„Dunărea de Jos” University of Galați

Doctoral School of Mechanical and Industrial Egineering

UNIVERSITAS
GALATIENSIS

Ph.D. THESIS

(ABSTRACT)

Modern GIS techniques for determination of the territorial risks

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Prof. Ph.D. Eng. GEORGESCU Puiu Lucian

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Series **I4 Industrial Engineering** Nr. 52
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1. **Arseni, M.,** Rou, A., Bocaneala, C., Constantin, D. E., & Georgescu, L. P. (2017). *Flood hazard monitoring using GIS and remote sensing observations*. Carpathian Journal of Earth and Environmental Sciences, *12*(2), 329-334., ISSN: 1842-4090 (IF 2016 = 0.88)
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2. Constantin, D. E., Merlaud, A., Voiculescu, M., Van Roozendael, M., **Arseni, M.,** Rosu, A., & Georgescu, L. (2017). *NO2 and SO2 observations in southeast Europe using mobile DOAS observations*. Carpathian Journal of Earth and Environmental Sciences, *12*(2), 323-328., ISSN: 1842-4090 (IF 2016 = 0.88)
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1. Murariu, G., Hahuie, V., Georgescu, L., **Arseni, M.,** Iticescu, C., Murariu, A. G., ... & Nistor, N. (2017). *Study on the influence of atmospheric parameters on the accuracy of the geodetic measurements*. In AIP Conference Proceedings (Vol. 1796, No. 1, p. 040009). AIP Publishing., ISBN: 978-0-7354-1462
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2. Nacu, V., Stoian, I., Vele, D., **Arseni, M.** (2015). *IT system for monitoring climatic changes*. Modern technologies for the 3rd millennium, pp. 35-41, ISBN: 978-88-7587-724
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1. **Arseni, M.,** Georgescu, L. P., Circiumaru, A., & Mugurel, E. C. (2015). *The influence of the atmospheric temperature value on the accuracy of distance measurement with the surveying total station*. Annals of the University Dunarea de Jos of Galati: Fascicle II, Mathematics, Physics, Theoretical Mechanics, 38(1), pp. 20 – 25
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2. Gabriel Murariu, Valentin Hahuie, Lucian Georgescu, Maxim Arseni and Adrian Gabriel Murariu, *Investigation On Satellitar And UAV Cadastral Results. Case Study - Galati County Forest Areas*, TIM 15 - 16 - INTERNATIONAL PHYSICS CONFERENCE, West University of Timisoara, 26th – 28th of May 2016 http://www.timconference.uvt.ro/upload/TIM15- 16_Conference%20Schedule.pdf
3. Gabriel Murariu, Valentin Hahuie, Lucian Georgescu, Maxim Arseni and Adrian Gabriel Murariu, *Study on the Influence of Atmosheric Parameters on the Accuracy Of The Geodetic Measurements*, TIM 15 - 16 - INTERNATIONAL PHYSICS CONFERENCE, West University of Timișoara, 26th – 28th of May 2016 http://www.timconference.uvt.ro/upload/TIM15- 16_Conference%20Schedule.pdf
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Key words:

GIS, territorial risks, bathymetry, UAV systems, flood risk maps, one-dimensional flow, digital terrain model, interpolation methods, Siret River, roughness coefficient, hydrodynamic modeling

Introduction

The Ph.D. thesis "Modern Techniques GIS for Determination of Territorial Risks" approaches a research topic in the field of engineering, on the assessment of natural risks and hazards, using various modern engineering techniques and methods of geospatial assessment**.**

The research on GIS techniques and methods for determination of the risks and territorial hazards was focused especially on the definition and the combination of the modern methods of topography and surveying, geodesy, aerophotogrammetry and bathymetry, for the realization of flood scenarios in the lower course of the Siret River.

According to the Floods Directive 2007/60 / EC, flood risk assessment and management is based on the determination of flood risk areas and on the statistical evaluation of key indicators that have been exposed to natural hazards produced in an area over a period. The execution of these maps is a complex process of summarizing different techniques, such as hydrological and hydraulic modeling, based on a series of data that sufficiently accurately describes the map of the main channel and of the overbank areas.

Between 2005 and 2016, a series of significant floods occurred in the lower Siret River course.

The present study was initiated based on this strategy in to determine useful techniques and methods for achievement of hazard and flood risks maps. The perimeter in which the research was developed is located along the Siret River, from its confluence with the Danube River, up to 35 km upstream, adjacent to the village Independența.

In order to achieve the main purpose of the work, the following **main objectives** were accomplished:

- The full approach of research on study area which was not evaluated in the past;
- The determination of topographic, bathymetric and aerophotographic methods for exact data collection from the field;
- The combination of gathered data by different methods in order to obtain a digital elevation model of the land, including detailed cartography of the main channel and overbank areas of the study area;
- The achievement of hydraulic modeling for evaluation of the water level in the profile, the flow rate, the depths and the extent of the flooded areas;

- The transformation of the obtained results from hydraulic modeling into geospatial databases;
- Statistic comparison and evaluation of the results;
- Generation of flood risk and hazard maps in the studied area;
- Quantification of methods, techniques and tools with a solid scientific basis and identification of applicability solutions or simplified approach in the structures without specific scientific competencies;

The originality of this paper is the approach of research on a sector of Siret River (Danube - Sendreni - Independenta), on which similar researches have not been performed.

The thesis, according to the chosen option, is structured in 4 chapters and an introduction, where each chapter has its role in the presentation of the technical details and is structured so that the information is as accessible as possible. The thesis is based on an extended bibliography, exposed at the end of the paper.

The introduction of the thesis represents a solid argument for the topic choice, an emphasis on the importance of the field of study, as well as a short presentation of the conditions and objectives in which the study was developed.

Chapter 1*. Hazards and territorial flood risks on the Siret River. The state of the art of the research* presents the historical evolution of the hazards and the territorial risks in the Siret basin, the basin which includes the detailed analyzed area.

Chapter 2. *Materials, research and data processing methods*, presents detailed framework of the diversity of studies and methods used to develop the research.

Chapter 3. *Experimental results and discussions* is the experimental part of the paper. This chapter splits in two important parts: Part 3.1, *Experimental results on the determination of the precision of the used methods and tools* shows the results obtained on the research of measurement precisions of the used instruments. Part 3.2, *Determination of flood risk on the lower course of Siret River* is the most important part of the paper, which summarizes all the techniques and methods described in the other chapters and applied exclusively to the chosen study area.

Chapter 4. *Conclusions and research directions* is the part of the paper where all the conclusions and comments on the experimental obtained results are centralized, by generalizing them and acknowledging the importance of using the GIS systems in the field of engineering sciences.

In its entirety, the thesis represents a totality of several engineering techniques and methods actually applied to obtain results, which describe the vulnerable or potentially vulnerable areas in case of flood scenarios. Based on a current bibliography, I believe that this research is one of interest both locally, nationally and internationally, bringing a scientific contribution to modern GIS techniques for flood risk assessment in the field of engineering sciences.

Chapter 1. Hazards and territorial flood risks on the Siret River. The state of art.

1.1 Localization of the Siret Hydrographic area

The Siret Hydrographic Basin is located in the east-northeastern part of the country, and is characterized by the Siret River, which is the largest and most important tributary of the Danube River (Romanescu și Stoleriu, 2013). The Siret River basin covers an area of 42890 km2 in Romania, of which 28.116 km2 are managed by the Siret Water Directorate under the name Siret Hydrographic Space (SHS) (Figure 1.1).

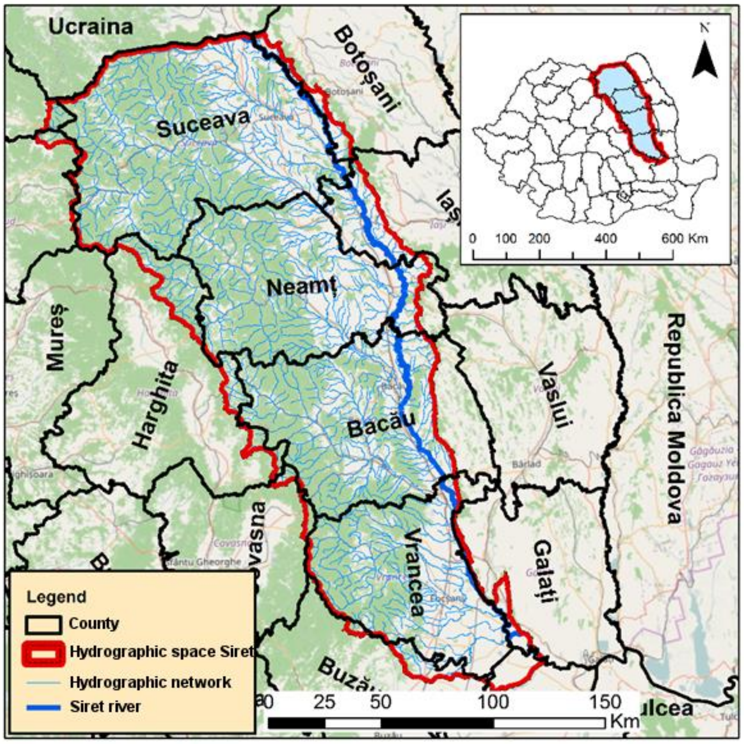


Figure 1.1. Localization of the Siret hydrographic area

1.2 The hydrography of the Siret hydrographic basin

The Siret hydrographic Basin covers approximately 18% of Romania's total area (Apostol și Machidon, 2011). The average SHB altitude is 515 m and the Siret River average inclination is 0.5‰ (REPRI, 2011; PPPDEI, 2014). The hydrological network along the Siret River is extremely developed with a length of 15175 km in Romania (Romanescu, 2009). The main source of water, which represents 75% - 80% for the hydrological network, is determined by the precipitation during the year. The Siret hydrographical basin does not have a regular shape, with more than 70% of the total surface, springs that flow from the Westside, while in the east it is represented only by the river Bârlad as the main tributary (Figure 1.2).

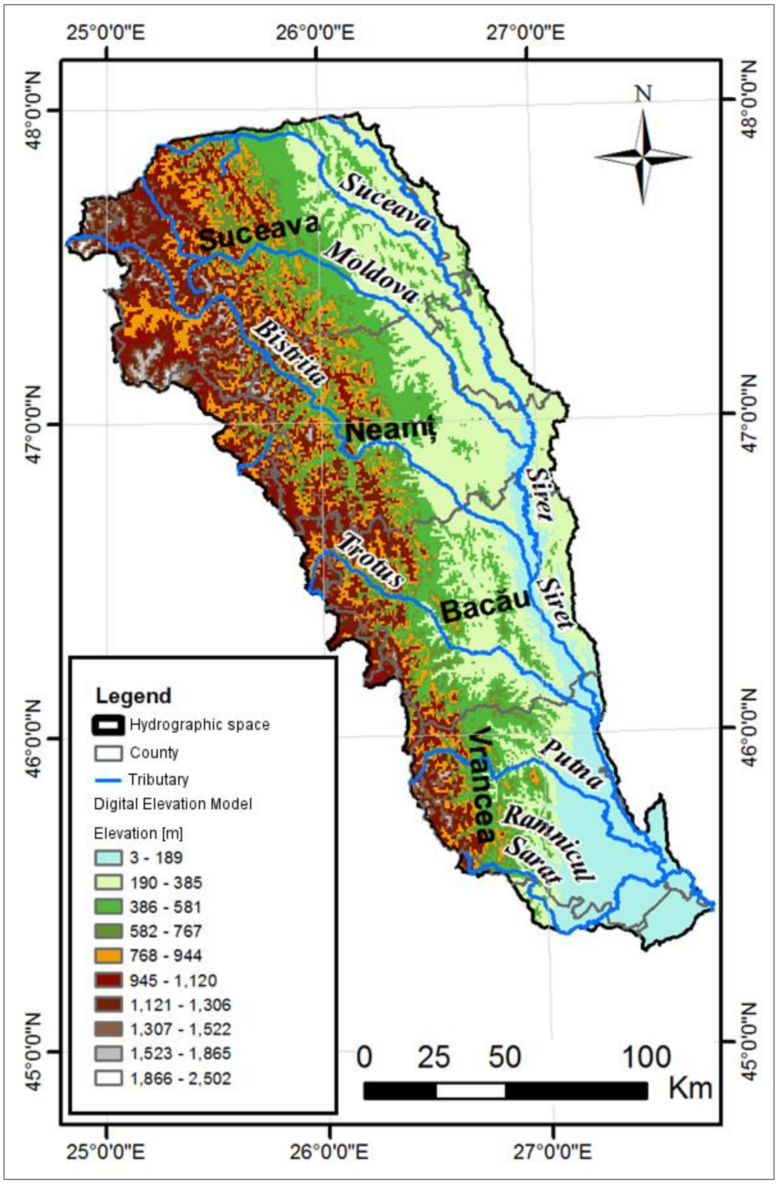


Figure 1.2. Siret River and its main tributaries

The relief the SHB is characterized by several areas with a large variety in terms of physical-geographic features, for example: the Eastern Carpathian mountain chain, the sub-Carpathian area, the Moldavian Central Plateau, the Southern plain area. The average altitude of the whole basin is 515 m, and for Romania's area it is 507 m (Radoane et al., 2003).

The climate has to support various seasonal modifications depending on altitude variation. In the SHB, the continental climate is predominant. Depending on altitudes, we have the following rainfall: the mountain area - 800-1000 l/m^2 (Rodoane et al., 2003; PMRI ABAS, 2016), sub-Carpathian area - 500-700 l/m^2 (Obreja,2012; PMRI ABAS, 2016), plain area - 450 -550 l/m^2 (Romanescu et al., 2013; Apostol și Machidon, 2011).

The vegetation the SHB is characterized by a large variety of species. The high areas are dominated by large coniferous forests (Obreja, 2011; Obreja et al., 2014). In the less mountainous areas, there are stones and small amounts of the forests covered areas. The zones with an average altitude are characterized by hardwood forests. The eastern and southeastern parts of the basin are represented by the vegetation characteristic of the steppe climate with a small distribution of trees on the surface, which has a diminished effect on the water absorption rate and the discharge capacity (Radoane, 2003; REPRI, 2011; Zaharia, 2014; Olariu et al., 2015).

1.3 Flood risk in the Siret hydrographic area

The concept of Hazard (H) is defined in the scientific literature as the probability of occurrence of a threatening or potentially harmful phenomenon for humans within a certain area within a specified time interval (Blaikie, 2003) and it may be global, regional or local.

Depending on the size of the effects, hazards are classified as low, severe or disaster (catastrophes).

The vulnerability (V), Cutter (1996), considers that the vulnerability represents the ability of a group of people to face, return and recover from the impact with a natural hazard. Adger (2006) describes the vulnerability as a measure that is expressed on a scale of 0% to 100% based on natural causes, economic causes and socio-psychological causes, which may be voluntary or involuntary.

The risk (R) represents the mathematical product of hazard and vulnerability, being expressed as the relationship between a phenomenon and its consequences. Wang et al. (2015) consider the risk to be an amount that defines the real exposure of a value before a hazard, by defining the degree of risk using the combination of an area and the vulnerability of the human society from the point of view of its preparation and reaction.

1.4 Flood history the Siret Hydrographic basin

Over time, the Siret River and its tributaries have produced considerable floods such as those from 1969 to 2016 (Figure 1.3 – 1.5).

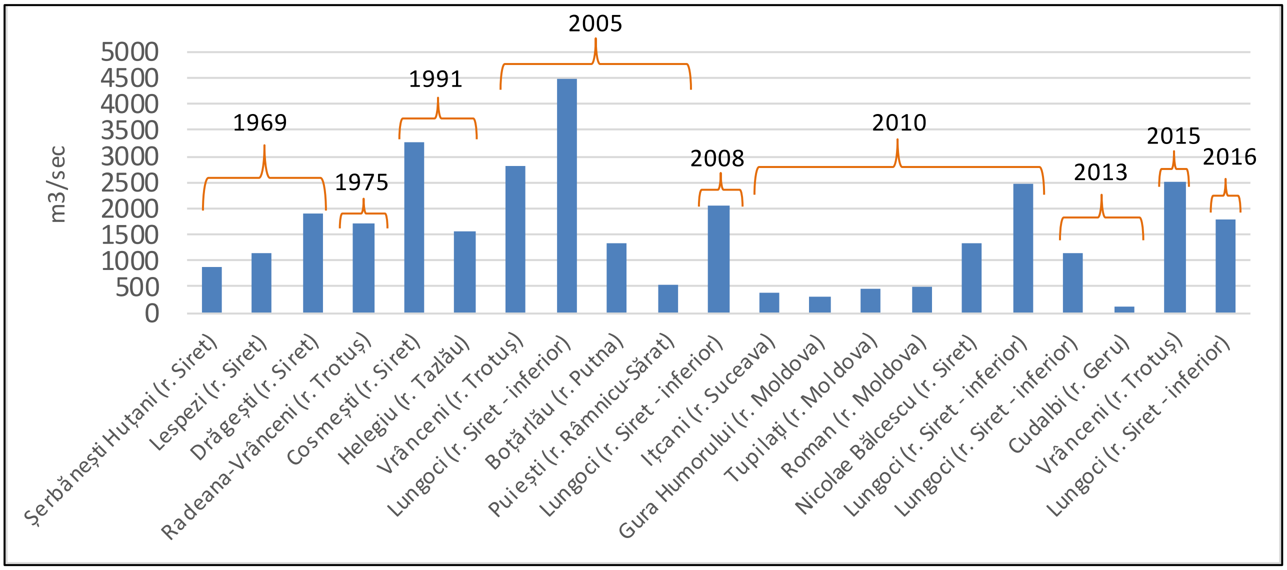


Figure 1.3. Maximum historical flows recorded on Siret River and its tributaries [I.N.H.G.A.]

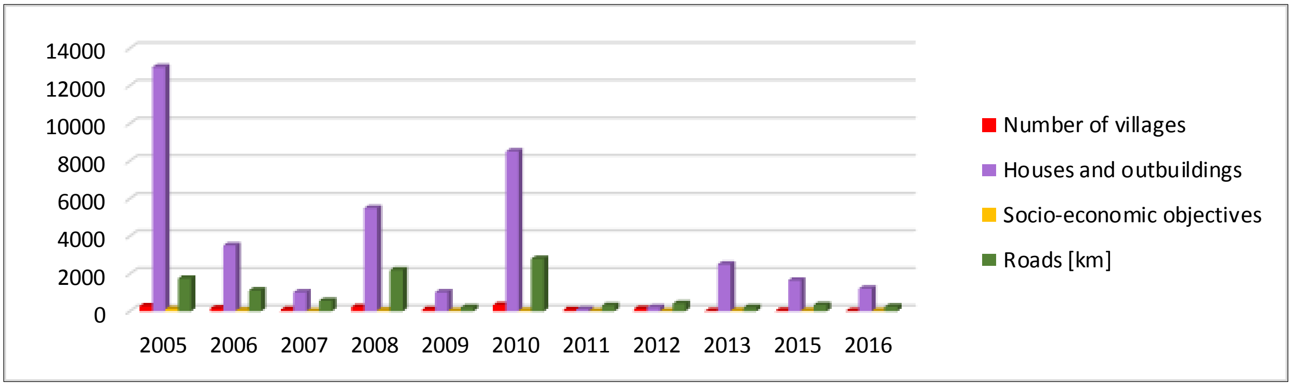


Figure 1.4. Damage caused by historical floods from 2005 to 2016 [I.N.H.G.A.]

