MORPHOLOGICAL CHANGES OF THE FLUVIAL ISLETS FROM THE DANUBE RIVER (TURCESCU ISLET – CERNAVODA SECTOR) BETWEEN 1908 AND 2016

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Abstract. The studied area in this paper, belongs to the lower sector of the Danube River and is comprised between Turcescu islet (km 345) and Cernavodă (km 297). This area is characterized by numerous branches, secondary branches and islets, indicating a state of hydro- morphological instability of the riverbed. The hydro-morphological changes that occurred over the time in the analysed sector, have significantly affected the morpho-hydrography of the secondary branches. The consequences of riverbed changes in the Bala branch-Danube bifurcation area were reflected by increasing the takeover capacity of water by Bala branch to the detriment of the Old Danube. As a result of this process, a deepening of the Bala branch occurs at low waters, endangering the optimal depths for navigation, the occurrence of critical points for navigation downstream, morphological changes of the islets and the main elements of the riverbed. Along the analysed range, the number of islets present in the Old Danube riverbed increased during the period 1908-2008; in the last part of the interval (2008-2016) the number remained unchanged. Also, it is observed an increase in the total length of the islets and also changes in their geometry and position.

Key words: fluvial islet, Old Danube, critical points, morphologic changes

1. INTRODUCTION

During the last centuries, many of the World's rivers have strongly been affected by human intervention in various ways (Surian, 1999).

The hydro-morphological parameters of a river may suffer changes, depending on climate, various tectonic, geological or hydrological factors, and/or human intervention (Perşoiu, Rădoane, 2011).

Since ancient times, a series of anthropogenic interventions have occurred in various degrees along the Danube floodplain. Important changes occurred primarily during the communist period when the most part of the floodplain was used for agriculture. As a consequence of these changes, over 3000 km of artificial levees were built on the main course of the Danube River, of which more than 1100 km are located in Romania. The narrowing of the riverbed as an effect of the hydro-technical works led to an increase in the current velocity and to a significant erosion of the riverbed (Constantinescu *et al.,* 2015).

The damming of the Danube River (at the Iron Gates Gorge) and of its major tributaries led to the creation of numerous artificial lakes along their courses and lowered drastically the Danube's sediment discharge that feeds the current floodplain. A series of islets along the Danube River course have reflected all these hydro-morphological changes over the time (Constantinescu *et al.,* 2015).

Fluvial islets are present in nearly all major rivers and they must therefore have some impact on the fluid mechanics of the system. A fluvial islet is defined as a land mass within a river channel that is separated from the floodplain by water on all sides, exhibits some stability, and remains emerged during the bank full flow (Wyrick, 2005).

Another definition says that the islets are positive landforms, specific to the fluvial relief, which occur frequently by the deposition of alluvial deposits, where the riverbed widens or decreases the slope, or the river receives a tributary with more or less rough alluviums than its own (Marin *et al.,* 2015).

This paper present in detail the morphological changes of the islets during 1908 – 2016 period, in the Turcescu islet – Cernavodă area and provides new data and completions to the paper "*Evolution of Danubian islets from Balta Ialomiței hydrographic system (Km 345-241) between 1908-2016*", which will be published in the Scientific Annals of the Danube Delta Institute in Tulcea no. 23/2017. We have chosen this sector because it includes numerous islets and it has at present a great importance in studying critical navigation points (on the length of 48 km, 7 critical points are located). Five references years were selected for analysis *i.e.*, 1908, 1960, 1990, 2008 and 2016, in order to show the recent changes concerning the Danube islets from the selected area.

The study presents the analysis of the hydrological regime combined with cartographic materials and the analysis of recent satellite images, using GIS technology to illustrate the results.

2. STUDY AREA

The Danube River is the second longest river in Europe (2857 km) after the Volga, originating in the Black Forest Massif in Germany at a relative elevation of 1078 m, and discharging into the Black Sea via Danube Delta (McCarney-Castle *et al.,* 2011).

