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MORPHOLOGICAL DYNAMICS OF THE ISLANDS ON THE LOWER DANUBE RIVER IN THE CĂLĂRAȘI-CERNAVODĂ SECTOR AND GIS ERROR ASSESSMENT

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Abstract. A diachronic analysis of the geomorphic units using a geographical information system (GIS) that integrates historical maps, aerial and satellite imagery is a useful method to explore fluvial morphodynamics. This study used the mentioned spatial data sources to investigate the morphological changes of the islands on the Low Danube River between Călărași and Cernavodă between 1864 and 2016. At the same time, the accuracy of the cartographic materials was evaluated to differentiate between real change caused by identification or positional errors. There is a general increase in area and number of islands in the study area in the context of decreasing sediment volume transported by the Danube.

Keywords: diachronic analysis, river island, accuracy assessment, mapping, Danube River

1. INTRODUCTION

The study of river planform at different temporal and spatial scales provides valuable information for river management. Due to its great ecological importance and because it is a vital European navigable axis, it is crucial to investigate how the hydrogeomorphology of the Danube River changes in time under the influence of natural and human control factors. The results of such investigations can lead to making better long-term decisions when designing local hydrotechnical amenities or planning conservation or restoration areas.

Anthropogenic impacts on hydrogeomorphology is one of the most important pressures on the Danube river, altering hydrological parameters (such as discharge and water level), sediment discharge, river planform and affecting ecological functions in the river and adjacent floodplain (Habersack, Jäger and Hauer, 2013). This has in turn socio-economic effects by eliminating the benefits offered by natural conditions, such as flood mitigation, nutrient cycling and pollutant retention (Gâştescu and Tuchiu, 2012).

Identifying geomorphic elements such as river islands and their spatial patterns (size, position, shape) over various timeframes is of interest in the analysis of river dynamics (Brierley and Fryirs, 2005). A broad view on fluvial evolution can be achieved by integrating historical and topographical maps with aerial and satellite imagery and mapping in a Geographical Information System (GIS) to display river conditions in different periods. However, one of the greatest challenges in the analysis of river hydromorphological change concerns the accuracy and error propagation generated by the nature of the data sources.

The analysis performed in this study focuses on the islands in the Lower Danube. Island dynamics is tightly related to erosional, sedimentation and transportation processes in the river channel, and therefore influenced by anthropic intervention such as hydrotechnical facilities and land-use change. The water and sediment regime of the Danube have been heavily influenced by human interventions along its course or on tributaries, affecting the number and area of islands.

River islands are mid-channel bars of larger size and higher stability compared to other bar deposits and they have a large capacity for sediment storage (Charlton, 2008). Their shape is often elongated and the sediment size decreases from the head to the end of the bar (Gurnell *et al.*, 2001). Vegetated mid-channel bars often develop around a bar core encroached by plants that continuously trapped sediment and expanded its size, or around rock outcrops. River islands can present a complex composition of various geomorphic elements on their surfaces, such as sand deposits or water channels.

The stability of the river planform can be assumed when the number of vegetated islands surpasses the amount of bar deposits, whose sediments can be easily entrained by the next flood events (Brierley and Fryirs, 2005). Anabranching rivers are characterized by their multi-channels that delimitate very large, stable islands that persist for decades or centuries (Knighton, 2014). The essential characteristics that offer insight into the history of the depositional unit are the boundary, shape and lithological structure, but also tree age can be used as a proxy (Kaczka, Wyżga and Zawiejska, 2008).

During the analysis of fluvial change several errors could alter the accuracy of the results that are propagated at every phase from data transcription to the final stage of analysis (Downward, Gurnell and Brookes, 1994). One type of error stems firstly from the process of co-registering the data sources to a common coordinate system during georeferencing (Hughes, McDowell and Marcus, 2006). The choice of Ground Control Points (GCPs) can further influence the quality of the result through its type and location – hard points (buildings, crossroads) are preferred over soft points (trees, rock outcrops) (Hughes, McDowell and Marcus, 2006) The image is warped to fit the GCPs and the result has a certain degree of residual error. Root Mean Square Error is often used as a measure of this type of error, but it could lead to over or under-estimation of geomorphological change so preferably independent test-points are used (Hughes, McDowell and Marcus, 2006; Lea and Legleiter, 2016). It was suggested that using test points independent from the GPCs used for georeferencing are more suitable for estimating errors (Hughes, McDowell and Marcus, 2006). The test point method has been used on studies on channel instability (Martin and Pavlowsky, 2011) and post-dam downstream changes

(Walter and Tullos, 2010). Precise localization of elements is unlikely, therefore an accuracy assessment must be performed to differentiate real change between one moment and another (Downward, Gurnell and Brookes, 1994; Mount *et al.*, 2003). This type of error shall further be called *positional error*. It is considered systematic and directional (Mount *et al.*, 2003) .

In addition, *identification error* is related to digitization inaccuracy coming from the process of translation of map elements into vector data and depends on the operator (Downward, Gurnell and Brookes, 1994; Walter and Tullos, 2010). True change is determined as what is exceeding the error threshold, equivalent to the total between positional and identification error (Downward, Gurnell and Brookes, 1994).

