FORUM GEOGRAFIC

Forum geografic. Studii și cercetări de geografie și protecția mediului
Volume ***XV****, Issue* ***2*** *(****December*** *2016), pp.* ***133-139***
*http://dx.doi.org/****10.5775/fg.2067-4635.2016.047.d***

Shape characteristics of fluvial islets based on GIS techniques. A case study: the Danube's islets between Giurgiu and Olteniţa

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Received on <09-10-2016>, reviewed on <20-11-2016>, accepted on <15-12-2016>

Abstract

This study aims to quantitatively characterize shape parameters of fluvial islets using GIS techniques. There were eight metrics selected for the analysis. For the automation of the workflow, all processing functions were joined into a single graphical model. For this case study we selected the Danube sector situated between the cities Giurgiu and Oltenita. We chose to track the evolution of the fluvial islets' shapes from 1864 to 2010. Information was extracted from historical data sources such as maps and ortophotoplans. The graphical model created was run for each studied year.

The results show major changes in the aspect of fluvial islets along the Danube reach. Between 1864 and 2010 the number of islets slightly increased with the total area ranging from 21.19 kmp to 27.96 kmp. In the period studied, the shape turned from a rounded aspect to a more elongated one. Knowledge of the information on the shape of those landforms is relevant for river restoration strategies, nature conservations of islets and maintenance of the protected habitats.

Keywords: *fluvial islets, Danube, shape, GIS, graphical model*

Rezumat. Caracteristici de formă ale insulelor fluviale bazate pe tehnici SIG. Studiu de caz: insulele Dunării între Giurgiu şi Olteniţa

Scopul acestui studiu este de a descrie cantitativ aspectul insulelor fluviale utilizând tehnicile GIS. În acest sens, au fost selectați pentru analiză opt parametrii morfometrici. Pentru automatizarea fluxului de lucru, toate funcțiile folosite pentru calcularea parametrilor au fost grupate într-un model conceptual. Ca studiu de caz a fost ales sectorul dunărean Giurgiu – Oltenița. Evoluția formei insulelor fluviale a fost urmărită pentru intervalul 1864 – 2010. Informațiile au fost extrase din surse de date istorice precum hărțile vechi și ortofoplanuri. Modelul conceptual creat a fost rulat pentru fiecare an analizat.

Rezultatele ilustrează schimbări majore în aspectul insulelor fluviale dunărene prezente în sectorul studiat. Între 1864 și 2010 numărul insulelor a crescut ușor, iar suprafața totală a acestora a variat de la 21.19 kmp la 27.96 kmp. În perioada studiată forma insulele fluviale a evoluat de la un aspect circular la unul alungit. Cunoașterea informațiilor privind forma acestor formațiuni geomorfologice este relevantă pentru strategiile de reconstrucție ecologică în lungul râurilor/fluviilor, conservarea și menținerea habitatelor protejate.

Cuvinte-cheie: *insule fluviale, Dunăre, formă, SIG, model conceptual*

Introduction

Shape describes the geometric form of individual spatial objects (Maceachren, 1985). It holds an important role in many fields such as Spatial Science, Mathematics, Computer or Cognitive Science. Nevertheless, the definitions, goals and applications in each discipline are little different. In geography, shape has been primarily used as a descriptive tool (Boyce&Clark, 1964), but the need for a quantitative measure of shape that could address geographical phenomena first came up during the quantitative revolution in the 1960's (Sovik, 2014). The evaluation of shape is challenging simply due to the fact that there is no universally agreement upon definition on how to quantify it. Shape indices tend to fall into two classes: 1) single parameter – such as area or perimeter calculations and 2) multiple parameter – involving more complex mathematical functions (Sovik, 2014; Marin, 2016).

A fluvial islet is a landform within a river channel, surrounded by stream-channel branches or waterways, which has some stability and remains exposed during bankfull flow (Picco et al., 2014; Wyrick, 2005). On the geologic time scale, a fluvial islet may not be permanent due to natural or human induced hydrological changes, but can remain in place over a long period. In the literature, the term of stability for fluvial islets is not usually defined precisely, but often the vegetation is a good indicator for this (Wyrick, 2005).

