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13. Some morphodynamic aspects concerning the meandred river section of the Sf. Gheorghe's arm from the Danube Delta Biosphere Reserve

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Abstract: Recent hydrological surveys dealing with high-resolution bathymetric data collection using an interferometric sonar were carried out to investigate the riverbed of some sections on the Sfântu Gheorghe arm of the Danube River located in the Danube Delta. The collected data was to enrich the available database on this river sections, especially in the bifurcation and confluence sectors of the meanders with the main river course. The data was harmonized with previous surveys and observations which allowed in depth analyses and a possibility to characterize the evolution of the meandered sections of the river. The approach in this study was to calculate the morphonynamics of the emerged surfaces (river banks), to analyze and characterize the hydro-morpfological structure of the meandered sections of the river, to compare and quantify the liquid flow rates and lastly to analyze and compare the evolution of the riverbed's configuration based on bathymetric profiles. This analysis responds and aims to be a support to the objectives of the Management Plan of the Danube Delta Biosphere Reserve and the Water Framework Directive given the fact that this specific arm of the river was heavily modified at the beginning of 90s in order to shorten the length of the river by cutting the meanders. This part of the Danube River had been rectified for 15 km altogether for the following meanders: Murighiol, Dunăvaț, Dranov and Ivancea which shortened the route with 32 Km. The benefit of these changes is clear: improve the water transportation by shortening the route, less time spent on transportation ergo, less fuel consumption. The downside is represented by clogging of the lateral connectivity, silting up the mouth of the river and of the adjacent water complexes. And for this balance alteration, several studies have been conducted in order to "keep an eye" on the area to ensure that the already fragile lateral connectivity with the adjacent water complexes inside the Delta is still present.
Keywords: Danube Delta, Wetlands, Riverbed, Hydro-Morphology, GIS.

INTRODUCTION

The Danube Delta is situated in the north-western sector of the Black Sea basin, in a mobile region of the terrestrial crust (the Predobrudjan Depression). Its limits are: 44°46'00'' N lat. (Periteasca), 45°30'00'' N lat. (South of Sasik Lake), 28°40'24'' E long. (Ceatalul Chilia), 29°40'50'' E long. (East of the Chilia secondary delta). As for its surface of 5,600 km^2, the Danube Delta, together with the floodplain sector between Ceatalul Ismail and Galaţi city, represent the most important terminal plain of any European river (except the Volga and Kuban deltas on the territory of C.I.S.). The Ukrainian part, about one-fifth of the total delta area, covers 125,000 ha of which 75,000 ha is land and 50,000 ha are water.

The Sf. Gheorghe arm is the oldest arm of the Danube Delta, which currently carries about 30% of the volume of water and sediments of the Danube. It derives from the Tulcea branch on the right-hand side of the bifurcation at kilometer 108.8, with mostly a single and meandering riverbed, which was naturally

preserved until 1988. The year in which a collective effort to regulate the watercourse began so that the six meanders of the arm were subjected to a "adjustment" necessary for the protection of the shore, strongly eroded, south of the mouth of the arm and also necessary for the economic activities to the detriment of: the hydrological and sedimentological equilibrium of the adjacent aquatic complexes; the sedimentation regime at the mouths of the channels and the mouth of the arm; the reed quality; the habitats; the water surfaces; the landscape quality (G. Romanescu et al., 2010).

The subject study responds to the requirements of national and international environmental and sustainable development policies and guidelines and it is of interest to the scientific environment for the following topics: behavioral studies of migratory fish, especially for sturgeon species, for the specificity of habitats and ecosystems that are dependent on certain physicochemical parameters of the water, impact studies and water flow improvement through hydrotechnical works etc. and of course for the enrichment of the poor hydrological data base on this Danube arm.

This ongoing study represents the main author's PhD thesis. It is mainly a technical study that aims to enrich the hydrological data for the Sf. Gheorghe arm of the Danube Delta in respect to riverbed mapping of the meanders and their connection to the main river flow and the adjacent channels. Its results will help other research domains to benefit of the knowledge and database to estimate the environment development based on the actual state of the riverbed. The main objective of the study is to map all six meanders using high resolution hydrological equipment and to evaluate the evolution of the riverbed correlated with the historical data (C. Trifanov et al., 2018) based on analysis of the emerged morpho-dynamics, analysis of the submerged relief, specifications of the meander's morphology and quantitative comparison of the liquid discharges.