In the context mentioned above, the main aims of this study are 1) to investigate the morphological dynamics of the islands on the Low Danube River in the Călărași-Cernavodă sector, between 1864 and 2016, based on diachronic analysis of cartographic data and aerial images 2) to assess the errors associated with the data sources. This paper seeks to reach these goals through the following operational objectives: 1) mapping the island geomorphic change; 2) quantifying the error inherent in every data source and exploring how this influences the results. Discussions on the possible causes of island dynamics are developed.

Study area and major factors controlling the river channel and island dynamics.

The study area is located on the Lower sector of the Danube River, an important region for wetlands and floodplain ecosystems. The Danube River basin includes 97.4% of Romanian river networks which covers an area of 232,193 km^2 (or 29% of the total basin) (ICPDR, 2015). Often the legal status of newly formed sand bars is unknown, due to the fact that the river forms the border between Romania and Bulgaria. (Doniţă, Biriş and Filat, 2008). The studied islands are located between the towns of Călărași and Cernavodă, on the Old Danube channel (Fig. 1). The largest islands in the Călărași-Cernavodă sector are Șoimu (1.04 km^2), Turcescu (3.13 km^2), Ceacâru (1.73 km^2), Tiul (3.22 km^2), Fermecatu (6.40 km^2), Saica (1.49 km^2) and they are subject to forestry management plans.

The dynamic of the river channel and islands in the Lower Danube can be attributed to several factors (e.g. lithology, hydrological regime, vegetation, human pressures). At large temporal scale, the major factors controlling the dynamics of the Danube River channel are the Black Sea water level variations, as well as negative tectonic movements. Within the studied sector, the Danube River has an asymmetric valley, with an extensive floodplain on the left and higher elevation on the right side, without terraces (DGAAR, 2005; Ielenicz and Pătru, 2005). The right side of the river has a Cretaceous base with rock outcrops and it is covered with Pontiene, Dacian and Romanien sediments, as well as a layer of loess

(DGAAR, 2005). The lithologic profile is structured on a bedrock of sandstones, marl, limestone and clays with a base layer of gravel and boulders (variable thickness), on which lies a layer of silty sands and gravel (3-5 meters) and a top layer of 2-4 meters composed of silty sands, and fine-grained sediments such as clays (DGAAR, 2005). Bar surfaces are mainly sandy, and low-lying strips are formed from fine-grained sediments (DGAAR, 2005; Popp, 1985).

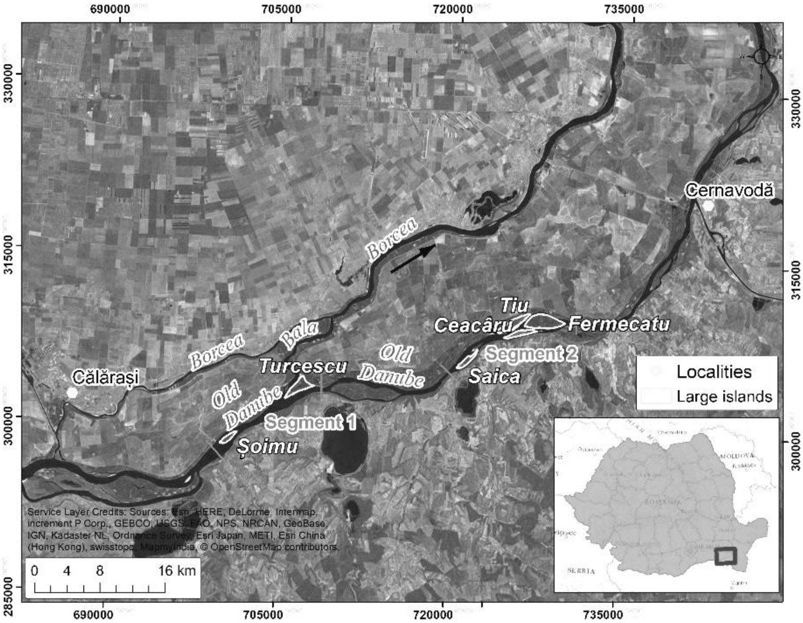

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Fig. 1 Location of the study area and islands

This sector has the largest width of the Danube floodplain with a maximum of 30 km. Two very large islands have formed (Balta Ialomiței and Insula Mare a Brăilei), with an area of 831.3 km², respectively 710 km² which initially were covered by large lakes and complex riparian ecosystems but closed up due to natural processes as well as draining (Nedea *et al.*, 2012). The embankments and the intensification of agricultural activities promoted the aggradation processes in this sector of the Danube, where Balta Ialomiței and Balta Brăilei are evident results of this process (Nedea *et al.*, 2012). They are surrounded by 2-3 branches of the river (anabranches), due to the decreasing slope and transport capacity (Constantinescu *et al.*, 2015). Typical geomorphological features of the Lower Danube sector are fluvial lakes formed through barring of river mouths followed by elongated islands (DGAAR, 2005). The river bed has a very low slope of 0.02 – 0.04 % (DGAAR, 2005) and the current velocity is about 0.8 m/s (Sommerhauser, 2003). The islands formed on the river have the tendency to accumulate sediments and to connect to the floodplain. Other geomorphological processes that take place are the anastomosis of backwaters and secondary branches, as well as breaching and flooding bars and deposition of fan-shaped deposits.