The Danube River is divided into three major sectors. The Upper Danube sector is comprised between the source and its confluence with the Morava River at Bratislava. This part is characterized by a pluvio-nival flow regime with high flow velocities and low water temperatures. The Middle Danube, from the Bratislava up to the Iron Gates dams, has a low elevation gradient and flows, through the lowlands of the Pannonian Plain. The Lower Danube crosses the Romanian-Bulgarian lowlands up to the Danube Delta at the Black Sea (Stagl, Hattermann, 2016).

The Old Danube is a part of the Lower Danube sector (Călăraşi-Brăila sub-sector), which is characterized by a floodplain of pond type, with the largest widths, 15 up to 25 km; the main levees are very wide, with heights of 3-10 m, and are associated with secondary levees and lacustrine depressions (Posea, 2005).

The area of interest is developed on terrigenous sediments. On this lithology, the Danube River has created numerous secondary branches, such as the Old Danube, situated on the right side of the course, adjacent of Dobrogean Horst (Stănescu and Stănculescu,1967).

The area studied in this paper is comprised between the fluvial milestone 345, located downstream of Bala branch (Turcescu islet) and the fluvial milestone 297 at Cernavodă (Fig. 1).

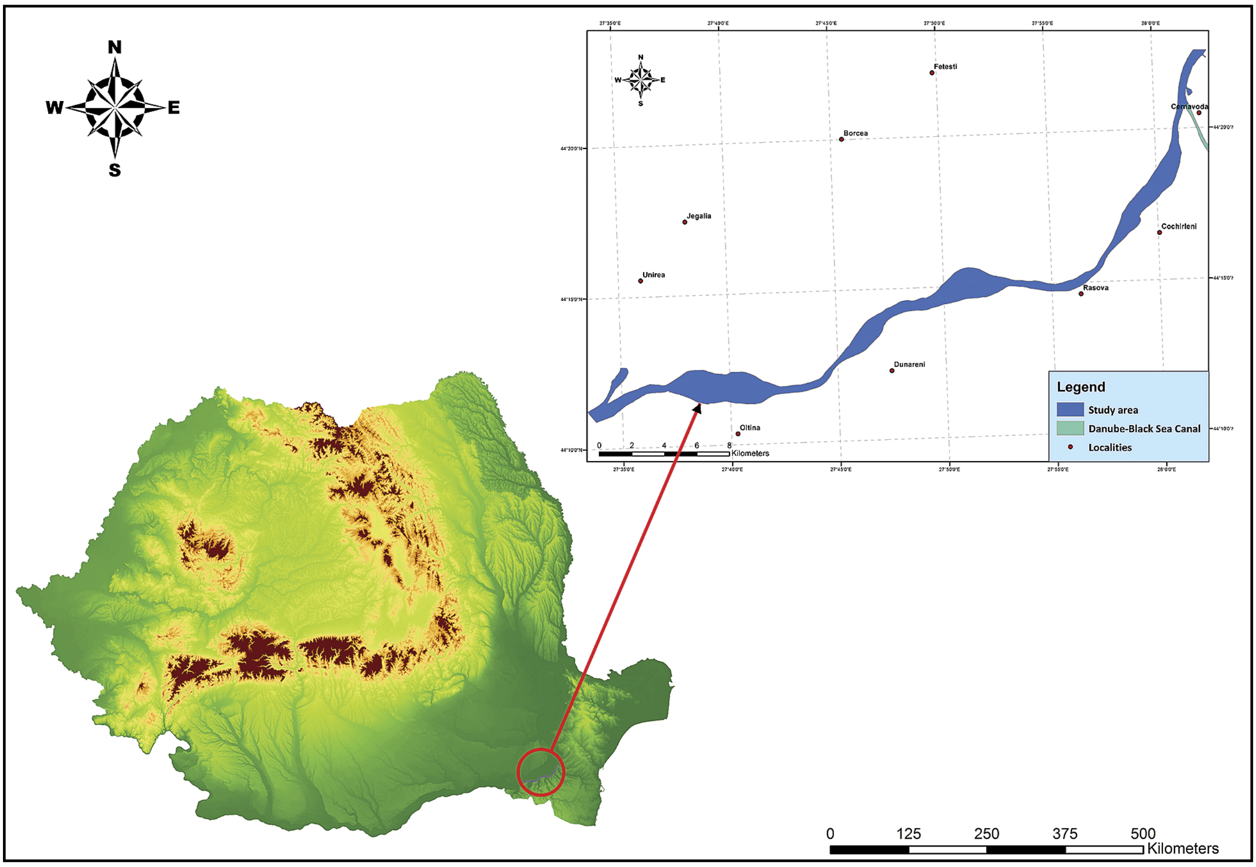

Fig. 1. Study area localization

3. METHODOLOGY

To highlight the morphological changes along the Old Danube between Bala bifurcation and Cernavodă, an inventory of the islets parameters (name, position within the riverbed, width and length) for the years 1908, 1960, 1990, 2008 and 2016 was made. We chose these reference years for the analysis because in the years 1908, 1960 and 1990 were performed the hydrographic surveys by the National Administration of Water Management in the proposed sector. The year 2008 was chosen as the intermediate year between the last hydrographic survey and 2016, but also because the available cartographic materials facilitated this option. The year 2016 was taken into account to highlight the latest situation of the state and evolution of the morphological parameters of the Old Danube riverbed.

To calculate the morphological changes occurred on the Old Danube islets from the selected sector during 1908 - 2016, we analysed the hydrological regime of the Danube during 1921 – 2015 period. Available hydrological data are: the annual mean levels, water discharge and the annual mean suspended load discharge. The water levels were extracted from the publications of the Danube Commission of Budapest, Galaţi Lower Danube River Administration and from the hydrological yearbooks.

The morphological changes of the Old Danube riverbed in the horizontal plane have been analysed and determined using cartographic materials and satellite imagery. Regarding the width of the Old Danube riverbed in the selected sector, we made measurements in 49 sections, whereby the riverbed widths were obtained at each fluvial milestone starting with km 345 up to km 297.