Fluvial islets are present in the channels of the most rivers. They result from complex processes that take place in the river channel and have a morphological, an ecological and economic importance. Also, they are good indicators of the natural state of a river system and are largely influenced by changes in hydrological parameters and anthropogenic activities (Picco et al., 2014, Sadek, 2012). For these reasons, river islets have sparked the interest of many researchers. Significant studies have been carried out to investigate the morphology and morphometry of fluvial islets (Wyrich, 2005; Ricaurte et al., 2012, Kiss&Andrási, 2014; Raslan&Salama, 2015).

The purpose of this paper is to quantitatively characterize shape parameters of fluvial islets, using

Open Source GIS techniques. There were eight metrics selected for the analysis, namely: Islets number (IN), Length (L), Width (W), Elongation Ratio (ELONG), Area (A), Perimeter (P), Perimeter-Area Ratio (P/A), Shape Index (SI). For the work flow automation all processing functions were joined into a single graphical model.

Study area

The Danube River is the second longest river in Europe, with a length of 2.850 kilometers. It rises from the Black Forest (Germany) and flows to southeast to the Black Sea. The Danube course is divided into three main sectors: Upper Sector (from source to Bratislava city), Middle Sector (from Bratislava city to Bazias) and Lower Sector (from Bazias to the Black Sea) (Tockner et al., 2008).

The Lower Course flows over a distance of 1075 km (Gâştescu&Ţuchiu, 2012), between Bazias and Sulina City and touches the borders of Serbia, Bulgaria, Moldova and Uckraine (Buzea, 2010). Two large dams (Iron Gate 1 and Iron Gate 2) were built in the Lower Danube. This System induced some modifications of natural river regime such as reduced sediment transport capacity, followed by sediment deposition (Mladenovic et al., 2013). Also the embankment and drainage activities have altered floodplain and fluvial islets geomorphic processes (Constantinescu et al., 2015).

For the analysis presented in this paper, we chose as study case the fluvial islets from Danube sector situated between the Romanian localities Giurgiu and Oltenita (Fig. 1).

Fig. 1: Location of the study area

Database and methodology

In this paper we employed a diachronic study to investigate the shape characteristics of islets along the selected Danube River reach. We used historical maps and air photographs from different dates, but with similar scales (Table 1): Map of Southern Romania, Romanian maps under Lambert-Cholesky projection system - called "Planurile Directoare de Tragere", Romania Topographic maps and ortophotoplan from 2010. It should be noted that all maps used in this study are based on the topographic survey. So, we consider that their accuracy is reasonable. For example, the Austrian topographic survey between 1855 and 1859 served as a basis for the Map of Southern Romania (Bartos et al., 2014), which was printed in 1864 to Viena (Popescu-Spinteni, 1978). Romanian maps under Lambert-Cholesky projection system are the results of a series of Romanian, Russian and Austrian measurements and Topographic Map of Romania was made on the topographic and aerial survey between 1872-1980 (Năstase&Osaci, 2005).

It's important to mention that an inconvenience of using old maps and aerial imagery are the intervals between timepoints which are not equals, so the data isn't uniform. For this reason, the interpretation of the changes in the number of fluvial islets and their morphometric parameters takes into account the possibility of intermediate positionings and aspects, which have not been captured by existing cartographic and imagery documents.

Table 1: Description of the Historical Maps and Imagery Documents used in the analysis

Type of Data	Name (Source of download)	Year	Scale/Resolution
Maps	The Szathmary Map - „Charta Romaniei Meridionale" (http://charta1864.ro/)	1864	1:57.600
	1: 20.000 Romanian maps under Lambert-Cholesky projection system - called Planurile Directoare de Tragere (http://earth.unibuc.ro/ download)	1920	1:20.000
	Topographic Map of Romania (http://opengis.unibuc.ro/)	1980	1:25.000
Ortophoplans	Ortophoplan of Romania (DTM)	2010	1:5.000

We chose a simple distinction between bars and islets based on the absence (bars) and presence (islets) of vegetation (Nicholas et al., 2013). So, the boundaries of all positive landforms of the river were digitized and islets were separeted from bars using the vegetation criteria. To explore the shape characteristics dynamics of fluvial islets we calculated a set of commonly used landscape metrics, based on the GIS shapefiles (Table 2). It should be noted that we used only Open Source GIS Software, such as WhiteBox GAT, Quantum GIS and SAGA GIS.