The Danube River, in its lower sector has a Ponto-Carpathian hydrological regime, with an average flow in the studied area of about 6000 m^3/s. Yearly flow peaks occur mainly in spring (about one third of the annual volume) caused by heavier rainfall and snowmelt), while in spring flow is less than 20% of annual volume (Zaharia and Ioana-Toroimac, 2013). The average annual amplitude of water level variation is about 291 cm at Olteniţa gauging station (located at approximately 62 km upstream from Călărași) (DGAAR, 2005). On the Lower Danube, there was an increase in discharge and water level due to upstream impoundments (Constantinescu *et al.*, 2015).

In 2006 there was the highest flood recorded in the period between 1840 and 2006 and it reached a water level of 737 cm at Olteniţa (Armaş *et al.*, 2015). The discharge reached a record value of 15,800 m^2/s at Baziaș, having a 100 year return period (Spahiu, Narcizia and Lidia, 2006). In 2003 there was the lowest discharge recorded in 100 years (1,640 m^3 at Porțile de Fier) due to a severe drought; the situation was so severe, that the nuclear reactor at Cernavodă had to be closed for one month (Spahiu, Narcizia and Lidia, 2006).

Vegetation has a characteristic riparian and water meadows composition and the dominant forest species on the floodplain and islands are willows and poplars, specifically *Populus alba*, *Populus nigra*, *Populus euroamericana*, *Ulmus*, *Ulmus laevis*, *Fraxinus excelsior*, *Salix alba*, *Salix fragilis* as well as *Quercus robur*, *Quercus pedunculiflora* and *Robinia pseudoacacia* (Doniţă, Biriş and Filat, 2008). The incipient stage of woody vegetation on sandy bars is often represented by shrubs of *Tamarix ramosissima* (DGAAR, 2005). Natural riparian *Salix* and *Populus* forests have been diminished because of extended areas of plantations with hybrid poplars and willows, and invasive species like *Fraxinus pennsylvanica*, *Acer negundo* and *Amorpha fruticose* (Doniţă, Biriş and Filat, 2008).

Populus americana is mainly found in plantations, however it has been noticed that is not very resistant to persistent flooding like *Salix* because of their superficial root system therefore plantations have been reduced despite the larger timber volume that it produces (DGAAR, 2005). Also, these plantations have experienced problems like drying due to the changes in the Danube's hydrological flow (Doniţă, Biriş and Filat, 2008).

Plans of large scale embankments of the Danube floodplain and the Danube Delta have been developed since the beginning of the 20th century to increase agricultural fields and protection against flooding (Doniţă, Biriş and Filat, 2008). In 1910 there were 7,100 ha of embanked floodplain. In 1962, there were already plans of embanking 435,000 ha of floodplain surface from a total of 573,000 ha (Botzan *et al.*, 1991). The evolution of embankments along the

Romanian bank of the Danube River is shown in Fig. 2. Their implementation was intensified after 1966, when there was a dramatic increase in non-submersible embankments of the floodplain and the two hydro power plants – Iron Gates I and Iron Gates II – were finalized in 1972 and 1984 respectively. Significant works were performed also on the Bulgarian side of the river (Stefan and Kirilova, 1979). These facilities alter the natural sediment regime of the river by obstructing the flow of water and trapping sediments behind the dams (Maximov, 2008).

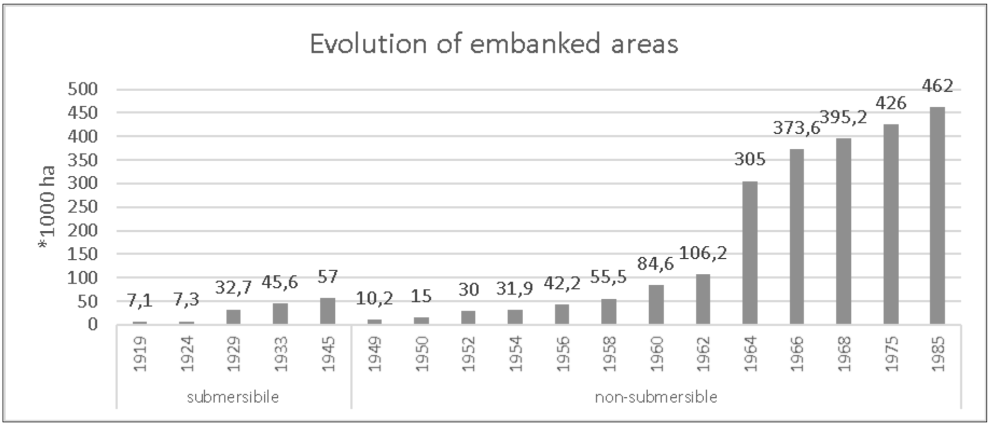

Fig. 2 Evolution of embanked areas on the Romanian bank of the Danube floodplain. Modified after Botzan et al, 1991

In 2008 there were 1,158 km of dams, a surface of 431,760 ha was embanked, 418,000 ha was drained and 225,000 was irrigated (Vişinescu and Bularda, 2008). Nowadays, the floodplain is reduced to about 20% of the initial extent, and the islands in the river channel are a part of this still existing forested area (Doniţă, Biriş and Filat, 2008). These facilities have greatly increased agricultural areas, however agricultural activity is nowadays less intense compared to the Communist period. Approximately 20,000 ha of forest surface have been cleared to make space for the embankments and draining of the floodplain (DGAAR, 2005).

