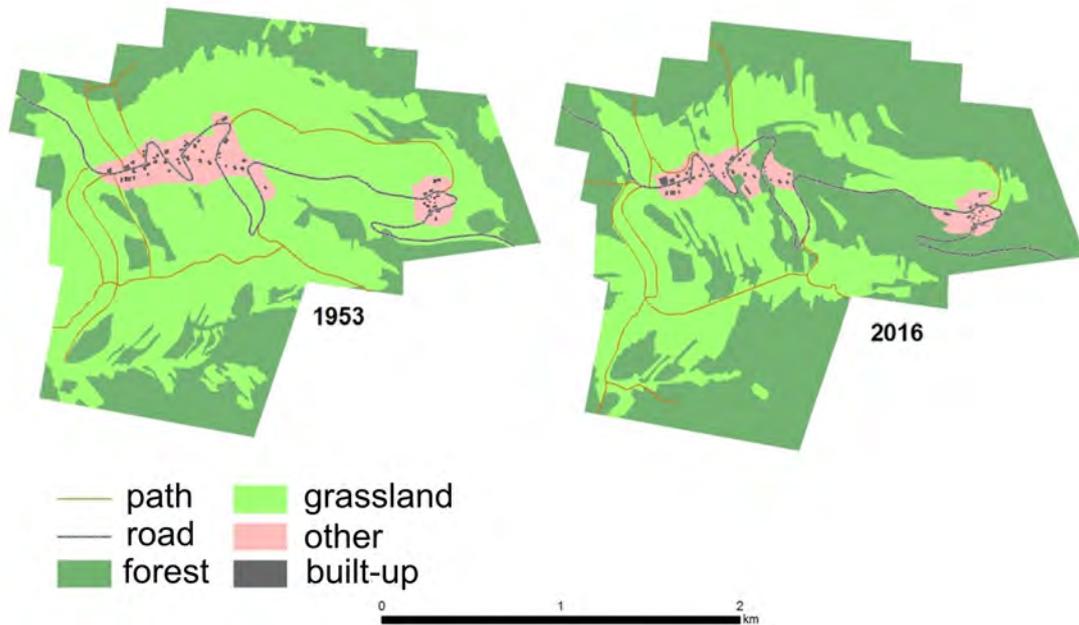


Figure 4 Digitized orthophotos of the Srní locality. Land cover as in the year 1953 (left) and 2016 (right).

We have as well tried to identify areas currently affected by the bark-beetle and *Gemmamyces Piceae* with the freely available satellite data. The locality near the Kalek municipality was chosen (see Figure 1) as cooperation with the forest owners was possible. The data from the Sentinel-2 satellite were used together with our own survey with the Tetracam multispectral camera. The free satellite data were used in order to work on large areas in different time periods. The own multispectral survey was used for verification of results. Within the student project, we have tested two software products for automatic classification – the freely available QGIS with the Semi-Automatic Classification Plugin and the ArcGIS Pro. With respect to the obtained results, we are unable to identify an early stage of bark-beetle infestation with the data and methods used. We are able to identify that the parts of the forests are weakened/diseased, but we are unable to say of this is because of the bark-beetle, *Gemmamyces Piceae* or extreme drought. In Figure 5 is presented the classification result focused on glades as a result of logging in the Ore Mountains as the classification results can be easily compared with the manual digitalization.

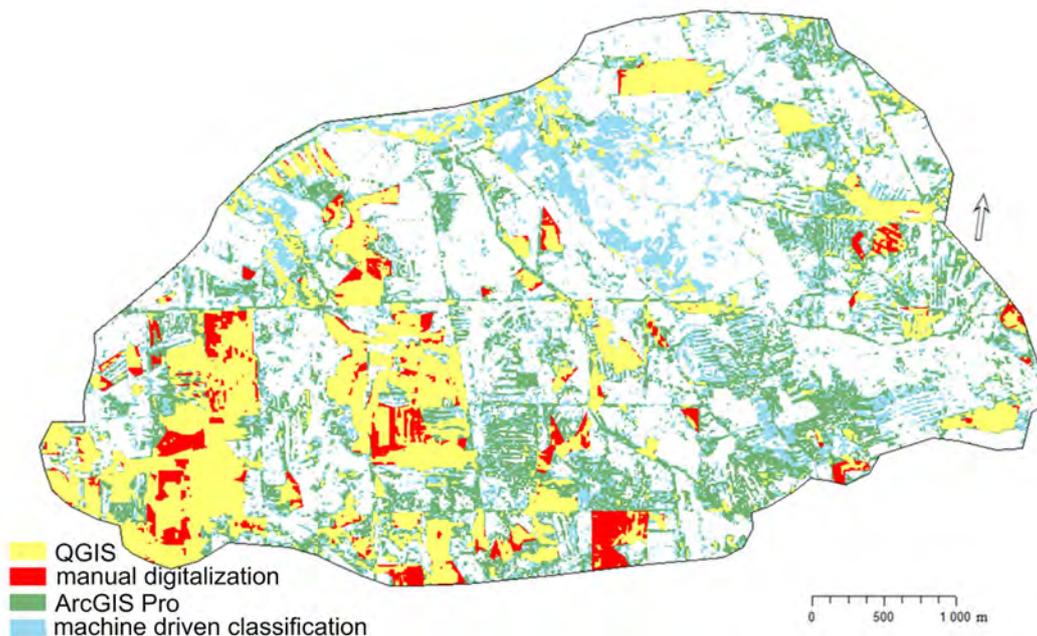


Figure 5 Example of Sentinel-2 classification result for different software used in the Kalek locality.

## Open-pit mining monitoring

This case study was focused on monitoring the mining activity in the region of town Most within the open-pit mine Vršany (see Figure 1). The monitoring was carried out in cooperation with the Vršanská uhelná, a.s. (a mining company). The cooperation was oriented on the evaluation of the accuracy of the produced DSMs as they were intended for the use by the mining company. The company supplied the reference data from their photogrammetric survey and RTK GNSS measurements and as well the precisely surveyed GCPs.

Several aerial surveys were performed in different time periods (February, April, and June 2015) and from different flight altitudes (300 and 600 meters). The data were processed in Agisoft Metashape with different computational settings in order to identify the ideal balance in-between the flight altitude and the computational time. The dense cloud generation with the *medium* and *high* setting was tested. The cluster analysis was performed in order to remove data that may decrease the accuracy of the datasets. The clusters were mainly identified in areas with active mining caused by the change of the landscape that has happened in-between our survey and the reference survey. The *Mean Protected Error* (MPE) was used to evaluate the elevation accuracy. An example of the landscape change within the mine is presented in Figure 6 and the resulting MPE in Table 1. Based on the achieved results, we can conclude that we will achieve higher accuracy at a lower flight level and higher quality of computation.

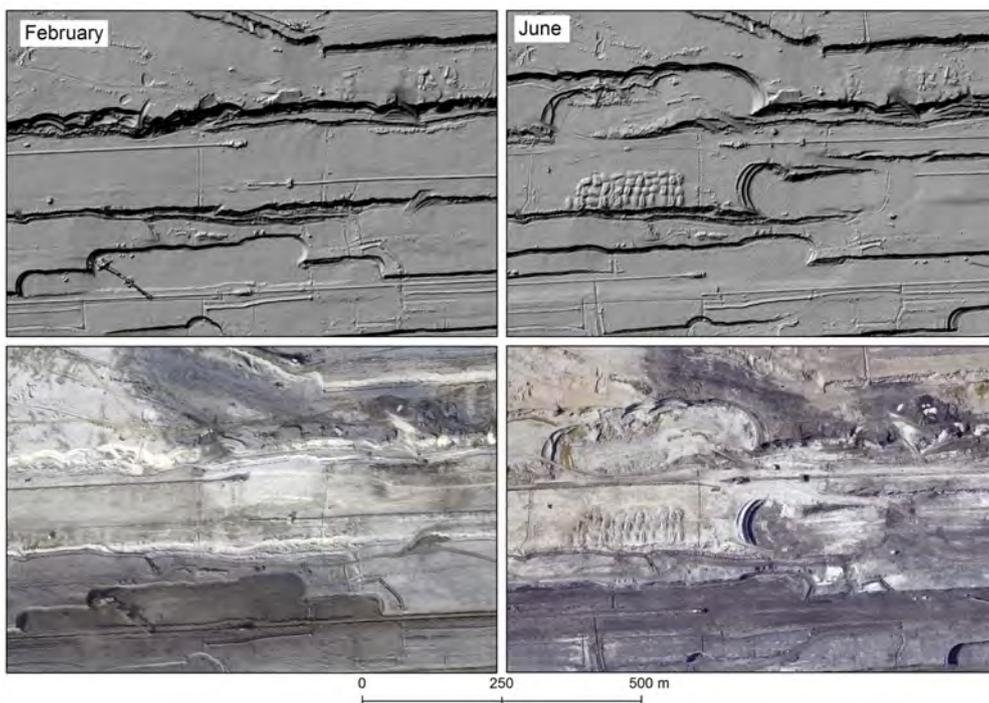


Figure 6 Landscape change within the open-pit min in February and June 2015

Table 1 Mean Protected Error for the tested flight altitudes and computation quality

Flight altitude	Computation quality	Mean Protected Error	
		With clusters (m)	No clusters (m)
<b>February</b>			
600 m	Medium	0,66	0,39
600 m	High	0,53	0,29
250 m	Medium	0,60	0,31
250 m	High	0,59	0,28

<b>April</b>		With clusters (m)	No clusters (m)
600 m	Medium	0,71	0,33
300 m	High	0,69	0,30
<b>June</b>		With clusters (m)	No clusters (m)
600 m	Medium	2,11	0,45
300 m	Medium	2,46	0,45
300 m	High	1,40	0,40
300 m	Ultra High	0,93	0,31

### Bathymetric mapping

Bathymetric mapping was for the first time used at our faculty in July 2014 at the Nechranice Reservoir (see Figure 1). Since then is the bathymetric mapping a common part of our research focused on the landscape changes happening in the water reservoirs in Czechia. The bathymetric data are mostly used for modeling of the bottom of the reservoirs in order to evaluate the changes in the bottom morphology or to find ideal spots for sediment sampling. An important part of our studies plays the archival data as with the information contained in the data (mainly in the old maps), we are able to reconstruct the pre-dam topography. The bathymetric data in combination with the reconstructed pre-dam topography allows us to estimate the sediment thickness and the possible evolution of the bottom of the reservoir.