Table 2: The 8 landscape metrics, with their abbreviations, formulas and meaning

Parameters	Abbreviation	Formula	Meaning
Islets number	IN	IN=n	Total number of fluvial islets from study area.
Length	L		Length (m) of each islet.
Width	W		Width (m) of each islet.
Elongation Ratio	ELONG	L/W	Is a measure of the length/width
Islet Area	Ai	Ai = A/1000000	Area (m²) of each islet, divided by 1000000 to convert to km².
Islet Perimeter	Pi	Pi=P/1000	Perimeter (m) of each islet, divided by 1000 to convert to km.
Perimeter-Area Ratio	P/A	Pi/Ai	Is the ratio of perimeter and area.
Shape Index	SI	100 * Pi/(2*√(π*Ai))	Shape Index is based on the ratio of perimeter to the square root of area.

It was a challenge to find a way to automatically calculate the length and width of each islet. Geometrically, they have an irregular shape, which makes it difficult to establish the parameters mentioned above by a computer. Thus, each irregular polygon needs to be framed by a rectangular polygon, which rotates according to the orientation of the original polygon. In literature, this operation is known as Minimum Bounding Rectangle (MBR), a 2-dimensional case of the Minimum Bounding Box (MBB). The number of open source GIS software that have implemented such an instrument is limited. We have identified and selected Whitebox GAT software for the creation of minimum bounding rectangles and automatic calculation of the maximum length and width. It should be noted that we chose this approach because we believe that the determination on maps or aerial images manually by using a measuring instrument is time consuming and involves a high degree of subjectivity.

For the automation of the work flow, most of the processing functions were joined into a single graphical model (Fig. 2), using the specific tool from Quantum GIS. The graphical model created has been run for each studied year.

Results and discussions

Count and area of fluvial islets

In the Danubian watercourse between Giurgiu and Olteniţa, for the entire studied period, it can be noted a large number of islets, with a maximum recorded in the 1920. The smaller number of river islets found before 1920 and the lower total area obtained for 1864 and 1920, can be explained by the agressiveness of the floods registered in 1850, 1862, 1897,1899 (Upper Danube) and in 1862, 1895 and 1897 (Lower Danube) (Melo et al., 2014). After 1920, the number of fluvial islets is preserved over 20, but overall it can be observed a slight downward trend of those. This can be associated with the anthropogenic activities from the upstream sector (the construction of the Iron Gates I and II), the embankment of the minor bed of the Danube River, lower sediment transport rates, wave actions and water streams led to physical degradation through reducing riverbed depth, sandbanks forming and islets. Analyzing the islets dynamics on different cartographical documents and images, it was possible to observe some changes in the active channel area during different periods. For example, the largest islets, remaining in the Danube watercourse over time, it can be observed a slightly downstream migration. Also, some fluvial islets were merged together into one islet, other merged into the river bank; some of them disappeared, while new ones were formed.

