IOSUD –„DUNĂREA DE JOS” UNIVERSITY OF GALAȚI

Doctoral School of Mechanical and Industrial Engineering

Ph.D. THESIS

(ABSTRACT)

Flood risk studies in the Danube Delta

Ph.D. Student,

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Series I 4: Industrial Engineering Nr. 81

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FOREWORD

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1. **Banescu A.**, Georgescu L. P., Rusu E., Iticescu C., (2018). *Use of GIS technology to support the navigation on the Danube river*. In’’International conference on traffic and transport engineering – ICTTE Belgrade 27th – 28th of September 2018 http://ijtte.com/uploads/news_files/ICTTE%20Belgrade%202018_Proceedings.pdf

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1. **Banescu A.**, Georgescu L. P., Iticescu C., Rusu E. *Analysis of the flood risk in DanubeDelta - Case study the Maliuc area*. Scientific Conference of Doctoral Schools of „Dunarea de Jos” University, Galati (CSSD-UDJG 2018), 07-08 June 2018
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List of projects

Research:

1. Improving the hydrological conditions in the aquatic natural habitats in DDBR for the conservation of biodiversity and fishery resources – Șontea – Fortuna, Matița – Merhei, Somova Parcheș lacustrine complexes (period 2020-2021, Responsible for data collection and field samples);
2. Improving the hydrological conditions in the aquatic natural habitats in DDBR for the conservation of biodiversity and fishery resources – Gorgova – Uzlina, Roșu – Puiu lacustrine complexes (period 2020-2021, Responsible for data collection and field samples);
3. Improving the hydrological conditions in the aquatic natural habitats in DDBR for the conservation of biodiversity and fishery resources – Dunăvăț – Dranov, Razim – Sinoie, Sinoie area – Istria – Nuntași, lacul Murighiol lacustrine complexes (period 2020-2021, Responsible for field data collection and technical project development);
4. Scent – Smart toolbox for engaging citizens into a people centric observation web – awarding participation in Horizon (period 2017-2019, Responsible for data collection);
5. Lucas – Land Use and Land Cover Survey (period 2018-2019, Responsible for soil sampling / Photointerpretation / Supervisor);
6. Research on the conservation status of the natural reproduction areas of fish in DDBR (period 2018, Responsible for collecting data from the field);
7. Management support project for the creation of the Romanian components within the Pan-European project of distributed infrastructure Danubius-ri (international center for advanced studies for river-sea systems) - DANS (period 2018-2019, Head of technical part);
8. Danurb (Danube Urban Brand): a regional network building through tourism and education to strengthen the “Danube” cultural identity and solidarity (2018-2019, Responsible for GIS modeling);
9. Assessment of the ecological status of aquatic ecosystems on the territory of the Danube Delta Biosphere Reserve (period 2019-2020, Responsible for field data collection);
10. Modeling and design of natural systemic solutions for limiting the influences of risk factors in integrated and sustainable spatial planning in the Danube Delta (period 2019-2020, Responsible for field data collection);
11. Elaboration of the topo-bathymetric study and the hydraulic model of Beleu Lake for the elaboration of the feasibility study regarding the ecological restoration of the Beleu wetland according to the terms of reference tor_rew / 04 of 06.05.2019 within the project „Restoration of wetlands and steppes of the Danube Delta (2019-2020, Responsible for hydraulic modeling).

Design:

1. Transverse and longitudinal profiles - Vard Tulcea Basin by topobatimetric elevations and axis tracings of the excavation area (period 2018, Project Manager);
2. Hydrological measurements in the Vard Basin by topo-bathymetric surveys (period 2019, Project Manager);
3. Hydrological measurements on the Danube between km 505 - km 511 (period 2020, Project Manager);
4. Ensuring a favorable conservation status for rescuing from extinction the European mink population - Mustela lutreola (species of community interest, critically endangered) - from Romania - SAVE E-MINK - RO (period 2020-2021, Responsible technical part);
5. Emergency Situation GD 299 / 23.05. 2019 "Works for unclogging the Letea and Sidor canals, within the commune of CA Rosetti, Tulcea county" (period 2019, Technical part manager).

Key Words:

Agricultural Establishment, digital terrain model, dynamic method, static method, hydraulic modelling, GIS analysis, bathymetry, flooding scenarios, flood maps, hazard maps, risk maps, Chilia branch, collating.

INTRODUCTION

The Ph.D. thesis „ *Flood Risk studies in the Danube Delta"*, treats a research subject in engineering, with regard to flood risk, using various instruments and modern engineering methods to analyse flooding scenarios.

From this perspective, the purpose of the research is to draft maps of the potentially floodable expansion areas for the localities in the Danube Delta.

In compliance with "**Directive 2007/60/CE**" entered into force in November 2007 with regard to flood risk assessment and management, it is based on identifying the perimeters with potential flood risk. The directive regarding floods aims to decrease and mitigate flood risks, especially for the on-going economic approaches, environment, cultural patrimony and human health. Thus, this action can be carried out by drafting hazard and flood risk maps.

In the Danube Delta, floods are hydrological events that can occur at any scale. These phenomena occurred ever more frequently in the past decades. Due to the geographical position and specificity of the area, as well as to the naturally unique character of the Danube Delta, there frequently occur hydrological hazards (abundant showers, sometimes accompanied by hale, river floods, strong storms, extreme temperatures etc). The flood process is influenced by the increase rate of the Danube water level. Depending on their ampleness, they proportionally affect a certain area of the Delta surface, especially the localities along the main arms of the river.

The floods in the Danube Delta become natural disasters when they affect human settlements. Most of the localities are found in floodable areas, especially those on the main arms of the Danube, presenting high flood risk. The hazard is determined by the collapse of the protection dams of the localities, due to severe high waters of the river and to their duration. The high waters press against the dam making it collapse, especially in vulnerable areas (a breach/breakthrough is made in a section of the dam, where the water enters), endangering the dwellings and households.

Once established the context of a specific flood problem to be approached, the flood risk must be identified and analysed. This implies hydrological and hydraulic analyses using special software, modelling these flood phenomena.

Thus, the main objective of this study is to assess two analysis methods of flooding scenarios as to determine the flood level of the localities in the Danube Delta, using low-cost equipment and less time-consuming simulation methods, with a view to obtaining the flood maps corresponding to the different flooding scenarios. The perimeter where I conducted this research is located along Chilia arm (from land strip Chilia up to its mouth into the Black Sea), this sector having approximately 111 km. The analysed localities are situated on the right bank of Chilia arm, more precisely, they are found within the agricultural establishment Sireasa.

With a view to achieving the main purpose of the work, the following specific objectives were reached:

- Analysis of the maximum levels and flows in the past 51 years;
- Development of my own methodology for two analysis methods for flooding scenarios;
- Update of the digital model of the land by carrying out land surveys on the protection dam (ordnance survey);

- Update of the minor bed model of Chilia arm by carrying out topo-bathymetric measurements;
- Making the digital model of the complex land by combining the updated digital model of the land with the minor bed model;
- Drafting flooding scenarios for the localities envisaged by this study, using the speciality software programs Hydrologic Engineering Centres - River Analysis System (HEC- RAS) and Global Mapper;
- Assessment of the flooded surfaces, depths and flow speeds of the resulted water following the hydraulic modelling and Geographic Information System (GIS) analyses;
- Drafting flood hazard and risk maps for the localities envisaged by this research;
- Comparative analysis of the results obtained after having applied the analysis methods for flooding scenarios.

The study, according to the option chosen, is structured into 4 chapters, plus introduction and the bibliography at the end of paper. Each chapter is structured such as the data and information contained be as handy as possible.

The Introduction to the thesis presents the motivation to choose this doctoral topic, the main objective, specific objectives and purpose of the research, starting the from fact that floods in the Danube Delta represent the most frequent hydrologic danger and many settlements, especially those distributed along the main arms of the Danube, are affected by this phenomenon which causes important damages, both to the infrastructure and to agriculture and households.

Chapter 1. Risks with regard to floods in the Danube Delta. The current stage of the research characterizes at length the Danube Delta which hosts the in-depth analysed study area, via a general presentation of the Danube Delta. It also presents the risk to flood in the Danube Delta, by describing concepts such as exposure, high waters, floods, risk and vulnerability. At the same time, it describes information referring to the history of floods in the Danube Delta, and the emphases falls on the impact of floods on the study area.

Chapter 2. Research Materials and Methods present in detail the data and instruments used to make the research, the analysis methods on flood risk, hydraulic modelling using the software Hydrologic Engineering Centres - River Analysis System (HEC-RAS) and GIS analysis with the software Global Mapper.

Chapter 3. Results and Discussions, represent the part of the work displaying the research results of this thesis and the preliminary studies on the assessment of various simulation methods to analyse flooding scenarios in the Danube Delta. Thus, the most important research made following the application of the hydraulic modelling dynamic method and GIS static analysis method. Sub-chapter 3.1, Results of the Hydraulic Modelling with HEC-RAS (dynamic method) and GIS analysis (static method) on Chilia arm, represent the most important part of the thesis, integrating all the methods presented on the previous chapter and applied to the established study area.

Chapter 4. General conclusion, my own contributions and potential research directions, is the part of the thesis describing all the conclusions and comments obtained from the analysis of the results. It is also this chapter to present my own original contributions and potential research directions, emphasizing the main aspects with regard to the techniques and methods which can be improved by additional analyses.

Thus, the work represents a collection of several engineering methods and instruments applied to obtain the results laying out the exposed flooded surfaces and risk areas. The research is structured such as to clearly show all the steps taken to analyse flood risk.

Chapter 1. Territorial Risks with regard to Floods in the Danube Delta. The Current Stage of Research

1.1. Characterization of the study area

1.1.1. Generalities

The river Danube crosses from its spring, in the Black Forest Mountains, to be more precise nearby locality Donaueschingen (Germany) and down to the Black Sea, ten countries with a flow length of approximately 2,858 km. As size, the river Danube is the second in Europe, after the Volga and has been building-up, in more than 12,000 years, one of the most beautiful and representative Deltas in Europe [1]. The Danube Delta is the complex result of the interaction between the river Danube and the Black Sea, and currently, it is largely under the influence of this river's activity. As far as the fauna is concerned, the landscape bounty, where the birds come ranking as the most important, the Danube Delta presents an aspect absolutely remarkable from the scientific point of view, being deemed a true laboratory where deltaic, economic and touristic ecosystems are built through its renewable resources. The surface of the Danube Delta is appreciated at approximately 4,178 km2 of which the largest share (3,510 km2) is on Romanian territory, being focused on the three main arms: Chilia, Sfântu Gheorghe and Sulina. In the Reserve there are 24 Territorial Administrative Units (Unități Teritoriale Administrative - UAT), where on the entire surface, we have delimited 20 strictly protected areas, with an occupied surface of 50,904 ha as well as buffer areas with an occupied surface of approximately 223,000 ha [2], [3]. Figure 1.1 presents the maps with the Danube Delta Biosphere Reserve (Rezervația Biosferei Delta Dunării - RBDD) overlapping the ortho-photo-plan.

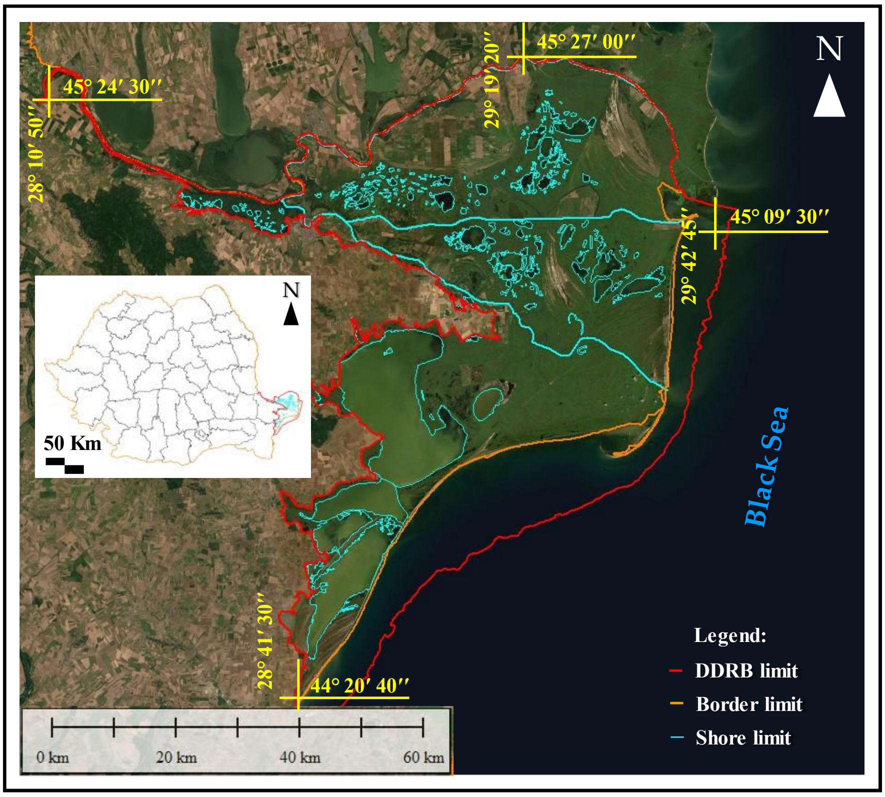

Figure 1.1. The limit of the Danube Delta Biosphere Reserve superimposed over the orthophotoplan [map made personally with the help of GIS data procured in 2020 from the Danube Delta National Institute for Research and Development (DDNI) and from https://cdr.eionet.europa.eu/ro/eu/n2000/envx_mrhg/]

1.1.2. The Main Morpho-hydrographic Units

The hydrographic network is a determinant sub-system from the point of view of the deltaic land operation point of view. The main hydrographic network is made up of the river's arms: Chilia, Tulcea, continued by Sulina and Sfântu Gheorghe. The arms of the Danube carry to the Black Sea approximately the entire debit of water and drifts of the river. The arms are well defined by important depths and widths and they are paired by well-built fluvial sandbanks. The secondary hydrographic network is made up of canals, natural channels, backwaters and brooks. They represent the communication among lakes and also among themselves and the main arms. On Sulina and Sfântu Gheorghe arms, important modifications were made, and namely shortening Sulina arm by 28.15 km and respectively by 39 de km, Sfântu Gheorghe arm [4]. These actions have determined benefits as far as maritime transportation on the arms is concerned. The length of the arms, respectively their width and slope on an average level in presented in Table 1.1.