The cartographic materials used were historical maps, such as: *The Danube Navigation Map of 1908, Austrian Topographic Maps - 1910, reprojected in Stereo 70, Danube Navigation Map between km 374 and km 234, scale 1: 25000, edition 1965 (elaborated after measurements from 1960)*, *Commission du Danube, PROFILE EN LONG DU DANUBE, de ULM (km 2586.3) a SULINA (km 0) - 1989*. The accurate positioning of the fluvial milestones on the Old Danube was made using the Navigation Maps of Lower Danube River Administration, 2003 edition, through the georeferencing the entire map sheets from the analysed sector, using Global Mapper software. The orthophotoplans provided by the National Administration of Cadastre and Land Registration (*2008 edition*) were used for the year 2008. For the year 2016, the measurements were based on satellite images provided by LANDSAT 8 OLI/TIRS, which were taken from the USGS (the United States Geological Survey) site. The satellite imagery analysis was carried out using the specialized software for remote sensing, ENVI version 5.1.

The islets and the Danube riverbed were obtained after georeferencing and digitizing the historical maps. The parameters that define an islet were automatically calculated in the Global Mapper. The interpretation of the information obtained through the analysis of the cartographic materials was done both with hydrological data and with the reference sources.

4. RESULTS

In the studied area we made an analysis over the time in the hydrographic node Danube-Bala branch as well as along the riverbed up to Cernavodă.

In the Danube-Bala branch node, it is observed an increase in the width of the water access on the Bala branch from about 600 m in 1908 (Fig. 2) to about 750 m in 1960, and about 840 m in 1990. The increase in time of the riverbed width on the Bala branch led to an increase in the water take-up capacity from the Danube branch (DDSA). Subsequently, this situation has changed, and the width of the water access through the mouth of the Bala branch has declined reasonably due to the hydro-technical works. Thus, at the level of 2008, the width of the mouth of the Bale was about 400 meters, but the construction of the new jetty at the Bala branch mouth has drastically reduced the riverbed width (DDSA), so that in 2016, the width dropped by half, reaching only about 190 meters (Fig. 2).

One of the most important factors influencing morphological and hydrological changes is the anthropogenic impact. From the hydrological and hydrographic point of view, Balta Ialomiţei functioned naturally, until the embankment and drainage work started. Under natural conditions, this area had the role to attenuate the floods in the periods with high waters of the Danube. The situation was totally different after the finalization of the dams, so that during floods, the water in excess could not be dispersed in the adjacent area, and it was totally directed downstream.