STATE OF THE ART

The study proposes to provide a picture as a whole of the morpho-hydrographic dynamics of the current Sfântu Gheorghe's meanders using GIS methods, field data collected using single and multi-beam sonars and ADCP for a holistic understanding of how the water circulates now to the aquatic complexes, adjacent to the Sfântu Gheorghe arm, and the support capacity of its riverbed for migratory fish habitats of national and international interest.

The real issue is represented by the morphological aspect of the arm as a result of the regularization works, namely the silting of the meanders. Besides the landscape preservation importance and the value of surface water bodies, their biggest value it is the contribution of fresh and oxygenated water to adjacent aquatic complexes. Note that access (channels) to aquatic complexes lie on the edges of the meanders and the rectification directly influences the equilibrium of water distribution flows: affecting the lateral connectivity. This leads to the eutrophication of lakes in the aquatic complexes by the low intake of fresh oxygenated water, which will determine their clogging thus, extensive habitat changes or even their loss. Clear evidence is the two channels (from downstream) Ivancea and Erenciuc North: completely silted. Now, the Perivolovca, Uzlina, Dranov and Dunavăț canals are threatened, which already show very low depths at their river mouth (C. Trifanov et al., 2018).

Regularization of Sf. Gheorghe's arm downstream from Mahmudia town was carried out on the basis of project 1274 elaborated by the Institute for Research and Development for Water Management at the command of Water Administration Office (O.G.A. Tulcea) no.1574. The work was part of the framework scheme for the Dobrogea hydrographic area and was nominated in the investment plan of the National Water Council. The regularization works consist of the rectification of the main meanders of the St. George arm in the Ivancea, Dranov, Dunavăț and Murighiol sectors. The total length of the rectification is 15 km and the shortening of the natural course of 32 km (Geological Center and Marine Geo-ecology, 1995).

The Danube Delta National Institute for Research and Development Tulcea, in 2015, elaborates the study "Analiza morfo-fractală a dinamicii hidro-morfologice a celor 3 brațe principale ale Deltei Dunării", phase 2 "Analiza complexă a macroformelor – meandrele și ostroavele Brațului Sf. Gheorghe". This study facilitated the collection of hydrological data from the Sfântu Gheorghe arm, thus creating an important database that can serve as a comparative study of the evolution of this flow sector. Currently, the present study, which aims to analyze the evolution of the meanders of the arm, creates a common database and harmonized with previous studies, thus highlighting the morphological changes of the riverbed related to the surveyed area. By updating the data on the morphodynamics of the riverbed, it

is possible to compare it with the historical periods of investigation and interpretation, using modern techniques accessible to the present study.

METHOD

This study is structured by addressing in particular each meander or group of meanders dealing with the aspects of emerged morpho-dynamics using GIS techniques (Figure 1), geomorphological analysis and structure by determining indicators of wavelengths of meandering curves by a method proposed by Bagnold 1960. Also, it deals with comparative analysis of flows and their distributions for this flow segment of the river and last but not least comparative analysis of bathymetric sections.