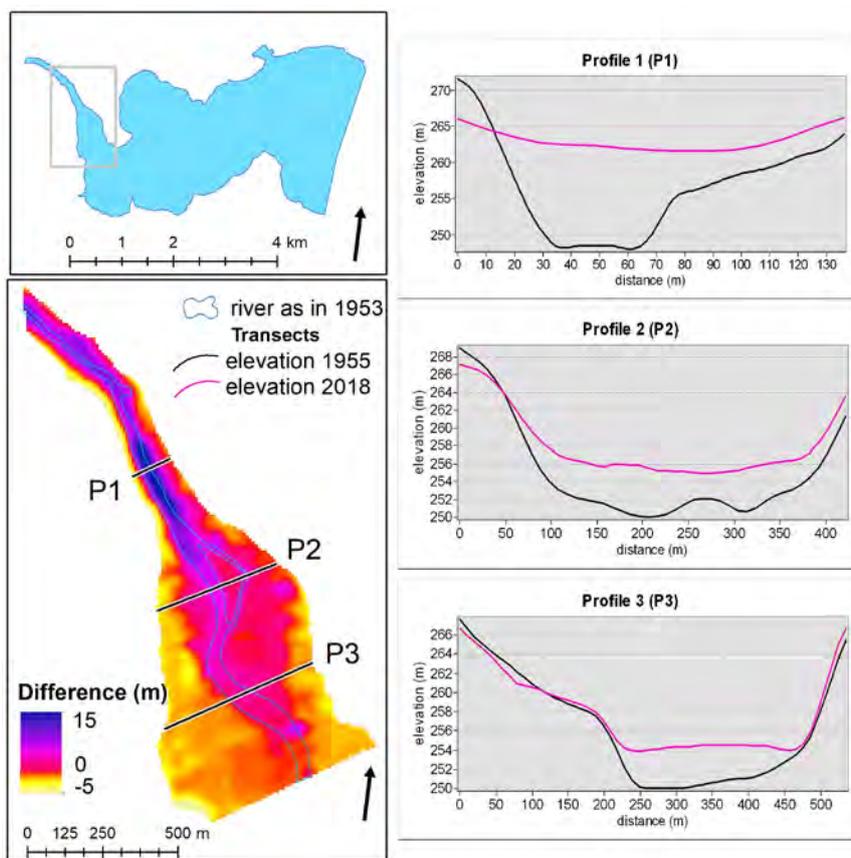


Figure 7 Estimated sediment thickness and comparison of bathymetric data and the pre-dam topography model. Image prepared based on (Grygar et al., 2020).

A very detailed study was performed at the Nechranice Reservoir, where several time periods were compared together with detailed pre-dam topography modeling (Pacina et al., 2020). The data were further compared to our photogrammetrical survey carried out during the extreme low-stand in autumn 2018. An example of a comparison of bathymetric data and the pre-dam topography model is presented in Figure 7 together with estimated sediment thickness. The pre-dam topography was derived from a 1955 map and compared to data surveyed prior to the extreme lowstand in 2018 (Grygar et al., 2020).

The bathymetric survey was performed on several reservoirs in Czechia (Grygar et al., 2018; Pacina et al, 2020) and the members of the project are from different institutions. An information system was thus established in order to share the gathered and processed data in an easy way. The ArcGIS Online platform together with ArcGIS Enterprise server technology was used to publish and share the processed spatial data. Within the web-mapping application, there are available processed old maps and archival aerial photographs for the studied sites, bathymetric data, sampling sites with required attributes, and other additional information. An example of the information system is presented in Figure 8

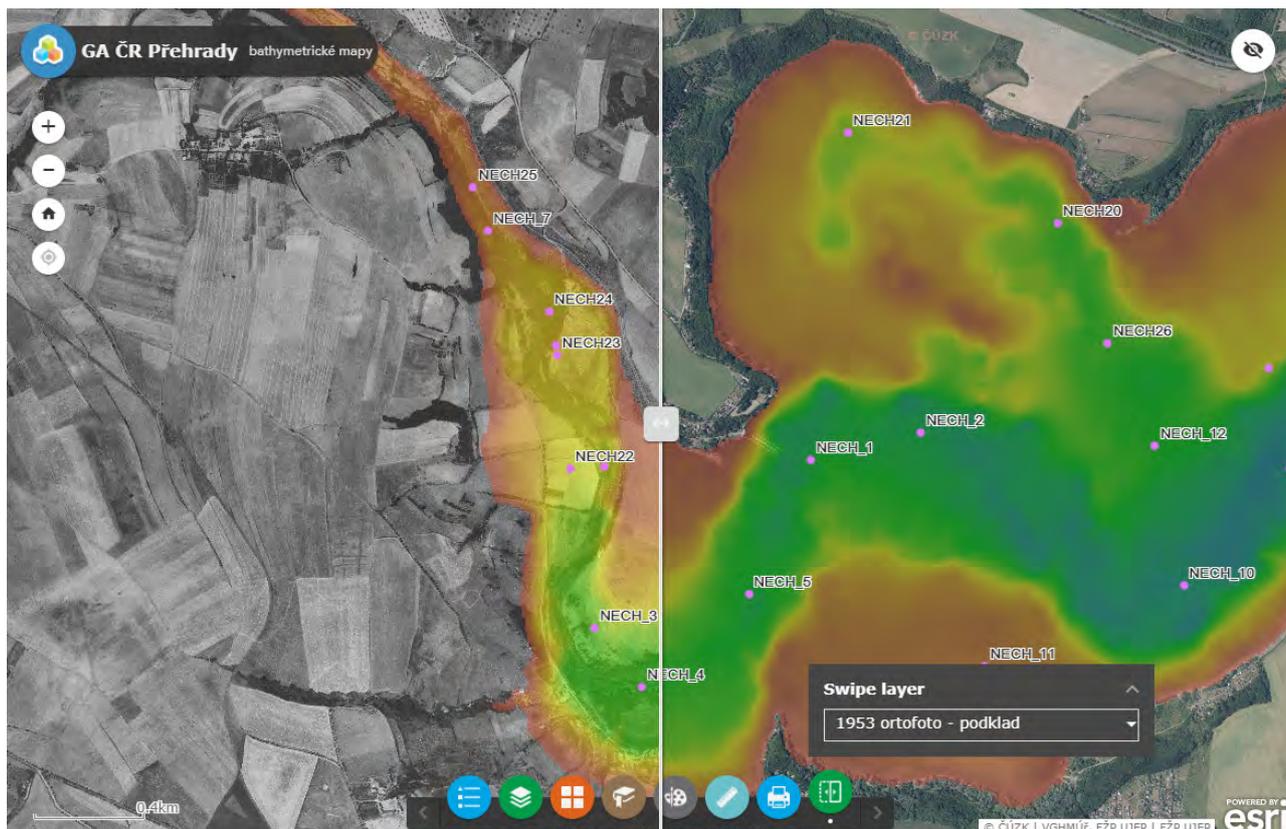
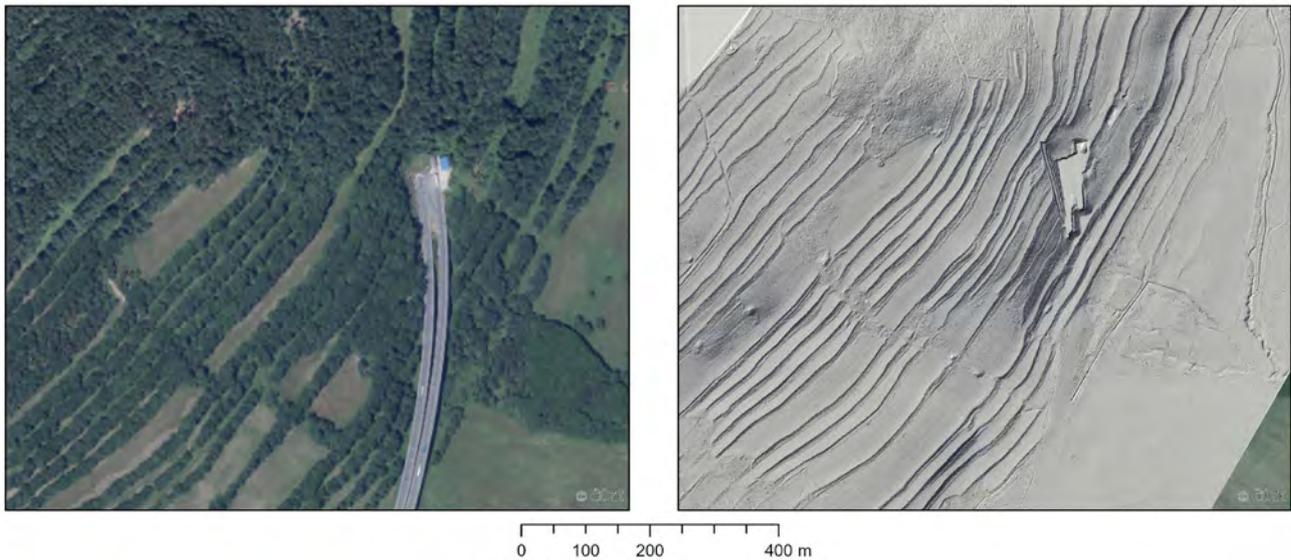


Figure 8 The web-mapping application showing the Nechranice Reservoir - bathymetrical data, sampling sites, archival orthophoto laid over contemporary orthophoto.