Following the completion of Iron Gates I and II, sediment load was significantly diminished. Sediment load decreased in the 1970 - 2000 interval by 55% compared to the 1921 – 1960 period, when measured upstream from the Danube Delta at Ceatal Chilia (Zaharia *et al.*, 2011). Sediments transported by the Danube diminished from 66 million t/year to 30.4 million t/year.

Temporal distribution has also been altered by impoundments, by noticing that transport happens mostly at large flooding events, and not uniformly along the year (Habersack, Jäger and Hauer, 2013). Due to the lower sediment loads, elevated rates of bank erosion were noticed (Doniţă, Biriş and Filat, 2008). Bed incision is also present on the lower Danube, with an yearly erosional rate between 1 – 3.5 cm (Habersack *et al.*, 2016). Hydropower plants have evident effects on the local environment, as well as cascading effects on downstream and upstream regions. These facilities plants trap sediments in the reservoir behind the dam and the "hungry waters" that are released which are almost void of sediments increase erosion downstream (Kondolf, 1997).

The sediment retention at the Iron Gates power plants works in conjunction with the other damming works and hydro power plants on the tributary rivers. Embanking and climate change factors have increased the water level on the Lower Danube River by 40-50 cm (Zaharia and Ioana-Toroimac, 2013) especially on the Bala-Borcea channels (Botzan *et al.*, 1991), while on the Old Danube branch the decreasing water depth in the summer can be problematic for navigation (Nedea *et al.*, 2012).

2. DATA AND METHODOLOGY

2.1.Data and tools

This paper is based mainly on the treatment of spatial data extract from several sources (maps and aerial imagery), from different periods. A summary of the used data sources is presented in Table 1.

The main software used for creating a geospatial database was ArcMap 10.3. All sources and subsequent data were projected to WGS 84 (EPSG 4326). The year 2013 was chosen as a reference date against which to compare the other sources because of the availability and satisfactory resolution of the World Imagery basemap layer in ArcMap.

Table 1 Summary of data sources

Year	**Name**	**Scale/resolution**
	Historical maps	
1864	Map of Southern Romania	1:57,600
1910	Generalkarte von Mitteleuropa	1:200,000
1920's	Romanian maps under 'Lambert-Cholesky' (1916-1959) projection system'	1:20,000
	Topographic map	
1981	Topographic map	1:25,000
	Aerial imagery	
1960 (22.9.1966, 12.5.1968)	Declassified Satellite Imagery 1	1966 - 2.7 m 1968 - 1.8 m
1975 (29.06.1975)	Declassified Satellite Imagery 2	KH-9, 6 to 9.1 m
2005	Orthophotoplan	1:5,000
2013	ArcMap World Imagery basemap	0.5 m
	Satellite images	
1989 (25th June)	Landsat 4	30 m
2016 (7th September)	Sentinel 2A	10 m
	Forest management plans	
1971	Trapeze	1:5,000
2007	Amenajamente silvice ('forestry plans')	1:100,000

2.1. Islands dynamics analysis

To investigate the dynamics of the islands in the study area, two segments of approximately 15 km long have been delimited on a stretch on Old Danube channel, further called Segment 1 and Segment 2. Segment 1 represents the channel before the separation into the Bala channel, and Segment 2 is located south from Balta Ialomiței Island (Fig. 1).

The islands boundaries in Segment 1 and Segment 2 were digitized for every year (Fig. 3), and total number and area of islands for ach segment were computed to quantify the changes, based on the diachronic analysis. A visual analysis of island shape was also carried out.

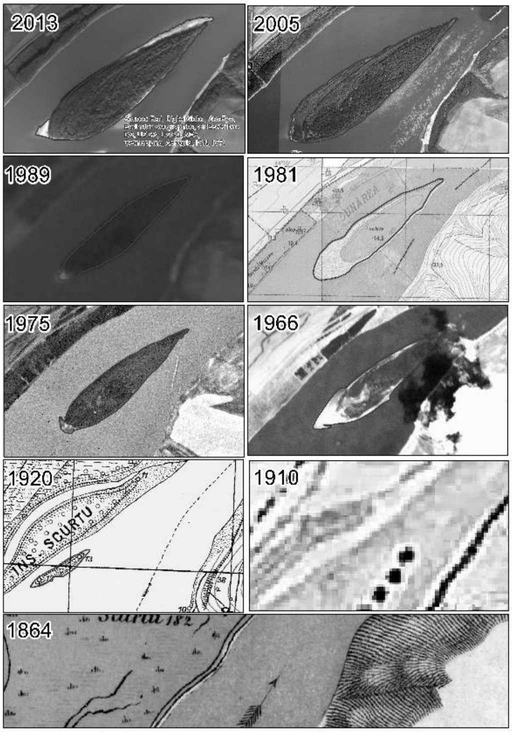

Fig. 3 Digitization of an island. Year 2016 is not shown

2.2. Accuracy assessment

To be able to distinguish real change in island dynamics, two types of error were estimated, namely the positional and the identification error. 25 test-points were identified on all the cartographic materials by finding corresponding hard points (crossroads, churches, buildings) with the 2013 reference layer.