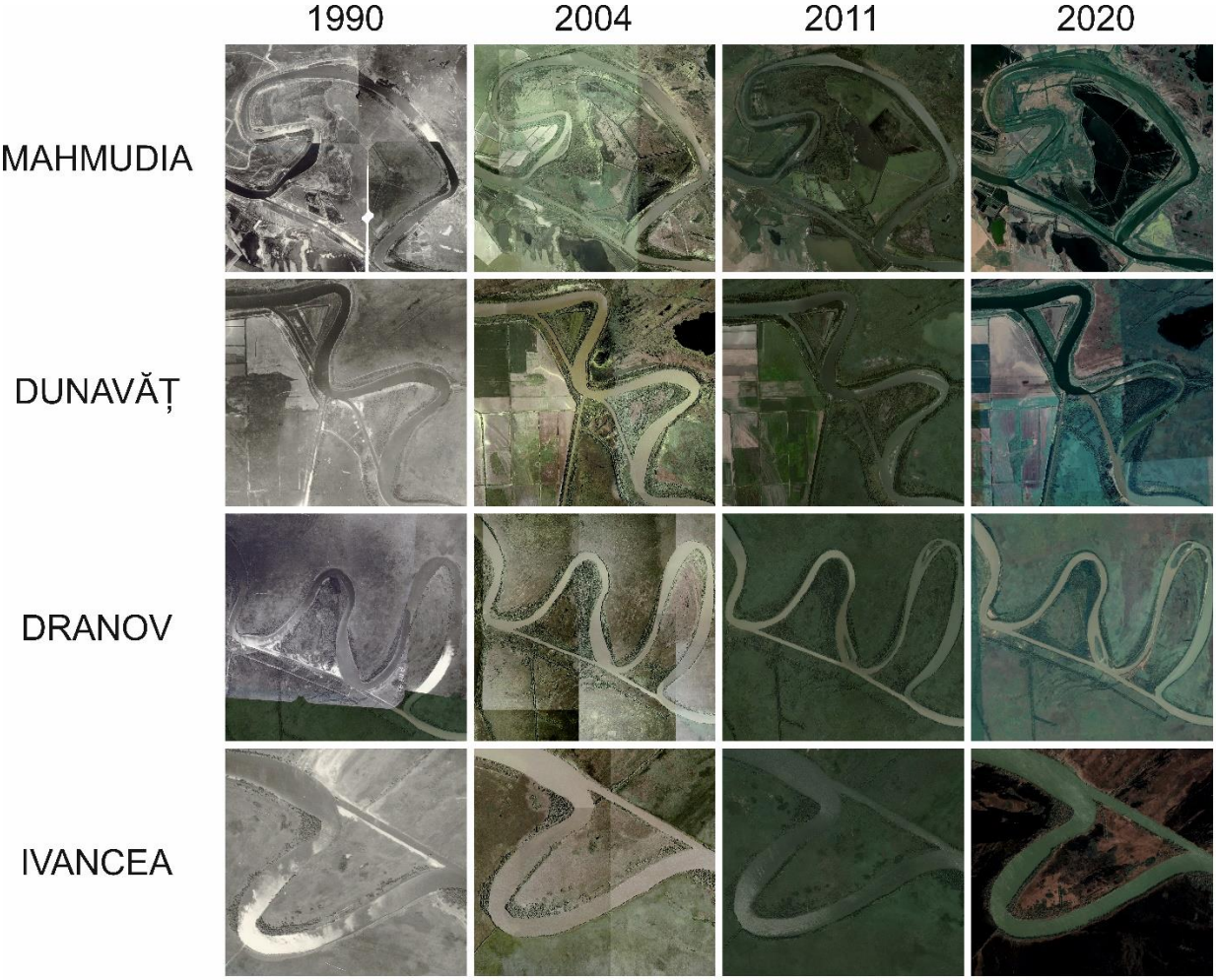

Figure 1 - Aerial images used to quantify the morphodynamic processes of the meanders investigated in the study.

The analysis of morphodynamic processes is performed using GIS techniques to highlight and quantify the sedimented and eroded surfaces for each meander and group of meanders. This involves a vectorization of each meander for a particular instance observed on available aerial images, namely: black and white aerial imagery for 1990 flight, transferred in digital and georeferenced format, aerial imagery from 2007 flight (ANCPI), aerial imagery for 2011 (CARTODD Project), the latest aerial images available through WMS services (Google) (Figure 1).

The vectorization and analysis processes are performed in specific GIS applications and are treated in particular for each meander and grouping of meanders separately. The data is represented in tabular format that quantify in hectares the areas determined separately for sedimentation and erosion processes but for this paper, the map representation was chosen, as an example for Mahmudia meander (Figure 2).