## LiDAR survey

The LiDAR survey is the newest technology (operated since November 2019) used at our faculty for observing the landscape changes. The airborne laser scanner Riegl VUX 1-LR allows collecting points from the 300 m altitude (the lowest allowed altitude for a small aircraft) with sufficient point density for analysis of landscapes hidden under the trees. So far we are testing the possibilities of this technology in different fields. One field of our study are the areas used for agriculture before the WW2 and abandoned after the war when the German-speaking inhabitants were deported. Although nature takes back this previously cultivated landscape, there are still identifiable anthropogenic elements in the terrain (stone walls, terrace fields), created mainly by a long-term selection of topsoil stones and naturally dividing the fields or to align the fields in the plane. The main task in processing the LiDAR is to filter the vegetation, as the “bare ground” surface is required for this type of research. Based on our experience, it is appropriate to perform the LiDAR survey outside the growing season, however, the laser beam has a problem penetrating dense stands of blackthorn bushes. The example of processed LiDAR data, in the Knínice locality (see Figure 1), compared to contemporary orthophoto is in Figure 9.



*Figure 9 Area with system of former terrace fields near Knínice. Contemporary orthophoto (left) and processed LiDAR survey - bare ground.*

## CONCLUSIONS

The remotely sensed data are excellent methods for studying landscape development/changes. The great benefit of processing digital data means that we are capable of comparing several time periods within one project (if sufficient archival data are available).

The photogrammetrical survey using digital cameras means a fast and operable method for the creation of high-resolution orthophoto or region of interest. The use of UAVs is nowadays very common and cheap, but with respect to the valid legislative and the size of areas required for survey the small aircraft is used for most of our surveys. The LiDAR survey is an appropriate addition to the photogrammetrical survey as we are capable of analyzing the land surface under vegetation (trees). The Riegl VUX 1-LR laser scanner is equipped with two Sony alpha cameras. These cameras are primarily used for the colorization of the resulting point clouds and thus they are equipped with a wide camera lens. This type of lens is not recommended for orthophoto creation, but as tested during our projects, the results are satisfactory.

The bathymetric survey is not that fast as the aircraft/satellite-based survey, nor it is that fast, but it is capable of obtaining very different types of data used for the analysis of landscape changes happening under the water. The sampling pattern is crucial for good results as too sparse data gathered during the survey may hide important features on the bottom of the reservoir. The presented information system is an excellent tool for sharing the processed data in-between the project members, as not every member has access (or skills to use) to GIS software.

## ACKNOWLEDGMENTS

The forest and landscape change analysis in the Ore Mountains and the brown-coal basin was supported by Project No.: UJEP-SGS-2019-44-001-3 covered by student grant competition at UJEP - Jan Evangelista Purkyně University in Ústí nad Labem.

The fieldwork in reservoirs was supported by the Czech Science Foundation, project. No. 17-06229S, led by O. Bábek, Department of Geology, Faculty of Science, Palacký University in Olomouc, Czech Republic.

The LiDAR survey was supported by the Internal Grant Agency of Jan Evangelista Purkyně University in Ústí nad Labem [grant number UJEP-IGA-TC-2019-44-02-2].

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## **BIOGRAPHY**

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# ADVANTAGES, DISADVANTAGES AND APPLICABILITY OF GNSS POST-PROCESSING KINEMATIC (PPK) METHOD FOR DIRECT GEOREFERENCING OF UAV IMAGES

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## **Abstract**

*The use of unmanned aerial systems (UAS) for image acquisition, which are then processed by the photogrammetric method SfM- (Structure-from-motion), is increasingly established as a suitable workflow for obtaining high-resolution topographic data (HRTD). During the last few years the development of high-quality IMU (Inertial Measurement Unit) and GNSS technologies, as well as specialized RTK (Real Time Kinematic) and PPK (Post-Processed Kinematic) solutions for UAV, can provide accurate parameters for the external orientation of the cameras used in UAV for photogrammetric capture. The use of such an approach has the potential to become an alternative to the use of ground control points (GCP) for georeferencing of the topographical data obtained from unmanned aerial vehicles. The conventional method of georeferencing by monitoring ground control points (GCP) provides reliable positioning accuracy in location but critically depends on the number and spatial location of ground control points (GCP). This limits the efficiency of the method in a time aspect. Applying direct georeferencing of images taken by UAV can overcome these limitations. Recently Post-processed kinematic (PPK) method georeferencing of images gradually develops and provides centimeter accuracy of high-resolution topographic data (HRTD) in specialized studies of the Earth's surface.*

**Keywords:** UAV; UAS; Structure from Motion; Photogrammetry; PPK Method

## **INTRODUCTION**

In recent years, unmanned aerial systems (UAS) have demonstrated significant capabilities with potential for applications in many areas such as: mapping, 3D modeling, extraction of three-dimensional point clouds and generation of orthophoto mosaics. There are already a number of examples of the application of short-range photogrammetry by UAS in studies of river systems (Casado et al., 2015), land cover (Passalacqua et al., 2015), three-dimensional modeling of buildings and facilities (Remondino et al., 2011; Dinkov, 2018a), archeology (Chiabrando et al., 2011), opencast mines (Ren, H., Zhao, Y., Xiao, W. et al., 2019), etc. In all these studies, the SfM (Structure-from-motion) method is used for image processing and quite acceptable results are demonstrated, comparable to traditional photogrammetry. The SfM method combines a significant number of images taken from different overlapping perspectives to recreate an environment - i.e. a 3D structure was obtained from a series of overlapping images. The principle of using randomly positioned images is possible thanks to advances in the development of automatic image matching. For example, this is the scale-invariant feature transform (SIFT) (Lowe, 1999), in which the key approach is the ability to recognize a physical characteristic present in multiple images regardless of the scale (i.e. resolution) of the images and the viewpoint of the image. In SfM, the positions and orientation of the camera are solved automatically, without the need to first have a network of control points with known 3D coordinates (Westoby et al, 2012). Instead, they are solved simultaneously using very repetitive iterative procedures for batch adjustment, based on database automatically extracted from overlapping images (Snavely, Seitz, Szeliski, 2008). Another important issue and subject of numerous studies (Mesas-Carrascosa et al., 2014) is the accuracy of digital products obtained after processing the images acquired by UAS. In recent years, solutions have had been implemented as additional GNSS systems in the UAS, through which centimeter accuracy is achieved in the coordinates of the taken images.

## Methods to georeference UAS survey and mapping imagery

UAS typically use a separate GNSS receiver that allows the drone to move independently and safely. Although the separate GNSS receiver is able to achieve satisfactory accuracy for safe navigation, the overall accuracy that can be achieved is far from what is needed for precise research. Most commonly used UAVs (for example, the DJI Phantom series) use GNSS receiver for navigation purposes and can be used to add positional information and coordinates to EXIF metadata of images acquired during flight. However, the positioning accuracy of these receivers is in meters, which necessitates the use of differential GNSS solutions for UAVs to achieve centimeter accuracy in positioning of the taken images.

- **Aero Triangulation – „AT“ (GCP method):** Aero triangulation (AT) is a process in which a mathematical relationship is established between aerial photographs, the camera (camera sensor) and the earth's surface. In order to correct the positioning error in UAS surveys, the so-called "ground control points" or GCP are used. GCPs are points that are visible in the images and for which the exact geographical coordinates are known. The use of GCP for georeferencing has proven to be a solid solution to achieve high accuracy in HRDT (James et al., 2017; Turner et al., 2016). However, GCPs must be placed and measured, and the accuracy strongly depends on the number of GCPs used and their spatial location (Sanz-Ablanedo et al., 2018). GCPs are typically measured with real-time kinematic (RTK) GNSS surveys, either with respect to a nearby base station, or with differential corrections sent by the Continuously Operating Reference Station (CORS). Both techniques are accurate to 1-2 cm in horizontal coordinates and 2-3 cm in elevation. The difficulties of this method arise from the cost of time, difficulties in placing the points on the terrain (landslides, glaciers, open pit mines) or lack of visibility (forests or bushes).
- **Direct image georeferencing (RTK/PPK method).** Unlike AT, direct georeferencing of images is the direct calculation of the position and orientation of the camera during shooting, so that each pixel can be georeferenced to the ground coordinate system without the need for ground measurements. Developments in GNSS/INS technology have contributed to a major leap in digital photogrammetry. GNSS records the coordinates "X, Y, Z" and INS (inertial navigation system) records orientation angles "w,  $\phi$ , k" during exposure. These measurements are integrated and form six parameters, which are called Exterior Orientation "EO" parameters, which are used in the collinearity equation for georeferencing (Dinkov, 2018b). In classical photogrammetry, the coordinates of control points are needed to solve the collinearity equations, which define the relationship between the camera, the image and the earth's surface. Two main modifications of kinematic measurements of GNSS are accepted for UAS applications based on the immediate availability of correction data during flights with the unmanned system. If the GNSS receiver of the UAS can communicate with the reference station in real time (using a radio connection), corrections may be applied simultaneously during the flight. This mode is called real-time kinematic correction (RTK). If we calculate the coordinates of the taken images, applying the corrections from the base station after the flight, the mode is referred to as a kinematic GNSS method with post-processing (PPK-method).