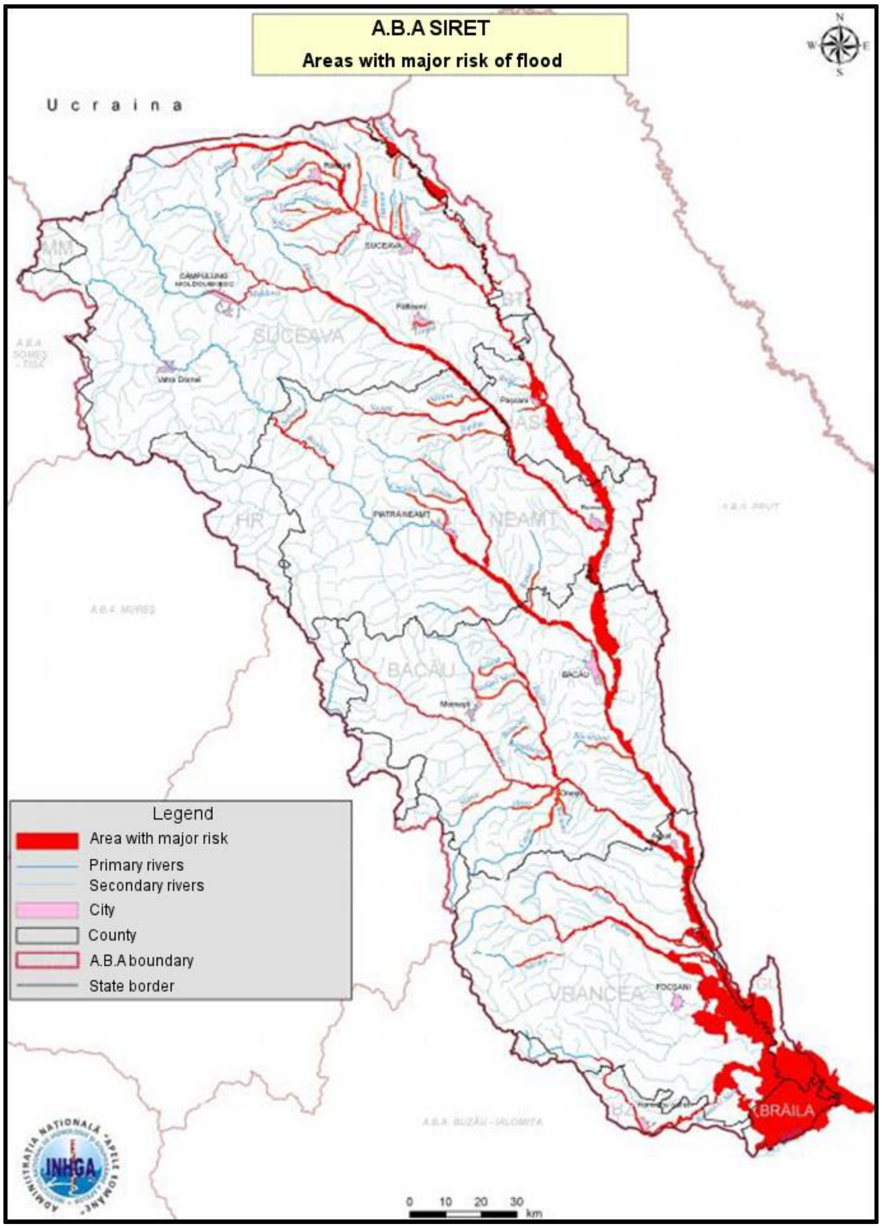


Figure 1.5. Areas from SHB with potential flood risk [http://www.rowater.ro]

Chapter 2. Materials, research and data processing methods

A variety of engineering studies and research methods (topo-geodetic, bathymetric, satellite image processing and hydraulic modeling) were used in the research process on territorial risks and hazards assessment in the study area. During the topographic and geodesic research, surveying methods have been analyzed and highlighted by aerial means (LIDAR, remote sensing, UAV); topographic surveying methods using GPS technologies and automated total stations, as well as processing and processing of data collected in the field. The materials and tools used in the research for this PhD thesis, were provided by the "Dunarea de Jos" University of Galati, Faculty of Science and Environment.

A number of software for data processing (ArcGIS, AutoCAD, HecRAS, Microsoft Excel, Statistical, SPSS, QGIS, TransDat) have been used in the research.

Chapter 3. Experimental results and discussions

3.1 Experiments and preliminary studies on the equipment precision and used methods

An important factor to generate accurate and admissible results in field of measurement tolerances is the detailed knowing of the measurement accuracy of the used tools and methods. Hereinafter are represented the most important preliminary experiments from the research.

Figure 3.1 presents the logical scheme with the four main experiments and the preliminary obtained results, necessary to highlight the equipment's errors and the measurements precisions, as well as the exclusion of the erroneous applicability in the researches on the Siret River.

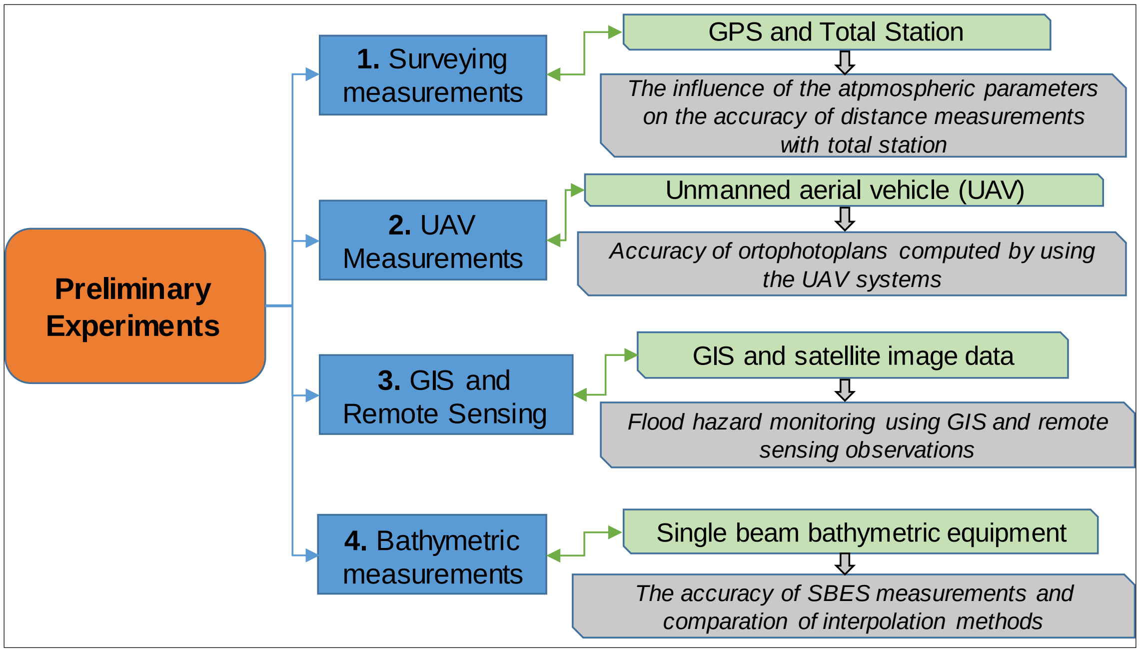


Figure 3.1. Logical flowchart of the main experimental preliminary studies on the accuracy of the used instruments

3.1.1 The influence of atmospheric parameters on distance measurements with topographic total station

The precursor phases of the development technique of electronic distance measurement can be considered Kerr’s discovery in 1980 and the development of radar during the 1930-1940 period (Paśagič și Parlić Risović, 2003).

The electronic distance measuring is based on the transmission and reception of electromagnetic waves of different frequency spectra. Distance is calculated by propagation time. In electronic distance measurements, the distance is determined indirectly, multiplying the propagation time by wave speed.

The planimetric system must be represented in the field by a geometric network composed of points with known coordinates in that system. The measurements were made in the local area, with the basic condition of the association between the local area and the national system, namely, for the recalculation of the point coordinates to be possible in both systems.

Considering this, the process of thickening the network was realized with accuracy similar to the free geodetic network. During the measurements, every kind of accidental error was excepted, especially the roughs. The study area, where the point network was realized, is located in the north-eastern section of Galati city, by the AltStil district (Figure 3.1).

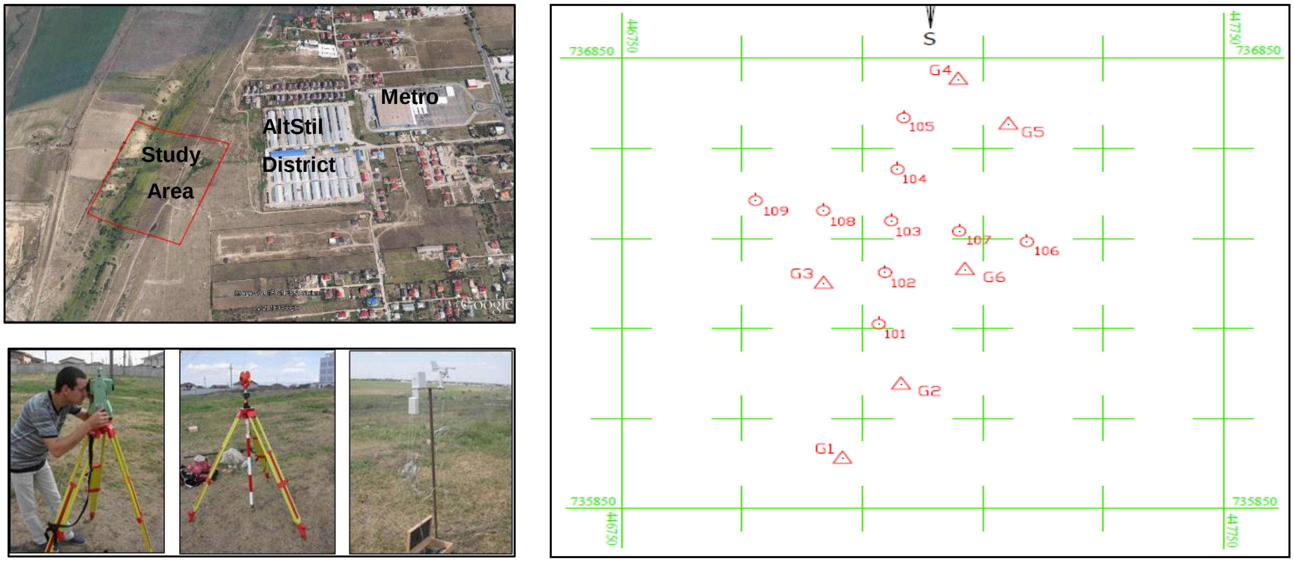


Figure 3.2. Study area and surveying grid [Arseni et al., 2015 a]

To determine the influence of the atmospheric temperature value on the EDM equipment of total station Leica TC(R)-705, the atmospheric conditions were measured beside the total station.

To analyze the influence of the temperature value on the EDM of the total station, three types of distance measurements were made. The first mode of measuring distances was executed with the default settings of the total station: *t (temperature)* = 12^{0}C; *p (air pressure)* = 1013mb; *h* *(relative humidity)* = 40%. The second set was achieved by keeping the default values of atmospheric pressure and relative humidity, while updating only the temperature value. The third set of measurements for each distance was achieved by updating the values of all atmospheric parameters.

According to Chandra (2005) [6], the error represents the difference between the measured value and the real value τ :

$$\varepsilon = x - \tau$$

The standard deviation is a measure of the difference between a distribution and a sample, and it is represented by:

$$\sigma_n = \pm\sqrt{\left[\frac{\sum(\mu - x)^2}{n}\right]}$$

The influence of the temperature value on electronic distance measurement is represented in figure 3.3, by representing the standard deviation between the types of measurements.

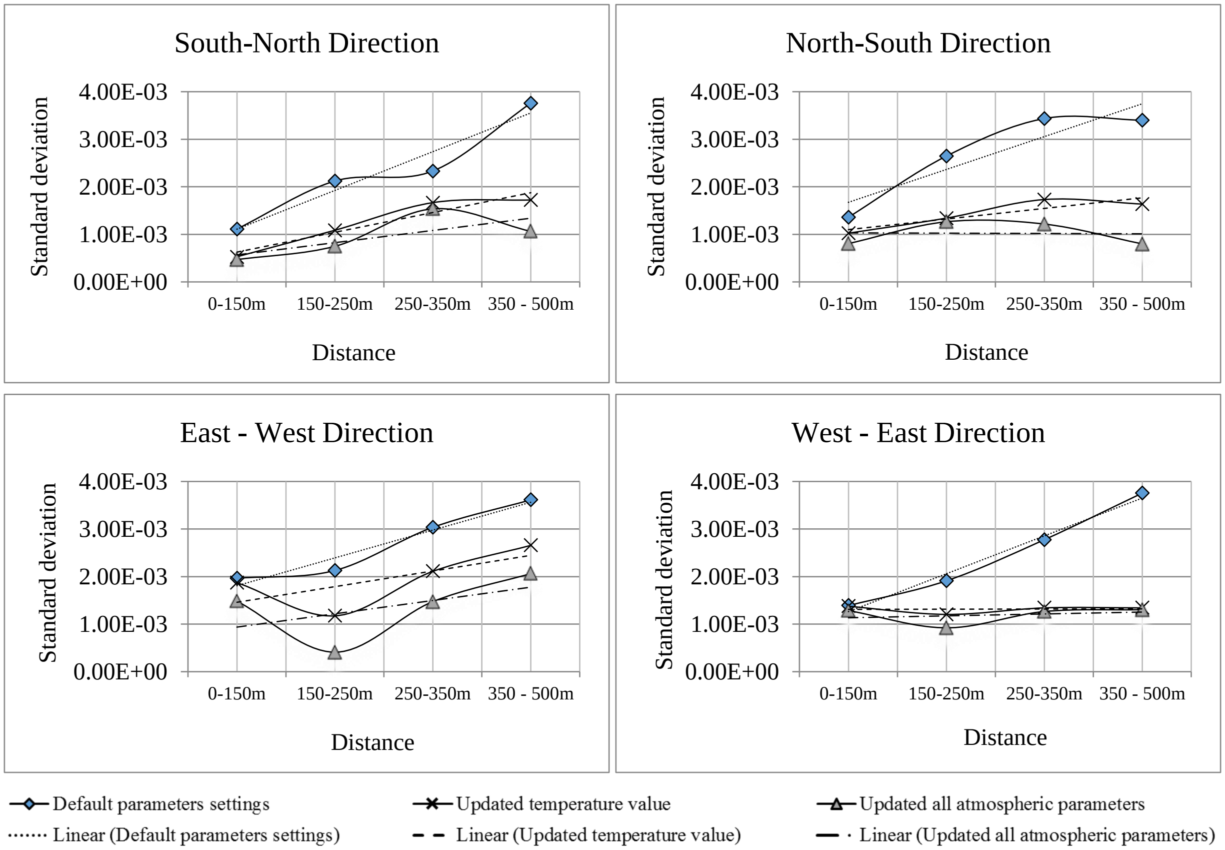


Figure 3.3. Representation of standard deviation of temperature updating depending of alignment direction

As it can be seen, the four represented charts are combined two by two. They are grouped by measuring directions and by curve profile that describe the standard deviation of the measurements.

For directions S-N and N-S, it can be seen an increase of standard deviation for distances between 250-300 m, irrespective of the total station setup. It is noteworthy that the linear trends of standard deviations are generally increasing. As measured distance is higher, the standard deviations are higher. The curve profiles presented for these two directions (S-N, N-S) are practically identical. Calculated values of standard deviation on S-N and N-S directions did not differ greatly between them, which means that the measurements were carried out properly in both directions and with minimal errors.

Analyzing the data obtained from measurements on E-W direction, it can be seen that the best accuracy is obtained for distances between 150 and 250 m (small standard deviations) and small precision for distances between 350-500 m. Linear trends from the east to west direction indicate a decrease in measurement accuracy, increasing their distances (as most authors mention in similar studies of accuracy and as it is expected from physical considerations).

The influence of the humidity value on electronic distance measurement, depending on type of measurements, is represented in figure 3.4 – 3.5.

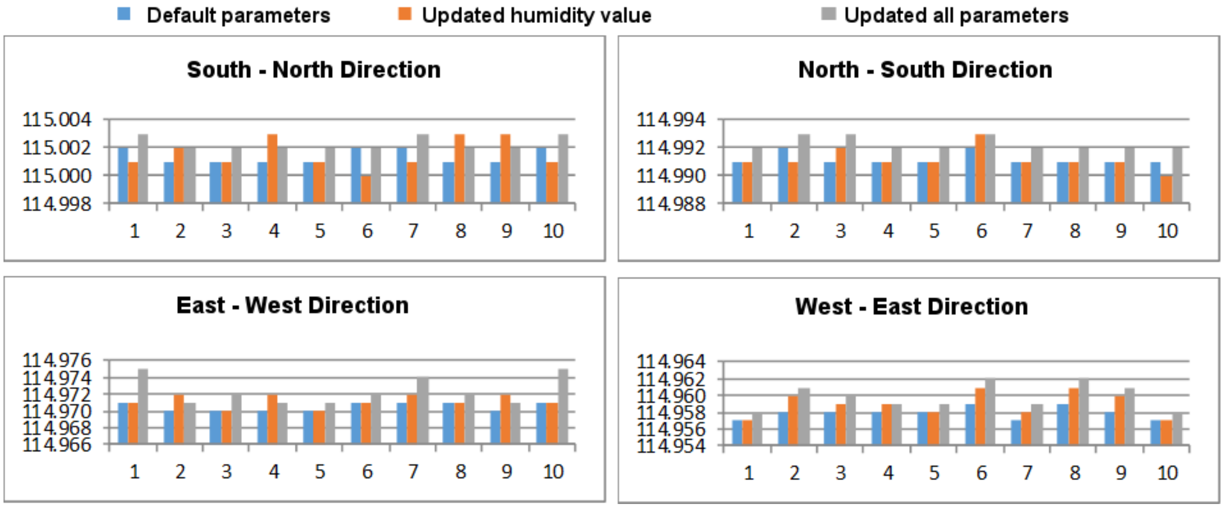


Figure 3.4. Representation of differences of distance between 0-150 m depending on the measurements types

The analysis of each chart leads to the conclusion that upgrading atmospheric relative humidity in the EDM equipment of a total station or accepting the calibrated value (the default parameter) does not have a major importance in distance measurements. All distances measured by the first two methods are practically identical. This result derives from the fact that the functionality of the total station is not affected by relative humidity, because the respondent module of determining the humidity is enclosed in the total station. Considerable variations occur when the third method of measurement is used, when measured distances are strongly influenced by other atmospheric parameters (temperature and pressure).

For short distances, about 150 m, the influence of relative humidity is between 1-2 mm, and for longer distances, about 500 m, the influence is between 1-3 mm. It follows that relative humidity does not influence the EDM equipment of the total station; otherwise, as indicated by most researches, the variation of relative humidity with 20% influences the refractive index and the distance measured with about 0.04 ppm (Rueger, 1990).

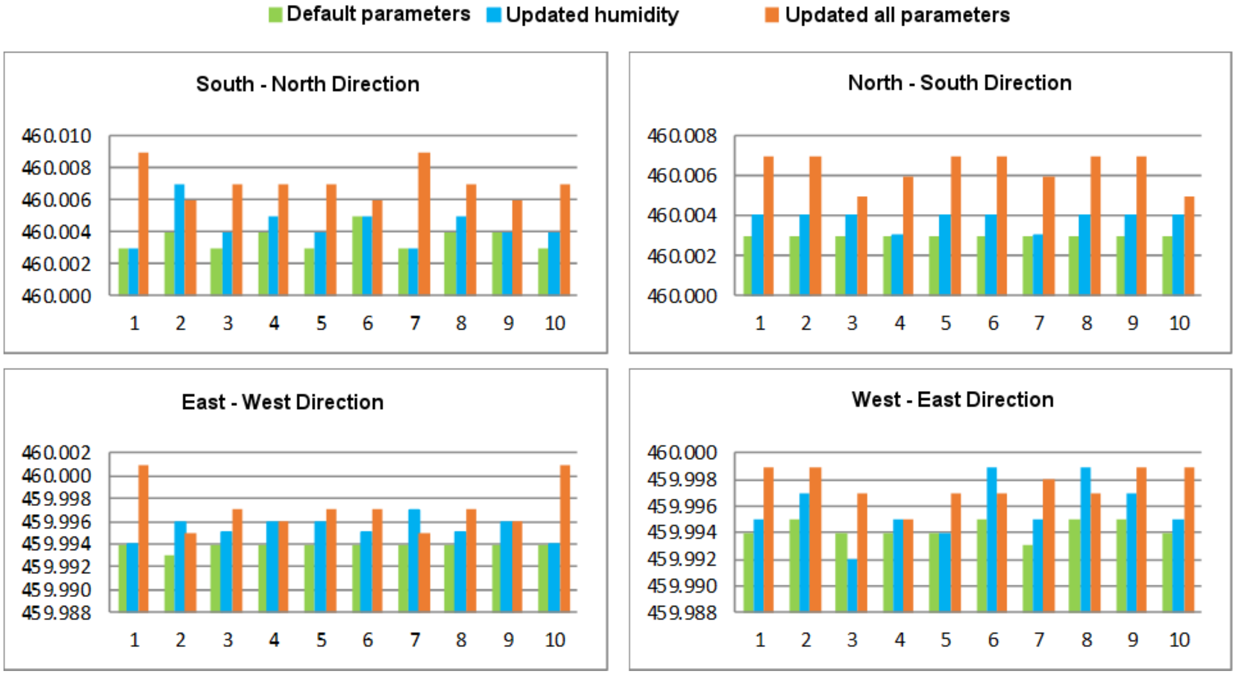


Figure 3.5. Representation of differences of distance between 0 - 500 m depending on the measurements types

Conclusion

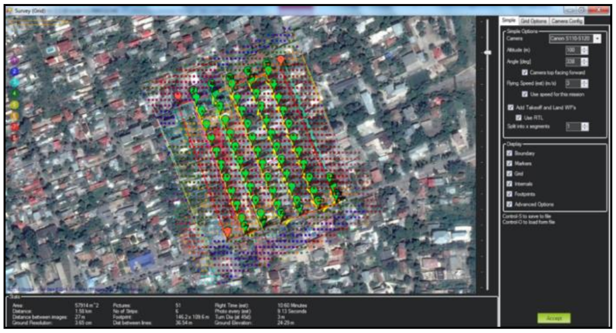
In electronic distance measurements, the main source of errors comes from the atmospheric environment, which has three important atmospheric parameters: temperature, air pressure and relative humidity. The most important is the environment temperature. The total station, used for distance measurements, uses EDM equipment, which, actually, measures the propagation time of the electromagnetic waves in the atmosphere.

