A NEW METHOD FOR MEASURING MEANDER PARAMETERS. THE LOWER JIU RIVER CASE STUDY, ROMANIA

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Abstract. The study of river channel dynamics at different time intervals is an element of interest in river geomorphology because it provides qualitative and quantitative information related to the river style and patterns of evolution. Old maps represent archives of extremely valuable information related to the natural and human environment, which provide the necessary data for such studies. This paper uses data from old maps to analyze the evolution of the Jiu River between 1857 and 2021. A new method for measuring meander parameters has been developed and may be applied to any type of river channel. The calculation and analysis of the parameters (sinuosity coefficient, length, amplitude, type, and shape) for each riverbed section led to the identification of distinct evolutionary patterns which were discussed in relation to control factors. We concluded that the Jiu river channel gradually straightened during the last 164 years due to upstream anthropogenic interventions such as dams and hydrotechnical works which reduced the natural riverbed dynamics reflected in low sinuosity and meandering levels.

Key words: diachronic analysis, river dynamics, fluvial geomorphology, anthropogenic impact, geomorphological evolution, Jiu-Danube confluence

1. INTRODUCTION

Diachronic analyses have been frequently used in fluvial morphology studies to document anthropogenic impacts on river morphodynamics (Warner, 2000; Schock *et al.*, 2017). These analyses provide important information on temporal changes in river channel dynamics through cuantification of lateral migration rates (Zamfir *et al.*, 2018) and offer detailed insights into large-scale evolution of braided sections and development patterns of meanders (Radoane *et al.*, 2013).

However, the current use of diachronic analyses lacks a standardised methodological approach, making it difficult to be replicated and scaled up on one hand and less feasible for results comparisons between different studies on the other hand. The major goal of this study is to provide a widely applicable approach for calculating meander parameters. Furthermore, we test this new method on the lower Jiu River demonstrating its practical efficiency.

2. STUDY AREA

The study area is located in the south of Romania (Fig.1), and it is a part of the Oltenia Plain, at the intersection of the Băileștilor Plain and the Romanian Plain. The studied river sector is located in the Jiu River basin, between Malu Mare and its confluence with the Danube River. The area altitude is low, being a typical plain, with altitudes ranging from 12 to 310 meters in the northern section. The river flows at an altitude of 70 meters upstream and 24 meters downstream, with a 46-meter level difference in the riverbed slope.

Quaternary deposits predominate lithologically, beeing made up of sands and gravel deposited by the river. Fluvial deposits occur frequently in the areas along the main valley, specific to alluvial riverbeds (Posea, 2005).