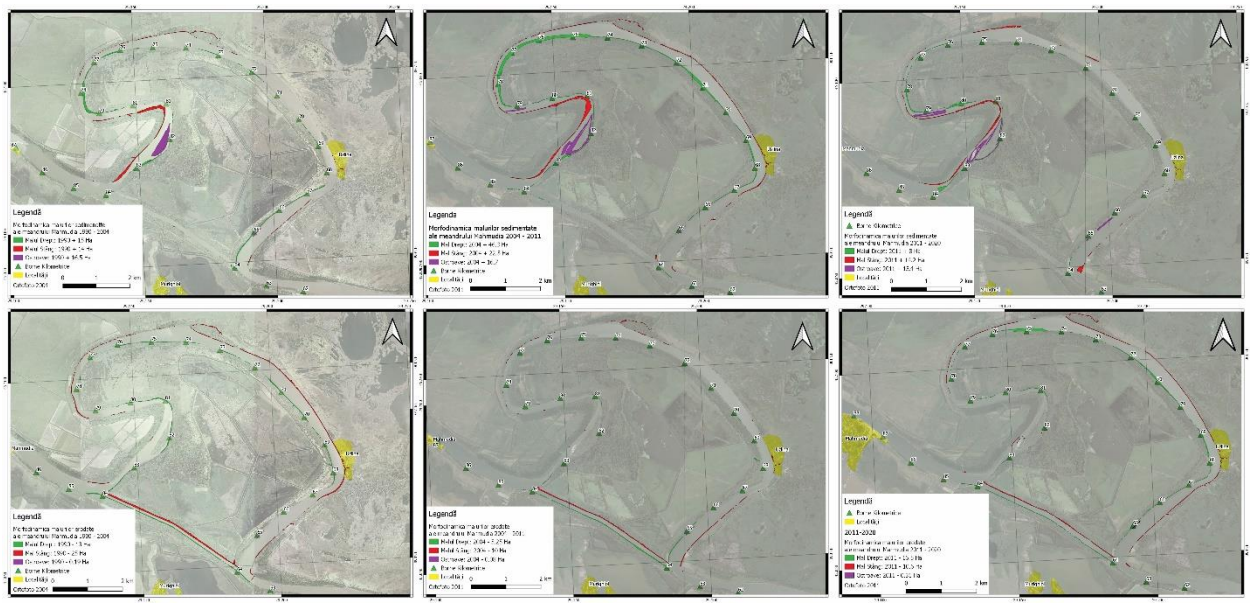

Figure 2. Maps of the evolution of the emerged morphodynamic processes for the Mahmudia meander. Up sedimentation processes, down erosion processes, for 1990 - 2004, 2004 - 2011 and 2011 - 2018.

The geomorphological and structural analysis of the meanders is performed by calculating the ratio between the radius of curvature (r_m) of the meanders and the width of the channel (d).

This indicator, which can be relatively constant but under ideal conditions, indicates a "standard" behavior of the morphodynamic processes that take place downstream of the meander's curvature. Bagnold (1960) showed that when the rm / d ratio decreases below 2, the meander resistance increases greatly and causes the formation of high turbulence zones, and implicitly, the increase of the "shear" force of the current (R.A. Bagnold. 1960) (Table 1).

In order to characterize the meanders of the St. Gheorghe arm, the critical values of the rm / d ratio were calculated for each meander by time series and the data are reported in tabular format, diagrams and maps of this ratio. For the purpose of this paper, only the tabular and map representation for Mahmudia meander were choosen as an example (Table 1 and Figure 3).

Table 1. The Mahmudia meander wavelength r_m/w ratio

Meander	Km	r_m (m)				d (m)				r_m/d			
		1990	2004	2011	2020	1990	2004	2011	2020	1990	2004	2011	2020
Mahmudia	81	248	327	343.4	356.3	158	114.6	82.4	57.4	1.57	2.85	4.16	6.2
Mahmudia	78	405	372.5	329.4	322	180	138.2	107.4	88.4	2.25	2.69	3.06	3.64
Mahmudia	68	490	535.2	497.8	481.4	165	176.5	158	160.6	2.97	3.03	3.15	2.99
Mahmudia	64	250	388.6	361.2	224.2	165	207.6	207.6	213.2	1.52	1.87	1.73	1.05