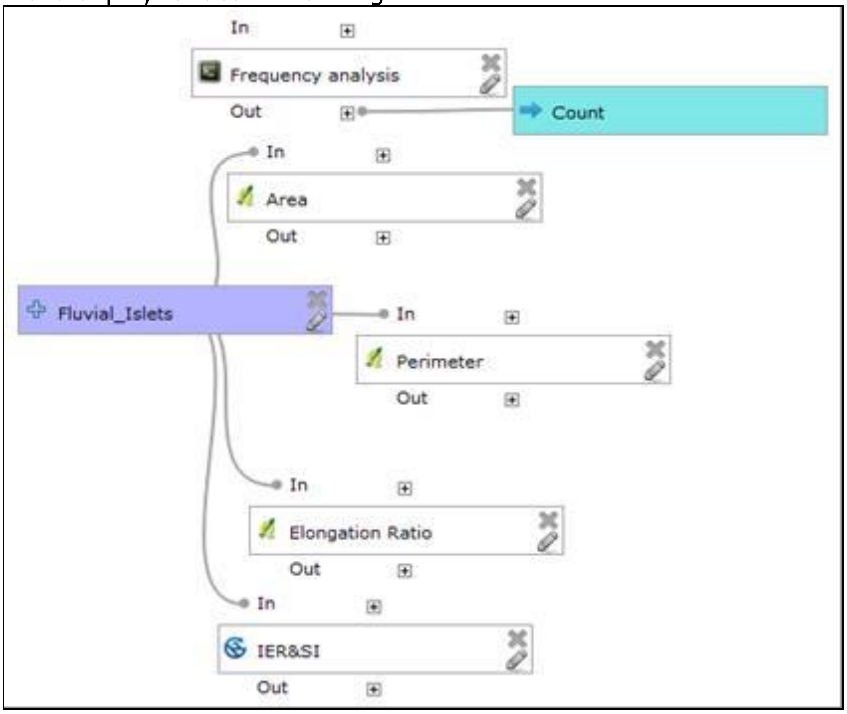

Fig. 2: The graphical model used in this study (Marin, 2016)

In the 1920-2010 period, the total area of river islets fluctuated, increasing and decreasing over time. The flood events occurred during the study period may have influenced the area and the morphology of river islets. For example, between 1920 and 1980 there have been five significant floods 1930, 1940, 1942, 1955 and 1970 (Pătruț, 2010) and between 1980 and 2010, four floods with major impact were identified: 1981, 2005, 2006, 2010 (Teodor et al., 2010) (Fig. 4).

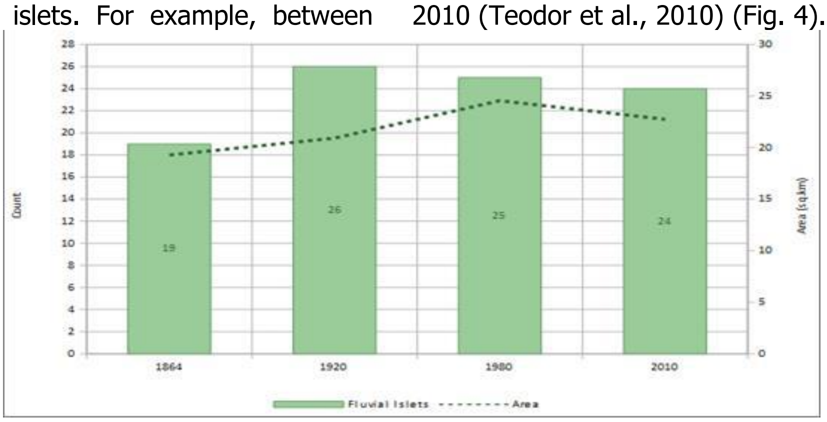

Fig. 3: Number of fluvial islets and total area

Elongation Ratio

Elongation ratio know as aspect ratio (Wyrich, 2005) is a measure of the length/width. It refers to the energy conditions of the river around the fluvial islets (Kiss&Andrasi, 2014). Using the classification proposed by Kiss T. and Andrasi G. (2014), we identified four classes: ELONG <= 2 for mostly

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*Volume **XV**, Issue **2** (**December 2016**), pp. **133-139***
*http://dx.doi.org/**10.5775/fg.2067-4635.2016.047.d***

round shape; 2 < ELONG <= 4 for round shape; 4 < ELONG <= 6 for elongated shape and ELONG < 6 for strongly elongated shape.

In Fig. 5, we observe that in 1864, most of the islets have elongation ratio between 2 and 4, which shows that their shape is round. Later, in 1920, of the 26 fluvial islets, 10 of them have a round shape and therefore fit in the category of elongated islets. After '79-'80 years, the number of islets with elongated shape and strongly elongated shape increase to 24. It's seems that the fluvial islets tend to reshape by elongating because of the reduction of its width. The high values of elongation ratio achieved in 2010 show that the general trend of the shape of river islets is to turn from a rounded aspect to a more elongated one. That means after '80 years the energy conditions of rivers is higher in the neighborhood of islets, so these landforms can develop dynamically (Kiss&Andrasi, 2014).