Table 1.1. *The main branches of the Danube [5]*

Branch	**Length (m)**	**Average width (m)**	**Slope at medium level (%)**
Chilia	111.000	340	0,015
Sfântu Gheorghe	110.000	348	0,017
Sulina	64.000	146	-

The pre-deltaic territories are surfaces incorporated to the surface of the Danube Delta and which belonged to Bugeac Plain, but due to the river erosion phenomena, these surfaces were separated, being located to the North of Chilia arm. These territories are made up of loess-content deposits and are highly differentiated from the bordering sub-units. In the Chilia field area, the altitude decreases gradually from the North to the South, in the same direction, the loess-content deposits being slightly covered by fluvial deposits. Thus, the landscape changes from the image of a true field in the North, to a deltaic one in the South. The surface of the pre-deltaic territories is currently approximated at 8,183 ha (of which 2,755 ha for Stipoc and 5,428 ha Chilia Field). The maximum identified altitude for Stipoc is 3.80 m and 7.10 m for Chilia Field [6].

Fluvial sandbanks were made in the Danube Delta due to the sedimentation processes inherent to flooding. They can be identified along the main arms of the Danube. The height of these fluvial sandbanks increases from upstream downstream. In the period prior to 1989 when there were reed-valorification campaigns in the Delta, canals and platforms were built to store the reed, resulting thus anthropic sandbanks, some of them even higher than the natural ones, them too being considered important references. As surface, fluvial sandbanks cover approximately 50,000 de ha (15% of the surface of the Danube Delta).

Marine sandbanks were the result of a combined action of the see and river phenomena. These sandbanks are distributed perpendicularly on the arms of the Danube. Marine sandbanks are mostly old barrier beaches having the same lithologic composition and similar genetic nature. These sandbanks look mostly like some interconnection of sand bars, in invert distribution from the North to the South and South – East for sandbanks Caraorman, Letea and Jibrieni, and from North – East to South and South – West in the case of sandbanks Chituc and Sărăturile. As surface, the maritime sandbanks cover approximately 35,000 ha (around 11% of the Delta surface) [7].

The depressions in the Danube Delta are characteristic elements. The fact that these depressions exist is due to the overlapping of the water surfaces with compacted surfaces and strips of land, which being compared to the dams located at various heights, make that most of the coverage area of the river influx to be sub-divided into smaller and smaller depression strips, throughout the decrease of the general level of the waters. The depressions in the Danube Delta are actually islands in the true sense of the word. The inland of the depressions is located beneath the height of the peripherical sandbanks and present a depression-like aspect, so that they become floodable when the water levels on the channels or arms increase. The depressions located exactly in the Chilia arm branching areas are mostly small islands. Their clogging is relatively constant, the hydrographic network and lakes either do not appear or are of no importance. Under flood regime, depressions have a unique phase. Thus, because of almost evenly clogging even small surfaces, inland division and sub-depression formation are not noticeable as the level of water decreases [8].

The moorlands are areas in the Danube Delta which are permanently covered or almost permanently, with water. Due to the fact that they are not sufficiently deep, moorlands are invaded by slush vegetation and reed. They are located either on lake shores, or independently in the case of former lakes which have reached an advanced stage of clogging. When these waters are high, several moorlands change into ponds, covering most of the depression perimeters in the actual Danube Delta. The approximate surface of moorlands covers on 3 hydrographs, almost 40% of its territory [9].

1.1.3. Relief

The Danube Delta, like the other deltas, represents a young formation, resulted from the relation between important factors controlling the coastal areas, respectively the variation of the sea level, tides, waves and currents, this one the one side, and the water debit in the inflow sector on the other side. From the morphological point of view, the Danube Delta can be deemed an alluvial plain in the making which is remarkable by a low hypsometry (altitude spread of approximately 16 m), of which a part is below the sea level. From the physical-geographic point of view, the Danube Delta is divided as following: the river delta and the maritime delta, constituting two large natural sub-regions.

A percentage of approximately 65% of the total surface of the Delta is meant for the river Delta, spreading from the end of Chilia arm downstream, to Caraorman sandbank and Letea sandbank. As far as the hypsometric configuration is concerned for the Danube Delta, this represents a support for all components such as: hydrography, soils, vegetation, human habitat, economic activity and others. The average altitudes and surfaces of the subunits are presented in Figure 1.2.

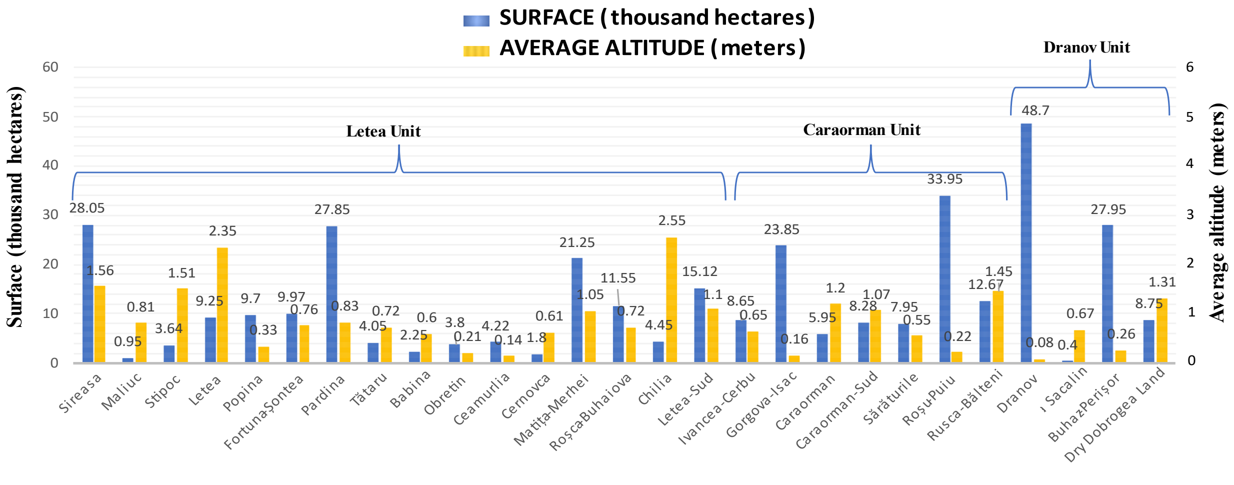

Figure 1.2. Area (thousand hectares) and Average altitude (m) of the Letea, Caraorman and Dranov Units [graph made personally with the help of data obtained in 2006 from DDNI]

Thus, in compliance with Figure 1.2, in the Danube Delta, the average altitude is of +0.52 meters, derived from adding and averaging the values on the hypsometric steps, from a total of 27 subunits. This are generalized at the level of the 3 existing units and finally throughout the entire deltaic territory. The 3 units are called as following: Unit Letea being made of 16 other sub-units, Unit Caraorman with 7 sub-units and Unit Dranov with 4 sub-units.

1.1.4. Climate

The Danube Delta climate is given by the Pontic influences (the opening to the Back Sea), continental influences and influences of the air in advection. Because the black Sea is a continental sea, its influence on the bordering areas is reduced. Instead, this is cumulated with the influence of the water and moorland surfaces in the Danube Delta. The largest influence is recorded on the first 25 km from the shore, a surface where the horizontal temperature and humidity gradients reduce considerably. As far as the air temperature is concerned, in the Danube Delta, the values are moderate. From West to East, the average annual values increase consecutively, together with the decrease of the influence of the inland and amplification of the sea influence. The average annual values range between 110C (Tulcea and Jurilovca) and 11.40C (Gura portiței) [10].

1.1.5. Human settlements

In the Danube Delta there are 28 localities. The population in these localities has encountered fluctuations throughout the period with regard to the evolution of the economic importance of the area. If we speak about the morpho-structural aspect, there are two types of villages and namely: the spread-out village and the collected village. The localities with a spread-out structure can be found both in the Danube Delta as well as in the bordering area. They are characterized as having a low density of dwellings. The localities with a collected structure are generally located on the continental field (Chilia Veche), on the non-floodable marine sandbanks, that is Letea and Constantin Alexandru (CA) Rosetti and Razim coastal plain. In this period, the number of inhabitants in the Danube Delta decreased by more than 3,500 inhabitants. This is given by the decrease of the annual average of 2.5‰ [11].

The numeric evolution of the population decreased in the period 1912 – 2011, even in the periods when the population saw some growth (Table 1.2).

Table 1.2. *The evolution of the population in the Danube Delta [12]*

Years	Rural	Urban	Total
1912	10.459	7.347	17.806
1930	12.135	6.399	18.534
1966	15.713	4.005	19.718
1977	9.046	5.484	14.530
1997	8.475	5.137	13.612
2002	9.694	4.601	14.295
2011	8.012	4.295	12.307

The period between 1948 – 1956 recorded the highest population growth of 12.6‰. This was due to the natural growth rate which recorded 13.4‰. The lowest natural growth rate was registered in the period between 1966 - 1977, due to a decrease in rural population. At the same time, the rural population at that moment reduced by a quarter and namely, more than 4,000 persons. The cause to have led to this demographic decline is the work force migration. A large part of the rural population left the Delta at the time of high floods recorded in 1970 and 1975. In mostly all localities in the Danube Delt, the population decreased considerably in the period between 1966 - 1977: Pardina, -19.3‰, Rosetti, -27.9‰, Ceatalchioi, -43.6‰, Maliuc, -30.0‰ [12]. The average population density in the Danube Delta is rather low, and namely 5.4 loc./km2.

1.2. Flood Risk in the Danube Delta

1.2.1. Concepts

An overview on the threat and effects which a danger can develop is closely connected to understanding and interpreting the following notions: **exposure, high waters, floods, risk and vulnerability.**

Exposure is given by the assets and values on the perimeters prone to floods. Exposure is presented as an additional component of the risk to destruction. It refers to what is affected by natural hazards, such as territories, properties, people and so on. In another train of thoughts, exposure is given by the material goods, by the presence of people or other elements which could be affected in the perimeters where floods occur [13].

Flash floods are natural phenomena represented by a sudden surge of the debit of a running water and which belong to the area of normal events of flow determining peak maximum moments in the evolution of river or stream flow. After the maximum threshold is reached, a sudden decrease of waters follows, but the rhythm is much slower in relation to the increase, and finally returning to the normal flow parameters [14]. High waters are among the most damaging types of meteorological disasters which mankind is facing these days. They can be caused either by extreme rainfall, man-made structure failure, such as dams, or by the complex interactions snow – water. The quick evolution of high waters imposes additional challenges for the early forecast in comparison with river floods. The structural measures adopted to reduce the impact of these events include the construction of physical components meant to improve the general resistance of draining systems, such as dams and retention ponds. The non-structural solutions include the adoption of regulations in using / occupying the land, personal training for receptive actions and implementation of operational quick warning systems against floods [15].

Floods in certain cases represent the effect which high waters have. Floods are natural phenomena to which our society is most frequently exposed, being deemed phenomena causing human lives losses, economic and environmental losses in the global context. Flood is the phenomenon of covering the entire land with a layer of water (coming from outflow of waters, rains) which can be stagnant or in motion. By its size and duration, it causes human victims and material damages, endangering the good run of the social-economic activities in the affected area. According to the European Environment Agency (EEA), floods are responsible for one third of the economic losses. Lately, floods represent the most frequent event together with storms. Floods are from the category of natural hazards that can occur at any scale, being presented in the specialty literature under this designation. Hazard represents the event that occurs together with a probability of occurrence in a certain area and on a certain date, of a destructive phenomenon [16].

Risk can be defined as the probability that the exposure of man and their properties to the force generated by a specific size hazard. Risk represents the probable threshold of human life loss, number of injured people, damages caused to properties and damages to the economic activities by a certain natural phenomenon or by a sum of phenomena within a period of time. We could say that the risk elements are given by the population, economic activities, communication ways, properties etc., exposed to risk in a certain areal. Risk can also be represented as a mathematical product between vulnerability and hazard, being displayed as a relation between a phenomenon and its consequences [17].

Vulnerability is a problem frequently concerning the scientific world in the risk management, bring new contributions both in definitions and in the mode of determination.

Generally, along the time, the term vulnerability refers to the incapacity to face the effect of an environment which not favourable, used though by the scientific media, it gains a unique sense, being explained in the content of the respective research. In another train of thoughts, the definition and method to assess vulnerability are given by each research individually, and in the end, they must be transparent in the specific context. Many definitions and methods assessing vulnerability represent evidence of diversity of opinions and of the meanings conveyed to this term. If we refer to the engineering approaches, we practically talk of physical vulnerability, as being the level of loss for a certain component or sets of components, located in the perimeter affected by a danger [18].

1.3. The History of Flooding in the Danube Delta

1.3.1. The Danube Delta Flooding

An important aspect in this research is knowing the aspects of the flooding process. Studying this process is a must, given the close connection between flooding the interior of the Delta and diminishing the future hydrotechnical constructions, marking the agricultural-forestry, reed-growing and fishy surfaces, setting up the various constructions, selecting the inhabitable surfaces etc. The Danube Delta is physical-geographical unit, the relief of which is only apparently shown as lacking diversity. Thus, although the relief energy embodied by altitude difference of only a few meters, these, together with numerous interior sandbanks located at various heights, make the Delta flooding occur as an especially complex physical process. This complexity is manifest both in time and space [19].