The exceptions were the year 1864 because of the difficulty of finding matching points (low-populated area, shifting landscape due to fluvial processes) and the year 1989 because of the resolution of the Landsat image. Therefore, the RMSE of these two sources was used as positional error instead of the test-point error. The Euclidean distance in meters between the points identified on the maps and on the 2013 layer was computed. The positional error (e_{xy}) for each year was further calculated as the average test-point error.

The identification error was calculated after repeat digitizing of a geomorphic element for every year at a consistent scale, following the method presented by Downward (Downward, Gurnell and Brookes, 1994). The side of one island was chosen and digitized 31 times (Fig. 4), then the distance between the first and the rest of 30 lines was averaged. The 95% confidence was computed for the averaged distance and the margin of error was used as identification error (e_{id}) for perimeter.

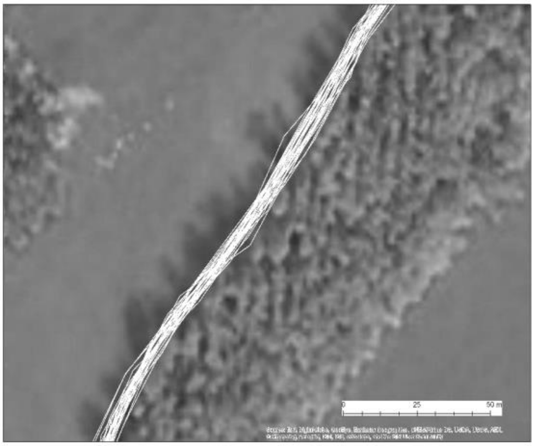

Fig. 4 Island boundary digitization (31 times)

Finally, the positional and identification errors were summed up to compute the total error. The combined error represents the total error of one year and of the following year and it is used to identify real change within an interval. A buffer that is equal to the total error values is created around the island limits for every year for mapping their evolution and assessing visually the variability of their position.

3. RESULTS AND DISCUSSION

3.1. Landform evolution

The results of this study show that the development of the islands between 1864 and 2016 was distinctive between the two segments (Fig. 5, Table 2). In Segment 1, the geomorphic units were relatively stable in terms of total area and number of islands along the years. In Segment 2 the number of islands was increasing between 1864 and 2016 and the island area was increasing until 2005, after which a decrease was observed (Fig. 6). In the recent period, there was a positive peak in 2005 in the number of islands for both segments.

Table 2 Island area total for each segment between 1864 – 2016

	2016	2013	2005	1989	1981	1975	1966	1920	1910	1864
Segment 1	4.19	4.32	4.79	3.78	4.26	4.09	4.28	6.82	4.64	3.40
Segment 2	14.40	12.82	12.71	11.19	11.00	10.97	10.81	8.70	1.80	1.85