When the temperature correction is applied, distances are corrected automatically. Thus, high temperatures ranging between 25-30^{0}C significantly influence the measured distances. For 350-500 m distances, measured with an updated temperature value, are 8-10 mm longer than those measured with the default settings.

3.1.2 Accuracy of ortophotoplans computed by using the UAV systems

Unmanned aerial vehicle (UAV) systems are nowadays a valuable source of data for mapping, surveillance and 3D modelling issues. It is a low-cost alternative to the classical manned aerial photogrammetry. With a typical photogrammetric pipeline, 3D results like DSM/DTM, contour lines, textured 3D models, vector data, etc. can be produced, in a reasonable automated way. Rotary or fixed-wing UAVs, capable of performing the photogrammetric data acquisition with amateur or professional cameras, can fly in manual (*manual*), semi-automated (*loiter or altitude hold*), and autonomous (*auto*) modes. The paper reports a review on UAV for geomatics applications, giving an overview of different UAV platforms, applications and case studies.

The mission for flight and data acquisition method is planned in the laboratory with dedicated software (Figure 3.6). It was create the polygon of interest area and the grid of the flight plan. Also, all settings have been adjusted and calibrated, such as altitude, angle of flight path, the flying speed, the takeoff and land way points, the overlap and sidelap of footprints, the delay on each way point, the focal length.



Camera: Canon S110-S120
Altitude (m): 100
Angle (deg): 338
☑ Camera top facing forward
Flying Speed (est) (m/s): 3
☑ Use speed for this mission
☑ Add Takeoff and Land WP's
☑ Use RTL
Split into x segments: 1
☑ Boundary
☑ Markers
☑ Grid
☑ Internals
☑ Footprints
☑ Advanced Options
Control-S to save to file
Control-O to load from file

Area: 57914 m^2
Distance: 1.58 km
Distance between images: 27 m
Ground Resolution: 3.65 cm
Pictures: 51
No of Strips: 6
Footprint: 146.2 x 109.6 m
Dist between lines: 36.54 m
Flight Time (est): 10:60 Minutes
Photo every (est): 9.13 Seconds
Turn Dia (at 45d): 3 m
Ground Elevation: 24-29 m

Figure 3.6. Overlap of photograms (75% x 75%)

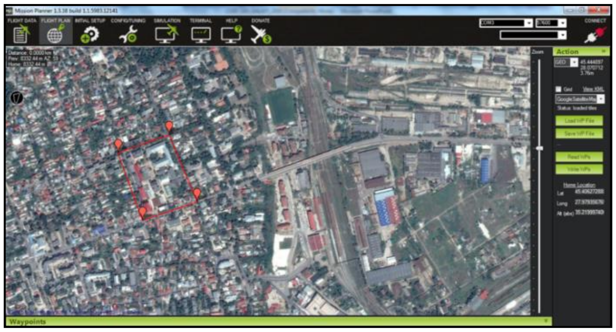


Figure 3.7. Study area – „Dunărea de Jos” University Campus

To achieve the main purpose of this study an octocopter X8-M was used (Figure 3.8 a). The take-off and landing operations are strictly related to the employed vehicle and its characteristics, but the vehicle is normally controlled from ground by a pilot with a remote controller (Figure 3.8 b).

During flight, the platform is normally observed with a first person viewer control station – FPV Diversity RX (Figure 3.8 c). To capture images from aerial flight in our study a digital camera Canon S110 was used (Figure 3.8 d).

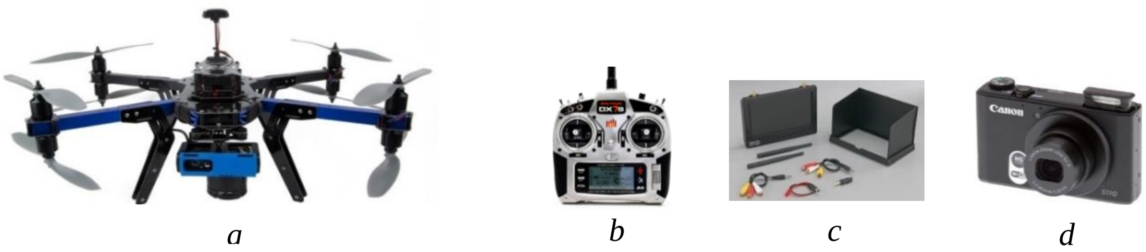


Figure 3.8. Equipment used to study the AOI

Using the GPS data collector mounted on UAV system we can generate direct georeferenced images. It is no need for local survey of the reference point. If we want to generate very high accuracy orthophotoplans we can use point on field measured with an RTK GPS system. The flight data of the octocopter is written to a memory card in a certain interval whereas every entry contains a timestamp in GPS time. Synchronization between the internal camera clocks with regards to GPS time is by then achieved manually.

The obtained orthophotoplan has a superior resolution to those obtained in a conventional manner. The obtained accuracy is of 2cm/pixel or better and it can be obtained by georeferencing the photograms using the ground control point marks (Figure 3.10).

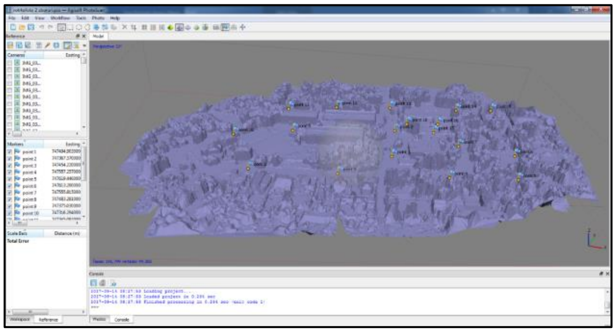


Figure 3.9. Dense cloud point obtained from data proccesing

Figure 3.10. Ground control point marks

In figure 3.11 and figure 3.12 are represented the quantitative overlaps of photograms, and the residuals of the area where the overlaps is minimal.

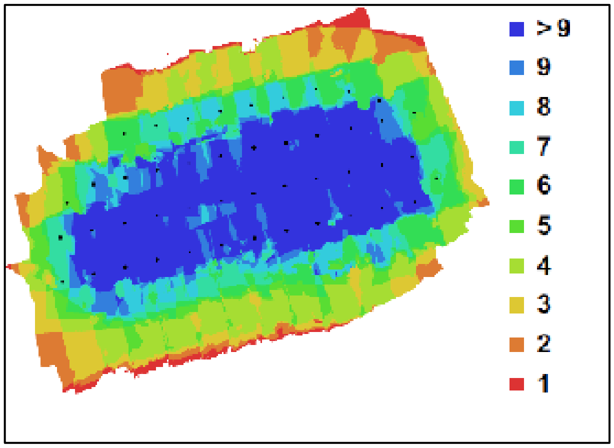


Figure 3.11. Number of photograms overlaping

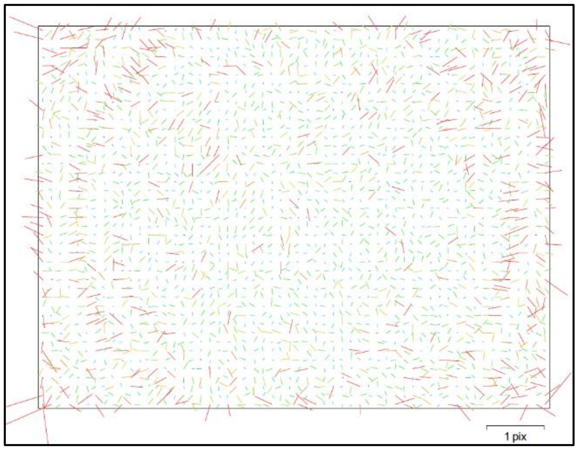
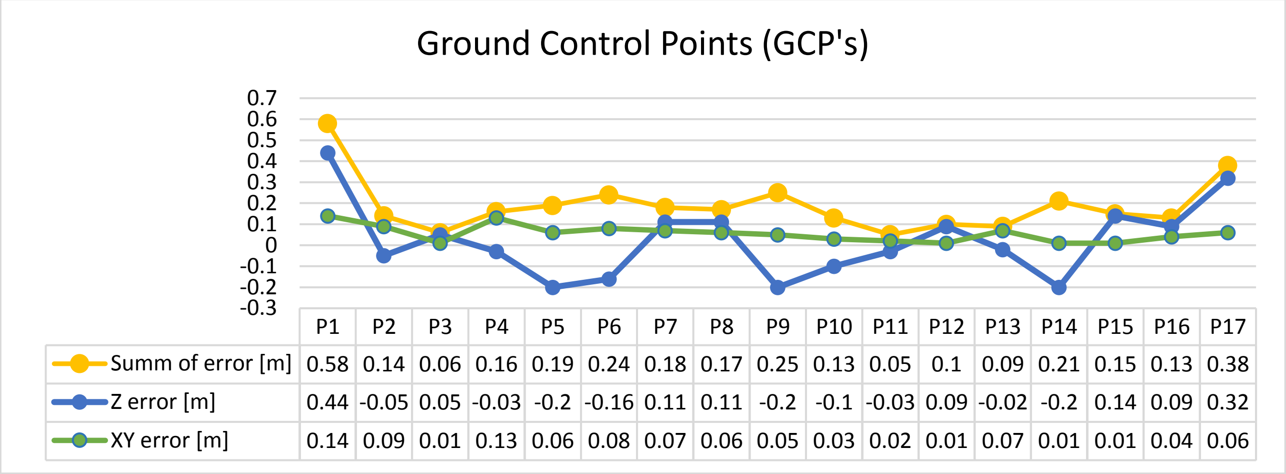


Figure 3.12. The residuals of Canon S110 digital camera

The maximum error of elevation values of 0.22m, between the measured and predicted values was find for point P1, because there are only two photograms that overlap. In figure 3.13 is represented the differences and errors between the measured and predicted values.



	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17
Summ of error [m]	0.58	0.14	0.06	0.16	0.19	0.24	0.18	0.17	0.25	0.13	0.05	0.1	0.09	0.21	0.15	0.13	0.38
Z error [m]	0.44	-0.05	0.05	-0.03	-0.2	-0.16	0.11	0.11	-0.2	-0.1	-0.03	0.09	-0.02	-0.2	0.14	0.09	0.32
XY error [m]	0.14	0.09	0.01	0.13	0.06	0.08	0.07	0.06	0.05	0.03	0.02	0.01	0.07	0.01	0.01	0.04	0.06

Figure 3.13. Partial and total errors for ground control points

To generate the digital elevation model was used the dense cloud point map, composed from aproxximative 5 million points. The total area of digital elevation model is A=84100 m^2. The figure 3.14 represents the result of generated digital elevation model and the 3D model (figure 3.15).

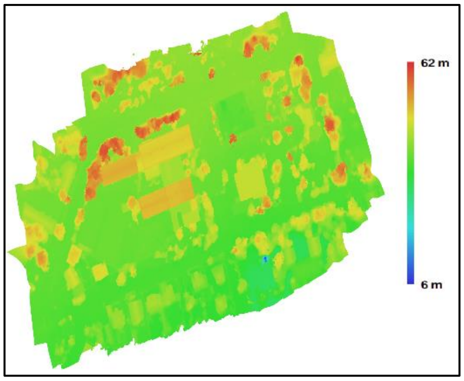


Figure 3.14. DEM, resolution=13cm/pixel, density=59 points/m^2

Figura 3.1. 3D Model of surface

Conclusion

This preliminary presented research is an overview of existing UAV systems with particular attention to geomatics applications. We can use a UAV system in different domains and this can improve efficiency in our work. The great advantage of UAV systems is the possibility to generate rapidly high resolution images, orthoimages and ortho-rectified images. Another advantage is the importance of UAV in the development of cadastral applications.

If we analyze the structure of UAVs we can mention that the rotary wing of UAV platforms can be used in different land conditions. Combining the 3D geographical information systems and UAV we can quickly generate flood hazard maps, analyze land cover changes, new buildings and many critical situations in many cases.

3.1.3 Flood hazard monitoring using GIS and remote sensing observations

Flood is considered to be a major natural disaster which affects many parts of the world. Geographical Information System (GIS) can be used to visualize the extent of flood and also to analyze the risk of disasters. The objective of this study is to generate a flood hazard map using satellite image data from Landsat 5. To characterize the land cover types it was used an innovative Semi-automated Classification Processing (SCP) tool. An experimental study was conducted on the downstream of Prut River Romania, more exactly nearby Cârja (Romania) village situated on the right bank and Goteşti (Moldova) village situated on the left bank of Prut river (figure 3.16) and Șendreni study area near Galați city (figure 3.17). To monitor the effects of flood was used the supervised classification of two Landsat 5 images for this 2 location acquired on 2010 when a severe flood was affected the above mentioned areas. This research presents a very rapid and affordable method of flood monitoring that could be very useful for the emergency management plan of the local authorities.

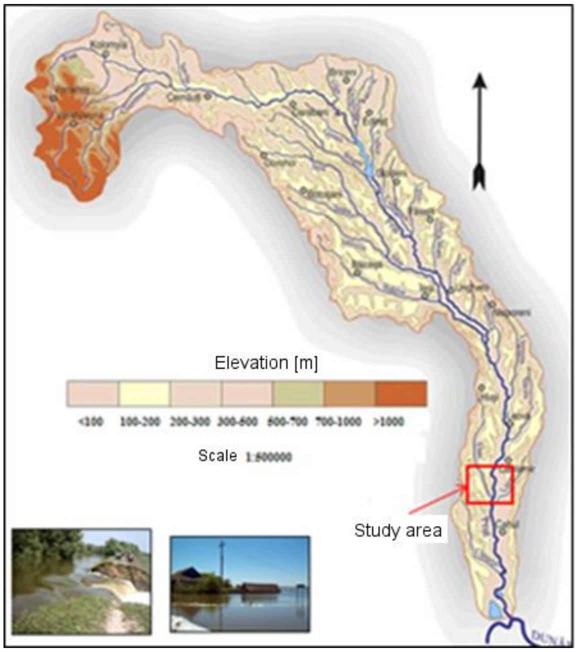


Figure 3.15. The map of the Prut River basin and the study area [https://www.icpdr.org/main/activities-projects/flood-action-plans]

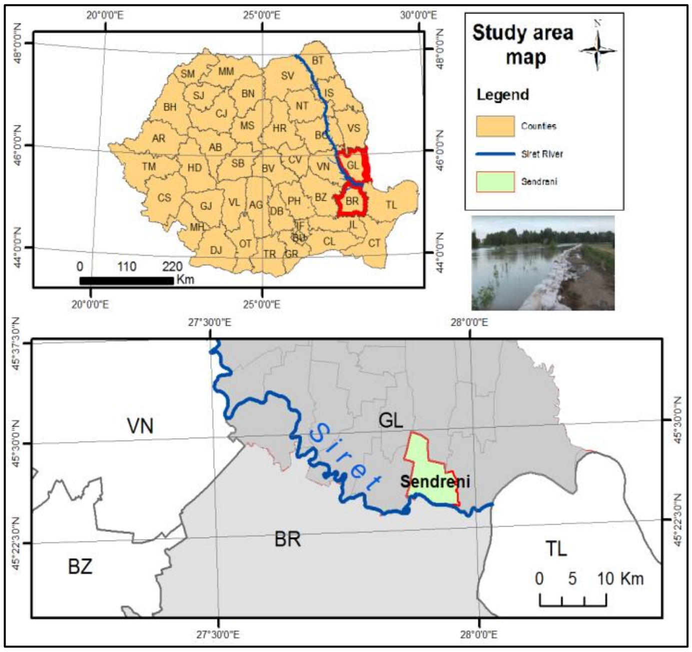


Figure 3.16. The study area – Sendreni village

For flood monitoring we classified a Landsat image acquired on 01.05.2010 (before the flood) and a Landsat image acquired on 14.08.2010 (during the flood), in order to assess the land cover change using a semi-automatic approach. The following workflow (figure 3.17) illustrates the main phases of semi-automatic classification used for this research:

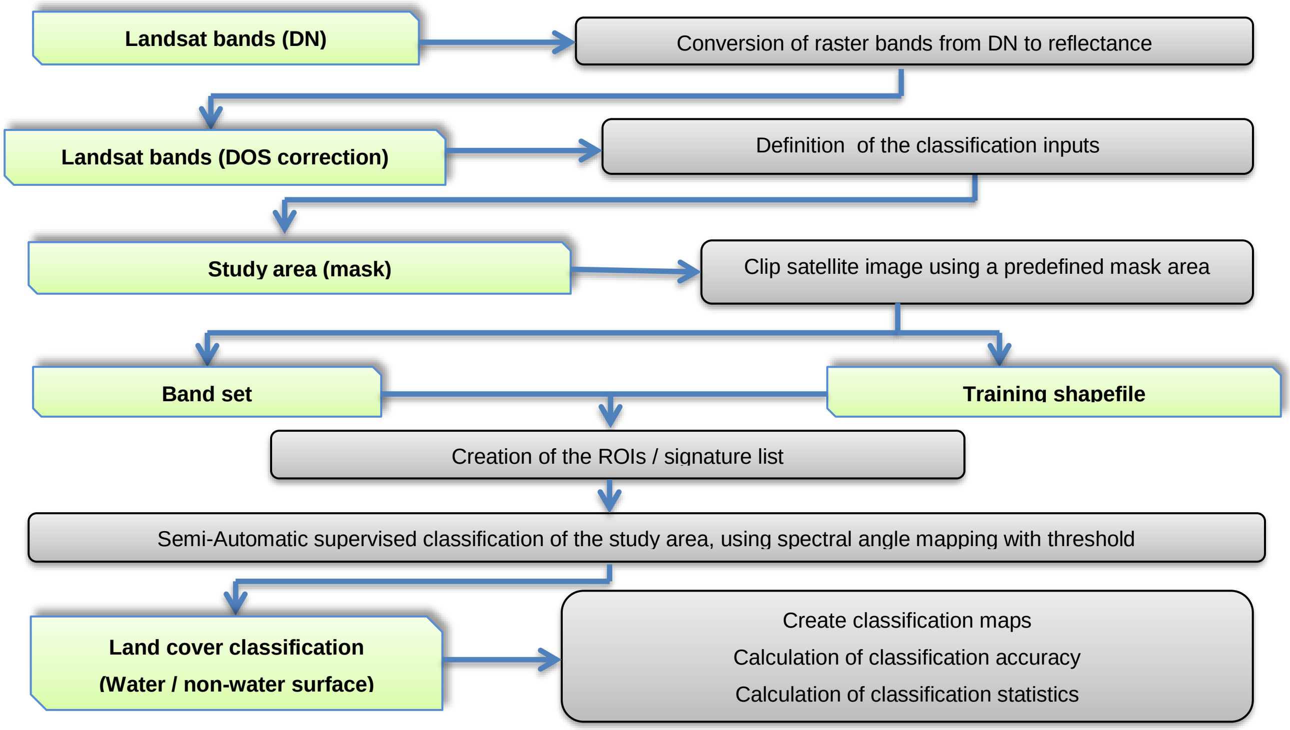


Figure 3.17. *Workflow of the main phases of classification*

The spectral reflectance properties were analyzed in order to identify the pixels that characterize the water surface. Remote sensing technique is based on the measurement of reflected or emitted radiation from different bodies (Demirkesen et al., 2007). The reflectance properties of an object depend on the particular materials and its physical and chemical state, the surface roughness as well as the geometric circumstances. These differences make it possible to identify different earth surface attributes or materials by analyzing their spectral reflectance (Lunetta et al., 2006) pattern or spectral signatures (Figure 3.18 – 3.19).