1.3.2. Hydrotechnical Works for Damming the Enclosures in the Danube Delta

The first operations of damming-in and regulation of the river were carried out in the course of the 18th century, as a consequence of the “Imperial Direction for Navigation”. This direction was issued by Empress Maria Tereza in 1773. In this sense, the first embankments were carried out on the current surface of Hungary and Austria, to avoid flooding. Starting with the second part of the 19th century, after having been established the European Commission for the Danube, in 1856, on Sulina arm, the works to regulate the flow with view to improving the navigation ways started. In 1868 – 1902, the twists and turns of Sulina arm were cut by 9 canals. After these hydrotechnical works, the water debit on Sulina arm increased to a precursory value of 7 – 9 % of the river total water debit, up to 16 – 17 % in 1921, and subsequently to 18 – 20 % [20].

A part of the agricultural settings of the Danube Delta were carried out before the World War II by ait Tătaru, in 1939. Subsequently, building the agricultural settings was carried out after the 1960s, by interventions to drain and dam-in certain large surfaces of water and land, coming up to approximately 53,000 ha in 1990. Due to this area’s conditions, precarious to agriculture, only 30,000 ha are still in use nowadays. Of the most important agricultural settings, and by their size, we mention the following: Pardina with a surface of 27,000 ha, Sireasa with a surface of 7,550 ha, Ostrovul Tătaru with a surface of 2,600 ha, Murighiol-Dunăvăț with a surface of 2,540 ha, Tulcea – Nufăru with a surface of 2,350 ha, etc. It should be emphasized that on the perimeter of these settings released from under the consequence of floods, there are important unharvested areas, which were though not connected to the natural deltaic regime [21]. The agricultural settings as well as the others (fishy and forestry) are part of operational eco-systems, more or less, adequate to the purpose for which they were designed. In this sense, the draining actions lead to the dismissal of the former natural eco-systems and to establishing anthropic eco-systems [22].

The discharge of these surfaces from the natural regime did and does not affect too much the deltaic ecologic balance, and at the same time, and at the same time them being beneficial from the agricultural point of view. Transformations at a much higher level occurred in depression Pardina and depression Sireasa. Sireasa agricultural setting has a surface of 7,550 ha, being the second largest agricultural unit in the Danube Delta, based on the same concept of arrangements as Pardina agricultural setting. Damming-in the territories in the Danube Delta represented changes throughout time, with regard to the modality in which flooding phenomena act in the case when the protection dams built give in [23].

1.3.3. The Effect of Damming and Floods in the Danube Delta

In large and small hydrographic basins, hydrological events may generate especially important changes both upon the hydro-geo-morphological systems, from the physical point of view as well as on the socio-economic and ecological systems, such as material goods, imbalances of the surrounding environment and even loss of human lives. In our country, floods are hydrological event that can occur at various scales and ever more often [24]. In the Danube Delta, due to its geographic position as well as to the unique natural specificity, frequent hydrological hazards (floods, high temperatures, significant rainfall at times accompanied by hale, strong storms et) are favoured to occur. The floods in the Danube Delta, as a complex hydrologic system are significant in the evolution dynamics of the elements making for the natural system. In close connection with the river flowing process, the flood level in the Danube Delta supports both the alluvial processes, as well as the water supply of the aquatic facilities inside the Delta [25].

Due to the damming in the Delta, the Danube debits have not suffered significant changes, similar to the proportions taken over from the canals network. Thus, we can see a more accelerated flow through the deltaic territory, with a visible intensification of the alluvial phenomena. In the main units of the Danube Delta, the flooding phenomenon is distinct [26]. At Letea unit (with the space between the arms Chilia and Sulina) of the 152,000 ha, as much as it is the total coverage of this unit, approximately 44.10%, that is 67,000 ha, are dammed, meaning discharged from the flooding impact. At Caraorman unit (with the space between the arms Sulina and Sf. Gheorghe), of the coverage of 97,000 ha, approximately 12,500 ha (representing 12.90%) are dammed, and thus uninfluenced by floods. Dranov unit covers the entire depression of Dranovului plus a territory located between the Dobrudja land and Sf. Gheorghe arm (this perimeter encompasses more than 82,000 ha, of which currently, 24,250 ha (approximately 29.5%) are dammed-in and protected against floods [27].

In the Danube Delta, there is the danger of the dammed-in premises would give-in in the perimeters where in the course of time, protection dams sagging phenomena occurred, or if not, the exceptional danger of unleashing the infiltrations, suffusion and griffin due to the very intense period of high waters. At the same time, there is the continuous risk of erosions accompanied at times by landslides which endanger the houses and material goods. In this sense, the purpose was the valorification from the economic point of view (interests in the agricultural valorification of the area) [28].

At the time of designing the premises, no consideration was paid to the importance of the landscape and land, climate changes, hydro-morphologic modifications, wear and tear of the protection dams and high probability that these dams would give-in in the case of powerful high waters, hydrologic balance etc. In the Danube Delta, the localities distributed on the main arms are the most affected by floods, when the Danube’s levels exceed the normal values. Extreme phenomena such as high waters represent a major danger to the rural and urban settlements in the Danube Delta [29].

1.3.4. Impact of Floods in the Research Area

A major flooding event in the Danube Delta was identified in the summer of 2010 and examined in this research. The debit resulted as a consequence of the river flooding was of 16,060 m3/s, by comparison to the average debit of 6,658 m3/s (between 1965 – 2015, recorded at Ceatal Chilia). The maximum flooding level was recorded on July 6th, 2010 reaching the maximum level of 4.95 meters, measured in the reference system Black Sea Sulina (BSS), opposite the average level of 2.50 m. The agricultural setting Sireasa in the Danube Delta was strongly affected by this flood which produced significant losses on the localities inside the setting, as well as on the agricultural lands in the area. Sireasa agricultural setting is located to the North-West of the Danube Delta, in Tulcea County, on the border with Ukraine (Figure 1.3).

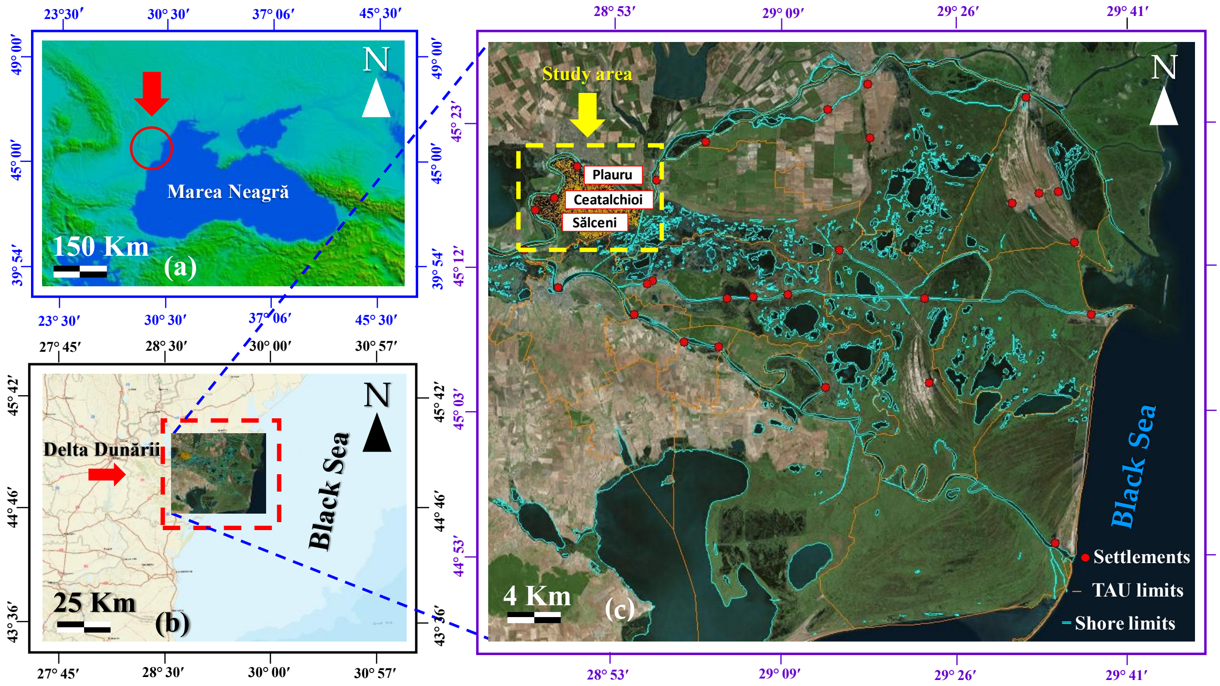

Figure 1.3. Geographical location of the localities in the Sireasa Danube Delta agricultural arrangement considered in this study, (a) the study area superimposed over the digital terrain model, (b) the study area superimposed over the topographic map, (c) the geographical position of the localities superimposed over orthophotoplan of the Danube Delta [map made personally with the help of GIS data procured in 2020 from DDNI and from https://geoportal.ancpi.ro/portal/home/]

Figure 1.3 presents the geographical setting of the localities in Sireasa agricultural setting in the Danube Delta taken into consideration in this research, the localities distributed both on the main arms as well as inside the delta, the UAT limits and banks' limits overlapping the ortho-photo-plan. Sireasa agricultural setting hosts within three localities (Ceatalchioi, Plauru and Sălceni) on the right bank of Chilia arm (Figure 1.4). Following the flooding events caused by the high levels of the Danube in the summer of 2010, the localities in Sireasa agricultural setting suffered, recording at that time significant losses for the households and infrastructure. According to several synthesis reports, an impressing number of houses and households were flooded, and the as far as the infrastructure is concerned, affected were the roads between the localities, communal roads and the county road. One of the causes of the flood was the Sireasa agricultural setting protection dam giving in under the pressure of high water in July 2010. The setting of the protection dam is presented in Figure 1.4.

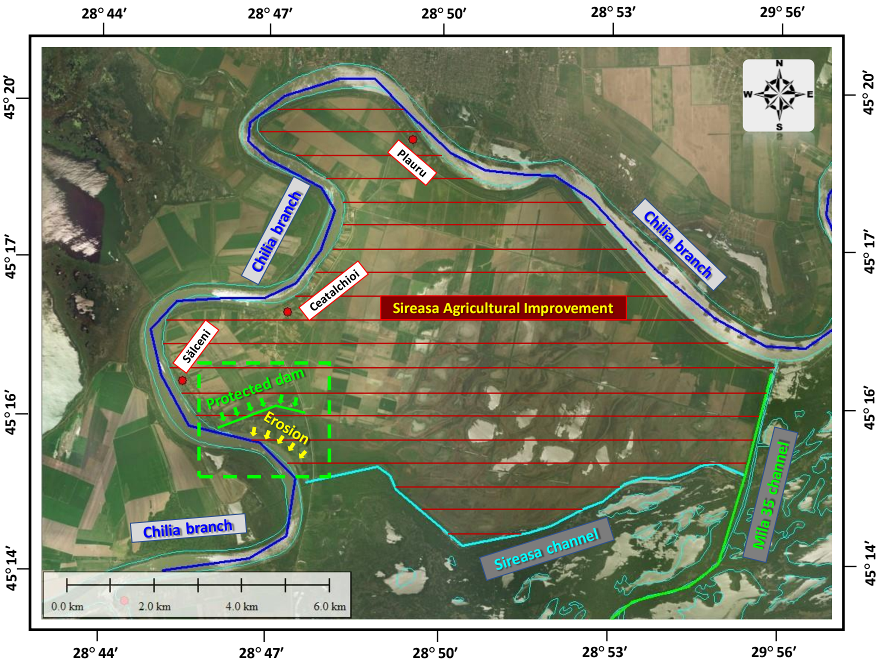

Figure 1.4. Geographical location of the localities, of the protection dam and of the erosion zone from the agricultural arrangement Sireasa Danube Delta [map made personally with the help of GIS data procured in 2020 from DDNI]

Figure 1.4 presents the geographical setting of the localities analysed in this research, the protection dam and erosion area at Sireasa agricultural setting overlapping the ortho-photo-plan. The giving-in was determined also by the repeated exposure of the protection dam to the high levels of the Danube during the spring – summer periods along the years. The exposure of the protection dam of Sireasa agricultural setting was due to the gradual disappearance of the right bank (the ground dam surrounding Sireasa agricultural setting on Chilia arm, by repeated intensification of the erosion phenomena (Figure 1.5).