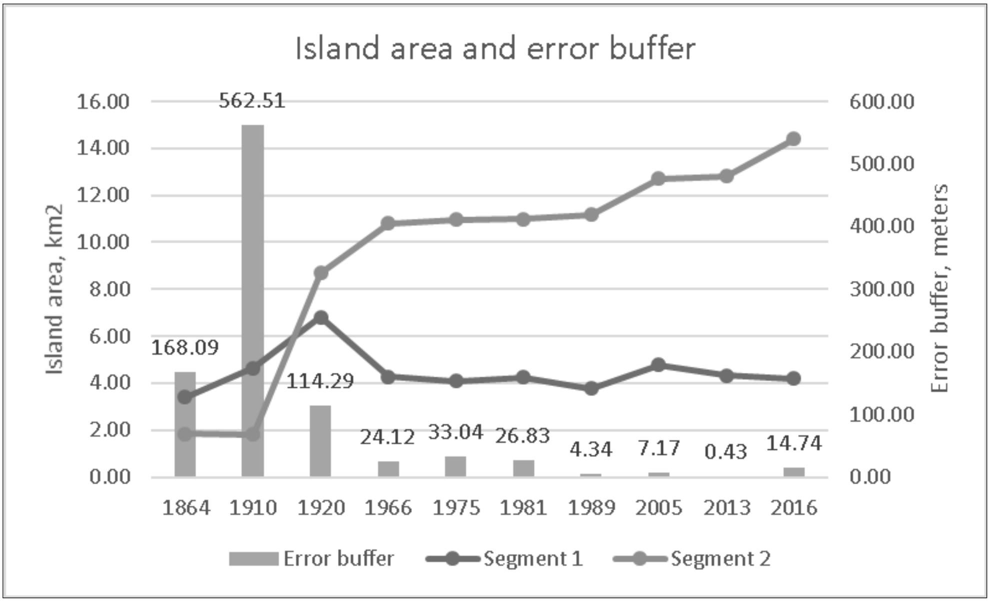

Fig. 5 Island area and error buffer

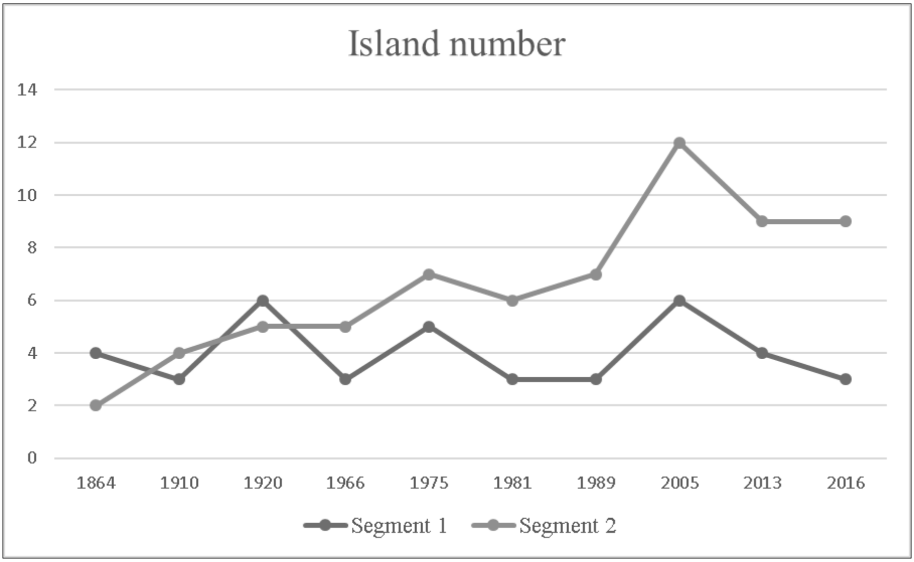

Fig. 6 Number of islands

The spatial evolution of the islands between 1864 and 2016 can be compared in Fig.7. The island boundaries are associated with the total error buffer for each year. The areas of certain change are the ones between the buffer zones, while the core area is incorporated into most of the perimeters of each year.

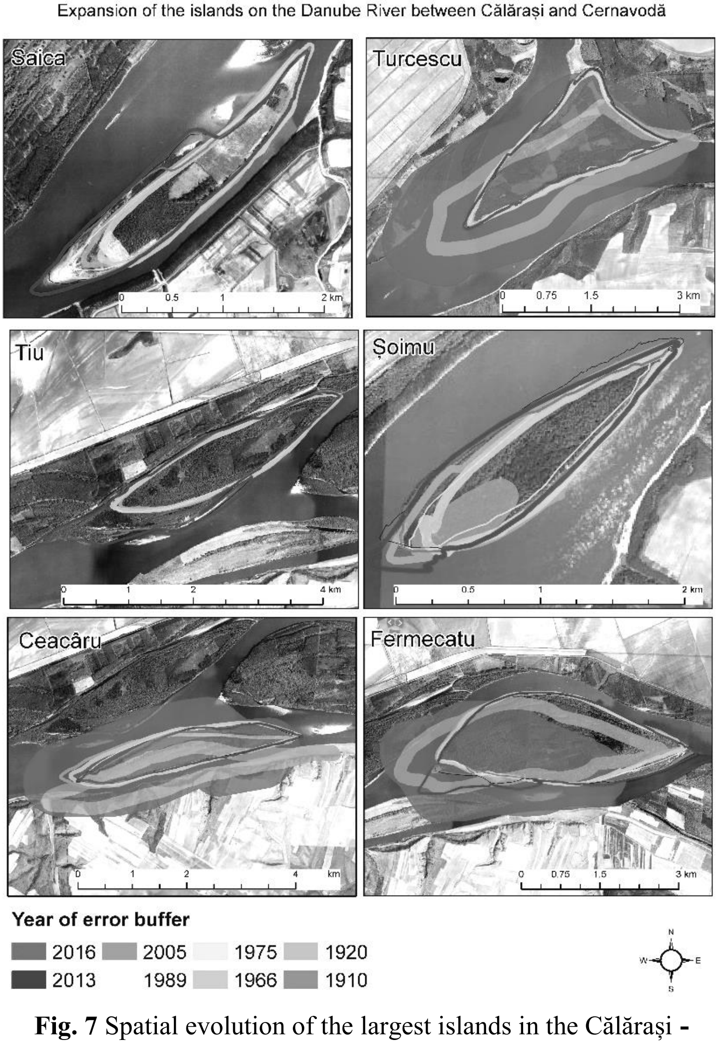

Fig. 7 Spatial evolution of the largest islands in the Călărași **-**

In Segment 1, the largest island – Turcescu – had a stable evolution after 966, while Șoimu varies around a similar value. The year 1920 is the origin year for Șoimu, while Turcescu was already existing as a small island in 1864.

Segment 2 displays a slightly different behaviour. While the largest island, Fermecatu, was stable up to 1989, afterwards is shows a constant increase, the same as Tiu, Saica and the area of other islands. Ceacâru Island shows a slight increase after 1966, and it starts to decrease after 1981. The genesis of Saica and Tiul islands is recorded in 1920, while Ceacâru firstly appears on the 1910 map. Fermecatu Island seems already existing in the 1864 map.

Two types of island shapes were identified: the most common one was an elongated shape with the wider part in the upstream part (Șoimu, Saica and Tiul) and elongated with a wide central part (Fermecatu, Ceacâru). The exception was Turcescu Island, which had a triangle shape with the base towards Balta Ialomiței.