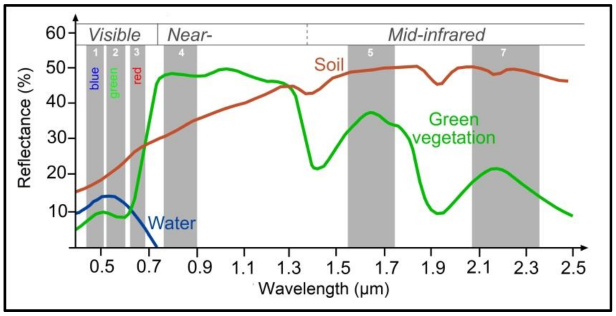


Figure 3.18. Reflectance of water, soil and vegetation in different wavelengths and Landsat TM channels (http://www.seos-project.eu/modules/classification/classification-c01-p05.html)

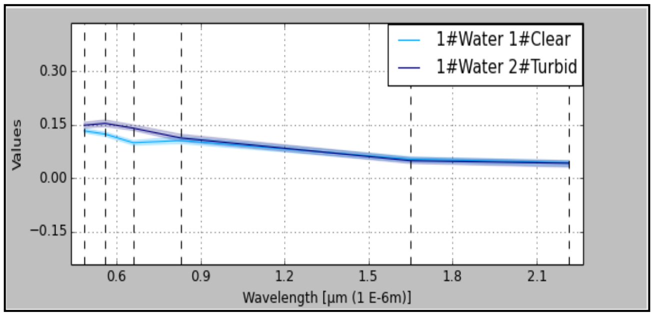


Figure 3.19. Reflectance of turbid and clean water (after post-proccesing with SCP tools)

For a better distinction it was used the 4-3-2 color composite scheme: the band 4 for the red band, the band 3 for the green band, and band 2 for the blue band (Figure 3.20).

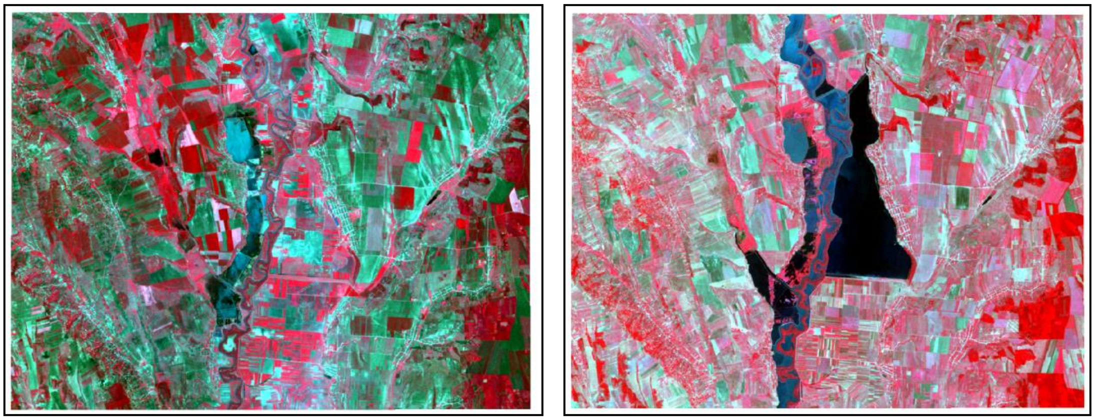


Figure 3.20. Color composite scheme 4-3-2: *left – before flood, right – after flood*

To analyse the flooded area, were collected spectral signature from the first Landsat image, and applied to the second image. In order to determine the water and non-water surface were used two classes. Using the Landsat TM data and the above described method, it was created maps representing flooded areas. If we analyze the land cover change map, it can be noted that the flooded area is represented in red, while the blue area is not flooded. Usually the area covered permanent by water is represented in green.

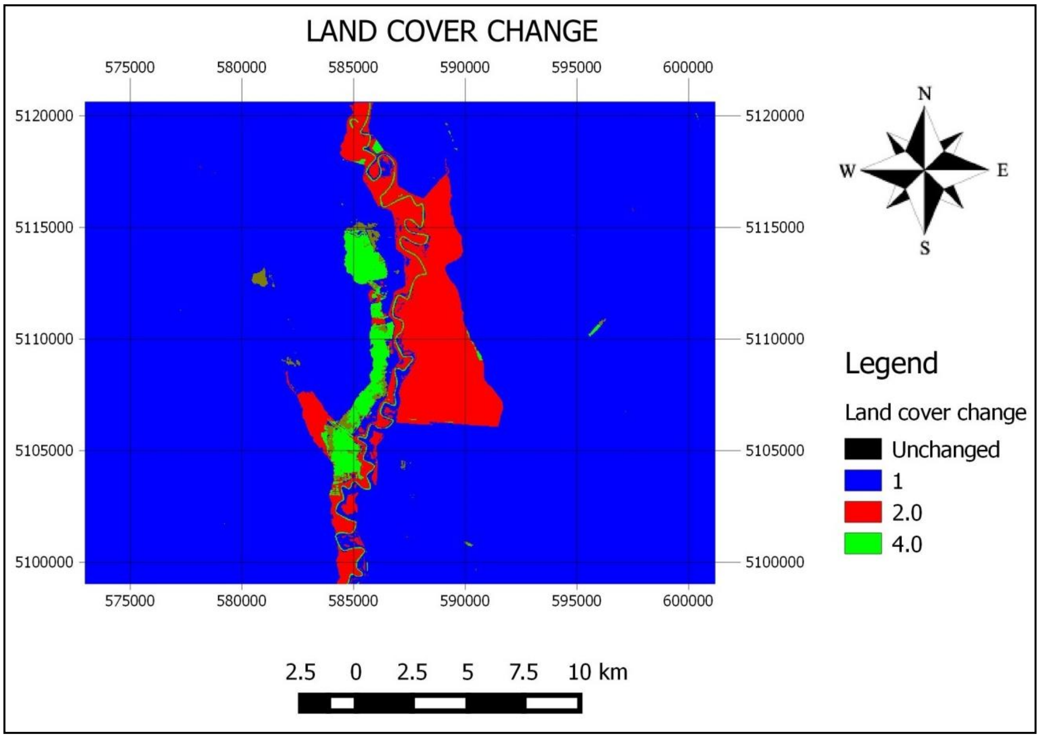


Figure 3.21. The flood extent map on 21 July 2010 – Prut river

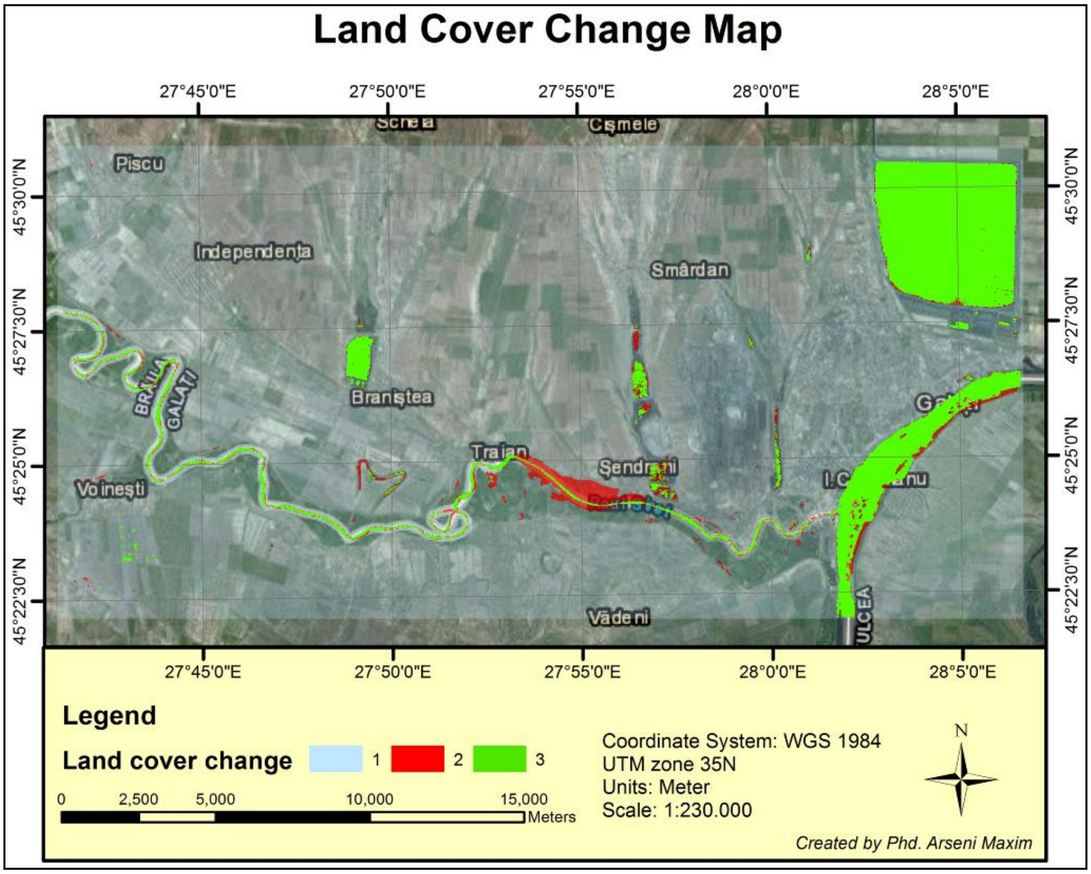


Figure 3.22. The flood extent map on 21 July 2010 – Siret river

Conclusions

Remote sensing technologies are very useful in flood monitoring damages evaluation. A simple and efficient method for mapping flood extent has been presented. With limited ground observation, most flooded and non-flooded areas derived from the analysis were verified. This method was based on a comparison of the reflectance feature of the water surface versus non-water surface on a pair of Landsat 5 image (one acquired before and other during the flood event).

The total flooded area derived from the satellite images, on 26 July 2010 for Cârja (Romania) village and Gotești (R.Moldova) village were 4230 km^2 or approximately 7% of the total studied area. The SCP tool is an efficient device for the semi-automatic classification of remote sensing images, which provides several tools for the images processing, the post processing of classifications, and the raster calculation.

The total flooded area results after the flood event on 20 July 2010 for Șendreni village was 619.29 ha, which represents approximately 1.30% of the total studied area. This value is minor reported to the total study surface. Taking into consideration that the total area of Șendreni is 4734 ha[12], the flooded surface of 619.29 ha is an important value that represents approximately 13%

from total surface. The flooding event that took place during the period June – July 2010 resulted in nature and material damages without recording human losses.

However, it should be noted that the successful application of Landsat images for flood damage assessment demonstrated the ability and the potential of remote sensing technique in monitoring floods and for estimating the flood regimes. More research is required to integrate other data such as digital topographic data and river networks measurements in order to improve the spatial accuracy and develop new algorithms for flood analyzing.

3.1.4 The accuracy of SBES measurements and comparation of interpolation methods

In our days the bathymetry is one of the most important techniques to measure the depth data, especially for surveying lakes, rivers, and other bathymetric projects. Catusa Lake has a strategic importance with its location in Galati city, especially for Sidex Galati, the country's largest steel mill. To achieve the main purpose of this preliminary research, it was used different bathymetric models to calculate lake volumes. The study aims to present an efficient method of bathymetric measurements for creating bathymetric maps, using a single beam echo sounder combined with RTK GPS technique. The results of the different models were compared to determine depth contours and location of maximum depth. This field measurement of water depth is unique for Catusa Lake and will be made later again to evaluate the accuracy of the various models created.

The bathymetric model represents the bottom surface of water bodies. It can be obtained by depth measurements from the top of the water. The depth is usually measured using single beam or multibeam echosounder. Single beam echosounder (SBES) still is the most common instrument used in ports, lake and river surveys, because it is an efficiency low cost and accessible instrument. Acoustic depth measurements systems measure the elapsed time that an acoustic pulse takes to travel from a generating transducer to the waterway bottom and back.

The primary objective of the bathymetric project was to develop the digital elevation model of the bottom and calculate the Catusa Lake water capacity. The lake is situated in the west part of Galati city (Figure 3.23). It is a tunnel valley lake app. 2100 m length (north-south) and maximum app. 225 m width.

To achieve the purpose of this study it was used a combination of topographic measurements and single beam depth technique. To determine topographic heights of the lake bottom it was used a GPS system South S82. The measurements with this equipment are very high precision and they give the possibility to measure direct the altitude above the sea (in our case altitude = 0m – Black Sea-Constanta). A 235 kHz frequency of Ohmex SonarMite /BTX Single beam Echo Sounder was used for the depth measurements from the mounted pole to the bottom of the lake. All these instruments were mounted on a mobile platform – inflatable boat (Figure 3.24).

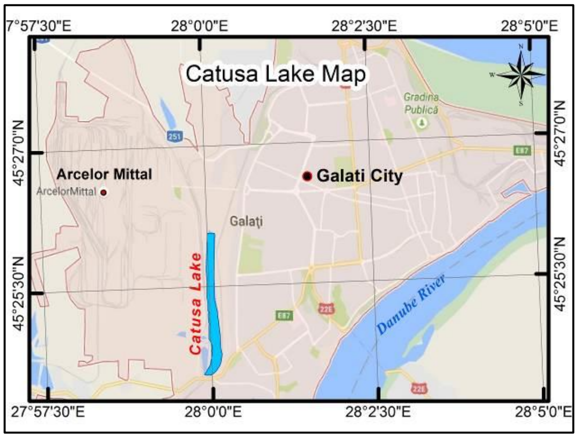


Figure 3.23. Study area – Catusa Lake

Figure 3.24. Used instruments and mounting method on an inflatable boat

Catusa Lake has a strategic importance with its location in Galati city, especially for Sidex Galati, the country's largest steel mill. In the last years, this lake has a significant decrease in water volume. Also on this lake doesn't exist any bathymetric measurements to determine the morphologic data to compare in time. The estimated maximum lake area for water level 6.28 m above the sea is approximatively 36 ha. To achieve high accuracy of bathymetric measurements and to record bottom height of lake, the measurements were performed in the different ways (Figure 3.25), in a jag and longitudinal alignments.There were registered 5864 values overall. The topographic and bathymetric measurement was performed in the local projection system – stereographic 1970.

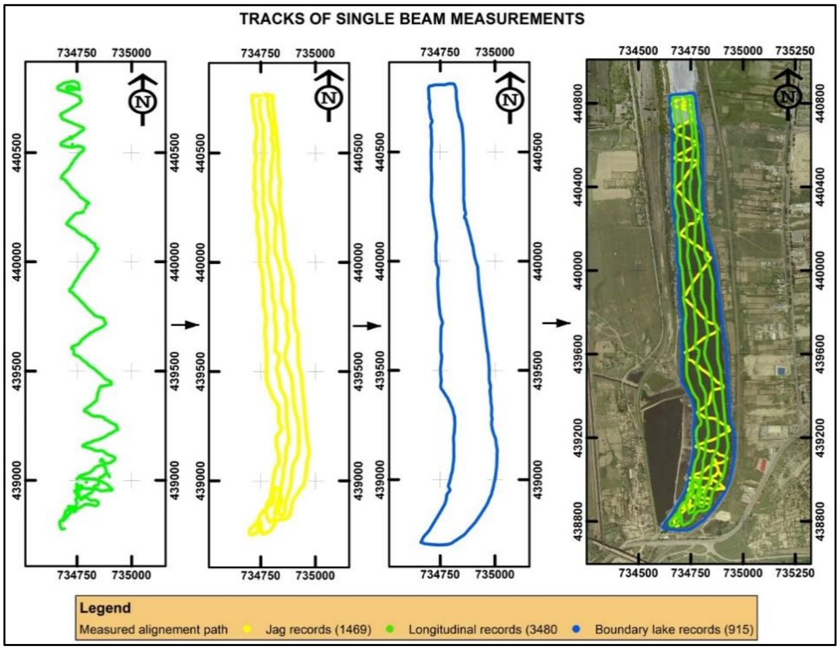


Figure 3.25. Jag and longitudinal method of depth measurements

To calculate the existent volume for Lake Catusa was used the following 4 interpolations method: Inverse Distance Weighting (*IDW*), Radial Basic Function with Completely Regularized

Spline (*RBF-CRS*), Simple Kriging (*SKRG*) and Universal Kriging (*UKRG*).

The statistical terms (Table 3.1) that are usually used to evaluate the performance of the methods are: mean, maximum, minimum, mean absolute, root mean square errors and other statistical values.

Table 3.1. Cross validation results

	IDW	RBF-CRS	SKRG	UKRG
Samples	5864	5808	5864	5864
MinMV	2.750	2.750	2.750	2.750
MinPV	3.474	3.576	3.553	3.691
MaxMV	6.281	6.281	6.281	6.281
MaxPV	6.281	6.281	6.259	6.000
MeanError	-0.032	-0.050	0.005	-0.039
RMSE	0.251	0.299	0.232	0.532

The basic statistical value which defines the dispersion of the frequency distribution of deviations between the measured and unmeasured interpolated values is the Root Mean Square Error (*RMSE*). Figure 3.26 represent a bar chart that indicates how closely the created model predicts the measured values.

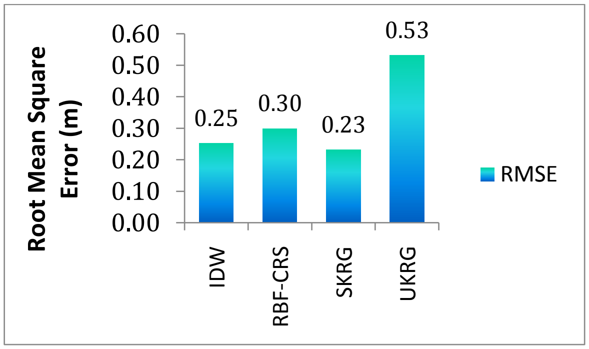
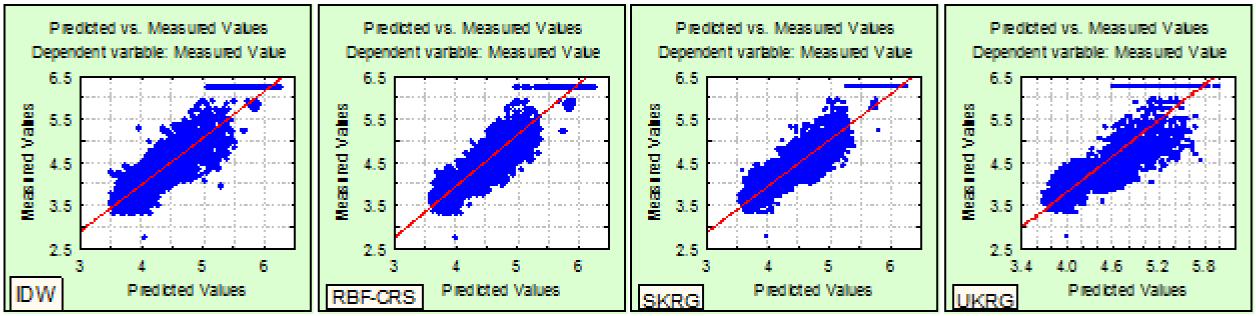


Figure 3.26. The standard deviation of the residuals

A good model can be obtained when this error is smaller and is close by zero. The best result of RMSE is observed at SKRG interpolation method. A good representation is confirmed by the scatterplots (Figure 3.27), where the SKRG distribution between measured and predicted values is better constrained.



a) b) c) d)

Figure 3.27. The relationship between measured and predicted values

Each interpolation method produced a bathymetric model for the bottom of the Lake Catusa. To analyze the models, one-meter contour lines for each bathymetric model were created (figure 3.28).