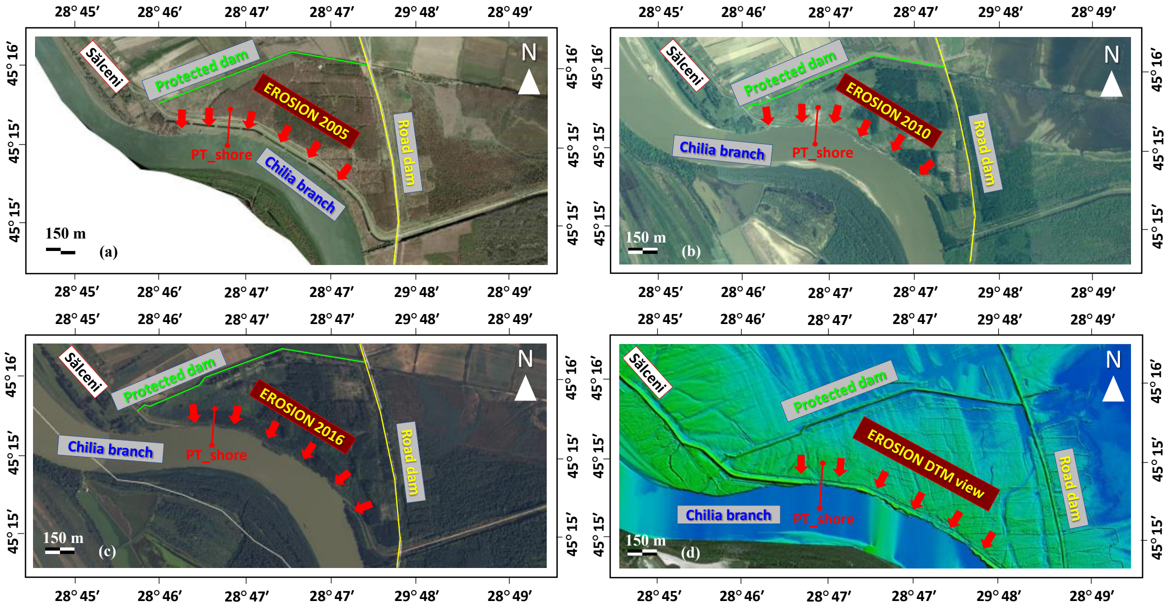

Figure 1.5. Location of the protection dam and the erosion area of the Sireasa Delta Danube agricultural arrangement, (a) orthophotoplan view 2005, (b) orthophotomap view 2010, (c) orthophotomap view 2016, (d) digital terrain model view 2011

Figure 1.5 presents the setting of the protection dam and of the erosion area at Sireasa agricultural setting. The setting is overlapping the ortho-photo-plana of different years and the Digital Model of the Land (MDT). Due to the erosion phenomena in the course of time, an important portion of the right bank of Chilia arm was washed away by the waters, favouring thus the propagation of waters inside, exceeding the bank towards the protection dam of Sireasa agricultural setting. Vertical erosion produced the river flow in general. In the case when the right bank of Chilia arm, the problem of washing it away is given by the side erosion of the Danube, being a characteristic of the middle course of the river, determined both by the enlargement of the valley as well as by the deviation of the water course. Thus, Figure 1.6 presents four cross profiles (PT_mal) drafted in four different years (2005, 2010, 2016 and 2019) distributed in the erosion area in line with Sireasa agricultural setting. The profile distribution (PT_mal) for the years 2005, 2010 and 2016 is presented in Figure 1.5.

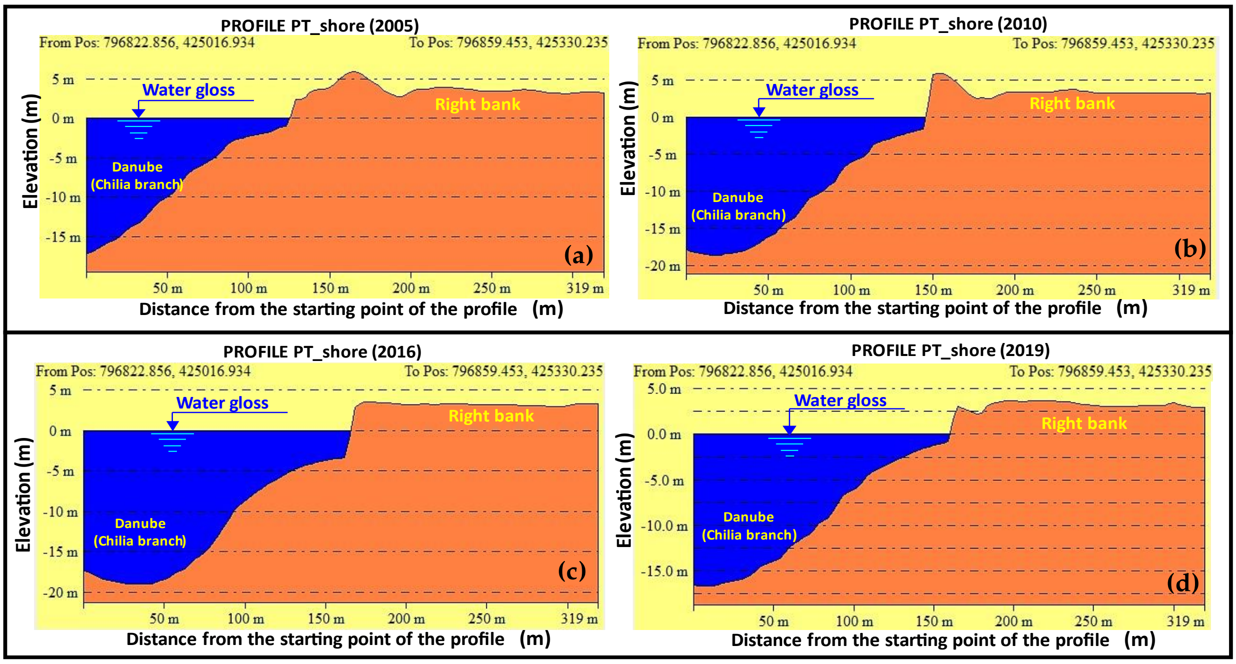

Figure 1.6. Transverse profiles in the erosion zone (right bank of the Chilia brnach) next to the Sireasa agricultural arrangement, (a) Cross profile view PT_Shore (2005), (b) Cross profile view PT_Shore (2010), (c) Cross profile view PT_Shore (2016), (d) Cross-sectional profile view PT_Shore (2019)

Analysing Figure 1.6 we can say that the erosion phenomena have changed the configuration of the bank and currently, the situation in 2010 can repeat in the case of occurrence of strong high waters on the Danube. Giving-in of the protection dam of Sireasa agricultural setting meant the gradual building up of a breach / breakage inside the dam of the agricultural setting which favoured the possibility of quickly passing through of an important volume of water inside the agricultural setting, progressively flooding the localities Sălceni, Ceatalchioi, Plauru and an important arable surface. Subsequently, after the waters withdrew from the agricultural setting, as a consequence of the Danube level decrease, the protection dam was fully repaired. This research analysis the scenario when the protection dam of Sireasa protection dam gives in again on new strong high waters on the Danube, and the localities are again gradually flooded. This hypothesis is supported by the fact that currently, the protection dam (with the intervention suffered after the great flood of 2010 and specifically its repairs) is degraded due to wear, representing thus a risk that it would give in again on new strong high waters. The wear of the protection dam is given by the important presence of sagging phenomena in the foundations of the dam and partial disappearance of the bank.

Chapter 2. Materials and Research Methods

When drafting this research regarding the analysis of the risk to flooding in the research area, a multitude of research methods and a complete series of data (hydrologic, topo-geographic and hydraulic) were used. Thus, several studies were drafted, necessary to update the digital model of the land and for the update of the minor bed model of Chilia arm. Following the updates made, MDT Complex was obtained. Processing the collected data was done by means of the GIS speciality software. The equipment and materials used for the land researches were furnished by the Danube Delta National Institute for Research and Development (Institutul Național de Cercetare – Dezvoltare Delta Dunării - INCDDD).

This research contains the analysis of two flooding scenarios for the localities in Sireasa agricultural setting. These flooding scenarios occur in the context when a breach / breakage grows in the protection dam of the localities, under the Danube's maximum level conditions. The difference between these scenarios is represented by the time when the breach in the protection dam remains open. Thus, the first scenario of flooding analysis was applied to the localities by modelling a real occurrence scenario of a breach of 20 meters in the protection dam, which remains present for 24 hours at the Danube maximum levels.

The second flooding analysis scenario was applied to the localities, by means of a GIS analysis (this analysis is static from the hydraulic point of view), which consisted in overlapping the information corresponding to the maximum level of the water over MDT. This thing corresponds to the most unfavourable scenarios and precisely the breach inn the protection dam for a longer period of time (more than 24 hours), at the same time with the maximum levels of the Danube's water. Thus, for the analysis of the protection dam breaking scenario, two methods were used: the dynamic method for the first scenario and static method for the second scenario. The steps taken in analysing the scenarios are summarized in a process diagram, presented in Figure 2.1.

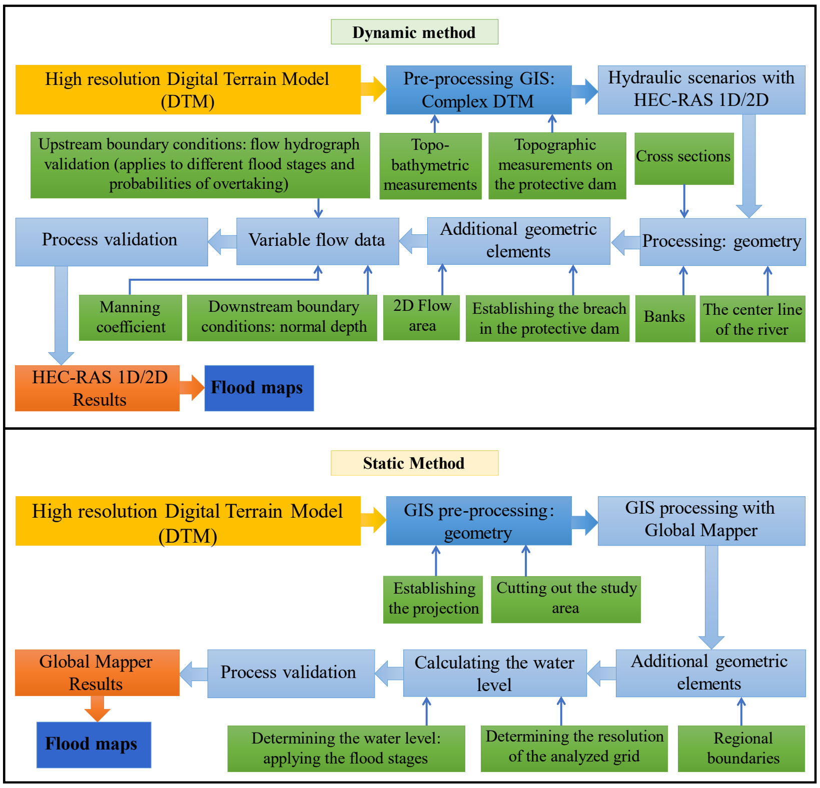

Figure 2.1. Diagram showing the methodology and main steps considered in this study

In compliance with Figure 2.1, the diagram implies a dynamic, continuous and interactive process. These stages do not make up a linear process, but move successively from one stage to another and vary largely from the results of each step. The diagram shows clearly that the entry data are very important in analyzing the flooding scenarios. The data collection process starts with an assessment at region level, an exploratory stage or even an investigation, which offers entry information for the diagram proposed. At the time of collecting the information, first raw data is procured (in this case we have topo-bathymetric data, hydrologic data, water debits and levels, cross profiles, topographic maps, MDT, satellite images, ortho-photo-plans, etc.), representing primary information which needs initial processing to be subsequently used. The information is collected from external sources, such as scientific studies, information regarding the administrative flow, images / photographs at various resolutions, maps at different scales or internal sources collected during the research, using a specific and corresponding method. This processing stage of the data collected assumes a tight approach and can be used to characterize in detail the elements analysed and finally to determine the effects of the floods.

After having collected and validated all the necessary information in the diagram presented, subsequent to the data processing followed the hydraulic modelling stage (the dynamic methos) and GIS analysis (the static method). The hydraulic modelling and GIS analysis use the information collected in the field or obtained from the specific stations, such as the hydrometric stations (collects data regarding the water debits and levels). As shown in Figure 2.1, the methodology proposed combines two analysis methods. In approaching each method, entry data are necessary, such as MDT, hydrologic data, topo-bathymetric data and topo-geographic data for the Danube Delta area.

Chapter 3. Results and Discussions

3.1. Results of the hydraulic methods with HEC-RAS (the dynamic method) and GIS analysis (the static method) on Chilia arm

The calibration of the hydraulic model was carried out first upstream of the research area, more precisely in the entry sector of the Danube into the Delta (Ceatal Chilia), and then downstream, at the inflow mouth of Chilia into the Balck Sea. The model calibration in the HEC-RAS software was carried out by alternative values of the Manning coefficients of rugosity, between 0.025 and 0.03 and by applying the discharge curves data from Tulcea Port hydrometric station. In the following step (unsteady flow from HEC-RAS model), to define the limit conditions, a hydrologic data analysis of the Danube was carried out, and this required the description of the water debit history for a period of time.

The water level for the measured sections upstream and downstream was calculated using the cinematic positioning in real time - Real Time Kinematic (RTK). To determine the level of the water surface for each cross section of the bed where the bathymetric measurements were made, three methods were used. The first method consisted in measurements with Global Positioning System (GPS) Global Navigation Satellite System (GNSS) SPECTRA PRECISION SP80, the second method consisted in measurements with the optic level LEICA NA 524, and the third method consisted in reading the values recorded on the hydrometric level gage (Patlageanca, Pardina, Chilia Veche and Periprava). For the data geo-referencing (space / global referencing) we used the geographic positioning data of each point in the profile of the bed and data regarding the depth of each point, that is the absolute level of the bed, with the Black Sea Reference system 75 (BS75). The data X, Y, Z were thus geo-referential data obtained for each point measured by Acoustic Doppler Current Profiler (ADCP) in the topo-bathymetric sections on the Danube arm. After the GIS processing of the topographic and bathymetric data, a new digital model of the minor bed and an updated m=digital model of the land were obtained.

Pairing the two models led to a complex digital model with updated data on the minor bed and protection dam. The next step in analysing the risk to flooding is the analysis of the flooding scenarios using the dynamic method. For the dynamic method, the specialized HEC-RAS 5.0.3 software was used. At the first step, MDT Complex was introduced to the program to define and process the geometric data. The geometric data used for the hydrodynamic simulation were obtained using the high-precision digital model with a space resolution of 0.5 m × 0.5 m. the following geometric elements are made up of the central line of the arm, bank lines, flow line above the ridges of the banks and 730 cross sectional lines, perpendicular to the arm flowing direction. Each cross profile contained the arm bed levels up to the banks, with variable lengths, starting from 800 m to 1.800 m. these geometric characteristics were used further on at the HEC-RAS hydraulic modelling step. An important step in the hydraulic modelling is assigning the rugosity values. The values of the Manning rugosity coefficients were established taking into consideration the nature of the bed, relief and vegetation elements surrounding the arm. The attributes of the floodable area were furnished by the high- resolution MDT topography. Thus, by the one/two-dimension (1D/2D) HEC-RAS hydraulic model, the 2D flow area was generated in the research are and upstream, by designing the grounds along the length of the arm, encompassing the analysed localities by defining limits. By defining these limits, the software succeeded to calculate the wave spread when flooding. After having met the limit conditions (upstream: debit hydrography and downstream: normal depth), the process was validated. The entry value for the normal depth was validated at 0.05. designing the grounds was carried out taking into consideration the scenario when the protection dam of Sireasa agricultural setting has a breach with an opening of 20 m which is maintained for a period of one day. Figure 3.1 presents the location of the breach in the protection dam of Sireasa agricultural setting. No reliable history information was available on the position of the breaches in the protection dam.