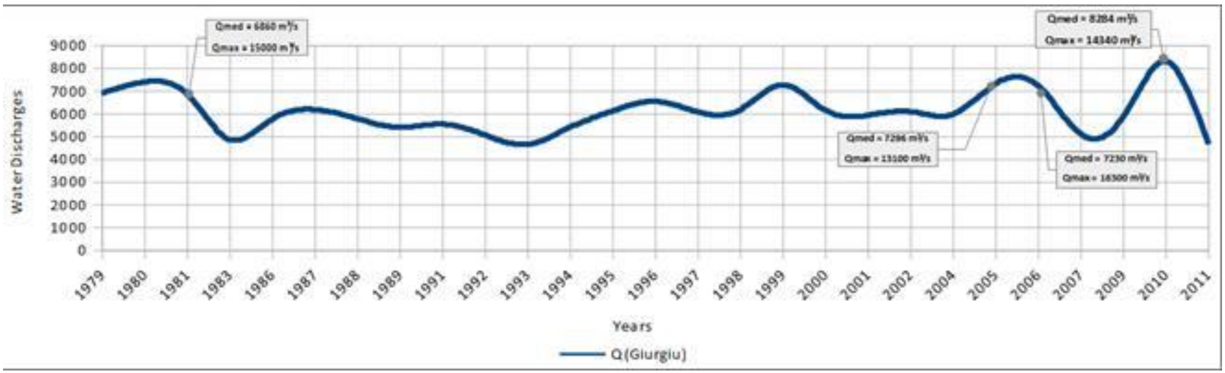

Fig. 4: Graphical representation of the annual average of water discharges at Giurgiu Station

(Sourse of data: Hydrological Station, Giurgiu)

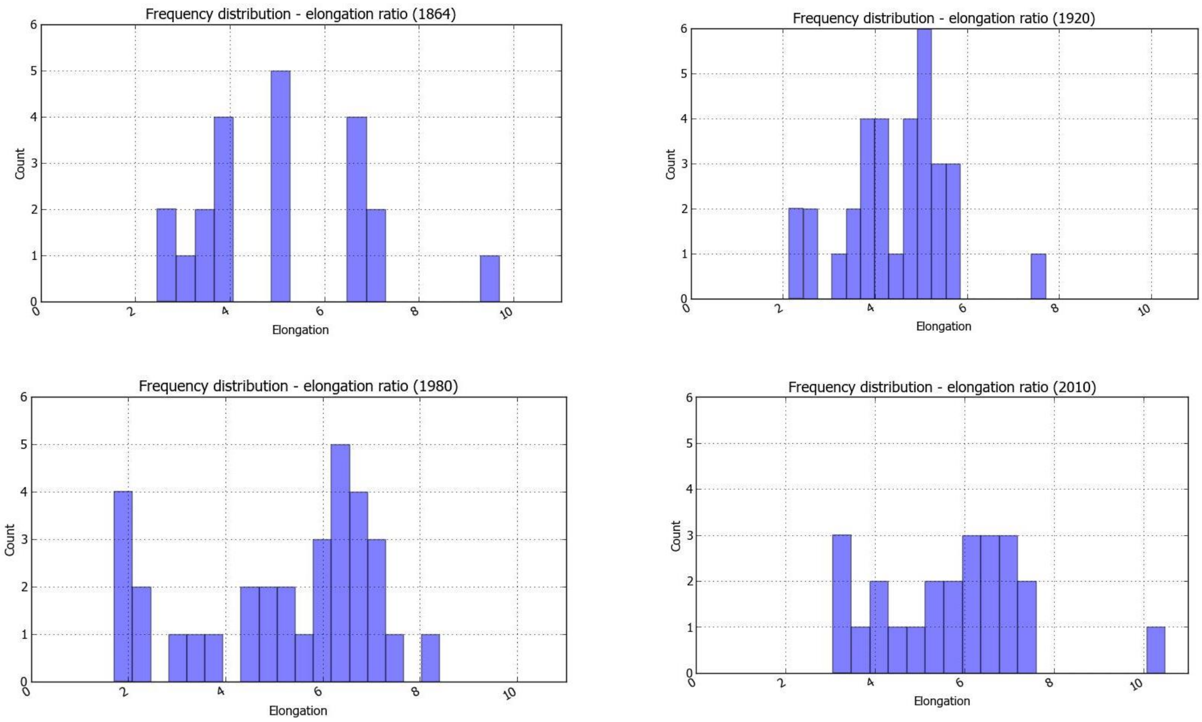

Fig. 5: Graphical representation of frequency distribution for elongation ratio (1864-2010)