In recent years, researches with the UAV in order for direct georeferencing of images is becoming more and more popular. A number of studies have shown the areas in which this method can be used: forest areas (Tomaščík et al., 2019), dam and riverbed erosion (Duró et al., 2018), landslides (Dugonjić Jovančević, S., Peranić, J., Ružić, I. et al., 2016), etc.

Štroner et al., (2020) presents the accuracy of this method, describing in detail its stages. They chose two test sites - urban and rural. In their study, they show the necessity of several flights to avoid possible errors and inaccuracies. They show that the presence of GCPs and CPs are necessary for the accuracy in horizontal and vertical direction: "Our results, however, prove that the use of a GNSS RTK receiver in a multicopter UAV without external verification is potentially very dangerous - a danger manifested predominantly as a systematic shift of the entire point cloud in the vertical components". Tomaščík et al., (2019) shows in their study that these methods are suitable for inaccessible forest areas. The results are satisfactory and they managed to obtain an accuracy of several centimeters: "In most cases horizontal RMSEs of the RTK/PPK method did not exceed 10 cm and vertical RMSEs were under 20 cm."

In this study is used post-processed kinematic method (PPK) for accurate georeferencing images from UAVs.

The purpose of the study is to evaluate the geospatial accuracy of the photogrammetric products (HRTD), obtained by the UAV/PPK method using a low-cost configuration one-band GNSS receiver (Emlid M+), DJI Phantom 4 pro serial drone and Snap-PPK kit for DJI Phantom. The results are compared to the traditional georeferencing approach – by using ground control points (GCP).

With the same configuration, a study was conducted in urban conditions of park infrastructure with vegetation, alleys and buildings (Dinkov, 2019), where results were achieved in centimeter accuracy using PPK for direct georeferencing of images from UAS, without the need for GCPs.

## METHODS AND EQUIPMENT

### Study Site

The study was conducted in a rural area on the land of the village of Plana, Sofia Municipality, near the Geodetic Observatory "PLANA" at the Bulgarian Academy of Sciences ( $42^{\circ} 28' N$ ;  $23^{\circ} 24' E$ ). The area is about 5 ha and represents a hilly terrain with a slope of about 8.3% from north to south, with an average altitude of 1200 meters. Predominant grassy vegetation with coniferous forest in the periphery of the surveyed perimeter (Fig. 1).

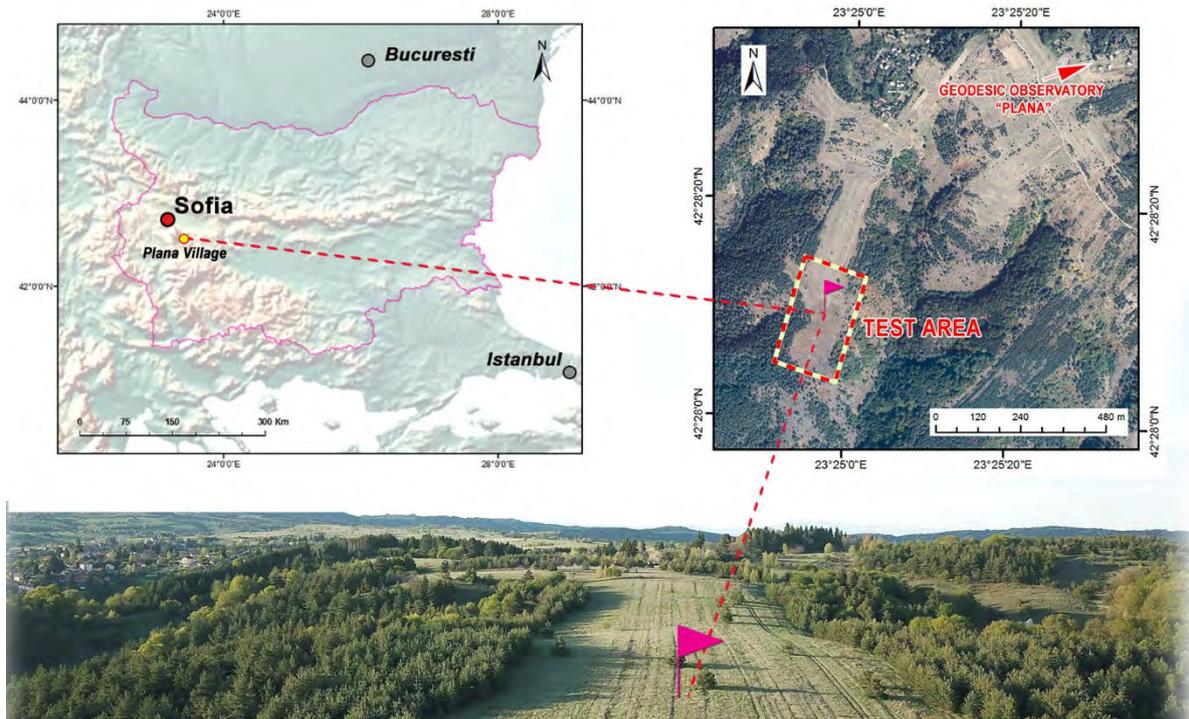


Figure 1. Location of study site

### Platforms and Payloads

This study uses a consumer class of UAV - DJI Phantom 4 Pro (P4P) – Figure 2(a). The P4P is equipped with a DJI FC6310 camera with a nominal focal length of 8.8 mm and a 1 "CMOS" 20 megapixel sensor with  $2.41 \times 2.41 \mu m$  nominal pixel size. The DJI FC6310 creates an image of  $5472 \times 3648$  pixels, which corresponds to  $13.2 \times 8.8$  mm. For implementation of the PPK-GNSS experiment, the platform is equipped with compact multi-GNSS-RTK receiver (Reach RTK kit, Emlid Ltd) with RTK / PPK capability as described below.



Figure 2. UAV and PPK-GNSS module: (a) Phantom 4 pro ; (b) Emlid Reach M+ and Tallysman antenna; (c) Snap PPK adapter kit for Phantom 4 pro

## PPK-GNSS Module

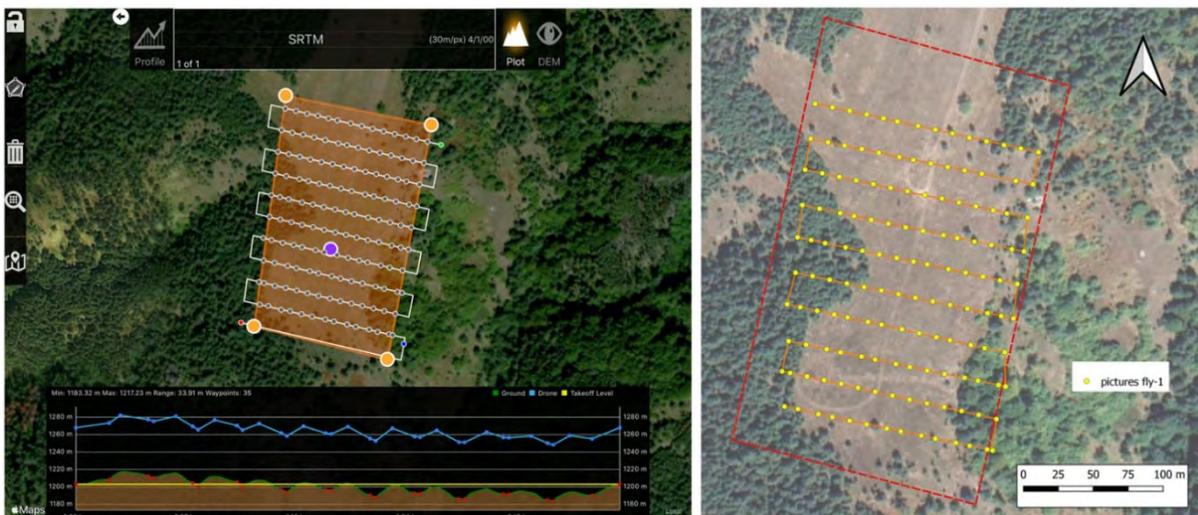
During the UAV flights, a Reach RS (Emlid Ltd) was mounted on a tripod located upon GCP to provide positioning correction input. The maximum distance between the UAV and the base station was 216 m. The receiver of the base is configured to log the raw data in a RINEX file at 5 Hz using the satellite GPS, GLONASS and GALILEO. UAV was equipped with a Reach GNSS receiver (Figure 2b) to log the raw data as UBX format using GPS and GLONASS satellites. The antenna model was Tallysman's TW2710, which covers the GPS L1, GLONASS G1, BeiDou B1, Galileo E1, and SBAS (WAAS, EGNOS, and MSAS) frequency bands. The antenna was mounted on a special plate, with the center right above the camera lens center to minimize the offset the shift between the antenna phase center and camera projection center. The antenna height was 23 cm and this difference between the antenna and camera projection center was considered during the post-processing.