In this study, the analysis of the hydrological regime changes is carried out. A survey of the multiannual variation of the Danube average levels at the Călăraşi, Cernavodă, and Hârşova gauge stations during the period 1921 - 2015 (Fig. 3), permitted to draw several conclusions:

- it is observed that the highest average annual rates of decrease in time of the Danube levels belongs to Cernavodă gauge station, and the smallest average annual rates of decrease were recorded at Călăraşi gauge station;
- the annual Danube level average in the Balta Ialomiţei hydrographic system shows a decreasing tendency over time;
- the highest annual average rates of decrease of Danube levels over time are recorded at the Cernavodă and Hârşova hydrometric stations and have values of - 0.79 cm/year, and - 0.26 cm/year;

It is observed an appropriate synchronism of the time variation of the Danube annual average levels in the studied locations.

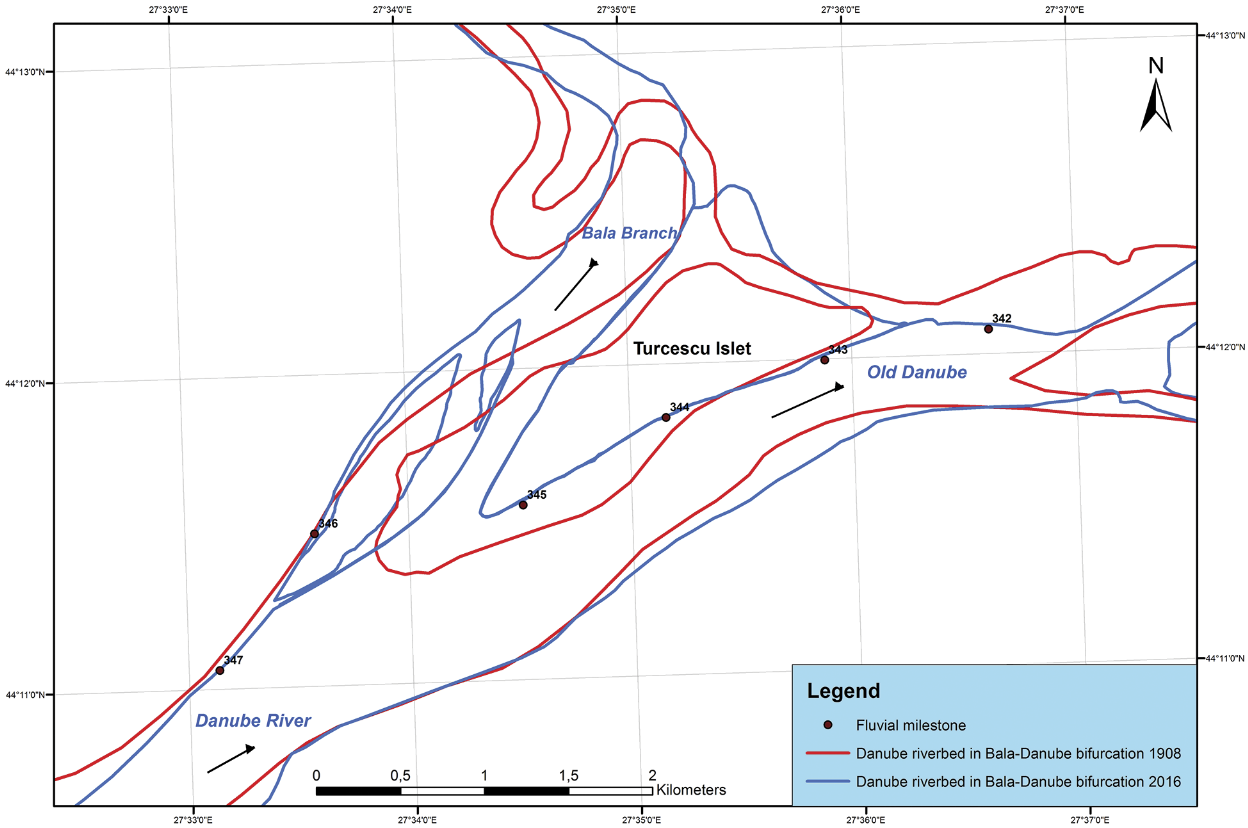

Fig. 2. Bala branch – Danube bifurcation km 345 (1908 and 2016)