Perimeter-Area Ratio

This parameter is, especially, used for the evaluation of habitats/distribution of species. It's important to know the values of this ratio for fluvial islets in the conditions that those landforms are a stopover and nesting place for many birds. Unfortunately, the measurement of this ratio doesn't give standardized values, so, in specialized literature, the calculation of a shape index is also recommended, in which case, reporting is done to a perfect circle (Lang&Klung, 2006). In Fig. 6 it is represented the frequency distribution for perimeter-area ratio between 1864 and 2010.

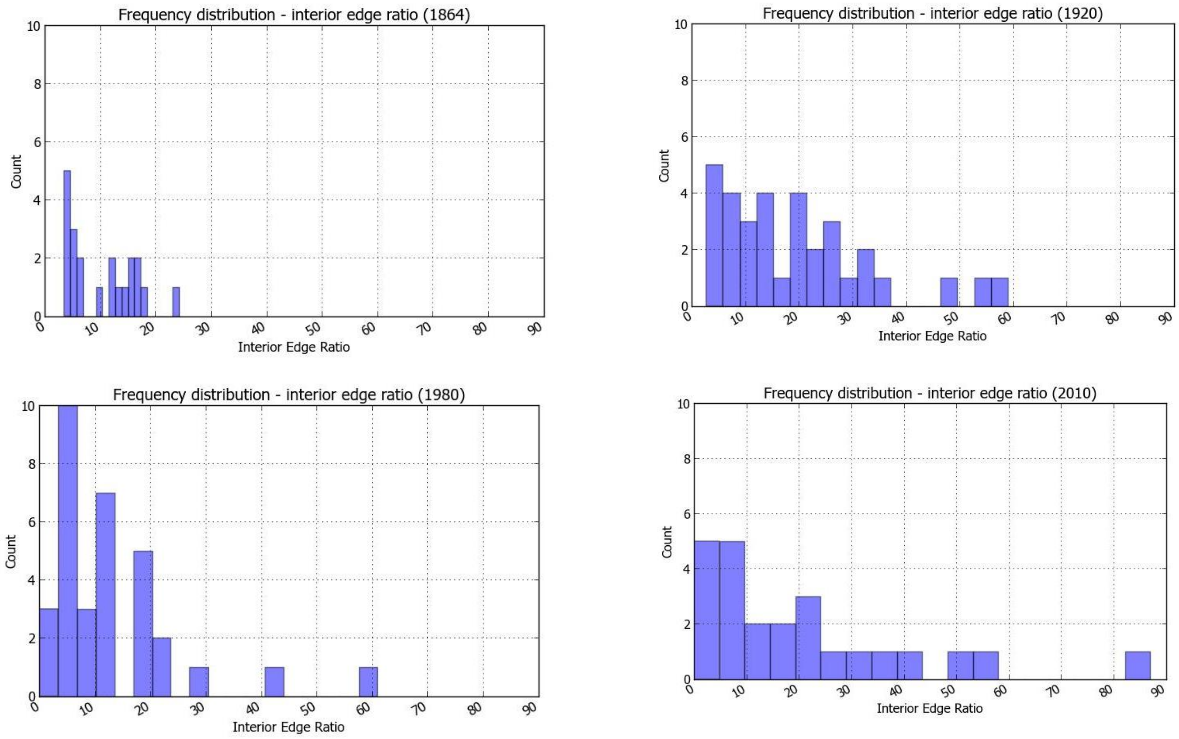

Fig. 6: Graphical representation of frequency distribution for perimeter-area ratio (1864-2010)

Shape Index

It is based on the ratio of perimeter to the square root of area. This index was proposed by Patton, in 1975, for quantifying habitat edge for species. If the polygon is a perfect circle its SI is 1 and as the aspect becomes more complex the SI increases (Comber, Birnie, Hodgons, 2013). For the years studied in this paper, values of the shape index for the river islets are greater than 1 (Fig. 7).