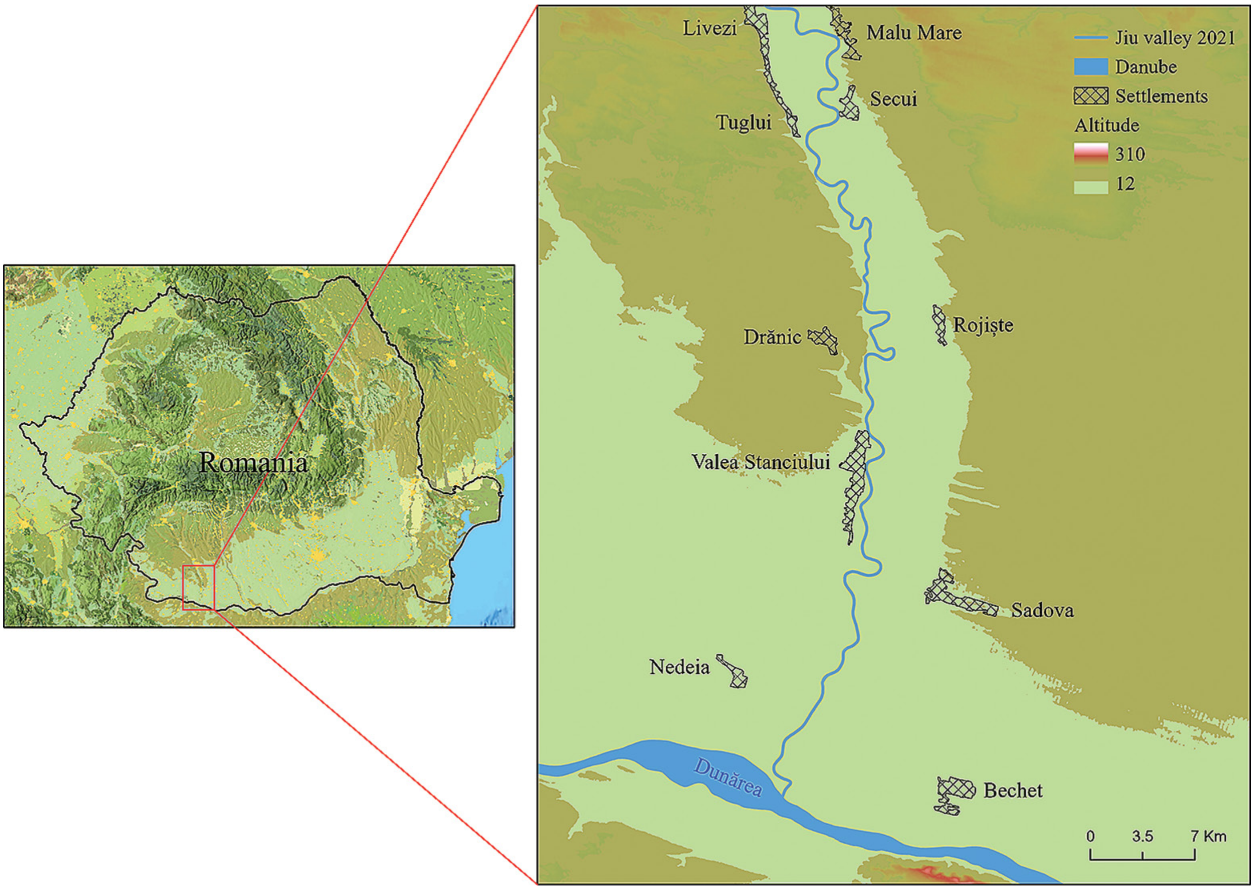

Fig. 1. Location of the study area.

3. METHODS

The primary database consists of old maps which allowed for a detailed study of the Jiu riverbed from a diachronic perspective. In this regard, we used two old maps: the Carol Popp de Szathmari map from 1857 (1: 57.600 scale), and the Geographical Service of the Army map from 1916 (1: 1,000,000) scale. According to the projection of the base point map, these were georeferenced in the 1970 Stereo projection. For more recent years we used the Topographic Map of Romania (1: 25.000 scale) and a 2021 gray Landsat 8 OLI satellite image to map the recent riverbed, which was then processed in ArcGIS Pro to determine its visible spectrum. Following the maps georeferencing, the Jiu River bed was then digitized for the four time periods using ArcGIS Pro.

Along with the basic maps, adjacent data was used to round out the final cartographic products. The archive was made up of the Romanian DEM, which was downloaded from the European Environment Agency website with a resolution of 25 meters, in order to determine the hypsometric steps and vector layers representing the hydrographic network and the network of localities, which were automatically extracted in QGIS by a plug-in (Table 1).

Table 1. Date base

Graphic products	Type	Source	Year	Scale/Resolution
Old map 1857	Raster	Carol Popp de Szathmari	1857	1:57.600
Old map 1916	Raster	Geographical Service of the Army	1916	1:1.000.000
Romanian topographic map	Raster	Military Topographic Directorate	1980	1:25.000
DEM	Raster	European Environment Agency	2017	25 m
Satellite image Landsat 8 OLI	Raster	Earthexplorer.usgs.gov	2021	30 m
Hydrographic network	Vector	OpenStreetMap	2021	-
Settlements	Vector	OpenStreetMap	2021	-

4. RESULTS

4.1. Proposed method for measuring meander parameters

There are several reasons why different methods of determining parameters have evolved over time. Some of the reasons could be the lack of a universally valid method with a high degree of applicability to any type of river, the very large differences in terms of unpredictable morphology in the field, compared to theoretical models that capture rivers with a perfect mathematical development and the lack of a deeper foray into this subject of methodology, which led researchers to adopt the primary method of calculation, frequently making its readjustments.

Existing methods have numerous limitations, including high subjectivity, low applicability, inability to highlight correlations and differences between studies. Although their variety is currently high and may give the impression of redundancy in the development of a new method, this is in fact necessary because a universally valid method that is accurate in terms of tracing the parameters to meanders, reduces subjectivity, is adaptable to the forms in the field and allows comparison of the obtained results (Fig. 2).