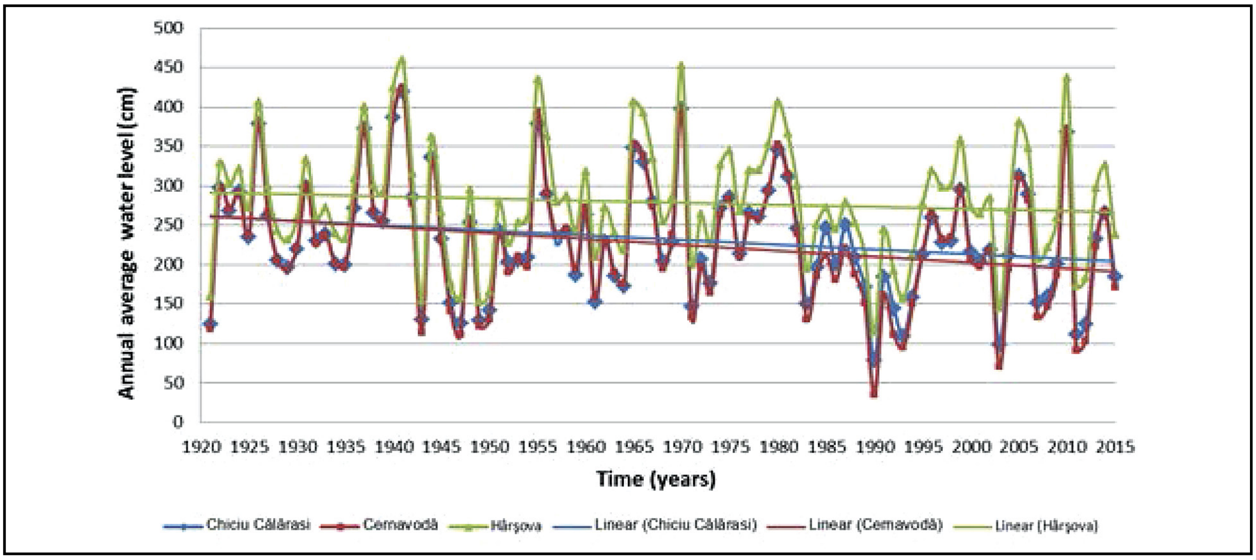

Fig. 3 . Multiannual variation of the average annual levels of the Danube at Călărași, Cernavodă and Hârșova between 1921 and 2015

To characterize the long-run water drainage regime on the Danube branch at Călărași, Cernavodă, and Hârşova, the average annual water flow rates for the period 1921 - 2015 were compiled. Figure 4 shows the variation of the average water flows at the three hydrometric stations, and there is a tendency to decrease at the Călărași and Hârşova stations, but not as obvious as at the Cernavodă station.

Regarding the suspended sediment discharge, the graph of the variation of the average annual flows of suspensions on the Danube branch of the Călărași, Cernavodă, and Hârşova hydrometric sections for the years 1921 - 2015 (Fig. 5) was drawn up.

From the analysis of Figure 5, the decreasing trend over time and the synchronism of variation of the average annual flows of suspended sediment in Cernavodă and Hârşova hydrometric sections are to be observed. This tendency of decreasing the sediment discharge is also observed in the case of the Călărași hydrometric section, but the synchronism of the variation of the suspended sediment discharge it is observed only until the Iron Gates I dam erection. From Figure 5, results that there are two thresholds for decreasing the amount of suspended sediment, due to the construction of the Iron Gates I and II dams in 1970, respectively, 1984.

The balance of the sediment discharge on the Danube branch between the Cernavodă and Hârşova hydrometric sections allows the knowledge of the morphological processes in the riverbed that occur in the respective sector. From the analysis of the multiannual average discharge of the suspended sediment, results the mean values of suspended sediment are equal to 1095 kg/s at Călărași, 461 kg/s at Cernavodă and 316 kg/s in Hârşova. The difference resulting from the input and output suspended sediment flows in the analysed riverbed sector gives the value of the suspended sediment flow that participates in the morphological processes of the riverbed.