To achieve the main purpose of this study and understand how the model influences the calculation of lake volume, we also calculated and graphically compared a transversal cross section for each of the models (Figure 3.29).

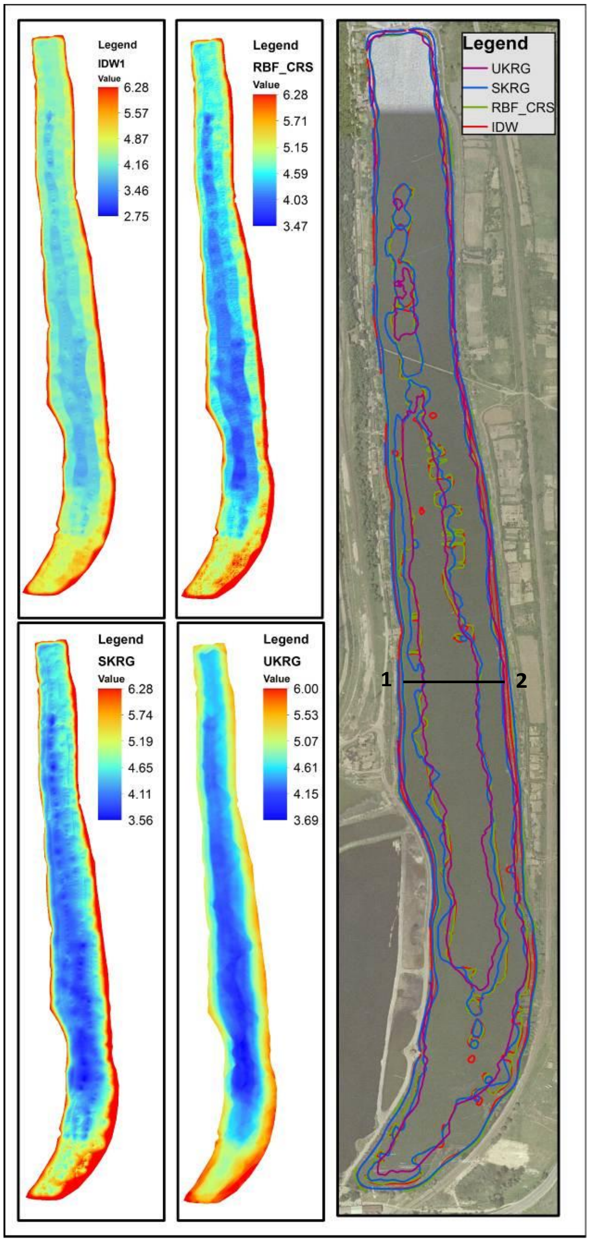


Figure 3.28. The obtained bathymetric models and 1 meter depth contours

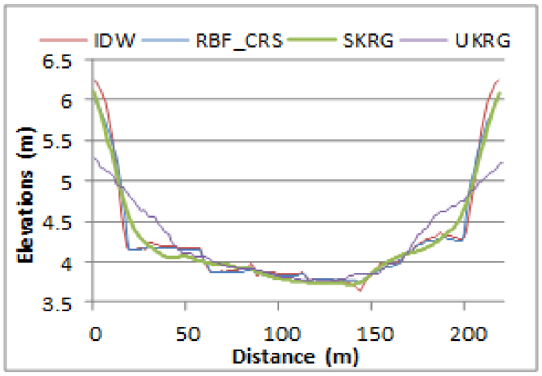


Figure 3.29. Cross section profile 1-2, represented in figure 8, from different interpolation method

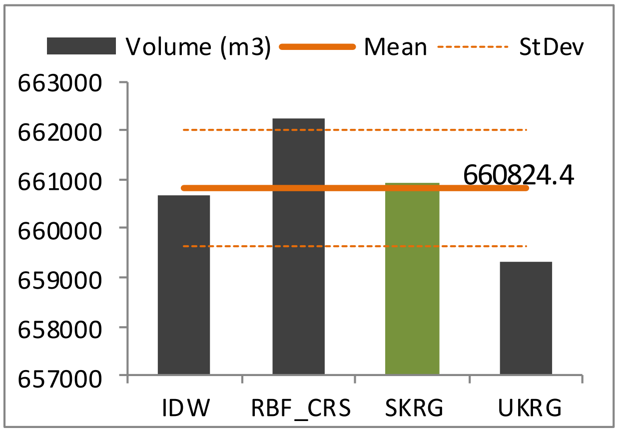


Figure 3.30. Volume calculated using different models

Lake Catusa volume was calculated from all four models and compared (Figure 3.30). The volume was calculated with 3D surface analysis package from ArcGIS.

The mean between volumes computed from all models was 660824.4 m^3 with a standard deviation of 1200 m^3. The good result of the volume values was obtained for simple kriging interpolation method. The second best result and which resemble with the result of SKRG method is model obtained by IDW interpolation.

Conclusions

To perform the bathymetric survey on Catusa Lake was used a single beam echo sounder combined with an RTK GPS system. To calculate lake volume was used four different bathymetric models. The bathymetric maps creating by single beam measurement depend on the accuracy of used interpolation methods. If we analyze the data of cross-validation results, the simple kriging interpolation has a 0.23 root min square error. The coefficient of the determination R^2 between the predicted and measured values also confirm that the SKRG is better, so that: $R_{IDW}^2=0.913$, $R_{RBF}^2=0.895$, $\mathbf{R_{SKRG}^2=0.925}$, $R_{UKRG}^2=0.639$.

The differences are observed for the cross section profile represented in figure 8. The SKRG interpolation method describes an attenuated and smoothed profile. We can remark that the volume calculated by IDW model is nearby the volume obtained by SKRG model. The two other values of volume obtained by RBF and UKRG are out of calculated standard deviation.

As a conclusion, it can be said that the creation of the digital elevation model of an area depends on the measurements number (in this case points number), the GPS signal effectiveness, and on the chosen interpolation method. The last one can help to calculate more precisely the plan and volumetric areas of the lake, and its morphometric analysis in time. The analysis points out that the measurements combination in a more uniform grid (combination between transversal and longitudinal bathymetric surveys) can provide a more high precision to the data processing.

3.2 Determination of flood risk on the lower course of Siret River

Following the studies and preliminary experiments on the experimental methods and precision of the used instruments, the Lower Siret sector, the Danube-Sendreni-Independenta sector (km 0-35), was chosen as study area for flood assessment. The given study area was chosen because there were no such types of measurements in this area. Also, this being a novelty from the scientific point of view as well as from the point of view of the considerable contribution to the existing databases at national level with 4 dimensional information (3 dimensions due to the spatial character of the element and 4th dimension due to the attribute element of each spatial entity). Hydrodynamic modeling for hazard and flood risk maps were made following the logic scheme presented in the figure 3.31.

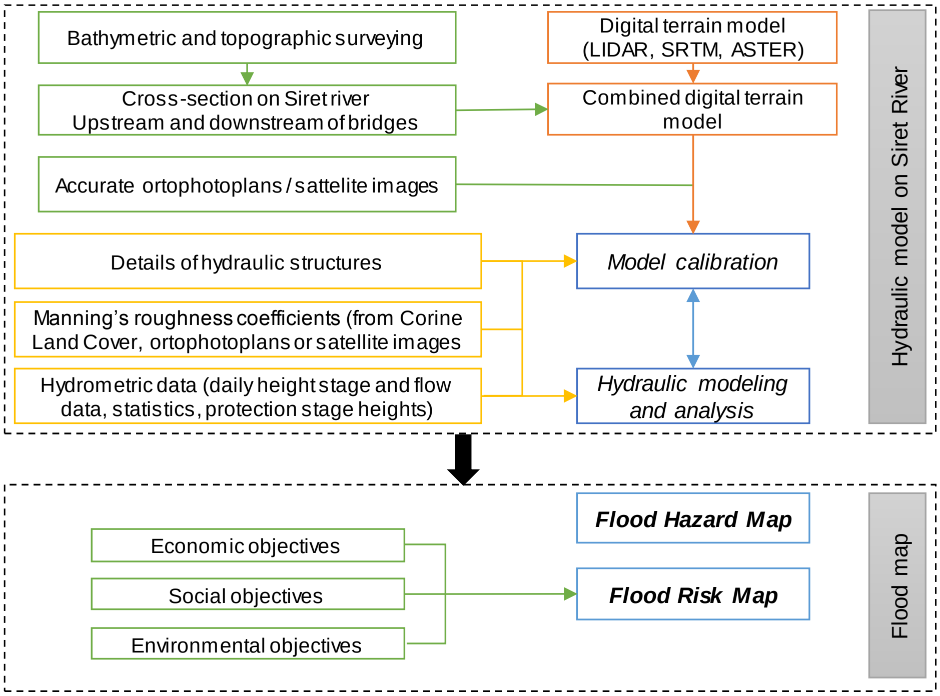


Figure 3.31. The logical scheme of execution phases of flood hazard and risk maps in the downstream part of Siret River (section Danube – Sendreni - Independence)

3.2.1 Localization of study area

The study area chosen for the hydraulic simulations is located in the southern part of the Siret hydrographic basin. The analyzed river sector has a length of 35 km, from the mouth of the Siret River in the Danube River, to the corresponding locality to km 35 - Independenta village (Figure 3.32).

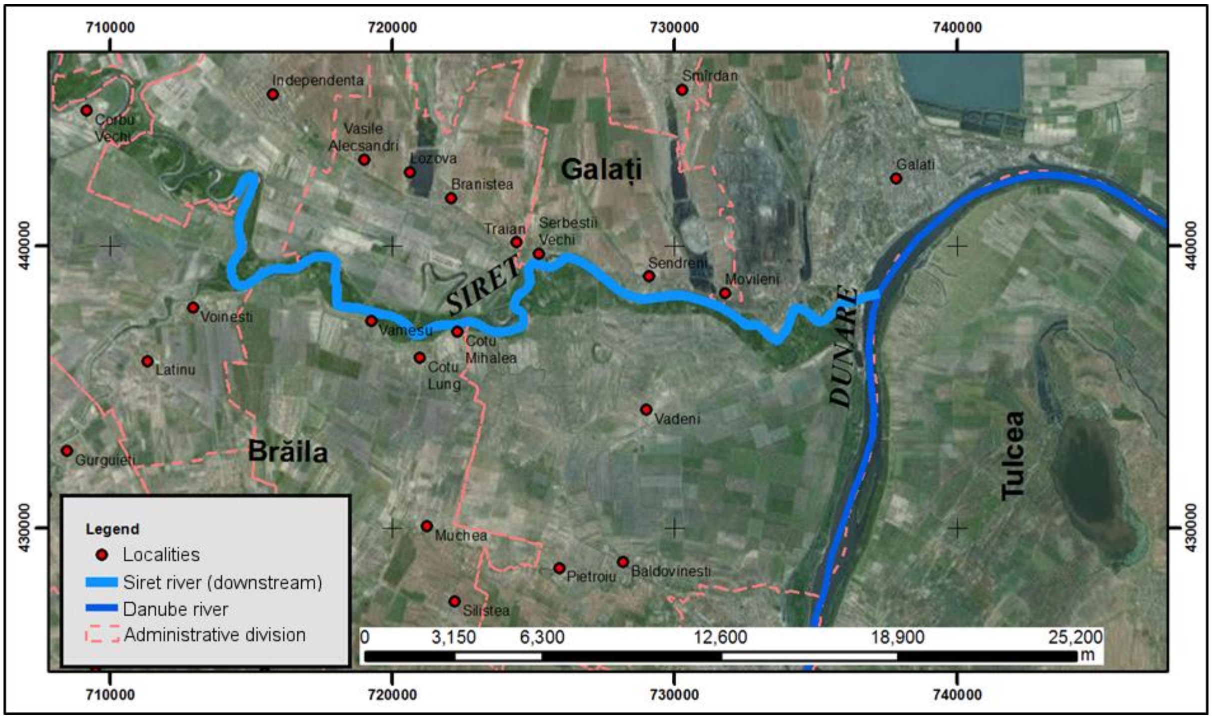


Figure 3.32. Study area located at the confluence of the Siret River with the Danube River

3.2.2 Topo-bathymetric surveying on the Siret River

The topo-bathymetric measurements were realized from downstream to upstream according the experimental methods described in the Chapter 3.1 (Figure 3.33).

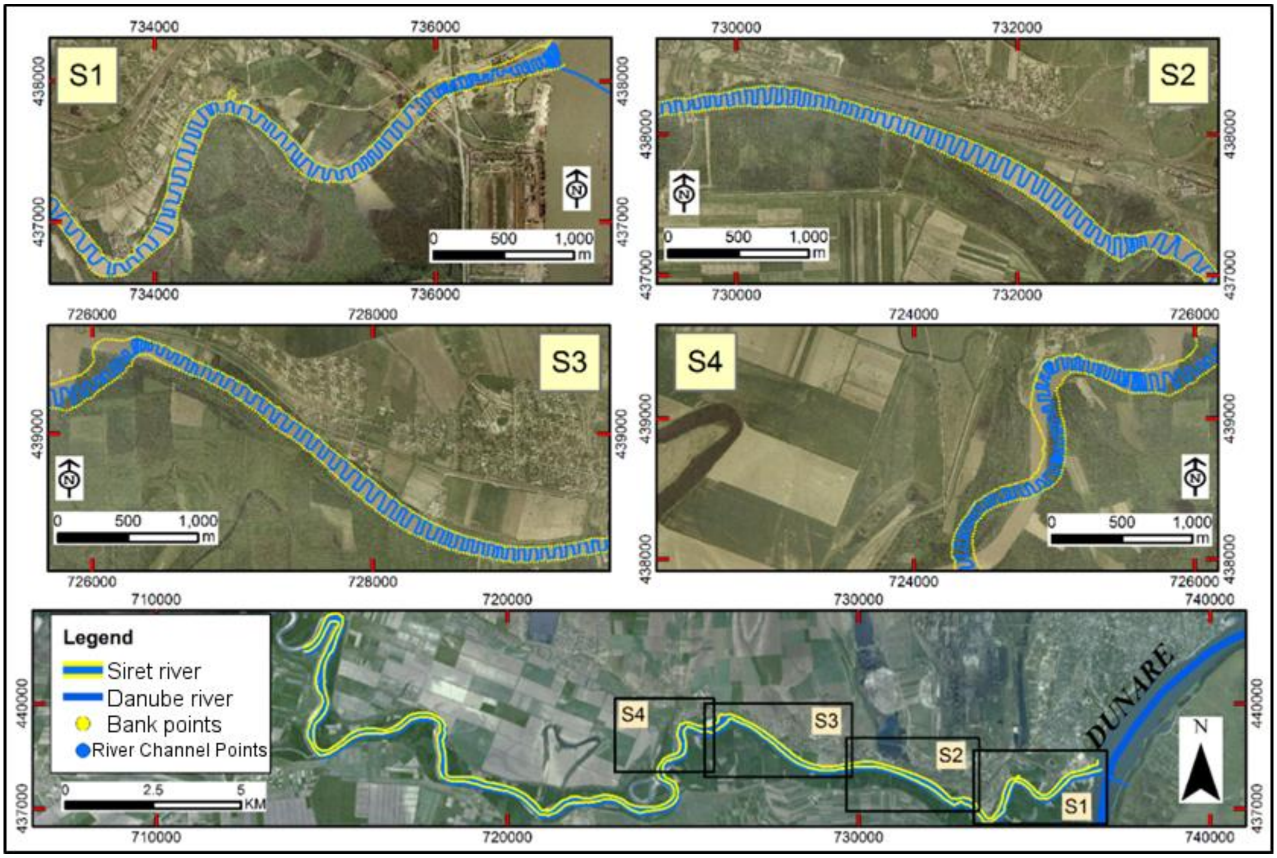


Figure 3.33. Gathering the field data in the sections S1 – S4 from downstream to upstream

3.2.3 Digital model of the field on Siret River, sector Danube -– Șendreni – Independența

The digital terrain model (DTM) is a widely used product and provides a three-dimensional representation (X, Y, Z) of the studied terrain areas. In this research paper, the term DTM can be defined as "a regular matrix representation of continuous variations of space relief units" (Burrough, 1986).

Following the collection of topo-bathymetric data and validation from the precision and quality point of view, a digital model was generated using the *Topo to Raster* interpolation method, with the help of the 3D Analyst Tools extension of ArcGIS geographic information program. The Topo to Raster method is a very accurate interpolation method, specifically designed to generate digital terrain models for hydrological analysis of the studied field (Childs, 2004). This method is based on the ANUDEM program developed by Hutchinson (1988, 1989, 1996, 2000, 2011).

The figure 3.34 presents 4 digital terrain models, obtained by 4 different interpolation methods (IDW, RBF, Kriging, Topo to Raster), for a 1500 m section of the river sector chosen for research development.

From a detailed analyze of the obtained digital models, it can be seen that the obtained DTM with the Topo to Raster interpolation method has a much smoother and flatter graphic representation, with lower sinuosity elements.

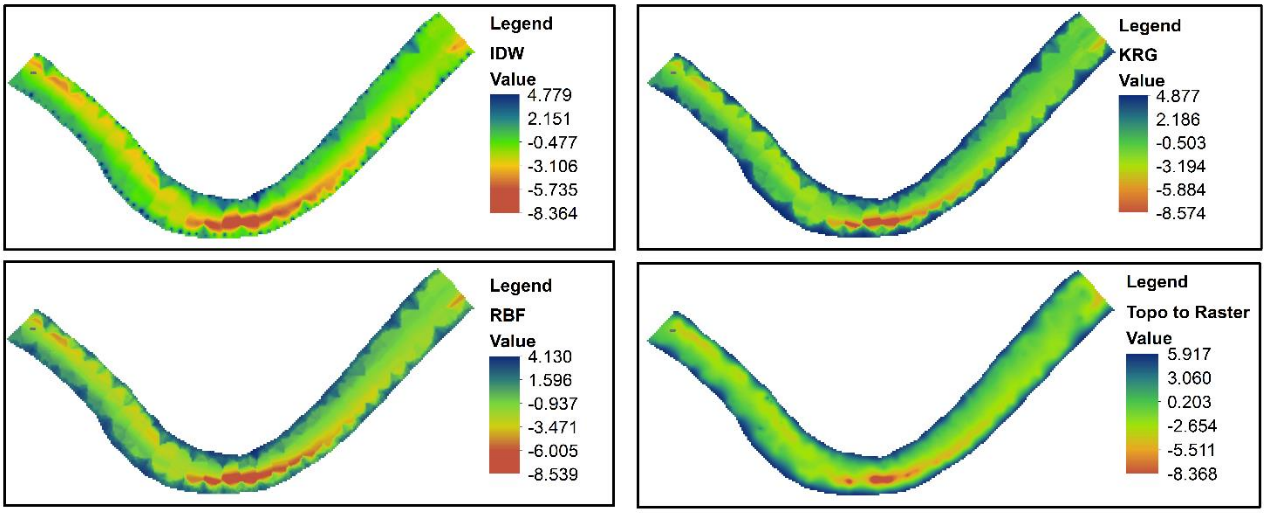


Figure 3.34. Digital elevation model of main channel obtained by using different interpolation methods

The following correlation coefficients were obtained from the statistical data processing:

IDW Method – R^2=0.9589; RBF Method - R^2=0.9469;

KRG Method - R^2=0.9694; Topo To Raster Method - R^2=0.9728;

Thus, the digital elevation model for the main channel riverbed is based on the Topo to Raster interpolation method.

3.2.4 Combination of multiple DTMs

The computing of hydrodynamic simulations on the Siret River requires the generation of a combined 3D model of the study area, consisting of the digital elevation model on the main channel and the digital elevation model of the overbank areas. The combined 3D models can be obtained with satellite imagery (SRTM - Figure 3.35, a; ASTER - Figure 3.35, b), laser scanning (LIDAR - Figure 3.35, c), or direct topographic (surveying) measurements.