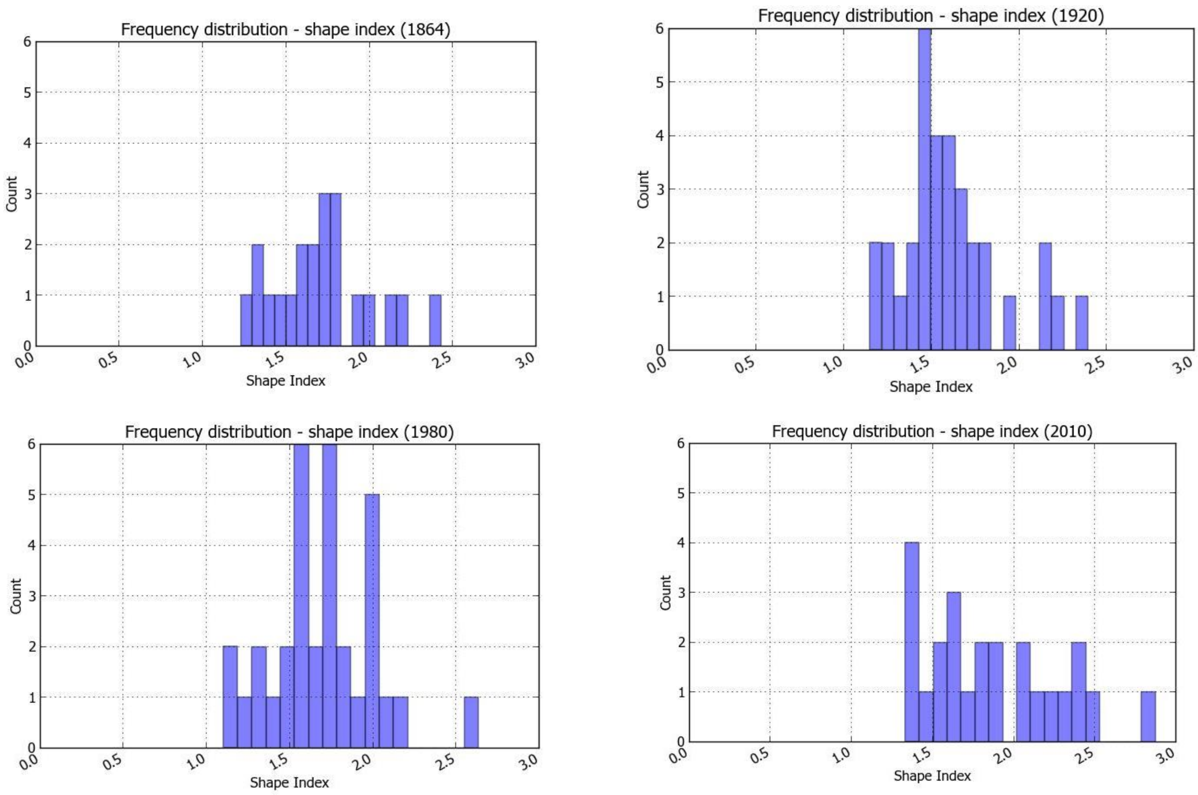

Fig. 7: Graphical representation of frequency distribution for shape index (1864-2010)

Furthermore, since 1980, the index shows values over 2.5 units. Taking into account the high values recorded for the rate of elongation and perimeter-area ratio, we can conclude that fluvial islets studied have an irregular and complex aspect.

Conclusion

During the period 1864-2010 (146 years), in the studied Danubian sector, the number of islets increased slightly between 1864-1920, after which their number remained constant. The total area of fluvial islets fluctuated, increasing and decreasing over time, but on the whole it grew from 21.19 sq.km to 27.96 sg.km. For a quantitative characterization of the morphology of fluvial islets we calculated some shape parameters. The values obtained for the elongation ratio, perimeter-area ratio and shape index highlights the general trend of those landforms to get a more complex and elongated aspect.

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