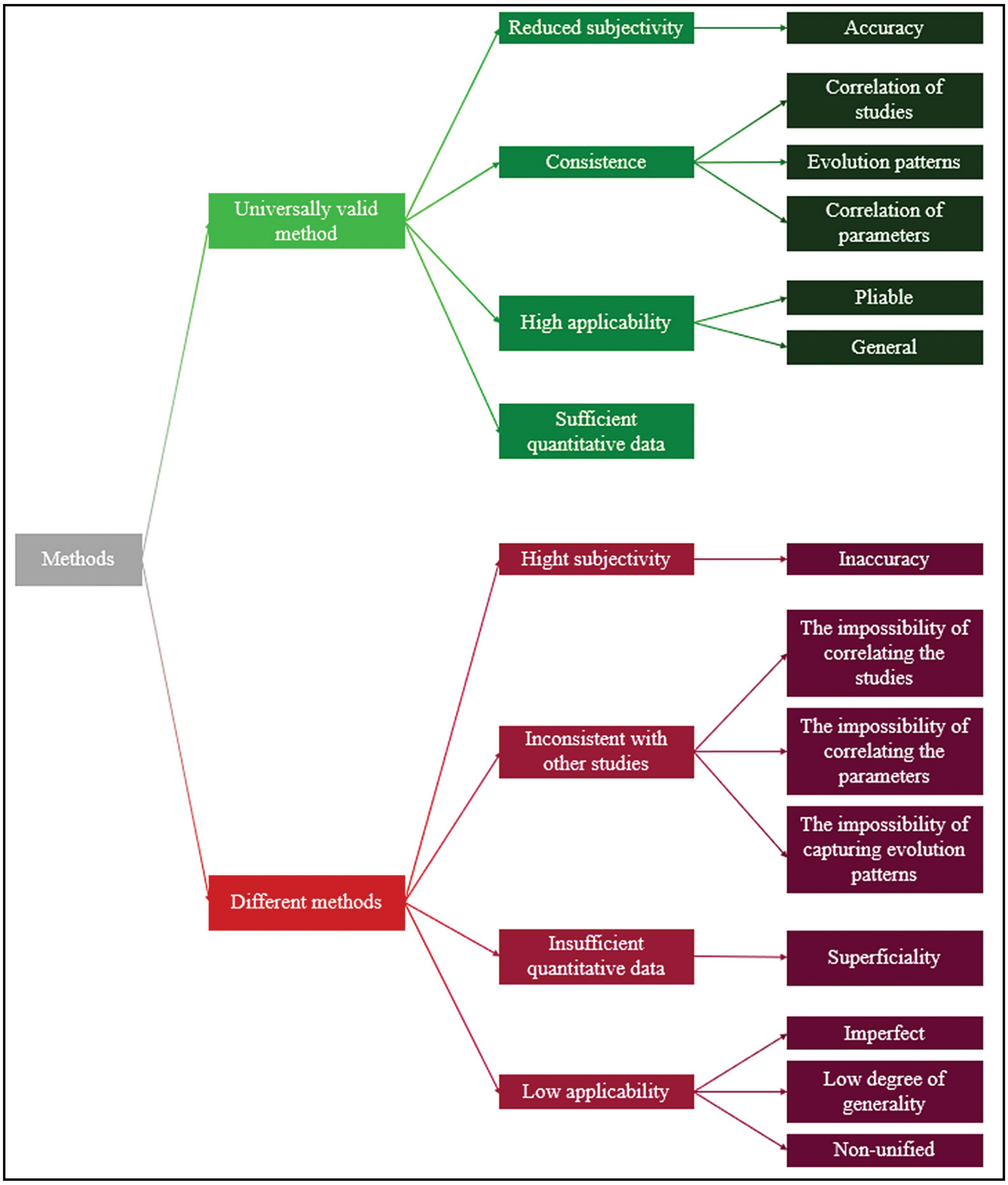

Fig. 2. The relationship between particular methods and universally valid methods.