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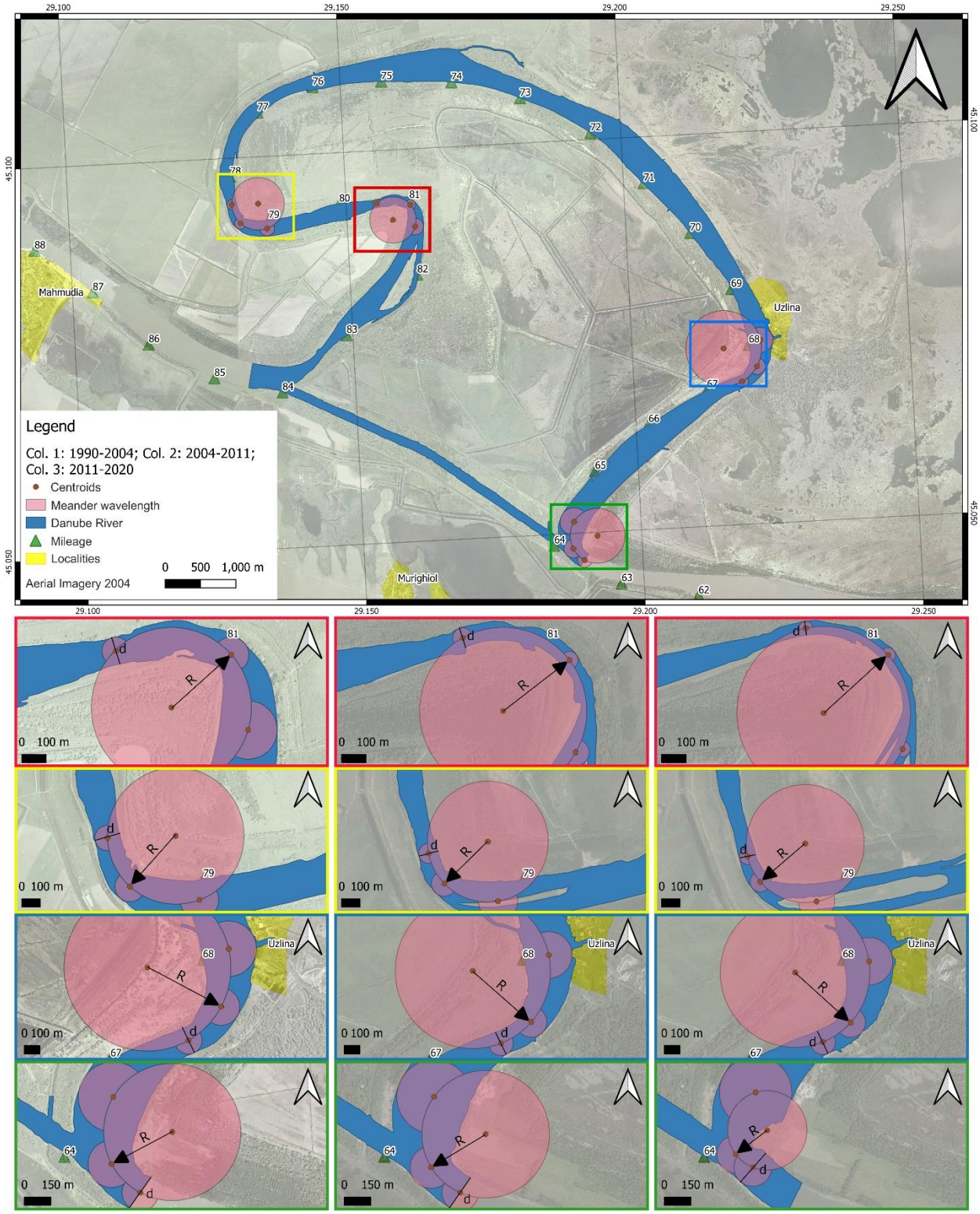

Figure 3. The approach in calculating the rm / d ratio and its variability in the analyzed time series (2004 left column, 2011 middle column and 2020 right column) for Mahmudia meander.

The analysis of liquid flows and water flow rates is performed for the same comparison years treated in the previous analyses and also treats each meander and group of meanders individually. The study illustrates the differences in flow rates at bifurcations and confluences of meanders with rectification channels, which shows their evolution that contributes to the overall picture of the entire flow of the river segment. The data are highlighted in tabular format according to the similarity of the sections reported

in the available documentation and those developed by INCDDD in the field. At the same time, these profiles are highlighted by placing them on maps. Water flow velocities are extracted from field data collection applications that serve as a support for interpreting the velocity distribution on water columns for each section. For the purpose of this paper, the Dunavăț-Perivolovca meander group was chosen as an example (Figure 4).