Between Călărași and Cernavodă, the mean value of suspended sediment flows, for the period 1921-2015, is 634 kg/s with significant losses of sediment at the confluence with Borcea branch (km 370) and Bala branch (km 345). Also, sediment deposition is influenced along the entire sector (between km 370 - km 297), showing an important diminution of the amount of sediments. These deposits are included, partially within the Danube riverbed, and another part contributes to the modification of the dimensions and the formation of new islets.

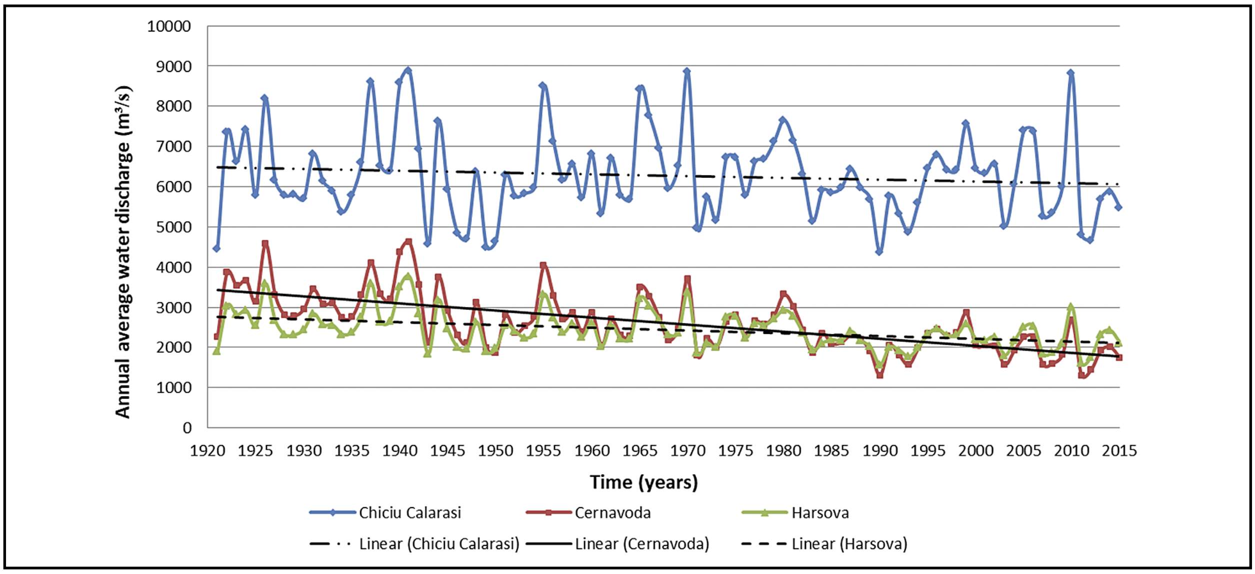

Fig. 4. The variation of the average annual water discharge of the Danube at Călărași, Cernavodă and Hârșova during 1921-2015