The works that take these parameters into account are numerous, having been studied since the first half of the twentieth century, and their designations for this work have been taken from the literature. Magdaleno *et al.* (2011) refers to meander amplitude and length. Marston *et al.* (2012) examines the relationship between meander shape and migration processes (Fig. 3a). Purkait and Sinha (2019) propose that the meander amplitude is drawn on the median axes within the minor riverbed (Fig. 3d and b). Charlton (2015) outlines the shapes of meanders (Fig. 3c and a). Annayat and Sil (2020) conducted a study on the dynamics of meanders viewing the meander as two consecutive loops (Fig. 3b).

It can be seen how the meander is considered to be a longer loop in some cases and two consecutive loops in others. In this case, the length is the straight line whose edges are in the middle of the neighboring loops, and the amplitude is the straight line that connects the meander's farthest end to the length.

In this sense, it is clear that there are numerous works that detail various methods of delimiting the parameters of meanders. Some use different terms to refer to the same parameter, while others are nearly identical.

Regarding the term meander used in the literature, some authors determine it as two successive loops, with the extreme points being along the riverbed in the middle of it (Annayat and Sil 2020), others see the meander as a single loop, which extends into the neighboring loops, the extreme points being perpendicular to them (Marston and Inci, 2012). The similarity between these cases consists of establishing the meander as being composed of a succession of loops. However, looking at the literature, it is evident how different sources refer to the meander as a single loop in a roundabout way. In this regard, Schwenk and Foufoula-Georgiou (2016) are working on a satellite-based study of meandering Ucayali River in Peru. In their paper, they define meander cutoffs as situations in which only one loop is highlighted, with the exception of compound meanders, which are discussed separately.