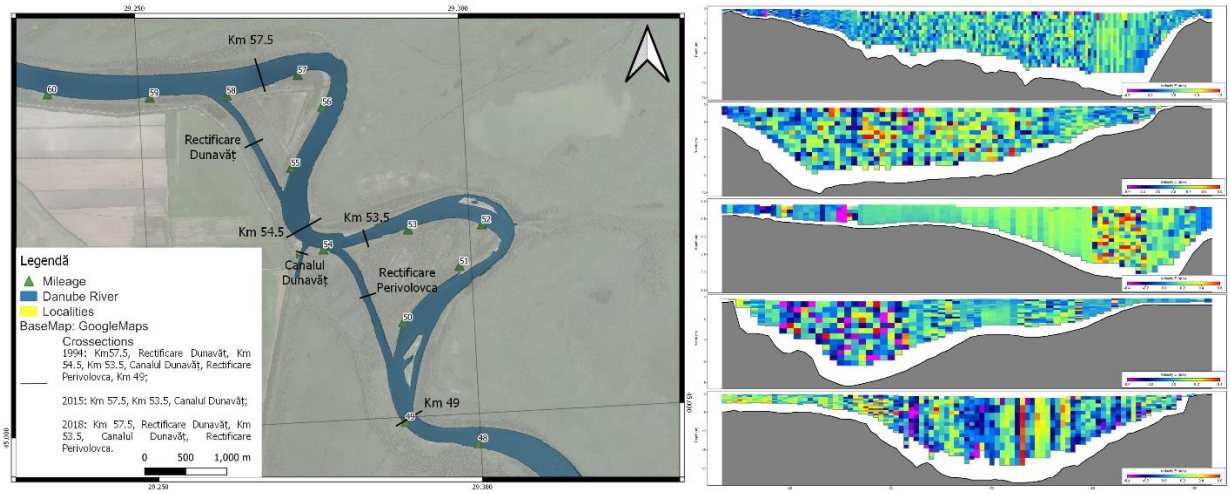

Figure 4. The positioning of profiles for determining water flows and velocities (left), water velocities related to profiles (right).

The analysis of the bathymetric sections is performed, as well as in the case of the previous approaches, individually for each meander and meandering group. Therefore, the depth data for each similar profile is extracted as a field position from each observation period. This similarity in field positioning of the profiles is mainly addressed to the years 1994 and 2015. Recent data have partially allowed the bathymetry of meanders to be collected with multibeam equipment that led to the creation of a raster GIS layer that highlights the depth values using a color shader. New geophysical equipment designed to obtain swath bathymetry in shallow waters enables detailed imaging that provides new information on morphology and causative processes (R. S. EILERSTEN, et al., 2008).

It should be noted that this bathymetric data collection was only possible where the depths in the field allowed access to the boat without too much risk, therefore, the inside of the meanders is excluded and their depths are detailed by single beam sonar crossections. The second aspect is the fact that the analysis of the comparisons of the submerged relief sections is made based on the values of depths and not elevations. The depths were calculated and brought to an altimetric reference system such as MN75 and MNS for 2015 and onwards, but the historical data from the 90s relate to depths.

Therefore, comparisons between harmonized bathymetric sections are brought to scale and are illustrated in the form of diagrams by highlighting the distances of the depth points along the profiles. Examples of these profiles can be seen in Figure 5.
At the same time, where available, it was populated with profiles present on the numerical model of the submerged relief.

Therefore, for this analysis, there have been developed graphs which are highlighting the shapes of the comparable sections on the mentioned years and at the same time, maps with the corresponding positioning of these profiles, some of which coincide with those of flows and speeds. In addition, bathymetric representations are illustrated that shows, in perspective, some morphological aspects of the riverbed (Figure 6) and also of the entire segment surveyed in the field using color shader to highlight the submerged relief for the chosen example on Sfântu Gheorghe arm - Dunavăț meandering section.