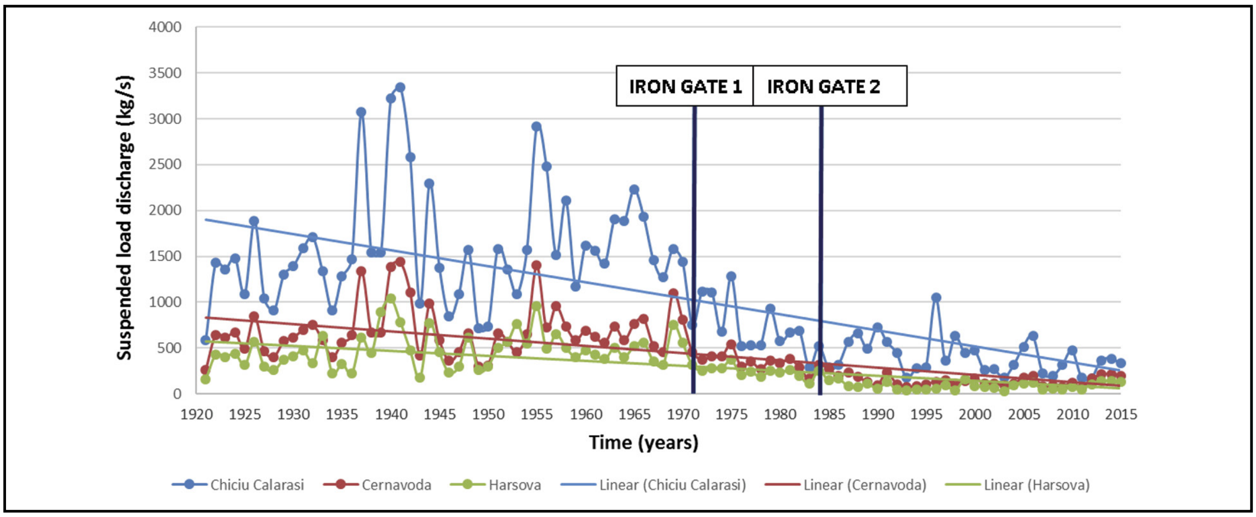

Fig. 5. The variation of the average annual suspended sediment discharge of the Danube at Călărași, Cernavodă and Hârșova during 1921-2015

Between Cernavodă and Hârşova, the mean value of suspended sediment flows, for the period 1921-2015, is 145 kg/s with deposition effects on the entire course (between km 300 - km 253) (DDSA). After analysing the available materials, more information about the change of the islets characteristics over the time in the Danube riverbed have been obtained. Using GIS software, some morphological parameters of the islets were calculated (average length and maximum width), which are highlighted in Figures 6, 7, 8, 9 and 10.

Based upon the data presented in the previous figures, there were calculated the synthetic data of the morphometric characteristics of the islets located along the Danube branch between km 345 and km 297 (Table 1).

The Table 1 shows that the number of islets has increased continuously since 1908 up to 2008, from 11 to 18, afterwards, these remains constant until 2016, when were recorded the same number of islets. This is due to the takeover of an increasing flow by the Bala branch to the detriment of the Danube. Regarding these issue, Bondar (2015), highlighted the following evolution of water discharge repartition on Bala branch and Danube downstream Turcescu islet. Thus, in 1921, the water discharge percentages on the Bala branch were 39% and on the right branch of Turcescu islet (on the Old Danube) was about 56%. The natural phenomenon of increasing water discharge on the Bala branch continued, reaching the 56% in 2010, with a reduction of water flow downstream Turcescu islet with a percentage of about 32%. In the year 2015, the annual decrease rate of water flow on the Danube, downstream of Turcescu islet, increases to 8 m^3/s/year (Bondar, 2015). The most islets are located on the right side of the Danube riverbed. The average lengths of the islets range from 2.2 to 3.05 km, Turcescu islet being the most stable of them.