The results show that the islands tend to increase in area and number in Segment 2 in the context of diminishing sediment volume in the Danube River, which may be due to a few elements, such as structure of alluvium, decreasing energy flow on Old Danube branch, channel engineering and neotectonic uplift of parts of the valley. In reviewing the literature, strong references were also found on the association between geomorphological processes in the river channel and vegetation development, specifically the way pioneer species stabilize sand deposits which facilitates suitable environments for new plants and increase sedimentation (Gurnell, 2015).

The main causes of the diminishing quantity of sediments transported by the river are the hydrotechnical facilities developed along the Danube (as mentioned above, in Section 2).

Coarse materials were observed in the lower layers of the lithological profiles on some islands, which might also play a role in their stability (Fig. 8). The lithological profile observed in the field is composed of alluvium formed by silt deposits under which there are sand deposits in horizontal lamination.

Fig. 8 Alluvial profile

The decrease in sediment volume in the Danube has accelerated the erosional activity on the river bed which contributed to the increase in island and sand bar area, encouraged by floodplain vegetation reduction upstream (Habersack, Jäger and Hauer, 2013). Embankments have resulted in increased streamflow and water levels, stimulating lateral erosion and bed incision, as well as increased velocity (Constantinescu *et al.*, 2015).

The water flow along the Danube River tends to deviate more towards the Bala and Borcea channels (on Bala channel the erosional processes are intense), while on the Old Danube branch the erosional and transport processes are diminished, leading to higher sedimentation. The differentiation between the channels is caused by the lowering water energy towards the Old Danube channel which is intensified by valley topography, due to higher elevation and rock outcrops on the right side thus forcing the river to deviate towards the more malleable left side (Nedea *et al.*, 2012). The presence of the Pârjoaia rock escarpment has been observed to greatly contribute to this deviation (Constantinescu *et al.*, 2015). The sedimentation resulting from intensified erosion upstream, combined with the deviation of water flow towards Bala channel, could explain the higher increase in island area on the Old Danube.

The lack of dredging works on the Old Danube branch is also considered a condition that stimulates strong alluviation and decrease in energy (Nedea *et al.*, 2012). The increased alluvia in the Old Danube branch is problematic for navigation, as well as the lowering water level in the summer which often does not meet the required depth for navigation, creating a "bottleneck" effect (Habersack, Jäger and Hauer, 2013). Engineering works are addressing the issue As the Old Danube is the main navigation channel and an alternative route would increase transportation time. Banks for redirecting the water flow towards the Old Danube River have been recently constructed (Fig. 9). Closing the secondary channels between river bank and islands would redirect water towards the main channel (Constantinescu *et al.*, 2015). However, challenges arise in the effort to maintain a balance between navigational requirements and conservation of the semi-natural state of the Lower Danube (Habersack, Jäger and Hauer, 2013).

Fig. 9 Recent embankments

The direction of island expansion in the two segments is mainly upstream, where also most of the variations between the analysed years occurred. However, some islands show disparities to this trend. Fermecatu and Șoimu had their initial increase towards the downstream side, between 1864-1975 and 1920-1966 respectively, and then changing the expansion direction towards the upstream. Ceacâru seems to have grown laterally and its origin might come from floodplain dissection, as it does not appear in the 1864 map but it already has a large size in 1910 and it is near the river bank. Most of the islands display the tendency to join the floodplain in their expansion. In some parts, it was problematic to distinguish the demarcation line between the island and the floodplain. The islands that show this development are Tiu and Ceacâru, as well as Turcescu which is almost joined to Balta Ialomiței, separated only by a narrow channel which is most often barred by sand deposits.

The role of riparian vegetation in landform development is crucial and there is a growing body of literature devoted to the topic of relationship between plants and geomorphology with research going back to the 1950's (Gurnell, 2015). Riparian composition has a very important role in determining bank stability and geomorphic unit formation, because of adaptations of riparian species to dense flooding and anoxic conditions (Naiman, 2005). The root system of the riparian vegetation increases bank roughness and regulates lateral stability through consolidation of sediments resulting in decreased erosion (Zanoni *et al.*, 2008). Spatial distribution and density of vegetation, as well as species, life stage and mortality are several factors that influence river morphology at different temporal scales (van Oorschot *et al.*, 2016).

Colonization of newly formed bars by pioneer species determines sediment deposition around these core areas, thus increasing bar surface (Zanoni *et al.*, 2008). This in turn allows for propagation of seeds and growth enforcing the positive feedback loops (Brierley and Fryirs, 2005), and can be subject to various turnover rates. New seedlings or vegetative parts tend to have a faster growth in sheltered spots on an established island, such as behind wood jams, which accumulate fine-grained sediment and further improves conditions for plants (Gurnell *et al.*, 2001).

3.2. Accuracy assessment

Table 3 presents the summary statistics for the identification error related to island boundaries. The 95% confidence interval was further used to compute the total error for each year. The largest value is associated with the 1975 aerial imagery and the 1910 historical map. Apart from the 1910 map, the lowest identification errors are occurring for the topographical and historical maps, while the identification is more inaccurate for the aerial and satellite imagery.