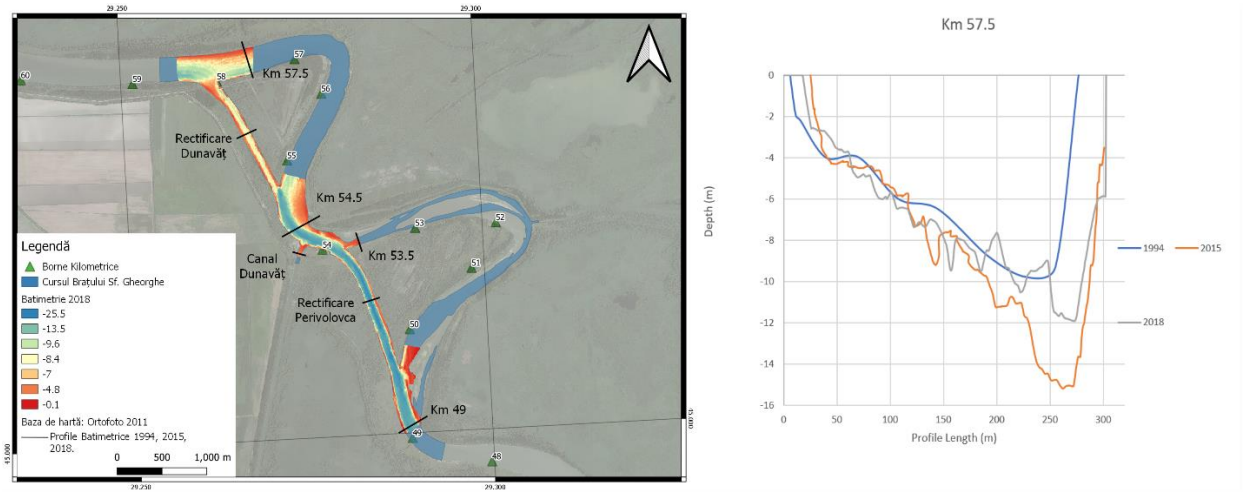

Figure 5. Right - positioning of comparison of the bathymetric profiles and submerged relief image, left - comparison example of a similar bathymetric profile for the surveyed years for Dunavăț meandering section.