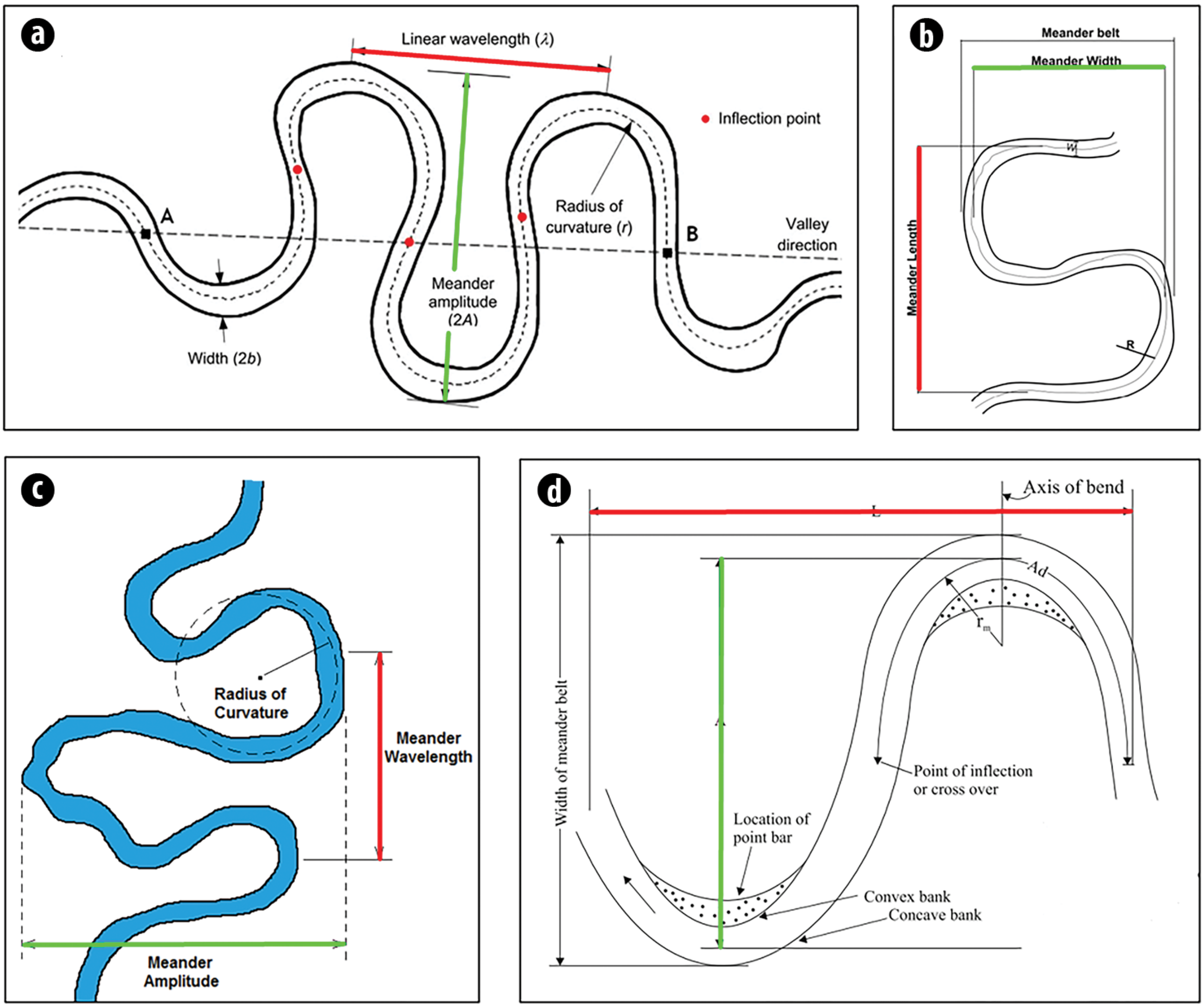

Fig. 3. Calculation of parameters according to different authors: Richard Marston, 2012 (**a**), Wajahat Annayat, 2020 (**b**), Charlton Ro, 2015 (**c**), Barendra Purkait, 2019 (**d**), with modifications.

If we take into account the structure of the meander, we can see that each loop forms its own minor landform. Thus, the concave and convex banks are formed differently for each loop depending on its arrangement, as well as related to the reindeer, which are formed only at the level of the loop itself, not extending into the neighboring ones.

In terms of riverbed parameters, it can be seen that the authors consider the meander to consist of two or more consecutive loops, while morphologically and in the literature, the meander is only a single loop. This observation is critical for the method's development in the following steps. Each meander loop was treated as an independent meander in the proposed method. The length was calculated by drawing a broken line at the base of each meander and intersecting it with the middle represented by the straight line segment, resulting in a stable reference line from which to measure each meander. In this case, the amplitude is the straight line drawn from the farthest point of the meander to the middle of the length (Fig. 4).

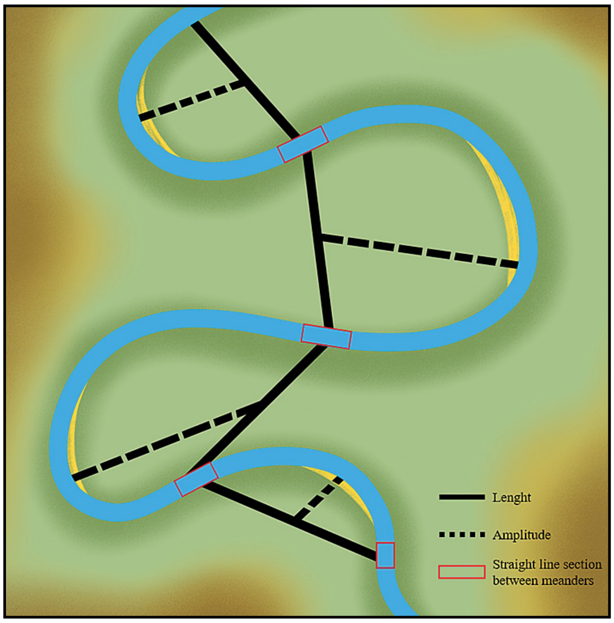

Fig. 4. Schematic illustration of length and amplitude of meander.

The type of meander refers to the number of ripples that the riverbed forms within a single meander. This parameter is determined visually based on the morphology of the meander, but auxiliary circles can also be used to outline their arrangement and frequency within the riverbed more clearly. As a result, simple, double, or compound meanders are produced (Fig. 5).

The shape of the meander refers to the degree of elongation or choking, which depends on the meander's ratio to a perfect circle. The geometry of the meanders can be determined visually, or a perfect circle can be drawn within each loop, and depending on the degree of overlap of the circle over the riverbed, elongated, round, or necked meanders result (Fig. 6).