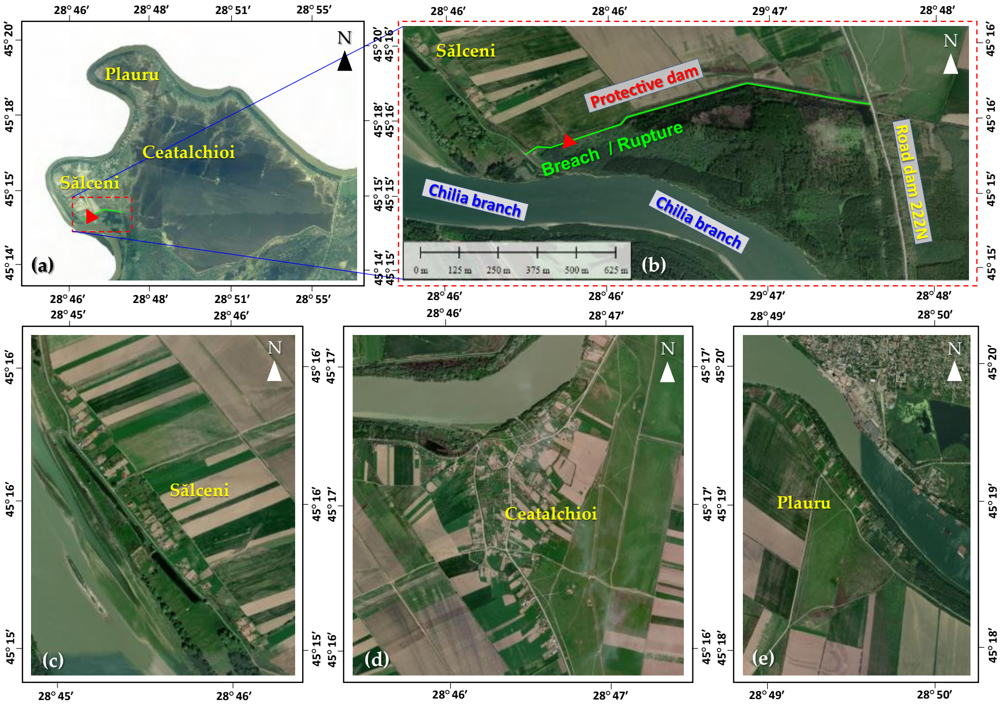

Figure 3.1. (a), (b) Scenario of rupture in the protection dam of the Sireasa agricultural arrangement represented on the orthophotoplan, (c) View of the locality of Sălceni on the orthophotoplan, (d) View of the locality of Ceatalchioi on the orthophotoplan, (e) View of Plauru locality on orthophotoplan [map made on the basis of topographic measurements performed personally in the field and on the basis of GIS data procured from DDNI]

From this perspective, the location assumed to input the breach was established having in view the most vulnerable area on the protection dam. In the hydraulic modelling, besides the maximum debit hydrograph, we applied several debit hydrographs corresponding to the flooding steps and transgression probability (10%, 1% and 0.1%). In the end, 21 flooding scenarios were obtained with the dynamic method (12 scenarios obtained after applying the flooding steps and 9 scenarios obtained after applying the transgression probabilities). The flooding steps applied to the localities are presented in Table 3.1, and the maximum debits for the transgression probabilities are presented in Table 3.2.

Table 3.1. *Flood stages applied to the analyzed localities în the sistem BS75 și BSS.*

Water level – Chilia branch					
Settlements	**Reference system**	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**
Sălceni	(m) BS75	3,52	3,92	4,32	4,72
	(m) BSS	3,74	4,14	4,54	4,94
Ceatalchioi	(m) BS75	3,34	3,74	4,14	4,54
	(m) BSS	3,56	3,96	4,36	4,76
Plauru	(m) BS75	2,98	3,38	3,78	4,18
	(m) BSS	3,20	3,60	4,00	4,40

For each locality, four flooding steps were applied with intervals of 40 de cm. The flooding steps were presented in the Black Sea Sulina system and Black Sea 75. They were calculated from the lowest to the highest level of flooding for each analysed locality. Thus, different localities flooding scenarios can be viewed for different water levels.

Table 3.2. *Scenarios for maximum water flows with probabilities of overtaking 10%, 1% și 0,1%*

Location	Probability of overtaking 10% (Q10)	Probability of overtaking 1% (Q100)	Probability of overtaking 0,1% (Q1000)
Ceatal Chilia	13.989 m^3/s	17.213 m^3/s	20.213 m^3/s

After running the transgression probability scenarios, flood hazard maps were obtained for the analysed localities, and then flood risk maps. The flood hazard maps cover the localities and adjacent areas which could be flooded in case of occurrence of a breach in the protection dam. Thus, low probability occurrence floods were analysed (0.1%) – flooding scenarios which occur once in 1000 years, above-average probability of occurrence floods (1%) – flooding scenarios occurring once in 100 years and high probability occurrence floods (10%) – flooding scenarios occurring once in 10 years. The flood hazard and risk maps obtained by applying flooding steps contain specific elements such as the water depth or level, size of the flood or flood flowing speed depending on the debit. To obtain flood scenarios, we made an analysis of the important historic data and events which occurred in the research area.

The maximum debits presented in Table 3.2 were made available by INCDDD. These data were the bases of obtaining the flooding scenarios. In HEC-RAS, the hydraulic calculations were made on July 6th, 2010 at 09:00, for 24 hours (the time frame when the flooding breach is maintained in the protection dam for the dynamic method). Thus, the scenarios were run by the execution of the debit simulator, delivery pre-processor and post-processor geometry, finally obtaining the results with the first method (dynamic). The hydraulic modelling process implies inserting and using a large number of data, both geographic and hydraulic. After having concluded the data input process and the model was validated (here included is also solving the errors on data and information input), the software was run and finally the hydraulic modelling results were obtained. For the static method less data was necessary by comparison to the precedent method. For the static method, the interest areas in the MDT were individually cut out, taking into consideration a sufficiently large perimeter to make the simulation.

The GIS specialty software was used to adapt these materials to the requirements of the hydraulic modelling program and to the dimension of the research area. Being a large research area, the size of the files used was considerable, which made data processing difficult in a subsequent stage and inputting the geographic data in the specialized program. The projection used was Solar Terrestrial Relations Observatory (STEREO) 70, with system BS75 for the levels. In the case of hydraulic modelling, the surface taken into consideration was spread throughout the entire length of Chilia arm, and in the case of the GIS analysis, the area was limited to the UAT of the localities on Chilia arm.

After running both specialty programs, there finally resulted 33 flooding scenarios (21 scenarios for the dynamic method and 12 scenarios for the static method), and the most relevant results were extracted for the three localities in the Danube Delta envisaged in this research. The results are maps which identify the potentially floodable areas of the localities analysed at Sireasa (Sălceni, Ceatalchioi and Plauru) agricultural setting. The flood limit represents the water spread for each case (scenario) taken into consideration and the water depth or level, depending on the method. The flood maps resulted from applying the dynamic method had a depth class ranging from 0,1 to 2 m. The flood maps resulted from the static method have depth set as a difference between the water level deemed to be that of the flooded surface and ground level (land height on MDT expressed in the system BS75). Approaching the dynamic method, the set of hydraulic scenarios was developed using the hydraulic model of Chilia arm to determine the flood surfaces for each locality. Both methods considered the maximum historic level reached in the summer of 2010 and maximum debits corresponding to the transgression periods.

The results of applying the maximum level were reflected in flood step 4. Subsequently, in order to obtain the flood scenarios at water levels lower than those in 2010, flooding steps were applied (Table 3.1) (the differences being at tens of cm or meters to the peak), such as to result several flood maps for each analysed locality, such as they are presented in Figures 3.2 and 3.4. All these in the case when the protection dam of Sireasa agricultural setting gives in. the scenarios in flood step 1 corresponded to the lowest flood level, while the flood scenarios in step 4 corresponded to the maximum flood level, and the flood scenarios of steps 2 and 3 corresponded to intermediary flood levels, between the maximum and the lowest level. By means of the hydraulic modelling software, initially, the flood limits can be extracted (as maps), and the scenarios can be viewed as video). Then, these results were used for additional processing or interpretation in GIS and other specialized programs.

The results were presented in the Ras Mapper module, using the hydraulic model 1D / 2D HEC-RAS at high resolution (MDT 0.5 m × 0.5 m). Figure 3.2 presents the propagation of the flood surface depth over the flooded area, 24 hours after the beginning of the simulation. The levels used in data processing with the dynamic method feature a system of BS75. The results obtained by applying the dynamic method identified the close flood areas and water depths in the localities, in the case of maintaining the breach onto the protection dam a 24-hour period. In Figure 3.2 we can see the fact that the water flows in the localities from one area to another, following the slope of the natural topography.

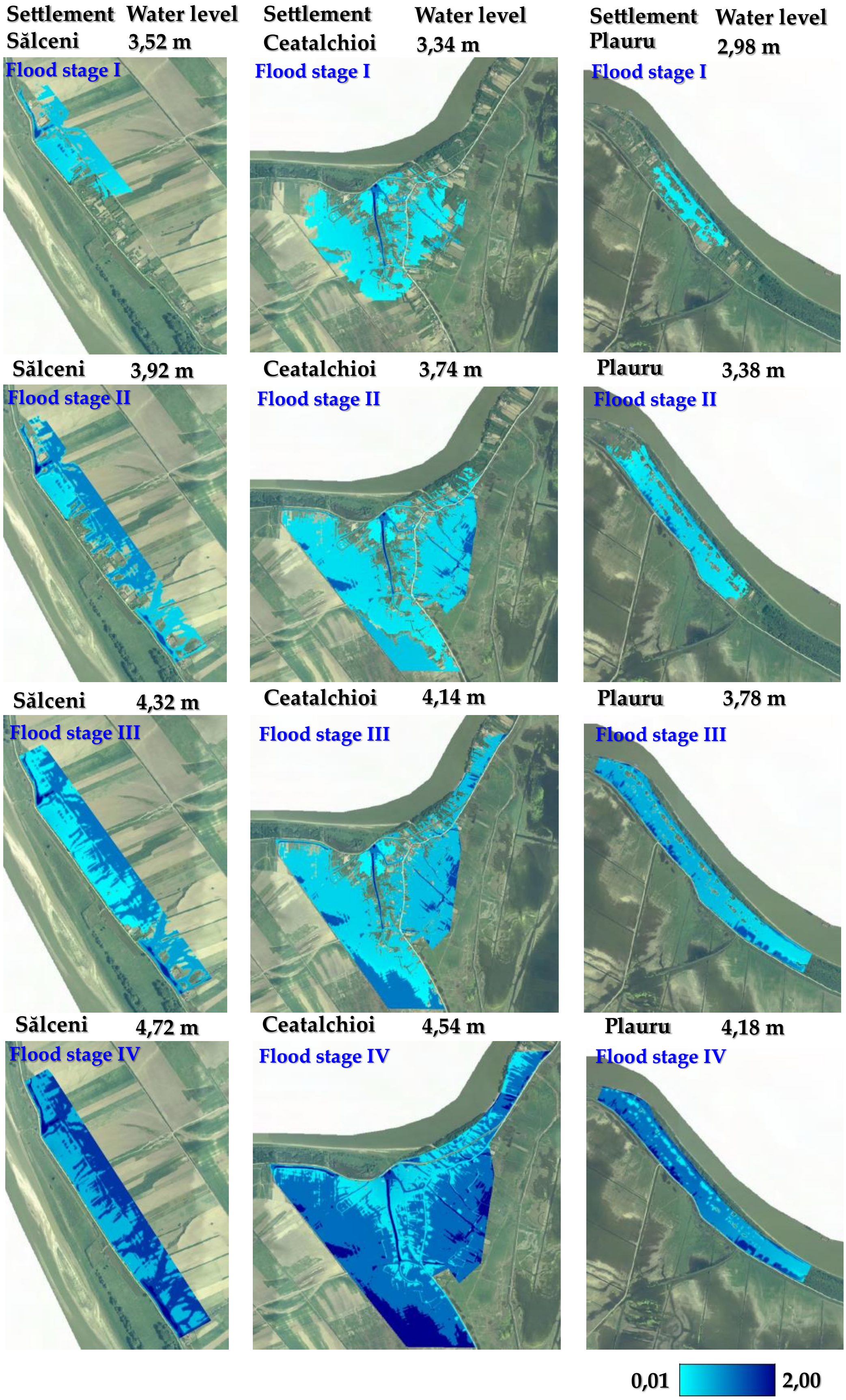

Figure 3.2. Flood scenarios for the localities of Sălceni (first column of subfigures), Ceatalchioi (second group of columns of subfigures) and Plauru (third group of columns of subfigures), corresponding to the condition of July 7, 2010, using Model 1D / 2D HEC-RAS , at MDT Complex, dynamic method

According to Figure 3.2, a12 flooding scenarios resulted for the studies localities, using four flooding steps (from 3.52 – 4.72 m for Sălceni, from 3.34 – 4.54 m for Ceatalchioi and from 2.98 – 4.18m for Plauru). Figure 3.3 presents flooding scenarios of the localities for maximum debits with the probability of transgression (10%, 1% și 0,1%).