Snap PPK - Figure 2(c) is an adapter kit to connect an Emlid Reach GNSS receiver to a Phantom 4 Pro ([www.tuffwing.com](http://www.tuffwing.com)). The kit snaps in seconds to Phantom 4 Pro - without any modifications. The front LEDs on a Phantom 4 Pro blink each time a picture is taken. A phototransistor detects the blink and a time mark is recorded in the Reach's log file. The time marks are extracted and combined with the pictures as precision geotags. Accuracy is further improved by setting the Phantom on a GCP target and taking a picture while stationary. This position is free from shutter timing errors, lever-arm errors, and camera calibration errors.

## Flight planning and performing

The parameters of the flight plan (flight altitude, flight speed, type of flight path, overlap between captured images) are critical for the GSD (Ground Sampling Distance) resolution of the final orthophoto mosaic and the spatial accuracy of the high-resolution topographic data (HRTD). Anyone who has tried to map uneven terrain knows that it is almost impossible to maintain consistent overlap when the altitude AGL is changing with terrain. Consistent overlap leads to consistent GSD and higher quality map processing results. In order to achieve uniformity in the scale of the images, the flights are planned and performed at a constant altitude of the UAS relative to the AGL terrain.

Two flight campaigns were conducted for the test site in May 2020. It was experimented with two flight planning software (Map Pilot and UgCS). The first campaign (hereinafter FP1) uses strips (rows) of images perpendicular to the longitudinal slope of the study area (Fig. 3).



**Figure 3.** Flight mission FP1: (a) Map Pilot work screen; (b) Location of the taken images

Flight mission FP1 was planned and was performed using the Map Pilot application for iOS ([www.dronesmadeeasy.com](http://www.dronesmadeeasy.com)). As of Map Pilot 2.1.0, the ability for the app to download terrain data to adjust flight plans according to the terrain below them is available as an in-app purchase. The Terrain Awareness feature uses SRTM (or Shuttle Radar Topography Mission) data that has been specially formatted for use with Map Pilot.

Flight FP1 was performed at a constant speed of 5 m/s at an altitude of 65 m following the terrain, taking 139 images with 80% forward overlap and 70% side overlap of the images. The resulting GSD for FP1 is 1.73 cm/0.68 in.

The second flight campaign consists of two flight missions (FP2, FP3), as on mission FP2 the direction of flight is perpendicular to the longitudinal slope of the site, while the second flight model (FP3) uses a direction parallel to the slope. This campaign uses the software UgCS for planning and performing the flights. The UgCS Photogrammetry Tool module ([www.ugcs.com](http://www.ugcs.com)) allows constant altitude flight planning over mapped terrain (AGL). This feature ensures preset image overlap and sequential GSD (Ground Sample Distance). UgCS, like Map Pilot, uses SRTM data (Shuttle Radar Topography Mission), but also has the option to enter a more accurate DEM by the user.

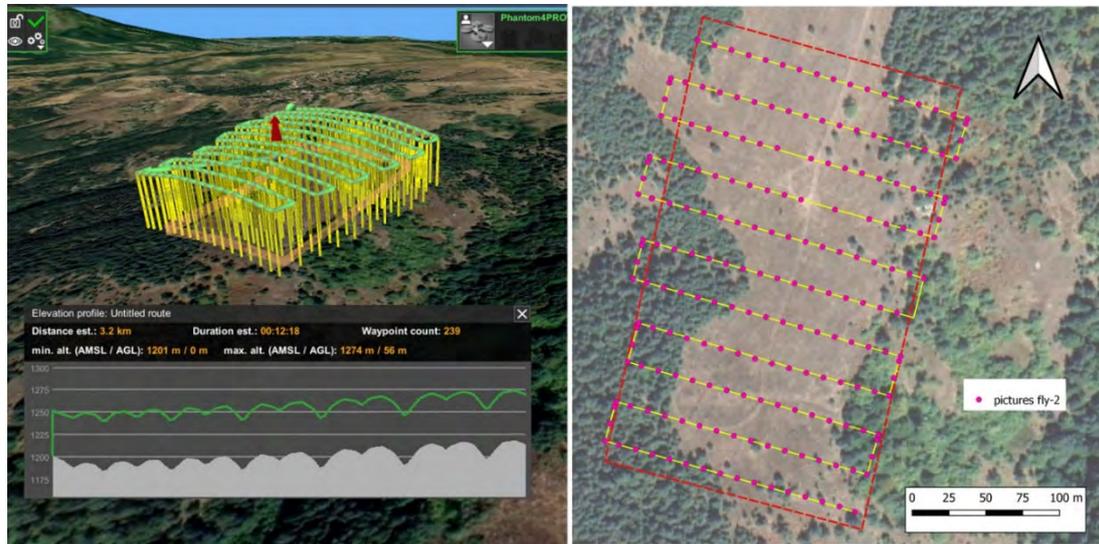


Figure 4. Flight mission FP2: (a) UgCS work screen ; (b) Location of the taken images

Other advantages of UgCS are the ability to resume the mission from a user-selected point (after a pause to change the battery), as well as to use the Make a shot (trigger camera) in waypoint mode, in which the UAV is positioned exactly at each set point from the mission to take image. This method depends on the autopilot's ability to record the waypoint, but the images are taken exactly at the planned locations. Phantom 4 pro records up to 99 points, then the next waypoint is submitted to the autopilot, and the operation can be performed while the UAV is in the air.



Figure 5. Flight mission FP3: (a) UgCS work screen; (b) Location of the taken images

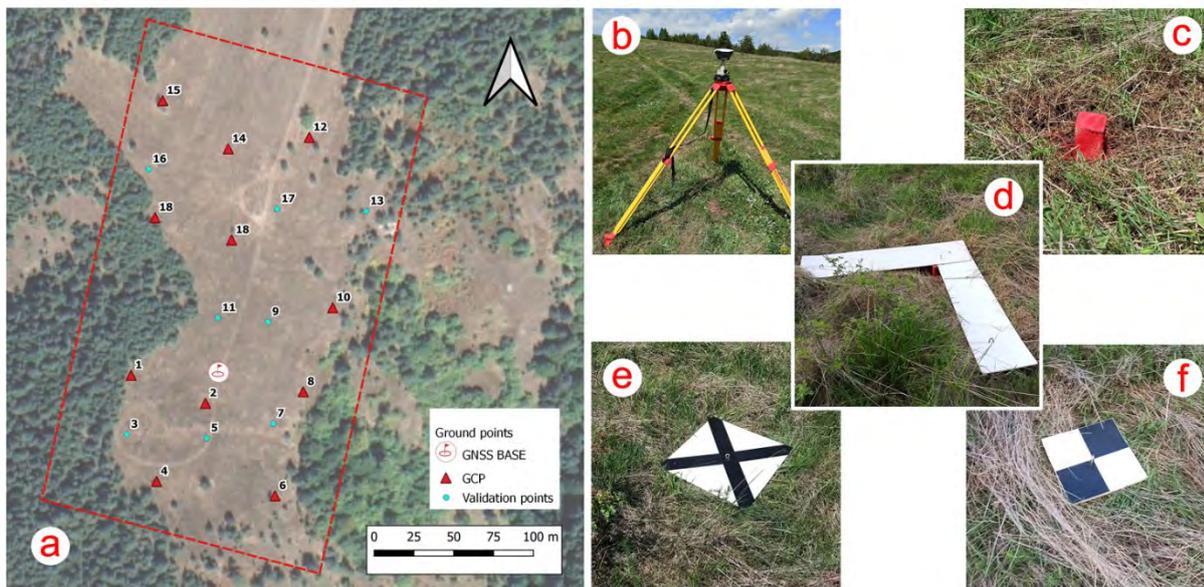
Flights FP2 and FP3 were performed at a constant speed of 5 m/s, at an altitude of 55 m following the terrain, and a total of 386 images were taken. The flight missions were designed with 80% forward overlap and 70% side overlap of the images. The first mission (Figure 4) was performed at the altitude of 55 m from the terrain and maximum speed of UAV of 5 m/s, also and the second mission (Figure 5). The resulting Average Ground Sampling Distance (GSD) for flights FP2 and FP3 is 1.54 cm/0.61 in

## GNSS measurements and image georeferencing

The GNSS campaigns had three different objectives: (1) measuring ground control points (GCPs) to be used in the air triangulation phase; (2) measuring validation points (VPs) to assess the spatial accuracy of the digital data obtained; and (3) recording raw GNSS data for post-processing to accurately coordinate the images taken from the UAV.

A total of 19 points were set and measured for accuracy assessment, of which 11 ground control points (GCP) and 8 validation points (VP) - Figure 6. GCPs are stabilized in the field (Figs. 6c, 6d) and participate in the verification of the accuracy of both campaigns, while VPs (Figs. 6e; 6f) are selected and measured individually for each campaign. The coordinates of the ground control and validation points were obtained by the GNSS RTK method with geodetic two-frequency receiver (Kolida – K5 PLUS), RTK solution with the 1YOCTO network ([www.1yocto.bg](http://www.1yocto.bg)). For a fixed solution, the declared accuracy of 1YOCTO is up to 5 cm.