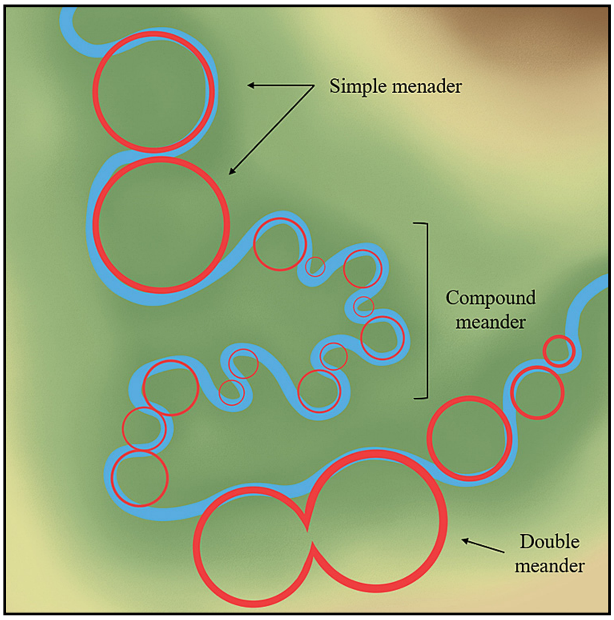

Fig. 5. Determining the type of the meander.

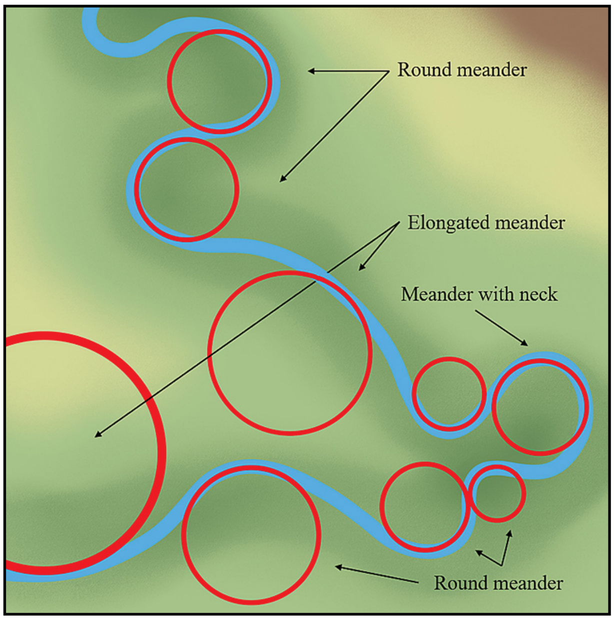

Fig. 6. Determining the shape of the meander.

4.2. Lower Jiu River channel dynamics between 1857-2021 (Malu Mare – Bechet sector)

Jiu River underwent significant transformations over the last 164 years (1857-2021), when comparing the four chosen years: 1857, 1916, 1980, and 2021. These variations are highlighted by the river parameters retrieved from the analyses of the cartographic materials (Table 1). The highest value of sinuosity (1.87) was recorded in 1857, and the lowest in 1916 (1.41), with the trend of sinuosity remaining stable over the last 40 years. The meanders average length began at 979 meters in 1857 and has steadily increased since then, reaching a peak of 1,186 meters in 2021. In 1980, the amplitude ranged from 387 meters to 290 meters (Table 2).

Table 2. River parameters

<table>
<tr><th>Year</th><th>Sinuosity coeficient</th><th>Average lenght (m)</th><th>Average amplitude (m)</th><th>Type</th><th>Shape</th></tr>
<tr><td rowspan="3">1857</td><td rowspan="3">1.87</td><td rowspan="3">979</td><td rowspan="3">303</td><td rowspan="3">74% Simple
26% Double</td><td>52% Elongated</td></tr>
<tr><td>40% Round</td></tr>
<tr><td>8% Necked</td></tr>
<tr><td rowspan="3">1916</td><td rowspan="3">1.41</td><td rowspan="3">1.025</td><td rowspan="3">290</td><td rowspan="3">81% Simple
19% Double</td><td>45% Elongated</td></tr>
<tr><td>51% Round</td></tr>
<tr><td>4% Necked</td></tr>
<tr><td rowspan="3">1980</td><td rowspan="3">1.5</td><td rowspan="3">1.186</td><td rowspan="3">387</td><td rowspan="3">84% Simple
16% Double</td><td>60% Elongated</td></tr>
<tr><td>38% Round</td></tr>
<tr><td>2% Necked</td></tr>
<tr><td rowspan="3">2021</td><td rowspan="3">1.49</td><td rowspan="3">1.186</td><td rowspan="3">370</td><td rowspan="3">87% Simple
13% Double</td><td>62% Elongated</td></tr>
<tr><td>36% Round</td></tr>
<tr><td>2% Necked</td></tr>
</table>