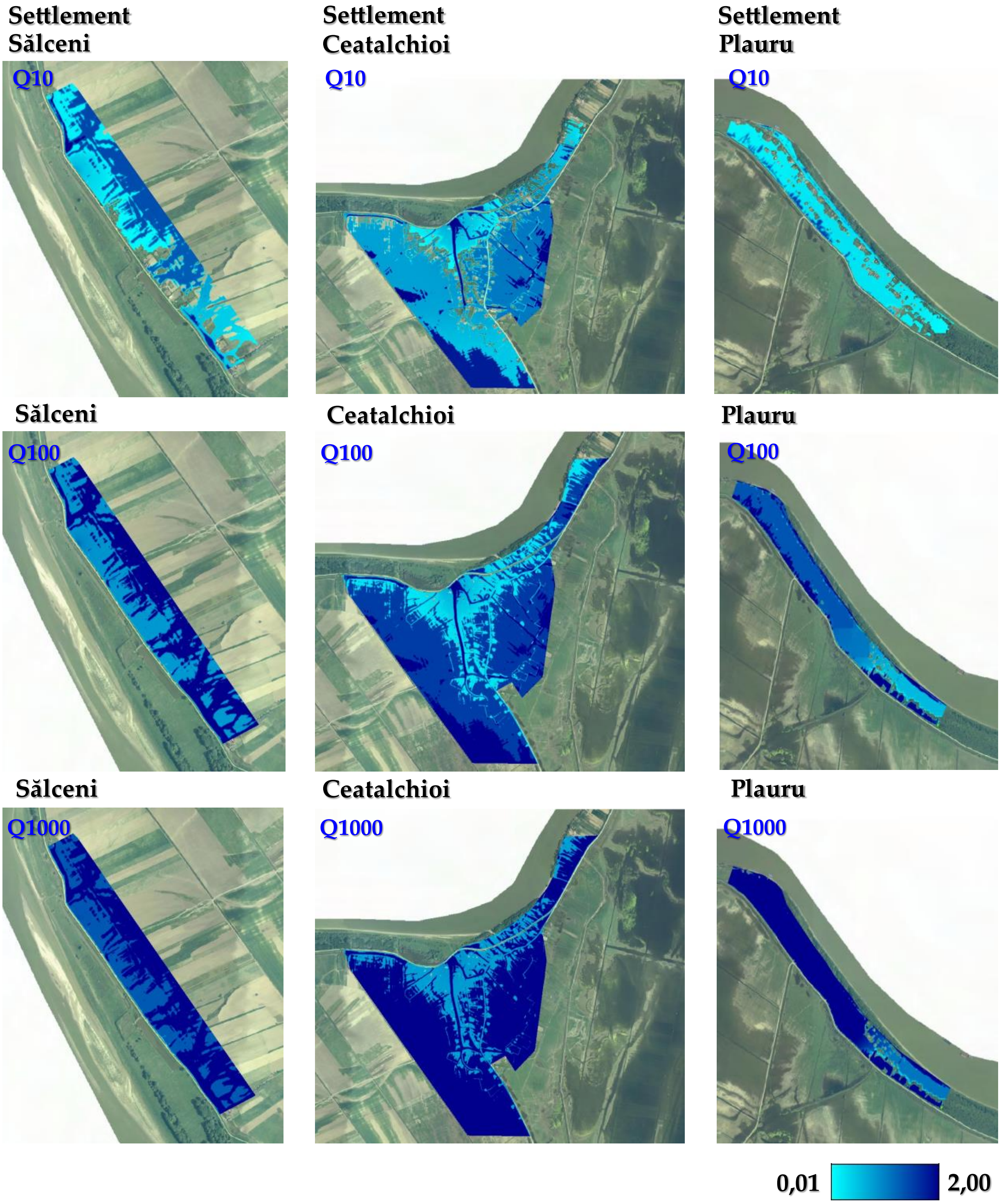

Figure 3.3. Flood scenarios for maximum flows with probabilites of exceeding 10% (Q10 = 13.989 m^3/s), 1% (Q100 = 17.213 m^3/s), and 0.1% (Q1000 = 20.213 m^3/s) corresponding to Sălceni localities (first subfigures column), Ceatalchioi (second group of subfigures columns) and Plauru (third group of subfigures columns), using Model 1D / 2D HEC-RAS, at MDT Complex, dynamic method

The results in Figure 3.3 present 9 flooding scenarios for the studied localities, using maximum debits with probability of occurrence. The dynamic method is much more complex by comparison to the static method, since it requires a much larger range of data and specific knowledge from the operator. If the main preoccupation is that of anticipating the current or future behaviour, obtaining the relevant data in the field is an important and integral part of the modelling process. The good results depend on the exact formulation of the problem and correct identification of the main parameters influencing the investigated phenomena. Analysing the most unfavourable scenario (flooding step 4 – maximum water level), several flooding surfaces resulted inside the localities (Table 3.3).

For the dynamic method, the flooding surfaces corresponding to the flood maps (Figure 3.2) were determined using the Aeronautical reconnaissance coverage Geographic Information System (ArcGIS) software. Using the RAS Mapper – Animator module in HEC-RAS, the maximum flooded surfaces in flooding step 4 were determined, and namely 3.02 km2 (for all localities), the simulated period being set between 09:00 a.m. on July 6th, 2010 and 09:00 a.m. on July 7th, 2010. The flood depth reached up to 1.74 m (flooding at flood step 4 at Sălceni), 1.52 m (flooding at flood step 4 at Ceatalchioi) and 1.68 m (flooding at flood step 4 at Plauru). Applying the 4 flooding steps, the flooded areas varied between 0.11 km2 – 0.42 km2 (Sălceni), 0.51 km2 – 2.01 km2 (Ceatalchioi) and 0.11 km2 – 0.59 km2 (Plauru).

Of the simulation results carried out by the dynamic method, we came up to the fact that the flooding extension covers the households, infrastructure elements and free land in different proportions from one flooding step to another. The large-scale use and hydraulic model role changed in the past years, mainly due to the significant progresses in computer modelling. These remain an important modelling instrument, especially in hydraulic designing of river structures and coastal engineering applications, as well as for the environment protection or physical entry data for mathematical modelling. Figure 3.4 presents the results of the static method. The results are presented as flood maps showing the potentially floodable areas of the analysed localities at the Danube Delta Sireasa Delta agricultural setting at flooding step 4 (maximum water level), in the case of maintaining the breach in the protection dam for longer than 24 hours.

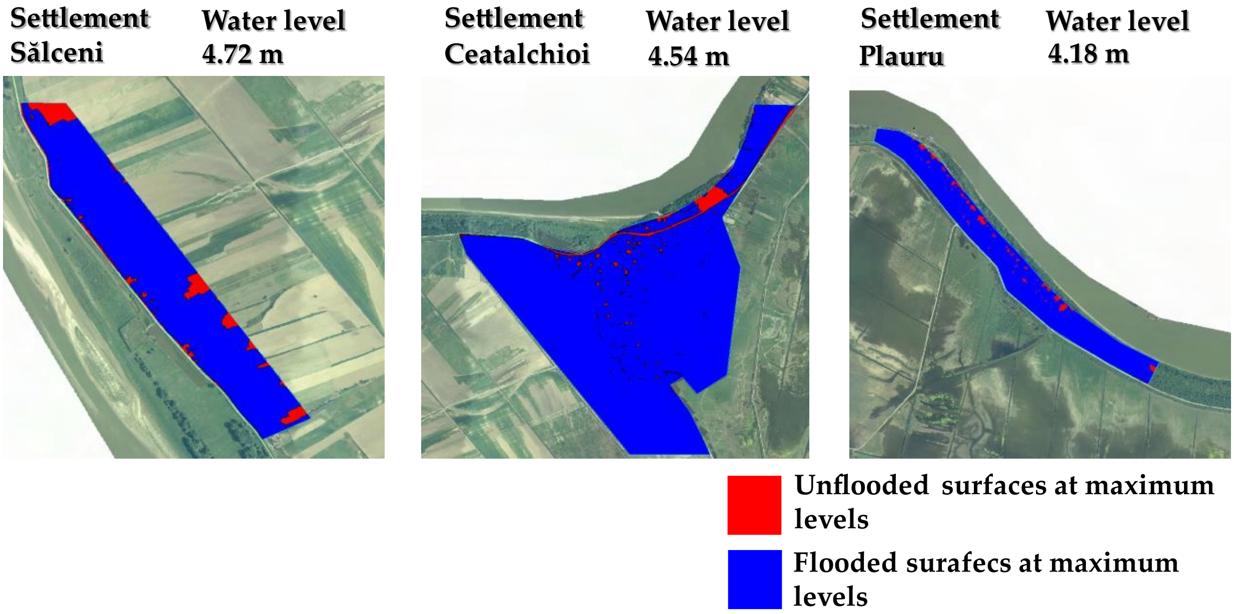

Figure 3.4. Representation of digital maps with flooded areas for the localities: Sălceni, Ceatalchioi and Plauru, by using GIS analysis, at DTM Complex, static method

The results obtained following the application of the static method in Figure 3.4 emphasize the flooding surfaces in the localities, corresponding to the maximum water level of the Danube, this being the most unfavourable situation (the water level on the Danube being the same with the water level in the envisaged localities, by maintaining the breach in the protection dam for a longer period of time). This method requires less data and information from the operator by comparison to the previous method. Analysing the results at flooding step 4 (the most unfavourable scenario), resulted flooded surfaces inside the localities, presented in Table 3.3.

Table 3.3. *Flooded areas of the localities analyzed in the flood stage IV, dynamic method and the static method*

Settlements	**Maximum water level (BS75)**	**Dynamic method**		**Static method**		**Difference (%)**
		Flooded surface (km²)	**Covering flood (%)**	**Flooded surface (km²)**	**Covering flood (%)**	
Sălceni	4,72 m	0,42	92,25%	0,43	94,45%	-2,20%
Ceatalchioi	4,54 m	2,01	94,73%	2,04	96,14%	-1,41%
Plauru	4,18 m	0,59	93,82%	0,61	97,00%	-3,18%

Table 3.3 presents the differences following the application of the two methods. For the static method, the flooded surface was determined using the Global Mapper software. With the comparison, we noticed that the maximum flooded surface at flooding step 4 was of 3.08 km2, following the application of the static method. The depth of the flooding surface reached up to 1.80 m (flooding step 4 at Sălceni), 1.92 m (flooding step 4 at Ceatalchioi) and 1.73 m (flooding step 4 at Plauru). To analyse, in percentage, the differences with regard to the flooded areas at all the other flooding steps (flooding step 1, flooding step 2 and flooding step 3), several graphs were designed to show the dynamics of the flooded areas of the analysed scenarios for the localities (Figure 3.5).

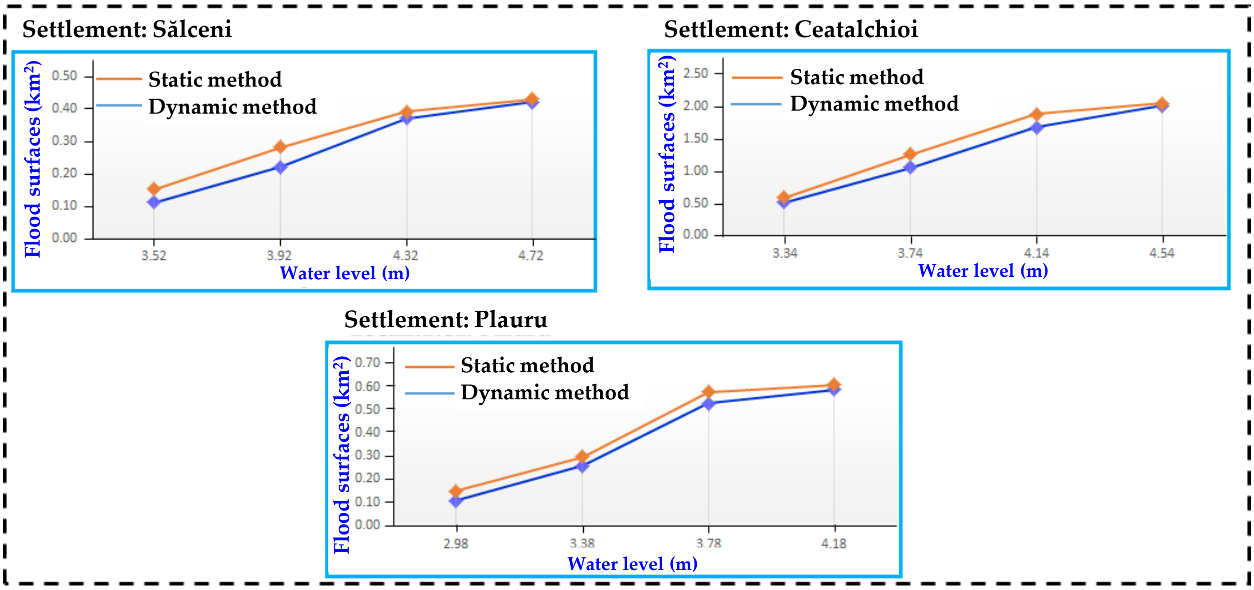

Figure 3.5. Differences of flooded areas for the analyzed scenarios using the dynamic method and the static method for the localities: Sălceni, Ceatalchioi and Plauru

Analysing Figure 3.5, we can say that the dynamics of the flooded areas for the analysed localities differ from one method to another. From the results displayed, it is visible that applying the static method on all flooding steps, the flooded surfaces were larger by comparison to the flooded surfaces obtained by applying the dynamic method. Figure 3.5 shows the fact that the flooded areas under the four flooding steps in the static method varied between 0.16 km2 – 0.43 km2 (Sălceni), 0.53 km2 – 2.04 km2 (Ceatalchioi) and 0.16 km2 – 0.61 km2 (Plauru). Referring to the first flooding step, the highest percentage differences between the two methods, regarding the flooded area, were identified at Sălceni (difference of 10.98%) and Plauru (difference of 7.95%). The lowest percentage difference at the first flooding step was noticed at Ceatalchioi (difference of 0.94%). For the second flooding step, the highest percentage, with regard to the differences on the flooding area, occurred at Sălceni (difference of 13.18%) and Ceatalchioi (difference of 9.42%), and the smallest difference was identified at Plauru (difference of 7.95%). On the third flooding step, the highest percentage differences with regard to the flooded area were recorded at Ceatalchioi (difference of 9.42%) and Plauru (difference of 9.54%). At the same time, the smallest percentage difference was found at Sălceni (difference of 8.52%).