The PPK method is used to calculate the exact positions of the images taken with UAV. For this purpose, a base station (GNSS BASE) is located on the field - fig.6a, where raw GNSS data are received and recorded through the receiver EMLID RS + (fig. 6b). During the flight missions with UAV, raw data are also recorded, as well as the moments of taking the images are registered with additional PPK-kit (fig. 2).



**Figure 6.** Ground control points and Validation points : (a) Scheme of control points; (b) Base station -Emlid Reach RS+; (c) GCP; (d) GCP+ground mark (e);(f) Validation points

The free RTKLIB software was used to process the raw data and obtain the coordinates of the captured images (Takasu, 2009).

## DATA PROCESSING

Georeferenced images were processed with Pix4D Mapper software ([www.pix4d.com](http://www.pix4d.com)). The software uses the SfM algorithm to generate 3D cloud points, DSM and orthophoto mosaics in the study area. The procedure consists of three main steps: (i) Initial processing, (ii) Generating cloud of points and (iii) Generating of DSM and orthophoto mosaic. All next steps are made separately, with some differences between the configurations. First, twelve subprojects were created to allow independent evaluation of all variables and their possible combinations (four georeferencing approaches, three flights). In the PPK solution method, the calculated camera positions are attached to the EXIF metadata of each taken image. For the 8GCP configuration this information has been removed and geotags from the original Phantom 4 Pro images were used. After the initial processing, all validation points (Check points) were entered for calculation of the accuracy. Next steps include generation of solid cloud of points, orthophoto mosaics and DSM.

## EVALUATION OF ACCURACY

Direct georeferencing does not require any GCP. In the SfM image processing process using the PPK-method for georeferencing, all GCPs are changed to "CHECK POINT", which are used to verify the accuracy of this method. The

evaluation of point cloud accuracy was performed using 11 GCP and 8 validation points (VPs) (which were not used in the cloud generation) by computing the differences between the coordinates of the checkpoints in the 3D cloud and those measured in the field by GNSS. Mean values and the root mean square error (RMSE) of the differences were computed for each flight to detect systematic shifts and block deformations.

The positions of the validation points were determined directly on the point clouds. The GCPs and VPs were marked in the Pix4D using built-in RayCloud 3D Editor.

Calculation of the root mean square coordinate errors:

$$RMSE_x = \sqrt{\frac{\sum_{i=1}^n \Delta x_i^2}{n}} \quad (1)$$

$$RMSE_y = \sqrt{\frac{\sum_{i=1}^n \Delta y_i^2}{n}} \quad (2)$$

$$RMSE_z = \sqrt{\frac{\sum_{i=1}^n \Delta z_i^2}{n}} \quad (3)$$

where  $\Delta x_i$ ,  $\Delta y_i$  and  $\Delta z_i$  are the differences between reference coordinates and the coordinates determined from the remote sensing data and  $n$  is the number of points in the set.

The  $RMSE_x$  and  $RMSE_y$  errors were used for the calculation of the root mean square horizontal error  $RMSE_{xy}$  as follows:

$$RMSE_{xy} = \sqrt{RMSE_x^2 + RMSE_y^2} \quad (4)$$

The  $RMSE_{xy}$  is one of the most common horizontal accuracy criteria for sets of points and was used as the main measure to compare data between the test sites and between various configurations of GCPs/VPs.

**Evaluation the accuracy of georeferencing for flight FP1**

**Table -1:** Flight-1: Errors & RMSE of check points for PPK-georeference process case.

Point	Error X(m)	Error Y(m)	Horizontal error (m)	Vertical error(m)
pnt1	0,054	-0,050	0,074	-0,015
pnt2	0,028	-0,020	0,034	-0,021
pnt3	0,031	-0,025	0,040	-0,054
pnt4	0,036	-0,056	0,067	-0,033
pnt5	0,049	-0,005	0,049	-0,006
pnt6	0,081	-0,035	0,088	-0,087
pnt7	0,044	-0,027	0,052	-0,113
pnt8	0,040	-0,055	0,068	-0,026
pnt9	0,033	-0,039	0,051	-0,110
pnt10	0,040	-0,045	0,060	-0,010
<b>RMSE(m)</b>	<b>0,046</b>	<b>0,039</b>	<b>0,060</b>	<b>0,062</b>

**Figure 7.** Errors in the position of the validation points for flight FP1

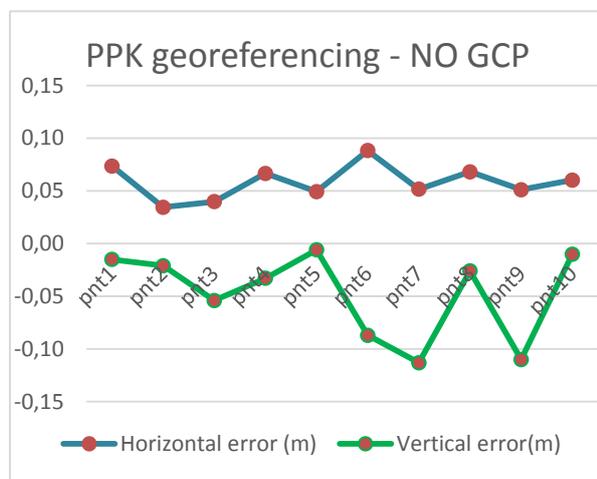
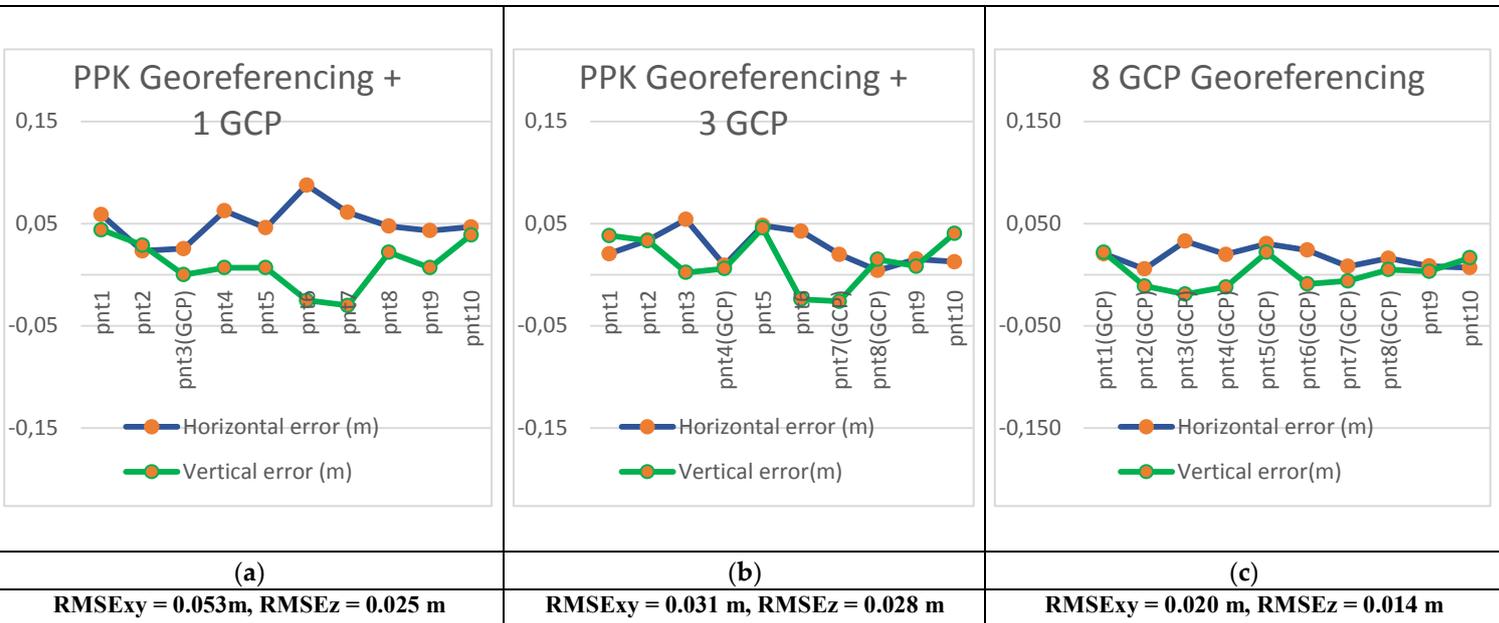


Table 1 shows the errors in the coordinates (X, Y, Z) of the validation points for flight FP1 when applying only the PPK-method for direct georeference. As noted, this flight was performed at a constant UAV speed of 5 m/s using Map Pilot. The errors were obtained as differences in the coordinates obtained from the 3D cloud after SfM-processing and those obtained by static GNSS field measurements. There is a slight systematic error in the values for position and height. But the overall estimate of position and height errors show values **RMSE<sub>xy</sub> = 0.060 m**, **RMSE<sub>z</sub> = 0.062 m**.