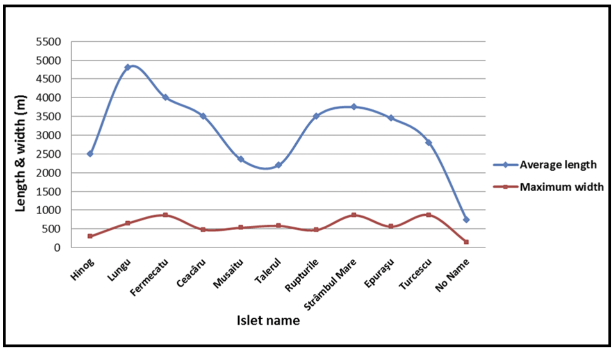

Fig. 6. Morphological parameters of the islets in 1908

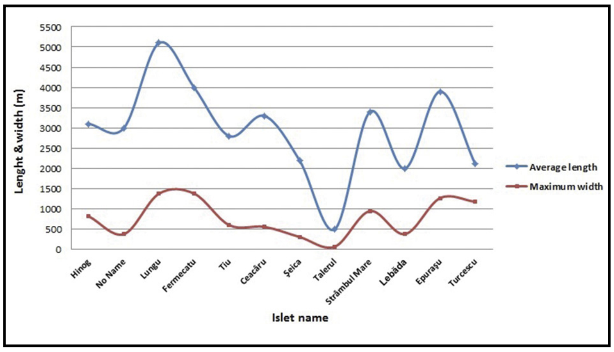

Fig. 7. Morphological parameters of the islets in 1960

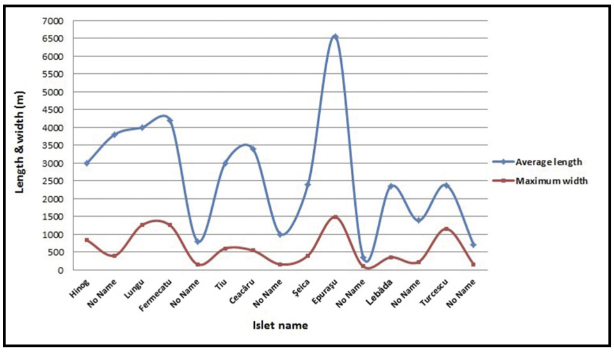

Fig. 8. Morphological parameters of the islets in 1990

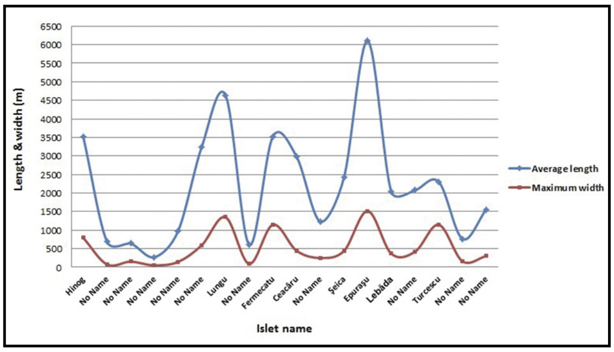

Fig. 9. Morphological parameters of the islets in 2008

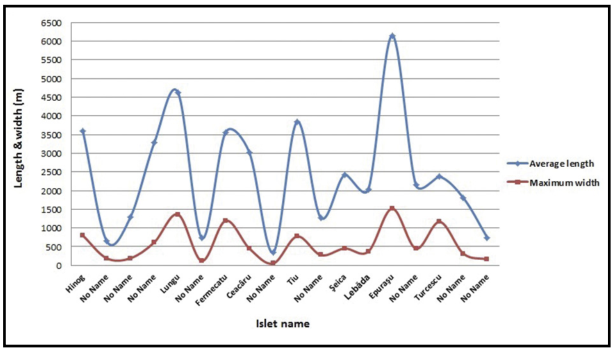

Fig. 10. Morphological parameters of the islets in 2016

Table 1. Morphometric characteristics of the islets

Morphometric characteristics of the islets from Turcescu islet – Cernavodă sector	Years				
	1908	1960	1990	2008	2016
Total number of islets	11	12	15	18	18
Total length of islets (km)	33.6	35.4	39.3	39.6	43.9
Average length of islets (km)	3.05	2.95	2.62	2.20	2.44
Number of islets on the left side of the riverbed	5	4	6	6	6
Number of islets in the centre of the riverbed	1	0	1	1	3
Number of islets on the right side of the riverbed	5	8	8	11	9

CONCLUSIONS

The hydrologic data and the cartographic materials play an important role to highlight the variability of the riverbed. In the studied section of the Danube, natural and anthropogenic factors influenced the hydro-morphology of the river. Major changes have been occurred both with regard to the hydrological regime of daily levels and water and sediment discharge.

Cartographic documents and satellite imagery reveal spatial changes of the Danube riverbed in the study area.

Over the years, the number of islets from the Danube riverbed increased during the period 1908-2008, afterwards their number remains constant up to the end of the studied interval. There is also an increase in the total length of islets and changes in the position of the smallest of them. Islets along the Danube course have directly reflected all these hydrological changes over the time.

From the examination of the data, results as a general conclusion that the riverbed is widening over time and the average depths also decrease. These results indicate that the Danube riverbed from the Balta Ialomiței hydrographic system is suffering a process of physical degradation, with negative consequences on the hydrological regime of the water flows, sediment and riverbed morphology.

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