Table 3 Identification errors related to island boundaries (meters)

Year	2016	2013	2005	1989	1981	1975	1966	1920	1910	1864
σ	1.68	1.21	1.17	0.96	0.89	2.84	1.28	0.73	2.51	0.25
Mean	6.64	4.00	2.98	15.38	2.90	8.73	7.10	2.33	8.57	4.60
ME	0.59	0.43	0.41	0.34	0.31	1.00	0.45	0.26	0.89	0.09
Average	1.14	1.21	0.98	2.1	1.22	1.2	1.94	1.25	1.61	2.82

digitized perimeter

σ – standard deviation of identification error
Mean – average values of identification error
ME – margin of error of identification error

The results of the identification (e_{id}) and positional error (e_{xy}) computed through the test-point method are presented in Table 4, together with total (e_{year}) and combined error (e_{comb}). As expected, the positional error increases for earlier sources.

Table 4 Total and combined error related to island boundaries (meters)

Year	2016	2013	2005	1989	1981	1975	1966	1920	1910	1864
e_{xy}	14.15	0.0	6.76	4.0	26.52	32.04	23.67	114.03	561.62	168.00
e_{id}	0.59	0.43	0.41	0.34	0.31	1.0	0.45	0.26	0.89	0.09
e_{year}	14.74	0.43	7.17	4.34	26.83	33.04	24.12	114.29	562.51	168.09
e_{comb}	15.22	7.64	11.55	31.15	59.81	57.15	138.41	676.74	730.57	168.09

e_{xy} – positional error
e_{id} – identification error
e_{year} – total error (positional + identification)
e_{comb} – combined error (year 1 + year 2)

The observed changes in the geomorphic units and their magnitude depends and is limited by the quality of the available data sources (Thieler *et al.*, 1994). In this case, the historical and topographical maps, aerial and satellite imagery all come with a certain degree of uncertainty which influences the results. An accuracy assessment of each one was required to distinguish the spatial patterns of real change and the buffer areas in which true change cannot be declared significant (Downward, Gurnell and Brookes, 1994). One of the main issues in studies that investigate the temporal changes is that the sources used have different scales, so it is important to place the results in this context. There are certain temporal and spatial requirements to capture the river behaviour (Downs and Gregory, 1995). It has been suggested that integration of data at an optimal common spatial resolution of a selected reference source would yield good results in long-term studies (Petit and Lambin, 2002).

Errors in historical maps come every step of processing and handling, from scanning, assembling to georeferencing to a common coordinate system. Prior to scanning, the paper maps can be subject to drying, moisture and other physical factors that damage in a heterogeneous way (Crowell, Leatherman and Buckley, 1991).

This is propagated throughout the process of integration in a GIS. There is also the issue of the obsolete coordinate systems of old maps which can be difficult to identify and can introduce error (Crowell, Leatherman and Buckley, 1991). A problem experienced with the 1864 and 1910 maps was the misalignment of some of the map sheets which occurred in the study area. Detailed information about the landscape is lost when using small scale or small resolution maps and images, such as the 1867, 1910 maps and the Landsat satellite image.

The accuracy of the georeferencing process influences the positional error and is dependent on the number, location and the nature of the chosen GCP, as well as the transformation used. The error is influenced by the placement of GCP, and it increases when moving from a flat surface to the valley slopes (Lea and Legleiter, 2016) and when going further away from the study area (Hughes, McDowell and Marcus, 2006).

The sources of digitization inaccuracy in aerial imagery is due to the ambiguous boundaries caused by shadows, clouds, shifts because of aircraft movements, but it also depends on the operator's knowledge on the topic (Crowell, Leatherman and Buckley, 1991). Topographical and historical maps are not affected by these issues and the information is presented in categorical representation.

These results further support the idea care should be taken when assessing geomorphological changes though the use of aerial images and maps to distinguish true change from variations in position because of data inaccuracy (Walter and Tullos, 2010). Geomorphological changes are considered to have taken place if they exceed the calculated errors (Mount and Louis, 2005). When representing data spatially, a buffer equivalent to the calculated errors created around the boundaries of the geomorphic elements of interest will help distinguish areas of change (Hughes, McDowell and Marcus, 2006).

4. CONCLUSIONS

Island dynamic on the Danube River in the Călărași - Cernavodă sector between 1864 and 2016 was investigated in this study. The differences in island area and number along the years were quantified, and their spatial distribution was mapped. These parameters unfolded trends in the dynamics of island formation in terms of expansion area and direction. At the same time, an accuracy assessment of the data sources was performed, and this has showed that quantifying the inherent errors can have a significant impact on the results. It is important to perform error assessment especially in temporal studies that deal with historical maps and data that varies in temporal and spatial scales. Errors can range from tens of centimetres to hundreds of meters depending on the data source.

This study could benefit from several improvements. Firstly, more historical data obtained systematically on riparian vegetation throughout the study period is required to better understand the dynamics occurring in the river channel. Moreover, more insight would be attained if phases of vegetation expansion would be correlated with stages in landform development. Turning to the accuracy assessment, some improvements to the error assessment could be made by incorporating a variable spatial error of the buffer zones (Lea and Legleiter, 2016). In addition, the problem of water level in the investigation moments was not considered, namely the exposure error (Walter and Tullos, 2010). This is directly influencing the results because the discharge varies between different years in the moment when the photo was taken, thus covering varying degrees of the island areas.

Interpreting this evolution in the context of complex feedback loops between erosion, transportation and sedimentation processes, as well as riparian forests spatial patterns, land-use change, and hydrological variations determines a better understanding of river behaviour.

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