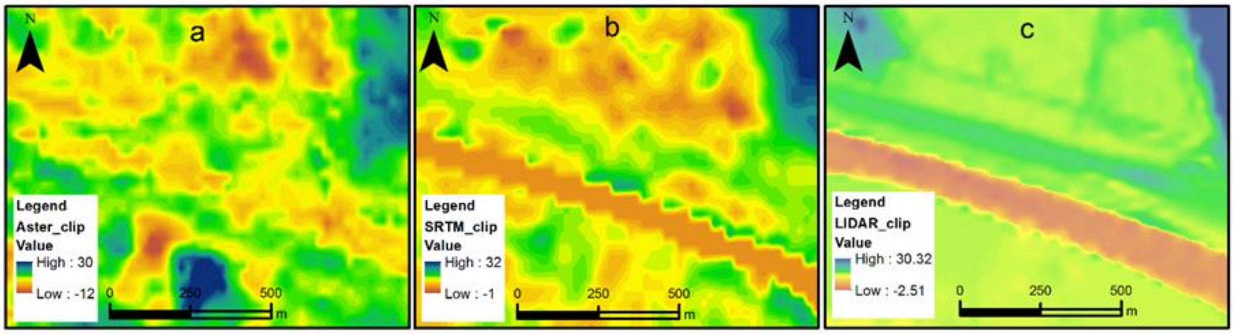


Figure 3.35. *ASTER– a, SRTM – b, LIDAR – c* image examples, for a river sector from the entire study area

The combined 3D terrain model used in the research was composed of the combination of the topo-bathymetric DTM of main channel with the LIDAR DTM of the overbank area. It was based on the comparison of a cross-sectional profile obtained from the four possible combination methods (Figure 3.36).

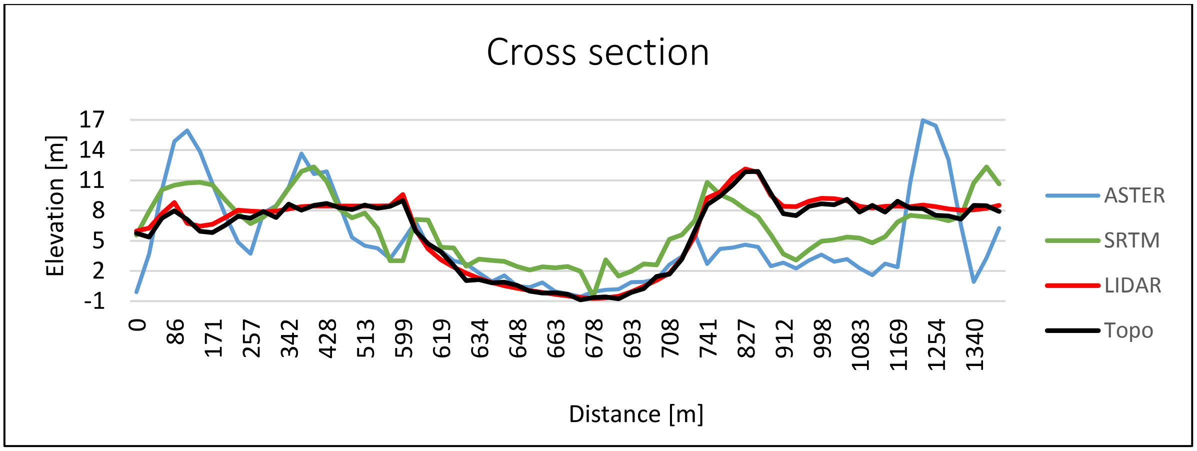


Figure 3.36. Cross-section profile generated from four different sources for the same planimetric points

3.2.5 HEC-RAS geometric model for Siret River, Danube-Șendreni-Independența section

Following the definition of the final DTM, which was obtained by combining multiple DTMs based on different types of topographic, bathymetric and satellite measurements, it was used to define the geometry shapes for the Siret River, the Danube-Sendreni-Independence sector. As Dysarz et al. (2017) and Bates et al. (2005) notice in their research paper, the definition of the geometric model of the river for the generation of hydraulic simulations is based on its correct construction and digitizing according to the cross sections created through the interconnections.

For the chosen study area, the cross sections were digitized taking into account the following elements, described in the Hydraulic Reference Manual HEC-RAS (HEC-RAS Hidraulic Reference Manual, 2010):

- The cross sections were defined at approximately equal distances along the course of the river, and in areas where there are bridges, accentuated declivities, roughness changes, or in areas where the meanders are very sinusoidal, the cross sections were geometrically spaced at as small distances possible, so as to describe as accurately as possible the geometry of the main channel;
- Cross sections cover at least the width of the river and the possible flooding area;
- The cross sections were defined perpendicularly to the main channel river, as far as possible both on the left and on right sides of the banks without intersecting them.

Considering that the average width of the river's wet surface is 100 m, it follows that the proximate calculated distance between two cross-sections is 200 m. This distance varies depending on the geometry of the river, with lower values in meander areas and higher values in more linear areas (Figure 3.37).

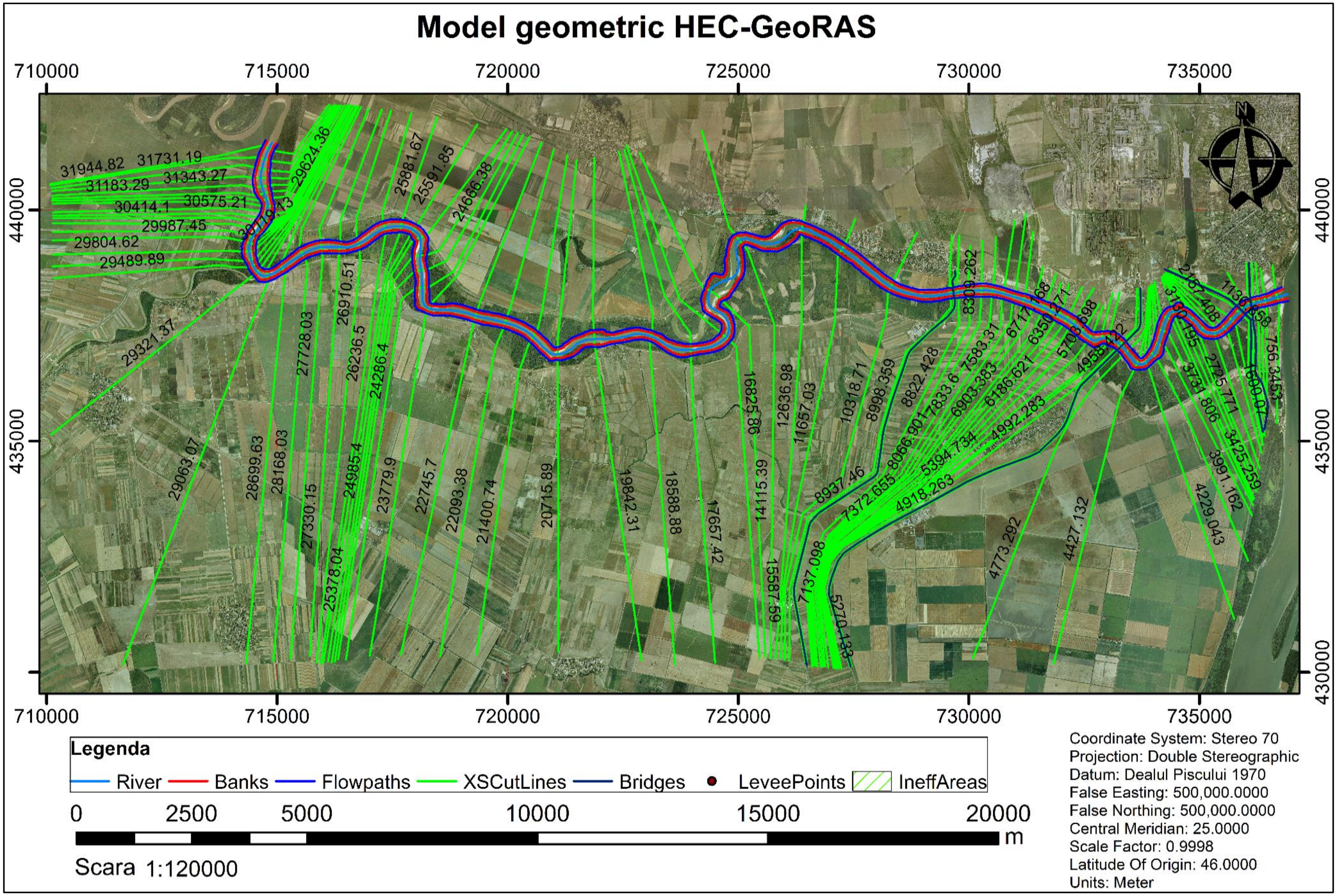


Figure 3.37. The ArcGIS geometric model for the studied river section using the HEC-GeoRAS too

3.2.6 Terrain roughness

Terrain roughness values are one of the important aspects in any hydraulic modeling. In fact, the roughness is almost impossible to determine by in situ measurements, so roughness are usually estimated from alternative sources, such as pedological maps, orthophotoplans or LANDSAT satellite imagery. To achieve satisfactory results in the literature, different combinations of roughness values have been modeled (Limerinos, 1970; Arcement and Schneider, 1989; Schumann et al., 2007). In given research, based on the physical characteristics of the minor and major riverbeds, eight classes of roughness presented in the table 3.2 were used.

Table 3.2. The *n* coefficients of roughness (Te Chow, 1959)

Category	Description	Minimum	Normal	Maximum
1. Minor riverbed				
	a. Sand-clay, multiple meanders, banks, rare stones	0.030	0.050	0.070
2. Major riverbed				
	a. Grass land	0.030	0.035	0.050
	b. Short grass	0.035	0.040	0.045
	c. Arable land	0.033	0.045	0.055
	d. Brushwood	0.070	0.110	0.160
	e. Thick trees, knobs, broken branches	0.080	0.120	0.140
	f. Broadleaf trees, willows, thick leaves during the summer	0.110	0.150	0.200
3. Urban area				
	a. Asphalt, pavement	0.012	0.015	0.020

Based on the available orthophotoplan (Figure 3.38), a map with eight different roughness classes described in table 3.2 was generated. The result of polygon limits for the determination of roughness coefficients is highlighted by a color ramp and represented in figure 3.39. The roughness coefficients distribution is presented in raster format in the figure 3.40.

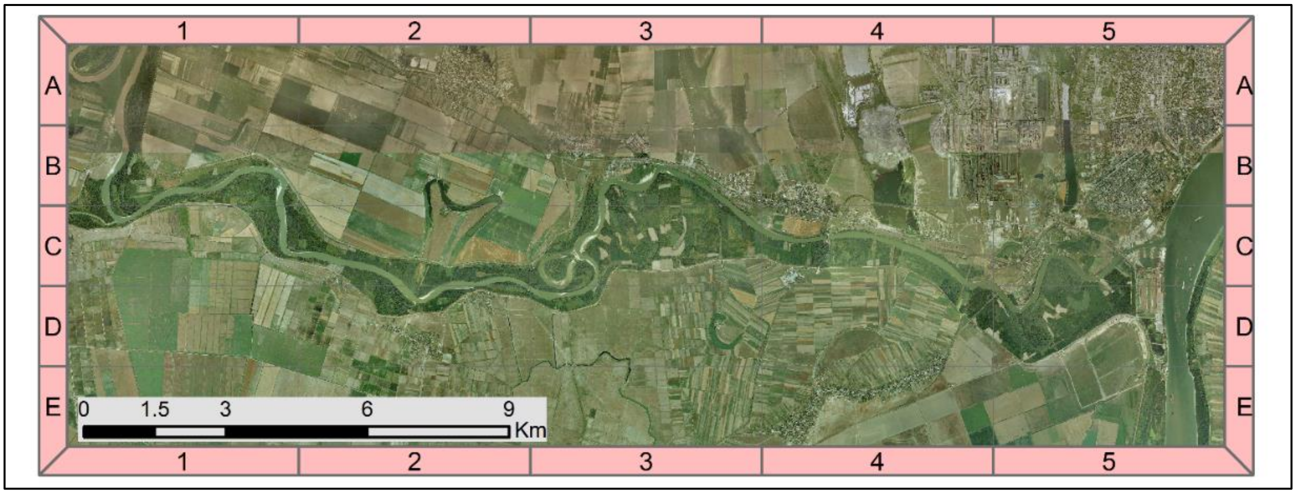


Figure 3.38. 0.5 m, precision orthophotoplan Galați – Brăila

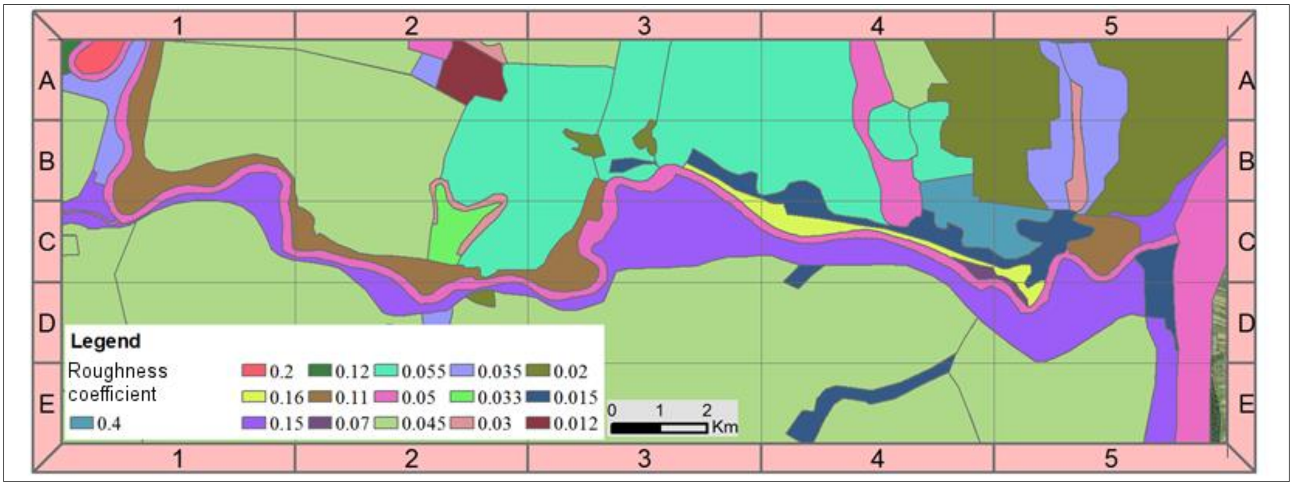


Figure 3.39. The roughness coefficients assigned by digitized polygons

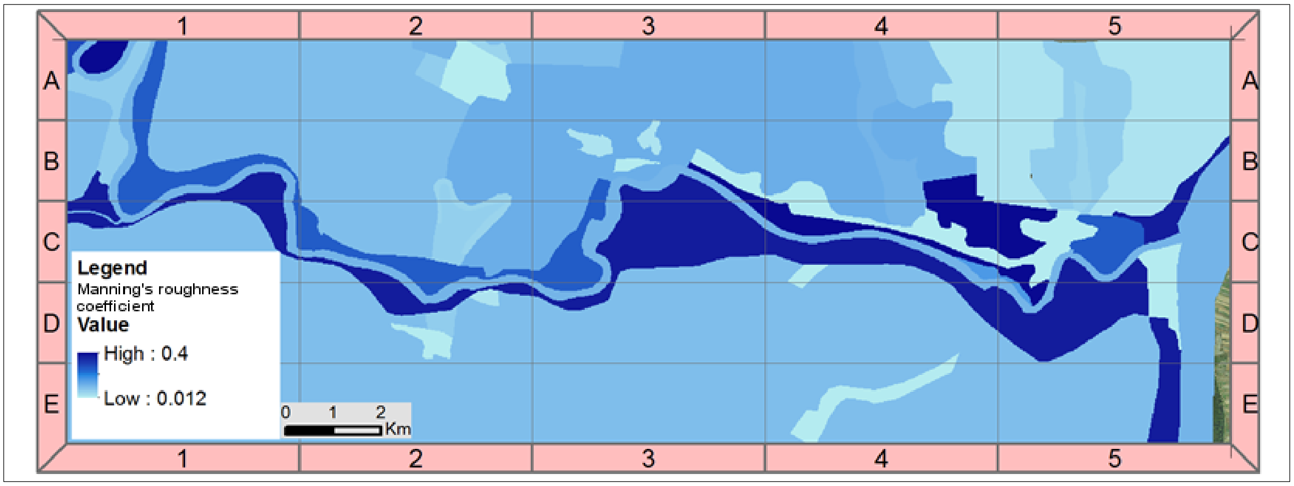


Figure 3.40. The rasterized map of roughness coefficient distributions

3.2.7 Bridges and elevated structures

The HEC-RAS Hydraulic Model is influenced geometrically by elevated structures such as bridges or conveyor lines across the entire width of the river. Thus, on the length of 35 km of studied river area were identified four elevated structures, of which two bridge type structures with road destination (figure 3.41 a, b), a bridge for rail transportation (figure 3.41 c) and a pillar structure for conveyor belt for the ArcelorMittal Galati metallurgical plant (figure 3.41 d).

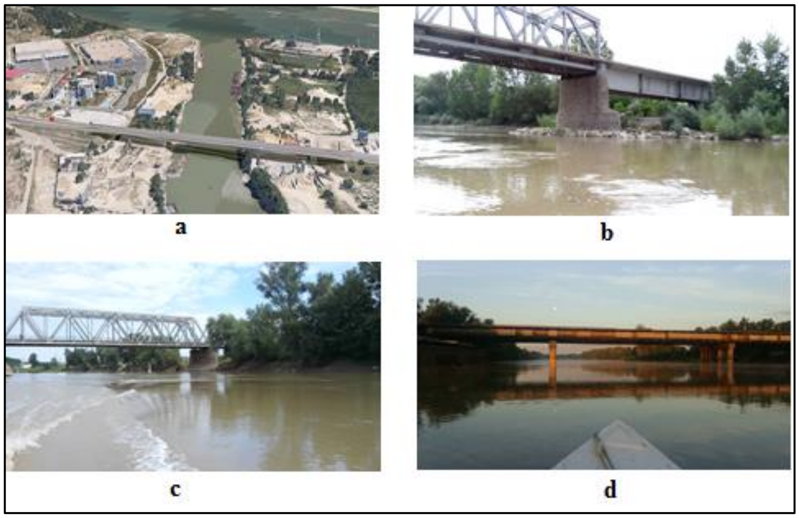


Figure 3.41. Elevated structures**,** *a – Galați-Brăila road bridge, b – Șendreni road bridge, c – Barboși railway bridge, d – ArcelorMittal conveyor belt*

Hydraulic modeling in HEC-RAS software is influenced by energy losses in those areas where are bridges, barrages or other elevated structures. For the determination of energy losses, the following geometric characteristics have to be considered: the upstream and downstream cross sections of the structure; the ineffective upstream and downstream area; the built bridge or the structure opening.

$$h_{ce} = C\left|\frac{a_1V_1^2}{2g} - \frac{a_2V_2^2}{2g}\right| \qquad (3.1)$$

where *C* – compactation or expansion coefficient.

The compactation and expansion coefficients directly act on the ineffective areas. In the table 3.3 are described the specific values of the compactation and expansion coefficients for four different loss energy types.

Table 3.3. Compactation an expansion coefficients [Brunner and Hunt, 1995]

Description	**Compactation Coefficient**	**Expansion Coefficient**
Without expansion losses	0.0	0.0
Gradual losses	0.1	0.3
Bridges specific cross-sections	0.3	0.5
Rapid losses	0.6	0.8

3.2.8 Calibration of the HEC-RAS Hydraulic Model

Due to the lack of a complex set of data on the studied area, for this research study, the model analysis and calibration were limited to the comparison of surface water levels from modeling with surface levels found in the scientific literature and in the field. These are based on the major flood that occurred in 2005 (Murariu et al., 2010) (figure 3.42). The water surface level was registered at the Sendreni hydrometric station.