**Figure 8:** Histograms of planimetric and vertical errors (dx,dy,dz) for the validation points for the different methods for georeferencing of the images for Flight-FP1

Figures 8 (a) and 8 (b) show the histograms with the errors in the position of the validation points after the inclusion of control points in the process of general georeferencing of the 3D cloud after SfM-processing. When adding 1 to 3 GCP in the georeferencing process, a gradual improvement in the accuracy of the validation points is observed as it reaches **RMSE<sub>xy</sub> = 0.031 m**, **RMSE<sub>z</sub> = 0.028 m** for PPK Georeferencing + 3 GCP. Figure 8 (c) shows the histogram with the errors in the position of the validation points, when only 8 GCPs were used for georeferencing of the 3D cloud after SfM processing, without the position of the individual images having weight (influence) in the calculations.

### Evaluation the accuracy of georeferencing for flight FP2

The scope of the studied area for FP2 and FP3 flights has been increased, due to which the number of control points (11 GCP) and of the validation points (9 VP) has been increased. The other difference from FP1 flight is the method of shooting - UAV is positioned exactly at the location determined by the flight plan and then takes an image. In FP2, the mission was performed with a pause to change the battery, after which it was resumed from the next waypoint. Position and height errors for validation points by the PPK-georeferencing method show values **RMSE<sub>xy</sub> = 0.040 m**, **RMSE<sub>z</sub> = 0.051 m** – table 2 and histogram - figure 9. It is obvious that the accuracy in position **RMSE<sub>xy</sub>** is higher than the vertical **RMSE<sub>z</sub>**. The maximum and minimum absolute values of horizontal error are 0.057 and 0.006 m, and for vertical error - 0.11 and 0.003 m.

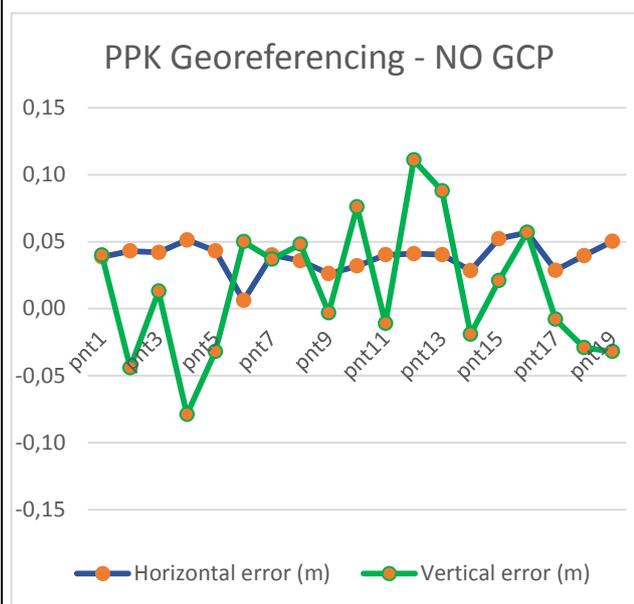
When GCP was included in the spatial point cloud georeferencing process, accuracy was improved by adding a single control point (GCP) - **RMSE<sub>xy</sub> = 0.028m**, **RMSE<sub>z</sub> = 0.039 m**. - fig. 10(a) and when adding three control points **RMSE<sub>xy</sub> = 0.030 m**, **RMSE<sub>z</sub> = 0.034 m**. - fig. 10(b).

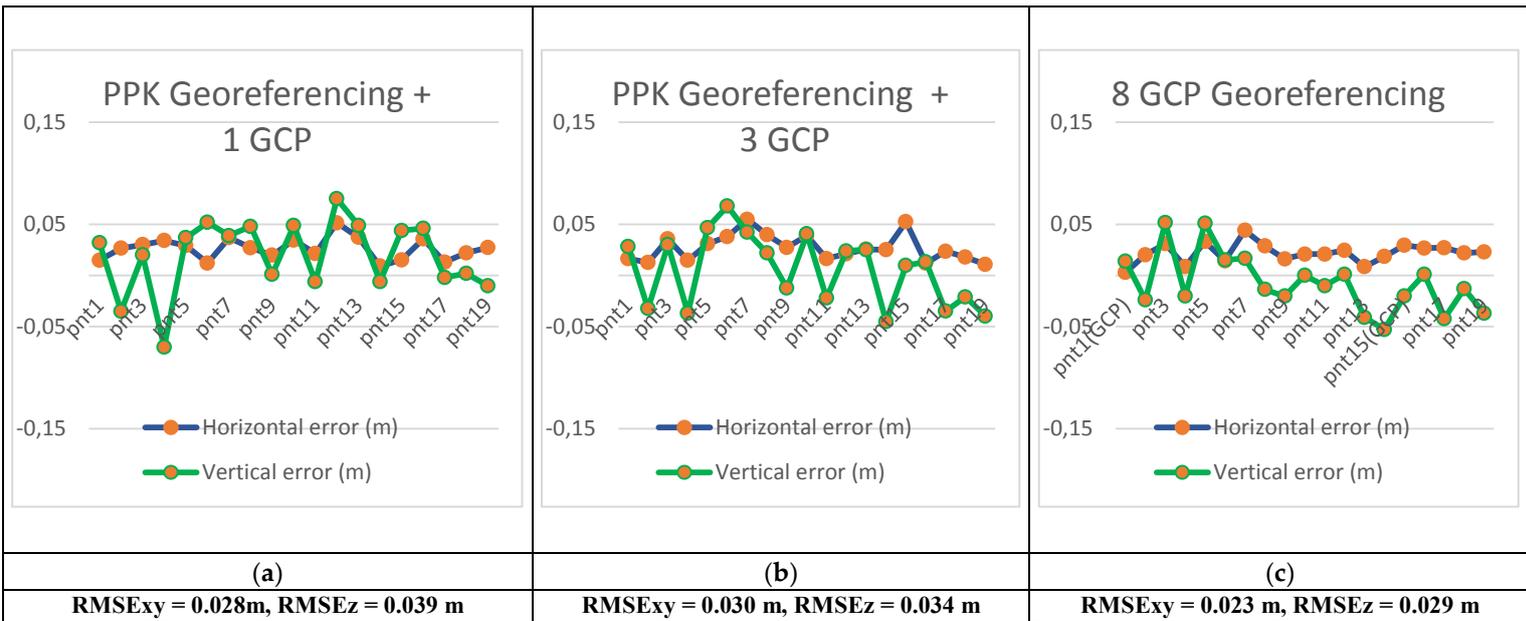
The classic way of georeferencing the cloud only through ground control points achieved accuracy in the control and validation points **RMSE<sub>xy</sub> = 0.023 m**, **RMSE<sub>z</sub> = 0.029 m** – fig. 10(c)

**Table -2: Flight-FP2: Errors & RMSE of check points for PPK-georeference process case.**

Point	Error X(m)	Error Y(m)	Horizontal error (m)	Vertical error (m)
pnt1	0,036	-0,014	0,039	0,040
pnt2	0,043	0,003	0,043	-0,044
pnt3	0,033	-0,026	0,042	0,013
pnt4	0,043	0,028	0,051	-0,079
pnt5	0,029	-0,032	0,043	-0,032
pnt6	-0,006	-0,001	0,006	0,050
pnt7	0,002	-0,040	0,040	0,037
pnt8	0,011	-0,034	0,036	0,048
pnt9	0,003	-0,026	0,026	-0,003
pnt10	-0,017	-0,027	0,032	0,076
pnt11	0,036	-0,018	0,040	-0,011
pnt12	-0,029	-0,029	0,041	0,111
pnt13	-0,016	-0,037	0,040	0,088
pnt14	0,022	-0,018	0,028	-0,019
pnt15	0,052	-0,005	0,052	0,021
pnt16	0,037	-0,043	0,057	0,057
pnt17	0,025	-0,014	0,029	-0,008
pnt18	0,027	-0,029	0,040	-0,029
pnt19	0,041	-0,029	0,050	-0,032
<b>RMSE (m)</b>	<b>0,030</b>	<b>0,027</b>	<b>0,040</b>	<b>0,051</b>

**Figure 9. Errors in the position of the validation points for flight FP2**





**Figure 10:** Histograms of planimetric and vertical errors ( $dx, dy, dz$ ) for the validation points for the different methods for georeferencing of the images for Flight-FP2

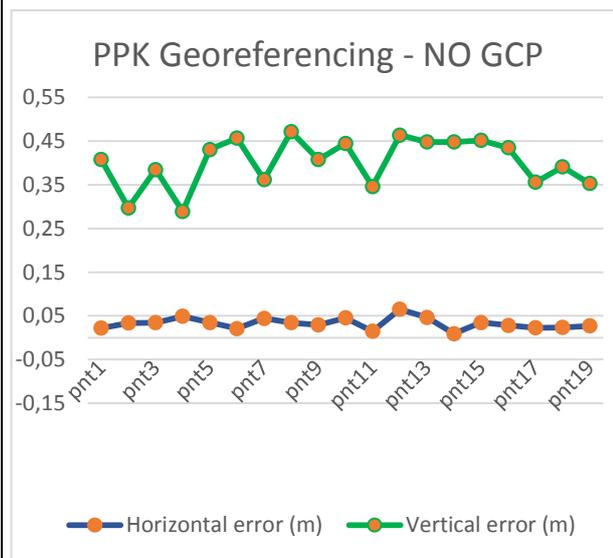
**Evaluation the accuracy of georeferencing for flight FP3**

Flight mission FP3 has the same range, altitude and flight method as FP2. The flight lines are perpendicular to FP2. In FP3, the mission was also performed with a pause to change the battery, after which it was resumed from the next waypoint. After processing the images georeferenced by the PPK method, it was found that in flight FP3 the errors in the position of the validation points are low:  $RMSE_{xy} = 0.035 \text{ m}$  with maximum deviation of 0.065 m. However, the vertical errors turned out to be significantly higher:  $RMSE_z = 0.406 \text{ m}$  with maximum deviation of 0.472 m. - table-3 and histogram – fig. 11. The reasons for these deviations in height can be poor satellite configuration due to adverse weather conditions during the flight.