The dynamic method gives the smallest percentage regarding the flooded area for the three localities. Is aspect is due to the fact that by the dynamic method, the land surfaces are flooded gradually, given the topography of the land. The floods occurred in localities, due to the presence of the breach in the protection dam are determined by the river debit. The surfaces flooded by the dynamic method resulted as a consequence of applying flooding steps 2 and 3, were smaller be comparison to the surface flooded by applying the static method. More than this, the physical-geographic factors had a certain influence on the flood flowing process of the dynamic method. Here the relief influences the size, and especially the distribution of the flood flow by its level of segmentation and by the size of the land slope in the localities envisaged. If we analyse the flood evolution on all flooding steps, in Figure 3.2 we can see that the flooded area increased suddenly at Sălceni (from 0.22 km2 at flooding step 2 to 0.35 km2 at flooding step 3) and Plauru (from 0.25 km2 at flooding step 2 to 0.52 km2 at flooding step 3). In the case of Ceatalchioi, the flooded area recorded a more constant increase at all flooding steps.

This thing was due to the fact that the land surface tends towards a softer slope by comparison to Sălceni and Ceatalchioi, where at intervals the slope becomes steep. At the same time, there are other factors to have influences the flowing process in the dynamic method, such as vegetation, which plays an important role in the flowing process, on the one side, influencing the formation of soil and on the other side, contributing to increasing the capacity of filtration in the ground and to reducing the erosion of the ground. Another important factor is the use of the land. This thing influences essentially and negatively the flood flowing conditions. Besides, the anthropic factor plays a very important role in the formation of flood flowing, especially by the changes brought to the natural system: changing the cover of the land (the natural vegetation was replaced with agricultural settings, most frequently in the Danube Delta – orchards, vineyards and human settlements), as well as the modifications to the Danube bed to provide for the necessary water (to irrigations, water requirements, electricity, construction materials etc), road networks, protection works against floods etc [30].

As a consequence of the increased intervention of the man on the natural systems, their natural evolution is disturbed, the changes being significant or fundamental. In this latter case, intervention causes breaks in the rhythm of natural development, imbalances which emphasize the involution of the respective landscapes. The comparative analysis of the results first of all emphasized the substantial effect of reduction of the flooded areas to a lower flood level of the Danube, with differences from one locality to another. The flood maps for the analysed localities offer information on the spread of the floodable areas and depth of the water at several flooding steps. Flooding scenarios were analysed in the case of occurrence of a breach in the protection dam of Siraesa agricultural setting during powerful flooding of the river, to investigate the impact on the research area with regard to the flooded areas, using two analysis methods. We also took into consideration the flood in 2010, relying on hydrologic data, records at the hydrometric station at Tulcea Port where daily data were recorded together with the data furnished by INCDDD and Administrația Națională Apele Române (ANAR).

Using GIS, the processing of these data can be done quicker and easier and into a more accessible interface. GIS using is essential in analysing the flooding scenarios all throughout the process, from its start and up to interpretation. GIS systems were used to facilitate viewing the research area and to input, refine and process the hydrological data necessary to the analysis of the flooding scenarios, as well as to interpret the results and present them as concisely as possible. To select the most adequate flooding analysis model, it is necessary to have access to the geographic information offering an overview of the water circulation system components. A high-resolution MDT is decisive to precisely apply the flooding steps and flooded surfaces [31].

The flood hazard maps are important for information display with regard to the spread of the flooded surfaces. Analysing Figure 3.3 we notice that a debit of 20,213 m3/s is a relatively high debit for the analysed arm section. The total water covered surface of the localities in the transgression probability scenario 0.1% is of 0.455 km2 (Sălceni), 2.122 km2 (Ceatalchioi) and 0.629 km2 (Plauru). In the case when we compare the results obtained by applying the debit Q = 13.989 m3/s (transgression probability scenario 10%) we can notice there are certain localities where the flood did not reach and areas where the flood measures up to 2 meters in depth. In each transgression probability scenario, the localities are flooded more or less depending on the topography of the land, which shows the water covered surface expressed in km2 resulting from the simulated debit. Figure 3.6 presents the comparisons of the results obtained by simulating maximum debits with transgression probability.

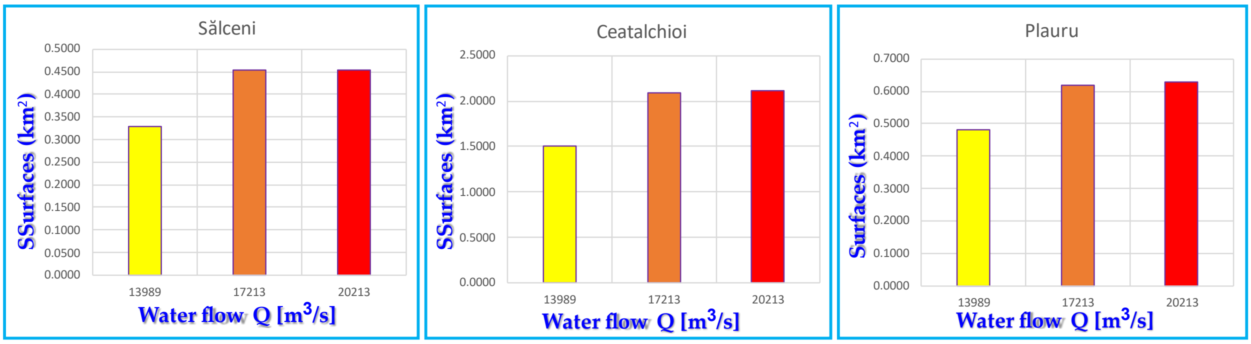

Figure 3.6. Comparative results of flooded areas according to the simulated flow

From the comparison (Figure 3.6) we can say that the debit simulated in the flood risk analysis of the localities directly influences the flooded surfaces. Analysing the distribution of the water flow speed in the studies localities, we can say that the results generated are different for each flooding scenario. Thus, analysing the three scenarios, the maximum water flow speed is 0.60 m/s (at Sălceni), 0.50 m/s (at Ceatalchioi) and 0.20 m/s (at Plauru). The medium water flow speed for scenario Q10 is 0.41 m/s (at Sălceni), 0.42 m/s (at Ceatalchioi) and 0.06 m/s at Plauru. The medium water flow speed for scenarios Q100 is 0.21 m/s (at Sălceni), 0.27 m/s (at Ceatalchioi) and 0.09 m/s (at Plauru). Anaysing the last scenario Q1000, the medium water flow speed is 0.48 m/s (at Sălceni), 0.39 (at Ceatalchioi) and 0.10 m/s (at Plauru). Taking nto consideration the fact that the debit when entering the breach increases depending on the scenario, the results obtained with hydraulic modelling show that the average water flow speeds in the localities are variable depending on the scenario.

For the development of the research, to identify the flooded buildings under the category of importance C (constructions of normal importance), we modelled the scenarios with transgression once in 10 years (the case which could appear more frequently) to finally obtain the flood risk maps of the analysed localities. They were obtained based on the flood hazard maps and researches made on the data and information pertaining to the elements exposed at the moment when the protection dam gave in. based on the risk maps, the potentially negative effects pertaining to the flooding scenarios are displayed depending on carrying out the economic activities, patrimonial-cultural, properties, the category of importance of the buildings and the surrounding environment. Figure 3.7 presents the flood risk map of the analysed localities with flooding scenario Q10. Based on ***Directive 2007/60EC***, the analysed scenario represents a high probability of occurrence.

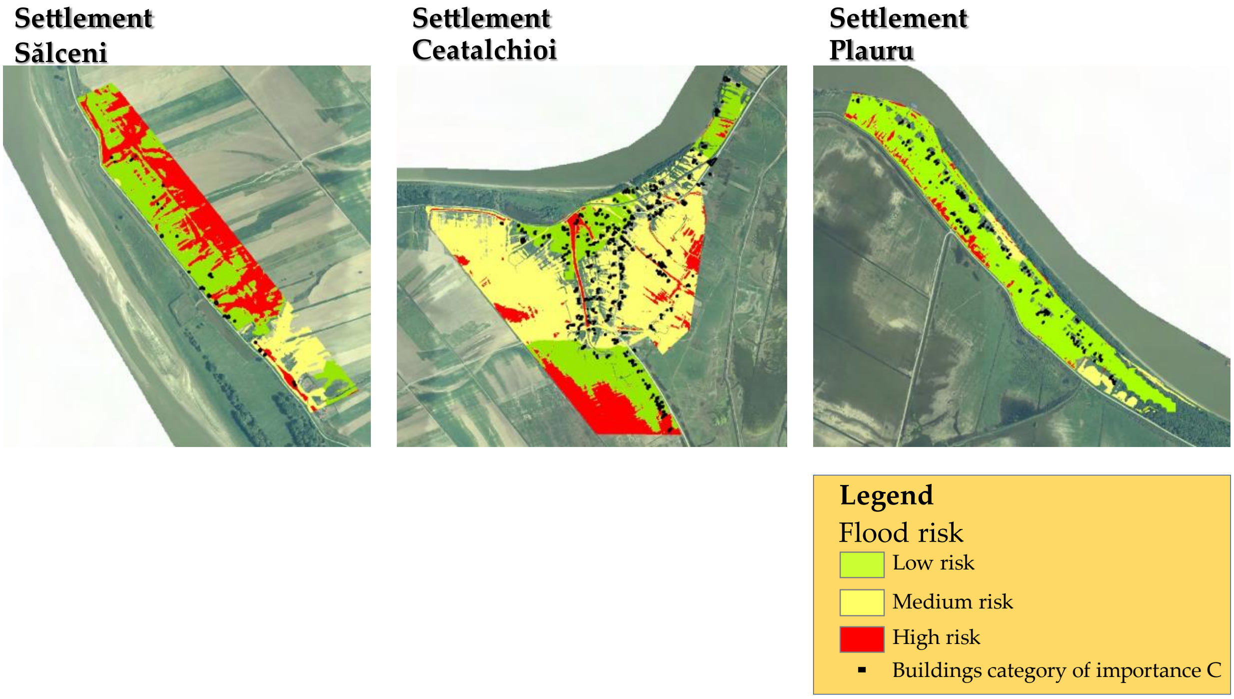

Figure 3.7. Flood risk for scenario with a probability of exceeding 10%

Based on the modelling already done and depending on the depths obtained, Figure 3.7 presents the 3 classes of importance: high-risk class (depths of more than 1.5 m), medium-risk class (depths ranging from 0.5 m and 1.5 m) and low-risk class (depths below 0.5 m). based on the flood risk maps, we identified the number of buildings with the C category of importance and the population in the localities displayed within the perimeter with potential risk. In the researched localities, live 719 inhabitants exposed to flood risk (70 inhabitants at Sălceni, 593 inhabitants at Ceatalchioi and 56 inhabitants at Plauru). Another important element is given by the number of buildings exposed to flood risk, under the C category of importance (constructions of normal importance). There are in all 805 buildings under the C category of importance (24 buildings at Sălceni, 664 buildings at Ceatalchioi and 117 buildings at Plauru).

In the research area, 646 buildings were identified as exposed to flood risk (22 buildings at Sălceni, 532 buildings at Ceatalchioi and 92 buildings at Plauru) which can be affected as a consequence of the flood caused by the protection dam giving in, with a probability of occurrence once in 10 years. In the course of the research, we calculated the flood depth for the scenarios with probability of occurrence, generated by the HEC-RAS software for each cell, based on to the subjacent land, taking into consideration the maximum flood depth of the calculation cell, regardless of the time when the maximum values were recorded.

As far as the affected buildings under the C category of importance are concerned, 40.40% (15 buildings at Sălceni, 160 buildings at Ceatalchioi and 86 buildings at Plauru), some of which can be potentially affected by a flood depth that would not exceed 0.50 m, and 57.43% (3 buildings at Sălceni, 362 buildings at Ceatalchioi and 6 buildings at Plauru), are potentially affected by a flood depth between 0.50 and 1.50 m. The buildings potentially affected by a flood depth that would not exceed 1.50 m, have a smaller percentage of 2.17% (4 buildings at Sălceni, 10 buildings at Ceatalchioi and 0 buildings at Plauru).

The failure of the protection dam, depending on its characteristics (such as, surface, width and height of the dam, etc) can generate flood waves which are significantly higher with regard to the release of the water volume and water speed than the flood waves generated by progressive flooding conditions, such as the localities with direct opening to the river, where no protection dams are provided and thus, they can lead to more significant economic losses and human casualties. Giving in of the protection dam to the pressure of high waters makes the water cover the surfaces in the localities in a much shorter time and at much higher speed. As the detection techniques Remote Sensing (RS) continue to improve, the data availability increases, more RS data shall be integrated and used in flood modelling.

In this context, the flood simulations based on Light Detection and Ranging (LIDAR) MDT offer the best results [32]. The 2D and LIDAR MDT flow models prove to be the perfect combination when it comes to precisely delimiting floods. In this way we can simulate for the different purposes of the past floods, using the hydrographs recorded at the measurement stations, or we can imagine a theoretical hypothesis such as the giving in of the protection dam, and thus, we improve the flood risk and hazard maps. This research was focused on an arm sector with problems on the right bank flow due to the erosion phenomena. The calibrated model showed plausible results with regard to the flood spread and was used for flood modelling, using debit hydrographs of 10, 100 and 1000 years, respectively debit hydrographs depending on the applied flooding step (flooding level).