A total of 73 meanders were recorded in 1857. Simple meanders made up 74% of the total, while compound meanders made up 26%. 38 percent were elongated, 29 percent were round, and only 6 percent were necked. In 1916, the meanders were reduced to 53, with 81% being simple and 19% being compound. In terms of shape, elongated meanders accounted for 45 percent, round meanders for 51 percent, and necked meanders for 4 percent. The meanders were 45 in 1980. Eighty-four percent were simple, sixteen percent were compound, sixty percent were elongated, thirty-eight percent were round, and two percent were necked. There were 45 meanders in 2021, with 87 percent being simple, 13 percent compound, 62 percent elongated, 36 percent round, and 2 percent narrowed.

The sinuosity coefficient reached its peak in 1857, after which it began to fall. The sinuosity coefficient exhibited a general decreasing trend with oscillations of the values in each year under consideration (Table 2).

For each period under consideration, the average length of the meanders gradually increases. This emphasizes the tendency of the river meanders to lengthen. It is possible to see an increase in the percentage of simple meanders at the expense of compound meanders. Simultaneously, the values show a decrease in the percentage of strangled meanders, emphasizing their natural capture, resulting in abandoned meanders. All of these factors point to the conclusion that the river overall tendency is to straighten.

To determine the morphological evolution of the riverbed from a diachronic perspective and to make a comparison from a dynamics standpoint, the river channel was divided into two sectors: upstream, between the localities of Malu Mare and Drănic, and downstream, between the localities of Valea Stanciului and Bechet. These are representative of the differences between the upstream and downstream sectors. The upstream sector had greater dynamics along the riverbed and meanders.

When comparing 1857 to 2021, it is clear that the Jiu river channel underwent significant lateral migrations. The riverbed moved 1,076 meters west to the north of Secui, 1,670 meters west to the west of Secui, 912 meters west to the south of Tuglui, and 886 meters southwest in the Teasc area. Notably, in 2021, the riverbed becomes almost straight in the east of Foişor and Booveni for a length of 5,500 meters.

The physiognomy of the meanders changes dramatically, from a riverbed characterized in 1857 by a greater number of meanders that are smaller in size and more irregular, to a riverbed in 2021 with a smaller number of meanders that are more regular, even relatively straightforward in some sectors. At the same time, the riverbeds of 1857 and 1916, as well as those of 1980 and 2021, have a relatively common sinuosity. In this regard, the riverbeds of 1857 and 1916 show a much more sinuous and irregular development. Riverbeds between 1980 and 2021 overlap quite well in large sectors (Fig. 7).

The riverbed in the lower sector did not migrate significantly, following a relatively close course in all of the years studied. It should be noted that the only substantial change occurred between 1857 and 1916, when the channel shifted 12.7 kilometers to the west. This phenomenon can have several causes, the most likely being an episode or series of episodes of flooding in which the flow was high, causing the fluvial cliff on the right side of the Jiu to rupture and change its course at the outflow (Fig. 8). Between 1916 and 1980, the river mouth underwent significant changes.