**Table -3:** Flight-FP3: Errors & RMSE of check points for PPK-georeference process case

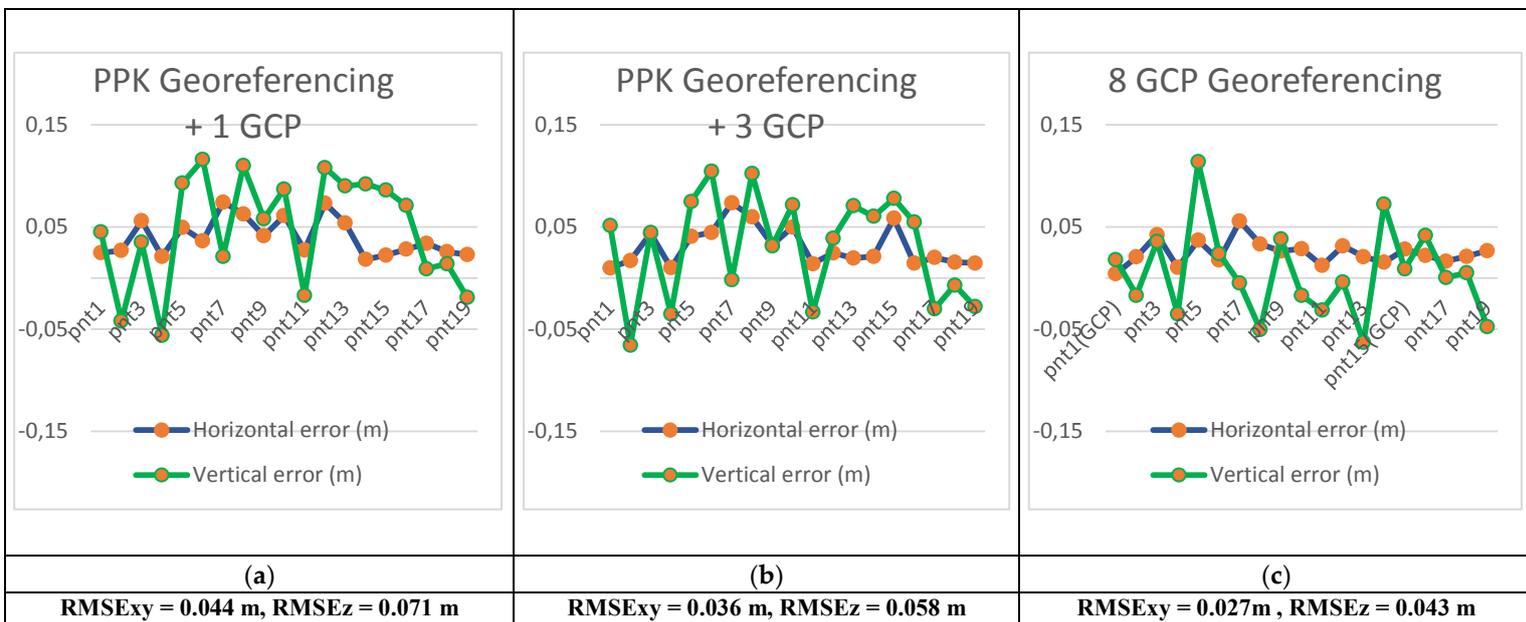
Point	Error X(m)	Error Y(m)	Horizontal error (m)	Vertical error (m)
pnt1	0,020	0,009	0,022	0,408
pnt2	0,030	0,015	0,034	0,297
pnt3	0,028	-0,020	0,034	0,385
pnt4	0,031	0,038	0,049	0,289
pnt5	0,033	-0,011	0,035	0,431
pnt6	-0,019	0,008	0,021	0,457
pnt7	-0,002	-0,044	0,044	0,362
pnt8	-0,015	-0,031	0,034	0,472
pnt9	-0,029	-0,001	0,029	0,408
pnt10	-0,037	-0,026	0,045	0,445
pnt11	0,014	-0,004	0,015	0,346
pnt12	-0,056	-0,033	0,065	0,464
pnt13	-0,044	-0,014	0,046	0,448
pnt14	0,004	-0,008	0,009	0,448
pnt15	0,032	0,013	0,035	0,452
pnt16	0,025	-0,013	0,028	0,435
pnt17	0,005	-0,022	0,023	0,356
pnt18	0,021	-0,010	0,023	0,391
pnt19	0,027	-0,002	0,027	0,353
<b>RMSE</b>	<b>0,028</b>	<b>0,021</b>	<b>0,035</b>	<b>0,406</b>

**Figure 11.** Errors in the position of the validation points for flight FP3



The use of GCP did not lead to better results in accuracy at (X, Y) position, but significantly improved vertical (Z) accuracy compared to purely PPK-georeferenced data: **RMSE<sub>xy</sub> = 0.036 m, RMSE<sub>z</sub> = 0.058 m** – fig. 12(b)

For FP3 flight, the accuracy of georeferencing the cloud using GCP alone achieved accuracy, respectively **RMSE<sub>xy</sub> = 0.027 m, RMSE<sub>z</sub> = 0.043 m** – fig. 12 (c)



**Figure 12:** Histograms of planimetric and vertical errors ( $dx, dy, dz$ ) for the validation points for the different methods for georeferencing of the images for Flight-FP3

## DISCUSSION

In the present study, the GNSS Post-Processing Kinematic (PPK) method for Direct Georeferencing of UAV Image was tested and compared with the classical method using ground control points (GCP). The selected test area has a varied topography and homogenous land cover.

The study proves that the classic "AT" (GCP method) for georeferencing provides better accuracy of processed digital products. The quality of georeferencing through ground control points depends on the number and distribution of GCPs Sanz-Ablanedo, E. et al., (2018), Rangel, J.M.G. et al.,(2018). The accuracy is improved by adding more and more densely distributed GCPs, which would increase study time.

The achieved accuracy in the studied data on the planned position, using the PPK-method for georeferencing, show stable values that do not exceed  $3 \times \text{GSD}$  and are comparable with the results obtained in georeferencing by GCP. However, the current results also show significant height deviations due to a systematic error, with the use of one additional validation point (in the middle of the block) eliminating the effect of the error. The systematic height deviations of the VP are reduced to approximately 15-100 mm and are thus at the same level of accuracy as the "AT" (GCP method) for georeferencing. The system for recording the moments for taking images - SNAP-PPK (using a photodetector to the P4P lights) is also debatable, with an offset between 12-15ms ([www. community.emlid.com](http://www.community.emlid.com)). This shift in time and its effect on accuracy is subject to our further studies.

The future research of the author's team of the PPK-methodology for direct georeferencing envisages testing of various open source flight configurations, dual-frequency GNSS receivers, as well as a direct system for recording the exact moments of the taken images.

## CONCLUSION

The implementation of PPK solutions for coordination of UAV images and the related direct georeferencing of photogrammetric blocks and 3D point clouds is a cost-effective step in using UAS in geodesy and photogrammetry. The affordable Phantom 4 Pro configuration studied in this paper, EMLID single-frequency GNSS receivers, and the Snap-PPK adapter kit provide enough opportunities for applications in the mid-precision range ( $> 3 - 4$  cm).

The use of PPK solutions can lead to a significant reduction in field activities and georeferencing costs, saving time and resources for stabilization and geodetic measurements of GCP.

### **Advantages**

The direct georeferencing approach is appropriate in conditions where it is not possible to measure GCP. The direct georeferencing method reduces the use of GCP by enabling high-resolution topographic data to be produced.

### **Disadvantages**

The main weakness is the systematic errors and inaccuracies in height, for which there is an easy solution by using 1 to 3 ground control points.

### **Applicability**

From the calculations it can be concluded that the PPK-direct georeferencing method can provide the necessary accuracy in a position that meets the requirements for plans and orthophoto maps at a scale of 1: 1000, and vertical accuracy can be used to produce topographic data corresponding to accuracy requirements for scale 1: 5000.

### **ACKNOWLEDGEMENTS**

This study has been accomplished in the frame of the research project "POST-PROCESSING KINEMATIC METHOD FOR PRECISE GEOREFERENCING OF UNMANNED AERIAL VEHICLE IMAGES FOR 4D MODELING OF THE EARTH'S SURFACE", № KII-06-M34/2, National Science Fund (2019-2021).

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**8<sup>th</sup> International Conference on Cartography and GIS**

Proceedings Vol. 1  
2020, Nessebar, Bulgaria

© Editors: Temenoujka Bandrova, Milan Konečný, Silvia Marinova

© Publisher: Bulgarian Cartographic Association  
1, Chr. Smirnenki Blvd.  
Sofia, Bulgaria, 2020

**ISSN: 1314-0604**

[iccgis2020.cartography-gis.com](http://iccgis2020.cartography-gis.com)