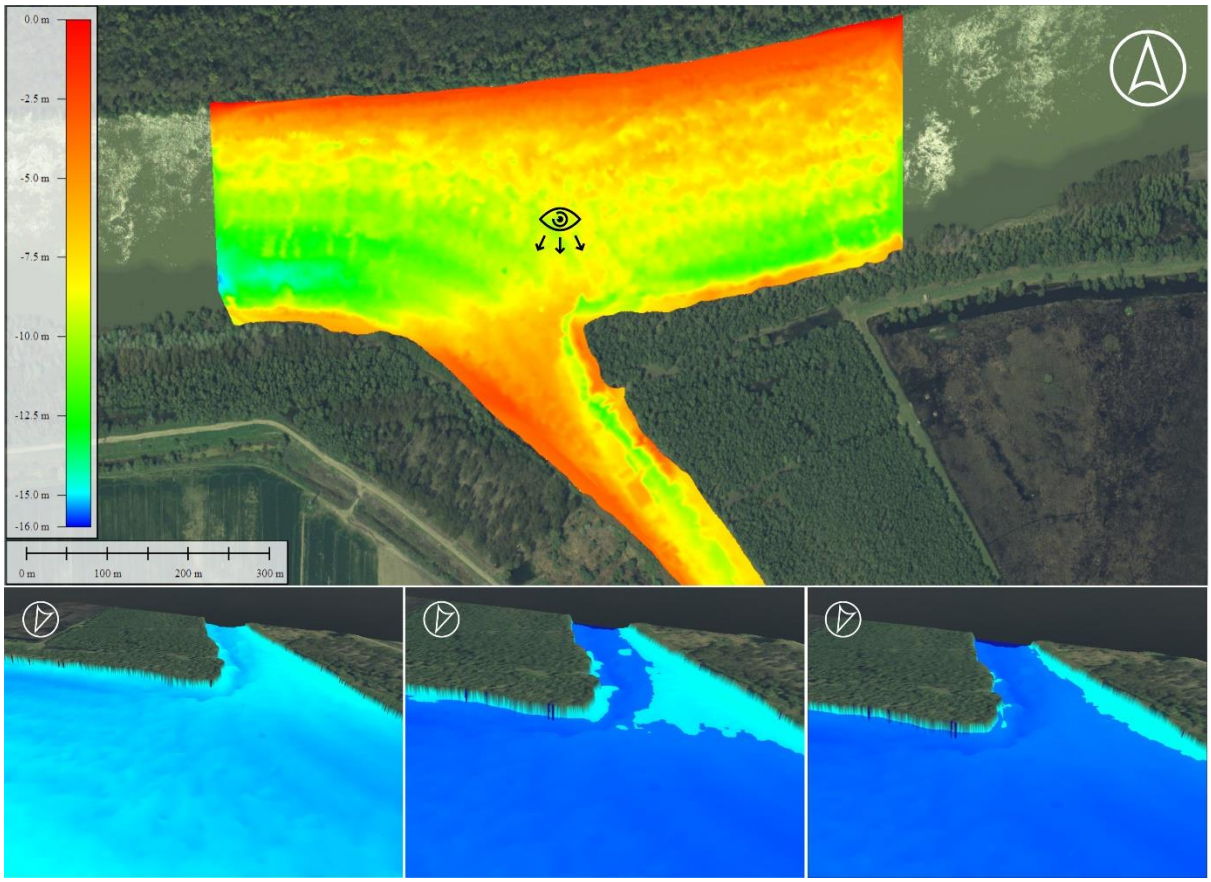

Figure 6. Perspective view of the configuration of the river bed at the fork of the main course of the Danube with the Dunavăț meander and the Dunavăț rectification channel.

Below, the three instances show the clogging of the right bank of the fork, near the mouth of the rectification channel by adding an exaggeratedly low water level (middle and right).

CONCLUSIONS

This analysis is intended to be a continuation of previous studies, namely "Studiul complex sedimentologic si geologic al modificărilor ambientale din Delta Dunării și zona litorală adiacentă determinate de amenajările hidrotehnice de pe brațul Sf. Gheorghe pentru identificarea măsurilor de protecție a ecosistemelor deltaice și litorale" developed by the Romanian Center for Marine Geology and Geoecology in 1994 and " *Analiza morfo-fractală a dinamicii hidro-morfologice a celor 3 brațe principale ale Deltei Dunării, Faza II – 2015: Analiza complexă a macroformelor – meandrele și ostroavelor Brațului Sf. Gheorghe* " by the "Danube Delta" National Research and Development Institute in 2015.

According to the overview of all the meanders of the Sfântu Gheorghe arm that was presented in this study, it attests the fact that any human intervention, no matter how well implemented, has repercussions in the future. And certainly not the repercussions are a threat because they were known and assumed when starting the project to regulate the watercourse but how they are managed when they present problems and / or threats on security, on the water regime balance and on species and habitats.

Of course, it was necessary to improve the navigation on the arm and shorten the route by about 30 km, which means a lot for the fuel economy and also the reduced navigation time. However, the impact on the balance of the hydrological regime, the morphodynamic processes, the liquid and solid flow, the changes of river mouth and last but not least the coastal area at that time, was to be felt sooner or later with varying intensities.

The fact that the flow velocity accelerated on the main course of the arm, through the rectification channels, this allowed a very intense lateral and vertical erosion, increasing its liquid and solid flow considerably. This generally leads to the sedimentation of bifurcations and especially of confluences with the rectified meanders, each of which, as can be seen, evolves differently.

Concerning the morphological changes of the meanders, the Dunavăț and Ivancea maintain a relative balance, so that they benefit from a considerable contribution of liquid and solid flow in terms of their relative positioning to the rectification angle.

The remaining meanders, on the other hand, have differentiated but sedimentary evolutions.
These meanders, that are subject to become oxbow lakes in the near future, can only be preserved through human intervention, which involves a financial effort that must be determined if it is feasible, if the preservation of water surfaces and lateral connectivity has beneficial advantages as a component part of the overall image and status of Ramsar site with worldwide recognition of the region as a resource of great natural and economic value.

The database created over time on the hydro-morphological changes of the riverbed of Sfântu Gheorghe arm and its analysis provides a richer knowledge about the otherwise normal evolution of the meanders after their rectification.

This enrichment of understanding of morpho dynamic processes generates new ideas and informed approaches in research and administration.
The data generated by the study facilitate new research project proposals but also serve the decision-making process in various aspects related to the environment, industry, transport and tourism.

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