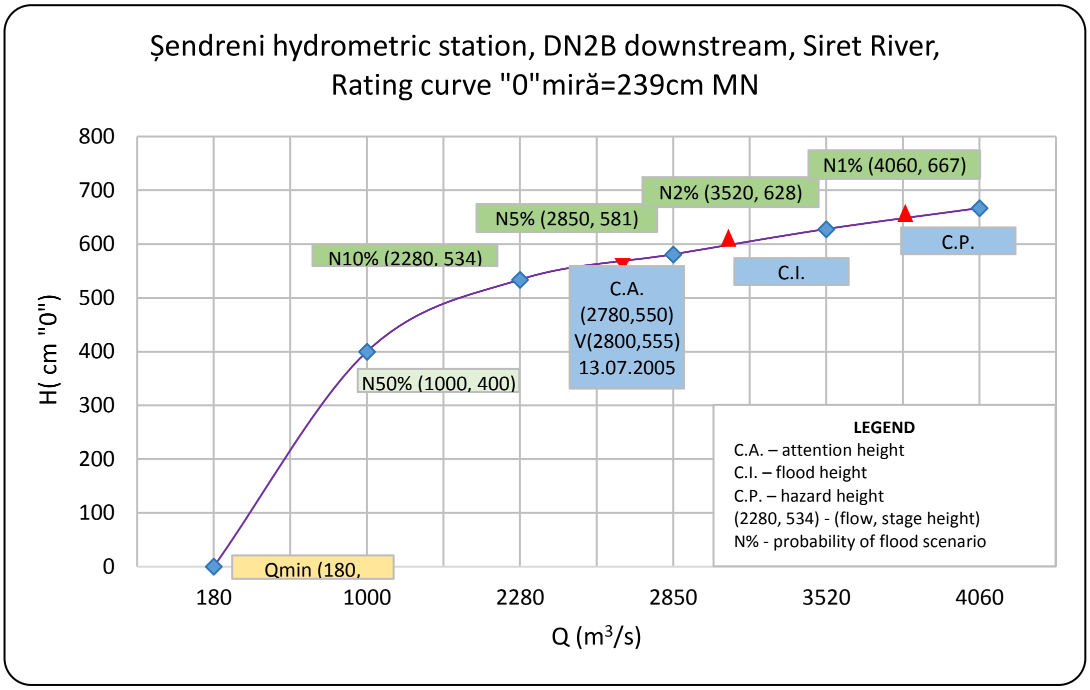


Figure 3.42. Registered rating curve values at the Sendreni hydrometric station during the 2005 flood year.

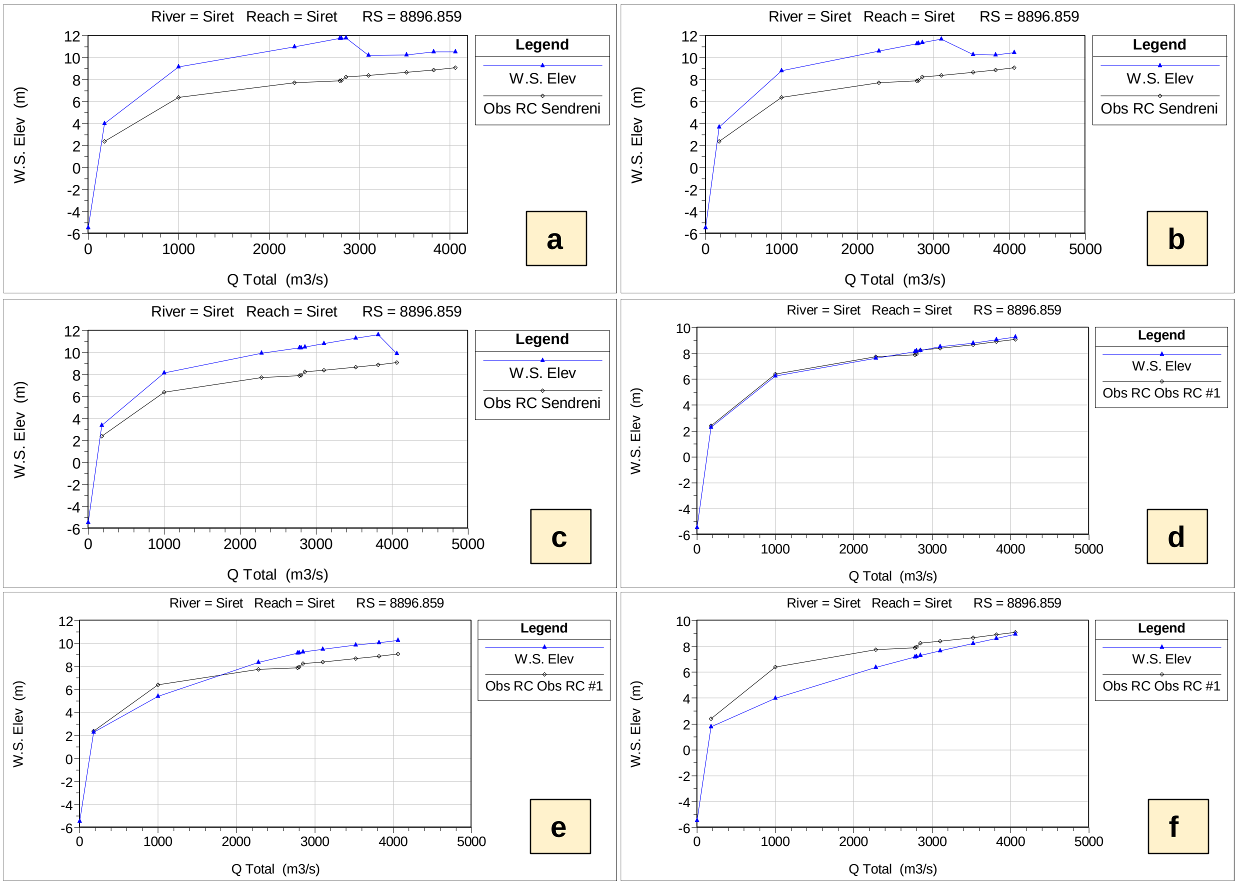


Figure 3.43. Model calibration with HEC-RAS tool according the roughnesses: ***a*** *– n=0.07;* ***b*** *– n=0.06;* ***c*** *– n=0.05;* ***d*** *– n=0.04;* ***e*** *– n=0.03;* ***f*** *– n=0.02*

The calibration of the model was performed by roughness coefficients modification in the minor riverbed so that the differences between the measured rating curve key and the modeled rating curve key were less than ±10 cm (Figure 3.43).

3.2.9 HEC-RAS hydraulic modeling

Given the importance and the main purpose of the research on modern GIS techniques for the determination of territorial risks, the hydraulic modeling is the key element for the realization of flood scenarios on the Siret River, the Danube-Șendreni-Independența sector. In this part of the chapter will be presented the results of flood scenarios by making flood maps, comparative analysis of flow growth and physical behavior of the river, by specifying the water surface levels in different important profiles, the speed of water flow in the profile and other specific characteristics of the hydraulic modeling.

According to ***"Directive 2007/60/EC** of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks",* hazard maps that are generated, cover geographical areas that may be flooded in the following cases:

a) Low probability floods or in extreme cases - N 0.1% = floods that can occur once every 1000 years;
b) Floods with medium probability - N 1% = floods that can occur once every 100 years;
c) High probability floods - N 2% floods occurring every 10 years.

Following the study on the overflow probability by Murariu et al., 2010, the following overflow probabilities are described from the Şendreni hydrometric station, which were the basis of the flood scenarios:

1) N10% - flow 2280 m^3/s, rod level = 534cm, „rod 0” = 239cm;
2) N5% - flow 2850 m^3/s, rod level = 581cm, „rod 0” = 239cm;
3) N2% - flow 3520 m^3/s, rod level = 628cm, „rod 0” = 239cm;
4) N1% - flow 4060 m^3/s, rod level = 667cm, „rod 0” = 239cm;

The maximum level resulting from modeling for the overflow probability of 1% is 13.57m, determined for the 31731m transversal profile. The surface level changes its growing course in the downstream part where the land levels are contracting.

The figure 3.44 presents the histogram of the occurrence frequencies of the variables describing the water surface level, the right and left bank levee points, for the N1 % flood scenario.

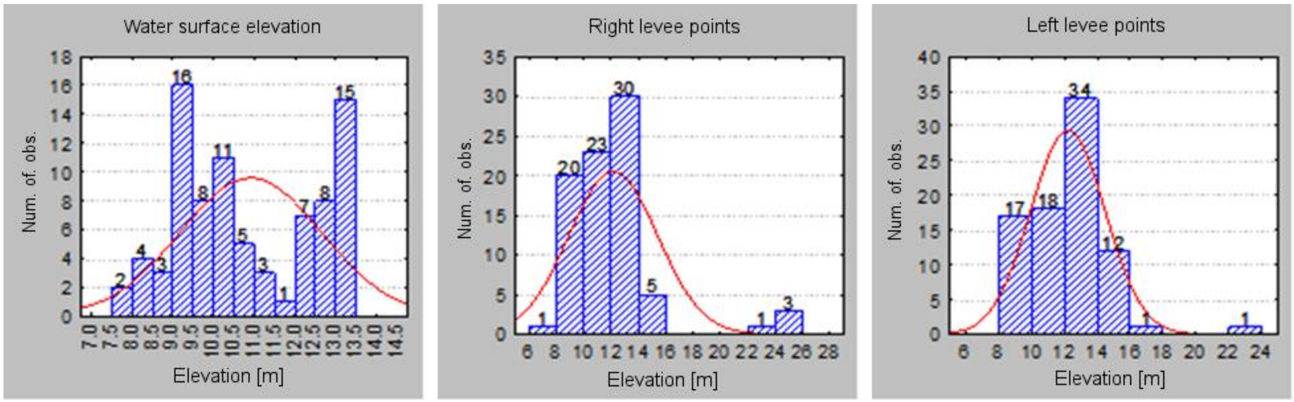


Figure 3.44. Histogram of elevation values occurrence frequencies for the of water surface level, right – left levee points

In order to achieve the main purpose of the paper, there were generated several flood maps different flows (figure 3.45, figure 3.46).

Flood hazard maps are required to get information on the flooded areas enlargement. Analyzing figure 3.45-a we can see that a flow rate of 500 m^3/s is a relatively small flow rate for the analyzed river sector. The total area covered by water is 393 ha

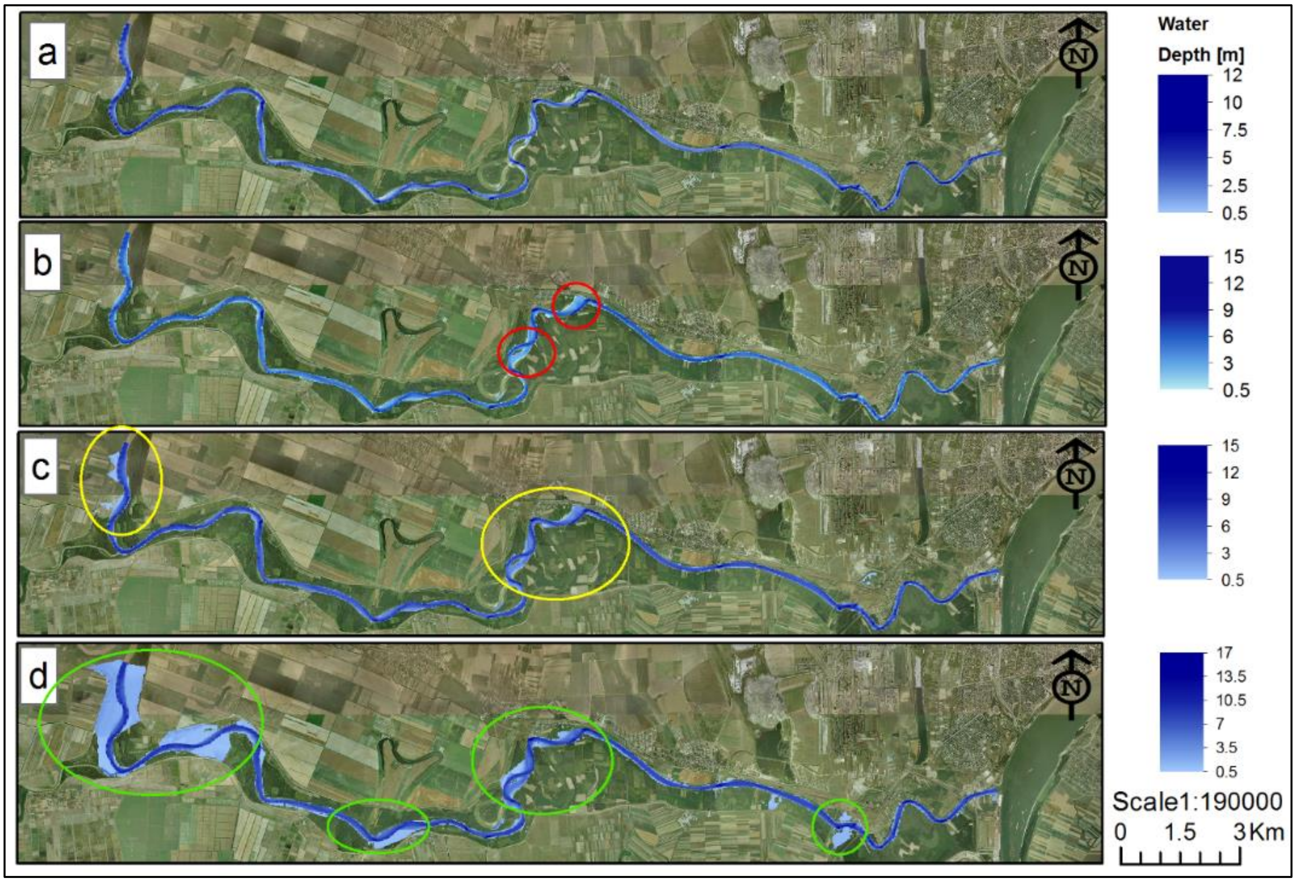


Figure 3.45. Flood scenarios and water depth: ***a*** *– flow Q=500* m^3/s, ***b*** *– flow Q=1000* m^3/s, ***c*** *– flow Q=1500*m^3/s, ***d*** *– flow N10% Q=2280* m^3/s

If we compare the results from the modeling for the Q = 1000 m^3/s flow rate, it is observed that in some areas, especially those with very sinus meanders, an increase of the water surface level is recorded (Figure 3.45-b, red mark). Thus, the surface covered with water increases with 61.5 ha.

For a specific flow of 1500 m^3/s there are areas where the water level exceeds the banks level but not that of the protection levees (Figure 3.45-c, the yellow mark), thus increasing the surface covered with water by about two times higher than for Q=500 m^3/s. With the flow increase till the overflow to the N10% - 2280 m^3/s, the result of the hydraulic modeling is represented by areas where the water level exceeds the banks level and the surface of these areas increase (Figure 3.45-d, green mark) to 861 ha.

The figure 3.46 presents the modeling results for flows ranging from 2500 m^3/s to 4060 m^3/s. As can be seen for the Q = 4060 m^3/s flow rate (Figure 3.46-d), the flood scenario covers almost the entire study area, with a total surface area of about 15500 ha covered with water.

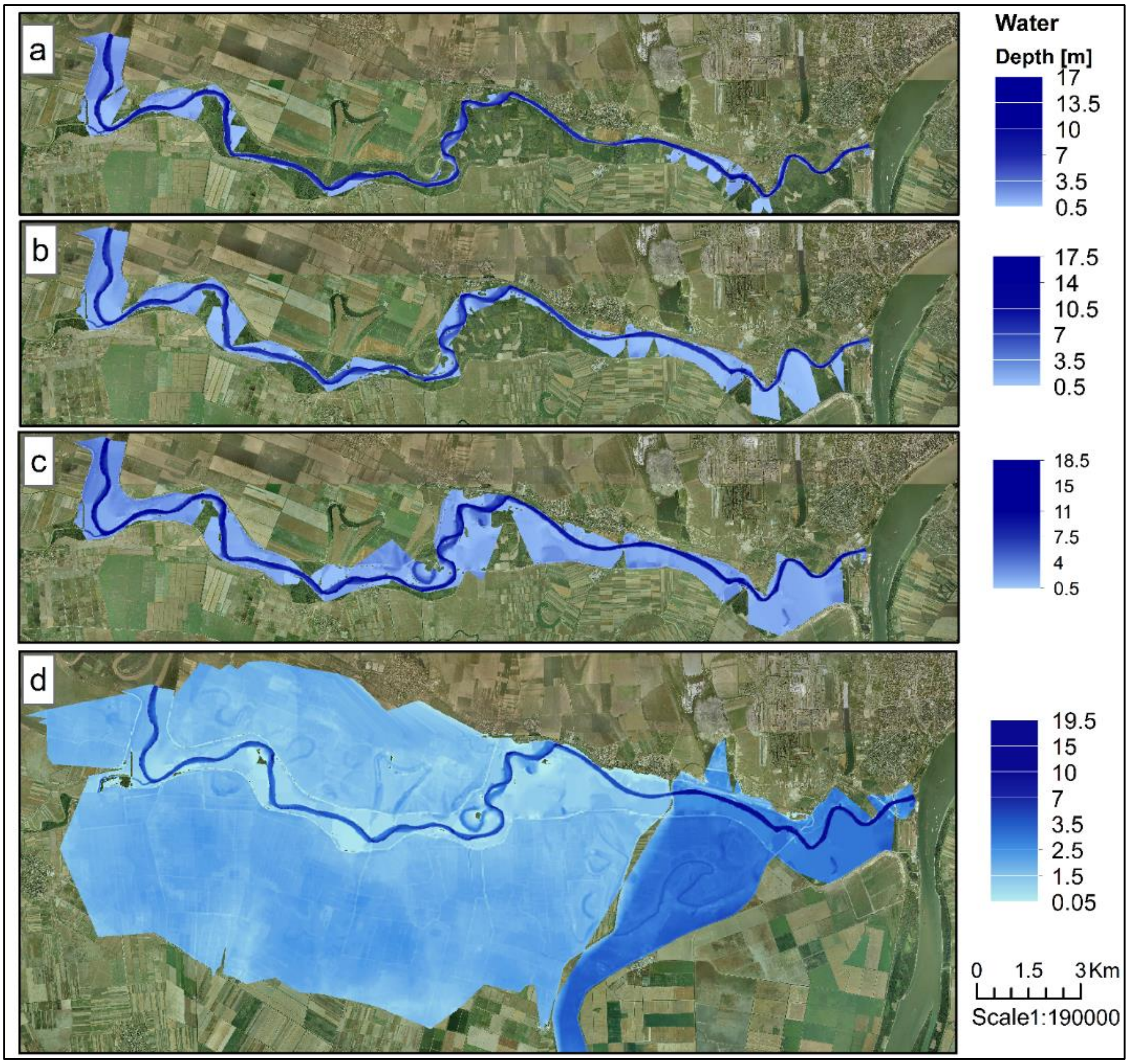


Figure 3.46. Flood scenarios and water depth: ***a*** *– flow Q=250 0m³/s,* ***b*** *– flow N5% Q=2850 m³/s,* ***c*** *– flow N2% Q=3520 m³/s,* ***d*** *– flow N1% Q=4060 m³/s*

Following the hydraulic modeling on the studied river sector, the flooded areas were extracted and analyzed, at different water flows. The figure 3.47 presents the flooded localities in case of a scenario with N1 % probability.