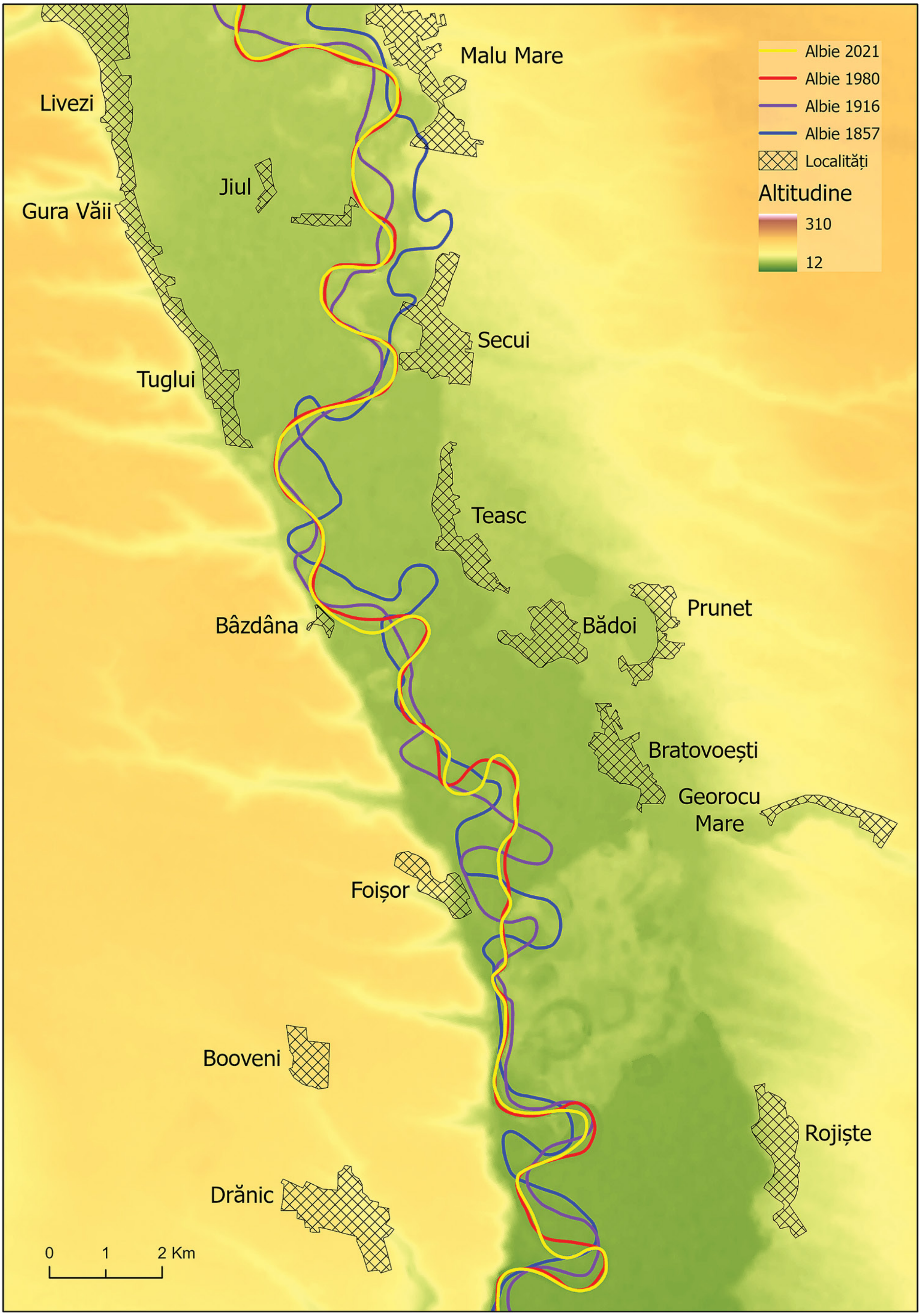

Fig. 7. Jiu course from 1857 to 2021 in Malu Mare - Drănic sector.

Fig. 8. Jiu course from 1857 to 2021 in Valea Stanciului - Bechet sector.

This morphological evolution can be explained both by the natural behavior of rivers, which tend to stabilize their course and straighten their riverbeds, especially if the local base level does not change, and by human intervention. Thus, it should be noted that Jiul reduced its dynamics between 1980 and 2021, after experiencing difficulties in a number of large sectors, including both banks. The embankment works began in 1960 as a result of several extreme flooding episodes. The embankments currently have a length of 41 kilometers in the upstream sector, on the right side of Jiu between Livezi and Tuglui and on the left side between Teasc and Drănic.

6. CONCLUSIONS

The Jiu experienced a more pronounced dynamic during the first half of the study period, between 1857-1916. The river tends to straighten and reduce its dynamics as the present approaches. The sequence of calculated values, as well as the physiognomy of the riverbeds, support these statements. Anthropogenic interventions have a significant impact on river bodies, altering their natural evolution and flow regime. This will continue to be a separate research topic to highlight the extent to which river dynamics are impacted.

The method described in this paper has numerous advantages for studying riverbeds and their constituent forms. First and foremost the arrangement of the parameters is clearly detailed, leaving no room for interpretation and significantly reducing subjectivity. Second, the method adaptability and applicability allow it to be used on a large scale, on any type of riverbed in any climate. Third, the method is simple to use and provides a wealth of quantitative data that can be used to highlight the most important riverbed features.

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