Thus, it is extremely important to approach these events in a way that reduces their negative influence on people and infrastructure. Simulating flood using hydraulic methods is one of the main instruments applicable on this purpose. The breaches (indicated by breakage lines) play an important role during flood transgression through protection dams and our results show that their inclusion may shorten or increase the simulation time depending on the duration of the breach in the protection dam. In the end, conducting the probabilistic simulations of breaking the protection dam has an immense importance to the emergency preparation actions and ideally such studies should be similarly made for all the vulnerable areas. The proposed analysis procedure of the floodable plain land to create 2D flood models with course resolution which would be capable to constantly simulated the flood spread on a large scale, could be beneficial to flood risk management in several ways. Such information is especially important to the local and county authorities. Incorporating the flood maps in the local development plan of the localities, the expansion and densification of buildings could be prevented in the proximity of the water flow or in the medium or high flooding level danger. All the more, the results can be used in landscape planning, in the process of assessing the impact on the environment or on the insurance industry.

Chapter 4. General Conclusion, My Own Contributions and Potential Research Directions

4.1. General Conclusions

The purpose of this doctoral dissertation is drafting expansion maps of the potentially floodable areas for the localities in the Danube Delta. This thing is possible b using the hydrologic data on the Danube's debits and levels, on the bathymetric and topographic data obtained by on-field measurements using specialized modern equipment, as well as by using the GIS, CAD specialty software, for the processing of the collected data.

The research was made using a hydraulic dynamic method and a GIS static analysis method in order to obtain the flood maps for various scenarios. Still within the research, the flood risk and hazard maps were drafted for the analysed localities, using the hydraulic model dynamic method.

An important conclusion was derived from the topo-bathymetric measurements and namely, in order to attain the main purpose of this study, a MDT Complex was necessary to be developed, by improving the LIDAR model with the bathymetry of the arm bed.

The digital model of the minor bed, together with MDT for the Danube Delta allowed for the simulation of several flooding scenarios for the localities and taking into consideration the various tests to flood. Achieving the MDT Complex for the study area, obtained by combining the digital model of the minor bed with the updated MDT, represents a new and unique MDT. What is more, we can mention that the hydraulic modelling results, in the case of the dynamic method, are directly influenced by the rugosity coefficient (Manning's rugosity coefficient), which in this research varied from 0.025 to 0.03.

The results obtained as a consequence of processing the data collected in the field lead to the conclusion that the protection dam suffered modifications in time, showing sagging and the outer slope disappeared, with differences of the crown of up to 77 cm between the situation in 2010 and the current situation. The results showed that for the first scenario when the dam breaks (the dynamic method), the flooded areas covered an area smaller than in the case of the second scenario (the static method), when the flooded areas covered a considerably larger area. The most significant differences were noticed for the localities Plauru and Sălceni. The results obtained showed also the flooded surface in percentage and forecast depth of the water at each studies locality. The increase of the Danube levels led to a gradual increase of the flooded surface inside the localities, in the case of a breach in the protection dam. The precision of the model's simulations depends large on the MDT precision, on a hydrological and hydraulic structure of the model and ground characteristics. The results obtained depend to a large extent on the precision of the equipment used for the measurements in the field, quantity of points collected, measurements methods used, and also on the selected method of interpolation. The interpolation methods used in this research to obtain the digital model of the minor bed and to update the MDT depended largely on the volume of data and information collected in the field. The profiles resulted from the Inverse Distance Weighting (IDW) method were the closest to the profiles measured in situ, this method being applied both to generate the minor bed model and to update the MDT in the protection dam area.

The static method used by means of the Global Mapper software requires more data and knowledge from the operator by comparison to the dynamic method. The second method requires complex data and information to draft a hydraulic model in HEC-RAS for a 1D / 2D simulation (field data, hydraulic parameters, debits, levels, types of graphic representation, networks, nodes, limit conditions).

The main geometric elements corresponding to the hydraulic model are given by the cross profile displayed at distances on an average of 150 m. With regard to the length of the cross profiles, as geometric element within the hydraulic model of Chilia arm, they must contain the width of the arm and flooding perimeter. The cross profiles must be distributed perpendicularly on the arm's flow direction, without intersecting one another throughout the entire length of the arm.

Using the static method when making the flood simulations does not require topo-bathymetric data, such as in the case of the dynamic method, which leads to the fact that the static method is exempt of the time and effort allocated to make the measurements in the field. The dynamic methodology has the advantage of inputting a series of much more complex data, including calibration data, which offer more confidence in the results obtained.

This study drafted the flood modelling in the case when the protection dam gives in, using the hydrologic data of 2010. In this research, the HEC-RAS model was calibrated and validated for the water peak levels at various measurement stations and flood spread. Besides, the flood risk analyses using the HEC-RAS model offered maps for the space variations of the flood depths, water speed, depth or speed product, the arrival of the floods and duration of staying in the localities at Sireasa agricultural setting. This study showed that the HEC-RAS 1D / 2D model is capable to model the water levels (stage) at peak flood. The flood depth map in the research area showed maximum depths of the water in several points in the floodable plain. Yet, the flooding water speed was maximum in the scenario Q1000.

The 1D / 2D hydraulic modelling techniques approach is more realistic by comparison to the static method, taking into account the fact that the actually flooded areas were determined for various scenarios when the dam breaks for a 24-hour period (the time when the breach remains open), which could allow for a real estimate of the material and human resources necessary to intervene in case of emergency. The approach with several scenarios allowed testing the water flow capacities in the settlements, determining the extent to which the surfaces inside the localities would be affected.

The envisaged area, located in the Danube Delta presents a high danger of flooding. Following the studies drafted, this research led to the conclusion that the localities in the Danube Delta are vulnerable in front of floods due to the protection dams giving in. The novelty of this work relies on presenting different complex techniques which can be used in order to assess flood spread by applying two different methods of flood simulation. At the same time, the used methods represent a solution at low or medium costs, at which flood maps could be generated in the areas which were not previously assessed.

This work assessed two simulation methods on determining the flood level for the localities in the Danube Delta at a local space scale using GIS and hydraulic modelling. At the same time, using the dynamic method, we drafted the flood hazard and risk maps of the localities.

Flood risk was determined using the 1D / 2D HEC-RAS hydraulic model. Flood risk is thus the information synthesis on the danger and vulnerability to flooding, which actually allows to define and extent of the areas which do not meet the requirement of an acceptable flood risk. Flood hazard and risk maps generation for the analysed localities was done in compliance with the Floods Directive.

The flood maps in the simulation of the hydrographs of 10, 100 and 1000 years were classified depending on the classes of danger. The hazard maps indicated the locations prone to being flooded in the three scenarios. The flooding areas identified in the localities can be used by the local authorities to adopt structural and non-structural measures depending on the assigned class of danger.

The results of the work can be applied especially in the fields of prevention, to mitigate risk to floods and manage crises. Its purpose should be fulfilled first of all be increasing the level of awareness among the public, with the risk to flood and furnishing information with regard to the risk of flood, to plan and built the space (rural / urban). Attaching flood maps to the local development plan of the localities could prevent the spread and irresponsible densification of constructions in the proximity of water flows or in average or high-level risk of flood.

From the methodological point of view, the importance of the work can be seen in the universality of the steps proposed to determine flood risk which could be transferred to other similar areas, prone to flood risk on a local space scale. Yet, additional case studies should be made in other regions as well to verify their general applicability.

4.2. My Own Contributions

Further on, I shall resume to several of my own contributions:

The historic analysis of the maximum debits and levels on a 51-year period represents my personal contribution in this research. The analysed data are especially important in flood risk analysis in the light of their application in calibrating the hydraulic model, aiming to obtain flooding scenarios. The hydrological data series used to calibrate the hydraulic model influence directly the results obtained in this work. My personal contribution is marked by the presentation of the average annual debit variations of the Danube entering the delta, between 1965 - 2015, where the years 2005, 2006 and 2010 were emphasized.

The development of my own methodology for two analysis methods of the flooding scenarios represents my personal contribution in this work. The diagram presented in Figure 2.1. indicates the methodology and main steps taken into consideration in this research. This implies a dynamic, continuous and interactive process. The stages presented are not a linear process, but they move successively from one stage to another and vary with the results at each step. This diagram depicts clearly that the input data were very important in the flood scenario analysis. This data collection process starts with an analysis at regional level, an exploratory step or even an investigation which offers input data and information for the proposed diagram. Applying the methodology finale led to achieving its purpose, tis being drafting the expansion maps of the potentially floodable areas, for the localities in the Danube Delta.

Updating the MDT by carrying out topographic surveys on the protection dam was a premiere in this research. Updating consisted in cutting off a portion of the MDT and replacing it with a digital model made based on the topographic measurements made in the field. The perimeter proposed for updating is represented by the protection dam (made of ground) belonging to Sireasa agricultural setting and a land in the vicinity of the dam. My personal contribution is marked by obtaining the updated digital model of the land, as a consequence of applying the in the IDW interpolar method overlapping the ortho-photo-plan drafted for the first time for this area and by the 3D presentation of the digital model. Another personal contribution is the comparison of the data measured on the protection dam with data in MDT of 2011. Following the comparison, resulted the fact that the body of the dam sagged in time, and the level differences are significant especially at the crown of the dam.

The update of the minor bed of Chilia arm by making the topo-bathymetric measurements represents an experimental contribution to this research. The resolution of the minor bed was calculated by a resolution similar to that of MDT LIDAR (0.5 m × 0.5 m), but it was brought to 1 m, which allowed for an easier input of the data in the specialty software used for this paper (HEC-RAS and Global Mapper). The vertical precision of the main canal was set at 0.10 m. To update the digital model of the minor bed, three interpolation methods were analysed and compared: IDW, Kriging (KRG) and Topo to Raster method. The bathymetric model of the minor bed used in this research is obtained using the IDW interpolation method. In this research, the update of the minor bed was a necessary condition to be subsequently able to draft the MDT Complex and 1D/2D hydraulic modelling, using the specialty HEC-RAS software.

Creating the digital model of the complex land by combining the updated digital model of the land with the updated model of the minor bed represents an experimental contribution to this research. To obtain the MDT Complex, the area containing the minor bed of the digital model was cut off and replaced by the minor bed model updated with topo-bathymetric measurements. Still within this operation, the area in the model to contain the perimeter with the protection dam was cut off and replaced by the model updated by the topographic measurements. All space information was organized in the GIS (ArcMap and Global Mapper) applications.

Drafting the flooding scenarios for the localities envisaged by this research, using the specialty HEC-RAS and Global Mapper software represents my personal contribution to this research. To obtain the flooding scenarios I made an analysis of the important historic data and events which occurred in the research are. Thus, the scenarios were run by executing the debit simulator, exit pre-processor and post-processor geometry, finally obtaining the results of the first method (dynamic).

My personal contribution was emphasized by the presentation of the 12 scenarios obtained following the application of the flooding steps and 9 scenarios obtained following the application of the transgression probabilities, resulting thus 21 flooding scenarios for the localities analysed with the specialty HEC-RAS software (the dynamic method).

My personal contribution was also emphasized by the presentation of the 12 scenarios obtained by using the specialty Global Mapper software (the static method) resulting thus the most relevant results extracted for the three localities in the Danube Delta envisaged in this research. Consequently, the flooding scenarios obtained by applying the two methods were analysed from the flooded surfaces point of view, and then compared.

Drafting the flood hazard and risk maps for the localities envisaged by this research represents my personal contribution in the sense that these offer more important information with regard to the flooded surface in the localities in the case when the protection dam gives in, the flood depth in localities and the information regarding the risk classes in certain areas in the localities, the buildings corresponding to the C category of importance and the affected population.

My personal contribution can be remarked by the fact that the resulted maps can be useful to urban planners who can directly attach the flood risk maps to the process of developing local development plans of the localities. Attaching the flood maps to the local development plan of the localities could prevent the spread and densification of constructions in the proximity of water flows or in the areas running average or high flooding risk.

As a consequence of this research, I succeeded to present a flood risk study for the localities in the Danube Delta. From this point of view, this analysis of flooding risk represents my own and original contribution to the studies on floods.

4.3. Potential direction of future research

This research can be further on drafted with regard to assessing flood risk by presenting significant or quantity analyses of damages. These analyses can be used to quantify and assess any potential direct or indirect damages in the flooded areas and also, the economic assessment in the protection measures against floods. The future activity of professional training shall have the same directions such as individual study, fundamental and applied research in the field of flood risk. All the techniques and methods used in this paper can be continuously improved by additional analyses on the interpolation methods such as Diffusion Interpolation With Barriers, Empirical Bayesian KRG or Radial Basis Functions, and thus important results can be obtained. Using the various measurement equipment for the bathymetry of the multi-fascicle type arm bed combined with the concomitant measurement of sediment transportation. Having in mind that the development of the economy is a continuous and quick process, it is necessary to use new products and technologies to keep up with the human requirements and their needs in connection with the risk and flood risk management. The recent technological development is felt more and more in the flood risk field, especially in data and information collection in connection with the topography of the land. In this sense, the light planes of the type Unmanned Air Vehicle (UAV) started to be used more and more frequently in the recent times, especially in the field of cartography, since flying is carried out without a pilot (autonomous flying) and automatically photographs the envisaged areas. The main advantages of the UAV type of planes are low costs and flight rentability. Very many researches show this ever-growing trend of using the UAV technology instead of the classic aerial platforms due to the advantages featured by this technology and high photographic precision which is comparable.

The use of other specialty software carrying out hydraulic modelling with a view to comparing the results in this paper and making new analyses of flood risk in similar areas.

Making for each rural and urban locality on the Danube Delta exposed to flood risk a unique conceptual plan to collect and discharge the rainfall waters, as to reduce, in the future, the damages caused by a systematic annual decrease and repartition of increasing the level of water-proofing by infiltration increasing actions. An example in this sense would be increasing the green areas and green buildings. Another action would be designing / making temporary service tanks to store high waters.

Drafting interdisciplinary researches in the field of risk and flood risk management to diminish the effects caused by floods in the urban and rural areas in the Danube Delta.

Creating partnerships with the national and foreign universities and research institutes to make project proposals in the field of flood risk and attracting funds, either national or EU. Obtaining the funds shall also be necessary for the participation to conferences or publishing scientific works.

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