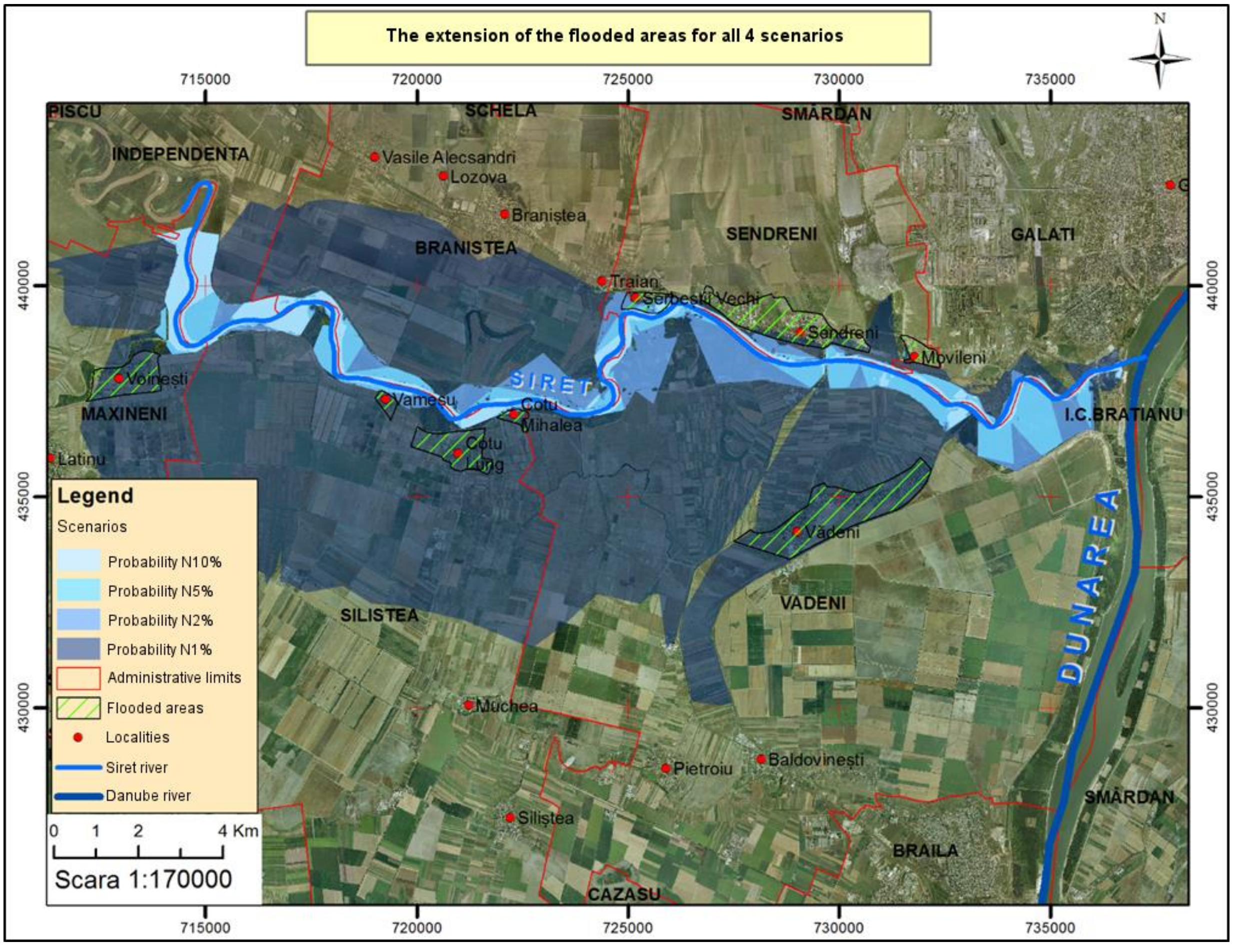


Figure 3.47. Flood scenarios that can occur once every 10 years, 20 years, 50 years, 100 years

Due to the fact that the digital terrain model covers only part of the studied major riverbed, some of the localities that are in the major riverbed were not included in the modeling, but they also have a low to medium flood risk.

According to **Directive 2007/60/EC**, this modeled scenario - N 1%, represents a medium-risk probability and 0.1% a high risk. Depending on the depths resulting from the modeling, the depth-specific pixels were reclassified into 3 classes: class 1 smaller than 0.5 m - low risk, class 2 ranging from 0.5 m - 1 m - medium risk, class 3 higher than – 1.5 m. The figure 3.48 represents the rasterized image of risk classes of localities that may be subject to a N1% medium risk.

Following the elaboration of the risk and hazard maps, were analyzed the statistical indicators describing the population, the existing cultural patrimony, the roads, the number of localities, disposed in the area with medium potential risk. In the research area, live about 9500 inhabitants in 8 localities and are exposed at the flood risk.

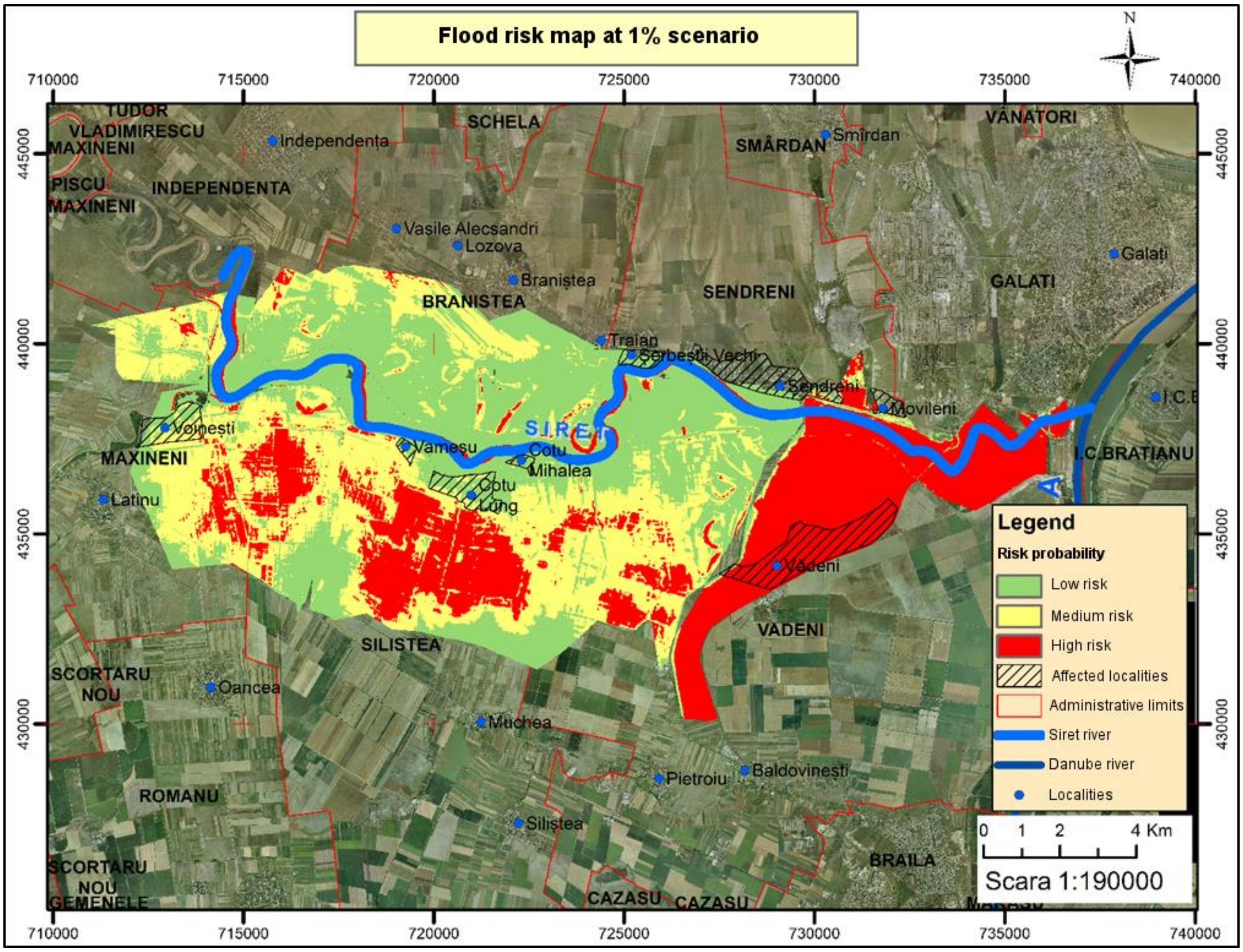


Figure 3.48. The flood risk for the scenario with an overflow probability once every 100 years.

According the **Directive 2007/60/EC**, an important category affecting the economy of EU Member States is the consequences of floods on infrastructure. Following the distances evaluation for each category of roads, 6 km of European road and 9 km of national road, 2 km of county road, 2.5 km of communal road, which can be subject to the medium flood risk.

Another important element is the cultural patrimony. This is as well a critical element the ***Floods Directive*** requires all Member States to evaluate. In this way, there were identified 7 churches and 1 cathedral, a museum and a cultural monument in the study area, and they could be affected by floods with a probability of occurrence once every 100 years.

Another series of key indicators is the consequences of floods on the environment. There have been identified several types of protected areas (Figure 3.49): 1 special bird protection area (ROSPA0071) with the two bodies, Pădurea Neagră (Black Forest) and Pădurea Dumbrăvița (Dumbrăviţa Forest), 1 site of community importance (ROSCI0162), 1 reservation of interest (RONPA042) - Balta Potcoava. All three protected areas are located in the flood plain of the Lower Siret (study area) and cover a total area of approximately 4725 ha.

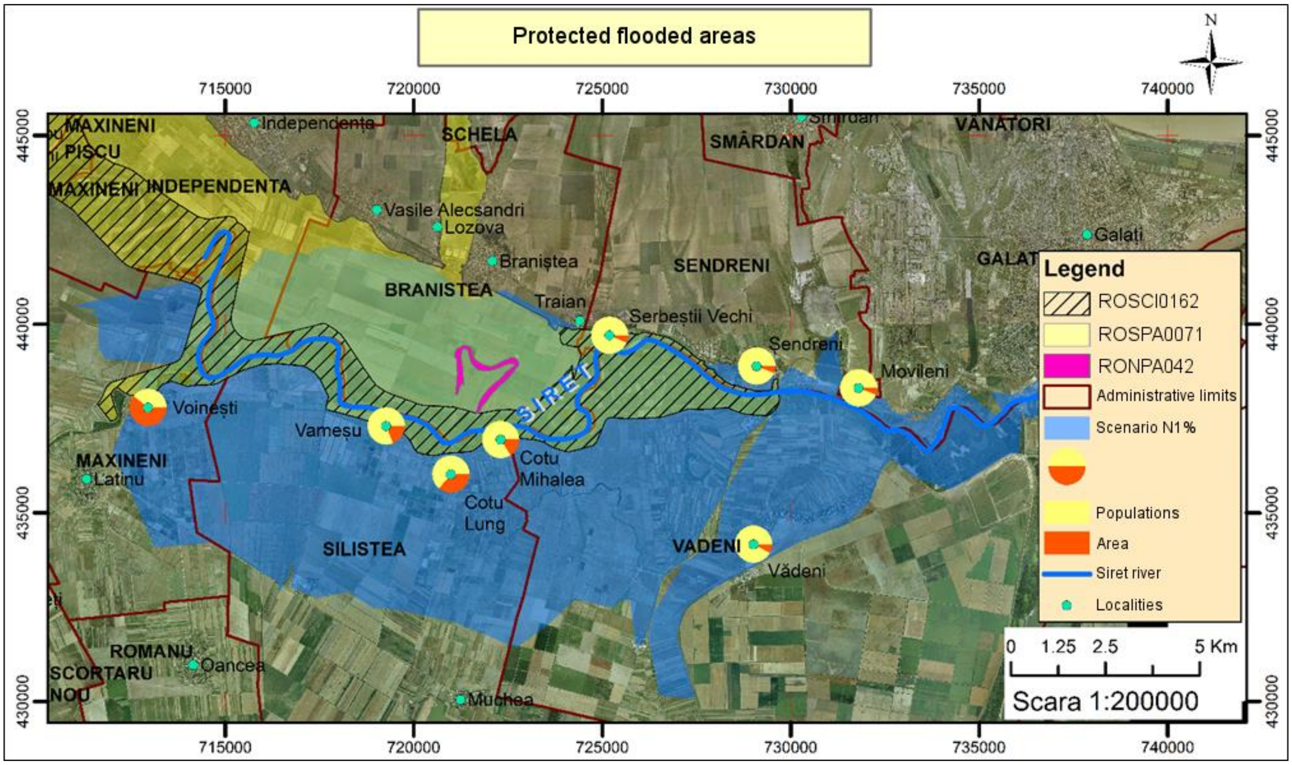


Figure 3.49. Protected areas that can be affected by the flood once every 100 years

Chapter 4. Conclusions, personal contributions and research directions

The aim of the given PhD thesis is to approach in the same research study different techniques and engineering methods in order to generate hazard and flood risk maps for the Lower Siret River sector. This is possible by using in the field surveying, modern measuring equipment of topography, bathymetry, aero photography and modern GIS-CAD techniques for processing satellite imagery and raw data obtained from terrain measurements.

4.1 Conclusions and personal contributions

Following the research on GIS techniques for determining the territorial risks, the following conclusions were drawn:

1) Topographic and geodetic measurements have an important role in determining the planimetric and altimetric coordinates of the topographical points.

Most engineers using topographic equipment disregard the real influence of atmospheric parameters during the measurements, performing measurements with the default values of the total station, thus obtaining erroneous results. Considering this, an appreciable scientific contribution was made by achievement distance measurements in order to determine the influence of atmospheric parameters over the measured distances with the topography total station. The critical parameter, *atmospheric temperature*, directly influences the measured distance with the total station. The measured distances with the updated temperature values can be changed by 10 cm for a length of 100 m at a temperature difference of 10°C. The other two analyzed parameters, namely *relative air humidity* and the *atmospheric pressure*, do not have a significant effect on distance measurements unless sudden changes of these parameters.

The variation of the atmospheric temperature affects the refractive index and the measured distance by approximately 10ppm, under the conditions of its determination with an accuracy of $\pm 1^0$C.

Thus, the detailed knowing of the total station behavior in terms of atmospheric parameters is necessary to obtain accurate results, and the correct use of topographic equipment in calculating the absolute coordinates of the measured points in the field.

2) Following the preliminary study realized with UAV technologies, we concluded that drones are currently one of the most available equipment used in various fields. With their help, it can be obtained experimental results for various research fields.

A personal contribution to the whole research was achieved through the study of the multi-rotor X8-M drone from the laboratory; it was designed to demonstrate that UAVs could replace topographical measurements in the field and provide an advantage in view of work rapidity having an easier and quicker post-processing operation. The advantage of the X8-M drone is its equipment with all the necessary modules for flying and automatically capture the photograms required to make very accurate orthophotomaps. The precision of the generated orthophotomaps by the used UAV equipment is ±5-10 cm in the horizontal plane, and digital elevation models have an accuracy of ±10-15 cm in the vertical plane.

3) An important conclusion is given by the obtained results from the preliminary study on remote sensing techniques and their applicability in determining the risks and hazards of floods.

An original side of this research is given by the method of using remote sensing, especially satellite imagery, to obtain geospatial results on two events produced by the flood hazard from summer 2010 in two different study areas.

The advantage of using this method of analysis is given by the work rapidity for extended areas. The satellite imagery use replaces field measurements that require significant effort and a large teamwork. The analysis method presented in subchapter 3.1.3 is an introduction to a new approach of mapping the floodplains and the damage they produce in the field of engineering sciences.

4) The bathymetric measurements made in the preliminary study described in subchapter 3.1.4 represent the most important phase in achieving the main purpose of the paper, namely to generate risk and hazard flood maps, for various flood scenarios, on the lower course of Siret River.

These determinations realized on a lake (which is an area with stagnant water) have led to the conclusion that the obtaining of a bathymetric model of the riverbed is possible only by determining the planimetric and altimetric coordinates from the lake ground. Collecting terrain points on a combined (transverse, longitudinal, and zigzag) alignment makes the measurement grid as uniform as possible and thus increases the density of the collected points and the accuracy of the results.

In conclusion, we can point out that in case of bathymetric measurements on stagnant waters (lake, accumulations of water), the points can be interpolated by the SKRG method. In the case of SBES measurements on river courses the points should be interpolated by the method TopoToRaster because the obtained bathymetric model has a much smoother and flat representation with low sinuosities and a correlation factor between the measured values with those interpolated by $R^2 = 0.94$.

5) The researches on modern GIS techniques and methods for assessing and determining territorial risks and hazards is a set of high-precision work, both in terms of raw data collection and in terms of their processing in the laboratory.

The obtained DTM for major and minor riverbeds for the lower course (Danube - Șendreni – Indepnența) by combining the LIDAR or UAV airborne techniques with the ground - bathymetry and topography techniques represent unique and new DTM for this area. This generates a result with a correlation factor $R^2 = 0.98$. This element contributes 90% to obtain correct results from hydraulic modeling and simulations. The precision of topographic and bathymetric measurements should be ±1-10 cm horizontally and ±5-15 cm vertically in order to achieve a digital precision elevation model.

6) A critical parameter in accurately defining geometric elements for hydraulic modeling in HEC-RAS is the resulting digital elevation model. The key of geometric model for the hydraulic simulation are the cross sections that are arranged at a width of about 2 x 1 river width (B), if the course of the river is with sinus meanders. The lower course of Siret River, describing the chosen study area, is a combined course, where there are linear areas, so the distance between the digitized cross sections can reach up to 2 x 10 river widths (B). Cross sections require a more dense arrangement in the moment when there are declivity decreases or roughness coefficient alteration of the ground in the minor riverbed.

7) The results of hydraulic modeling in the HEC-RAS program are directly influenced by the coefficient of roughness (Manning's roughness coefficients). The minor riverbed of the lower course of the Siret River is entirely characterized by a sandy-clay soil with multiple meanders and sand banks formed by sediment migration, rare stones that appear only in the areas where rehabilitation or banks improvement works, it is therefore appropriate to use a roughness coefficient of 0.040. The major riverbed has different land categories and therefore the roughness coefficients vary from one category to another, ranging from 0.012 to 0.10. The roughness coefficient is the critical parameter for calibrating the HEC-RAS model. It has to be adjusted in such a way that the differences between the modeling flow rating curve and the measured flow rating curve at the hydrographic stage should not exceed ±10-15 cm.

A new approach in this research thesis is the assignment of roughness coefficients automatically, depending on the boundaries of the polygons that characterize each category of land, digitized at the stage of geometric modeling using the GIS programs.

8) Once the calibration of the HEC-RAS model has been completed, the hazard and flood risk maps were generated for the study area, the lower course of Siret River. After the analysis of the obtained correlations between the flow rate and the river power, it can be mentioned that the river power is directly influenced by the water flow rate. Which is given by the obtained result of correlation of these two indicators of $R^2 = 0.7166$, in the case of a maximum flow of 4060 m^3/s. This is the reason why, in some areas, especially where the sinuousness of the river is more pronounced, sudden changes in the watercourse might occur over time.

9) The risk and hazard maps have been compiled in accordance with the *Floods Directive*, except for the scenario with an overflow probability N0.1%, for which there are no historical records. Overall, there are over 9500 inhabitants, 19.5 km of road infrastructure, 16.5 km of railway infrastructure, 8 social patrimony elements and 3 environmental indicators are vulnerable at a medium risk of producing a hazard once every 100 years.

4.2 Research directions

The given research is a collection of GIS methodologies and techniques for determining territorial risks and hazards. These techniques and methods are in continuous development and can be improved all the time, which is why we propose the following research directions:

a) The carried out investigations by using the modern interpolation methods IDW, KRG, RBF and Topo to Raster can be successfully replaced, and perhaps with superior results, through MAR techniques, based on the explosive theory of fractals, which is useful in more and more research fields.

b) The classical partial derivative equations which on which are based the software programs used in Chapter 2 can be further investigated, in the opinion of Creutz et al. (2009), for the purpose of analyzing this thesis, by determining the symmetry groups according to the Peter Olver (1977, 2000) method.

c) The use of multibeam bathymetric equipment on the same study area leads to the reduction of fieldwork time, to the use of data in the study of sediment transport and accurately determines the flow rates of water both horizontally and vertically. The obtained data by the multi-beam scanning on the minor riverbed generates a result that is represented by a larger number of points, structured in a uniform grid, as their determination is made by continuous angular scanning and a measurement frequency up to at 500 kHz in a more structured grid.

d) Another research direction would be the pursuit of the research on the minor riverbed morphology, morphometry and land topography of the major riverbed in order to complete the existing geospatial databases, comparing the results in time / space and predicting future areas of high-risk areas for various natural hazards (landslides, fires, deforestation, clogging, erosion, floods). At this point, we could mention that it is necessary to study the influence of the anthropic factor on morphological and morphometric changes of the minor and major riverbeds in the study area and we could propose the necessary measures to suppress this phenomenon for a long time.

e) All the hydraulic modeling is based on the land digital model. Thus, to improve it, some unmanned flight equipment can be used. By using wing-type drones, a low-cost topography can be determined from the point of view of the work team, as well as the price for a square kilometer measuring. Another advantage of the wing-type drones is the flight time, which is approximately 10 times higher than the propeller-type UAVs, and offers total coverage of the study area in only a few flights.

f) In addition, the optimization of the observations on land-based features (infrastructure, bridges, wooded areas, blocks, industrial areas) located in the research area could be achieved by acquiring precision satellite images (p = ± 15 cm). These images can be used for comparative study, correlations between outcomes, which can be drawn in long-term conclusions.

g) We consider it necessary to continue the observations on the lower course of the Siret River by extending the study area, including morphometric analysis of the Buzau River, which has a significant flow in the Siret, and Danube River in order to be able to generate results and conclusions about the "push-up" effect that is present in the study area.

h) An important element is efficient and fruitful collaboration between institutions and decision-makers in this field, so that research results can be used to complete existing national and local databases. In this way, a continuous exchange of good practices at the national and international level can be achieved by applying the respective methodology and techniques with the same complexity in other similar researches.

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