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Lateral Migration of the Jiu River Course between 1864 and 2018. Case study: Craiova – Zăval sector

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Abstract

In the last 154 years the Jiu river course from its confluence with Amaradia till the outlet, has undergone through serious lateral and length changes. The main purpose of this article is to highlight these changes and determine their magnitude and also to understand the future evolution of the Jiu course.
The results of our analysis showed that from 1864 until 2018 the Jiu river became shorter in the lower section, decreasing with 38.1 km, from 134 km to 95.9 km. Shortening of the course happened gradually. Thus, between 1864 and 1910, the length of the course decreased by 25.6 km, from 134 km to 108.4 km. From 1910 until 1970 there was a shortening of 11.9 km and between 1970 and 2018, the river shortened its course by about 0.6 km. The greatest lateral distance between its historical and present channels showed a maximum of 11.22 km on the outlet.

Keywords: *Jiu, levee, neotectonic movements, coefficient of sinuosity, lateral migration*

Rezumat. Migrarea laterală a cursului Jiului între 1864 și 2018. Studiu de caz: sectorul Craiova - Zăval

În ultimii 154 de ani cursul Jiului de la confluența cu Amaradia și până la vărsarea în Dunăre a suferit modificări laterale și de lungime. Scopul prezentului articol este acela de a evidenția aceste modificări și de a le stabili amploarea, cu desprinderea unor concluzii legate de viitoarea evoluție a cursului Jiului. Rezultatele analizei suporturilor cartografice au arătat că din 1864 și până în 2018 Jiul s-a scurtat în secțiunea inferioară cu 38,1 km, scăzând de la 134 de km la 95,9 km. Scurtarea cursului s-a realizat treptat. Astfel, între 1864 și 1910 lungimea cursului a scăzut cu 25,6 km, de la 134 km până la 108,4 km. Din 1910 și până în 1970 s-a mai produs o scurtare cu 11,9 km, iar între 1970 și 2018, Jiul şi-a scurtat cursul cu aproximativ 0,6 km. Cea mai mare distanță dintre cursul istoric și cel prezent indică o valoare de 11.22 km la vărsarea în Dunăre.

Cuvinte-cheie: *Jiu, diguri, mișcări neotectonice, coeficient de sinuozitate, migrare laterală*

Introduction

Scientifical research about how the rivers “behave” started to appear along with the raising of Fluvial Geomorphology, at the half of the XIX century. Wolman and Leopold published in 1957 the paper: ”River Channel Patterns - Braided, Meandering and Straight” in which they were concerned with channel pattern. Later, in 1977 James Brice wrote the paper: ”Lateral Migration of the Middle Sacramento River, California, where he extracted from topographic maps and aerial photographs the centerlines of the Sacramento river to a specific time. Then, he made an analysis of the channel form and its migration.

Rhoads and Welford tried to explain in 1991 why the rivers meander, i.e. migrate to lateral, and they wrote the paper: ”Initiation of River Mandering” giving a series of hypothesis such as: Coriolis force, Bar Theory and Bend Theory (Hooke, 2013).

Of course, there are plenty of scientific papers trying to explain rivers lateral migration, why they are creating meanders, always changing the morphology of the floodplains. Even in the Romanian literature there are some scientific papers concerned with fluvial systems and their evolution during time. In Romania, Rădoane et al wrote in 2013 ”River channel planform changes based on successive cartographic data”. The analysed rivers were Moldova and Someșul Mic.

Related strictly to the Jiu river, Ionuș (2013), wrote: ”Preliminary data on the Jiu River meanders in the lower course (South-West Romania)”. This paper is a complex study about Jiu river bed in terms of geometry and complexity of meanders in its lower sector.

Traying to explaian how the things work and why the rivers are creating meanders, we have to see the situation to a bigger scale and maybe to apply it to ours. Some authors which have studied the problem, the most prestigious being Rhoads and Welford (1991), found out that the major arguments that have been used over time to explain why rivers meander are: Coriolis force, energy arguments (excess, minimization), bank erosion and sediment effect, helical and secondary flows, inherent property of turbulent flow, interaction between flow and mobile channel, bar theory and bend theory (Rhoads and Welford, 1991).

Coriolis force is the force associated with Earth’s rotation and it moves objects to the right in the northern hemisphere, especially rivers, eroding the right-hand channel banks. Jiu flows through the northen emisphere, thus we used this concept to

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explain if it has an impact on meander formation and it was proved that Coriolis force associated with erosion are producing secondary currents, but it doesn't have the magnitude to cause significant deformation of the channel (Rhoads and Welford, 1991).

Bar theory suggest that: "deformation of the channel bed is the fundamental cause of meandering", (Callander, 1978), alternate bars developing prior to the initiation of channel curvature, but this theory has major limitations, because, as it was explained, it assumes that channel banks are inerodible and thus does not incorporate a mechanism for the initiation of channel curvature. (Rhoads and Welford, 1991).

Considered one of the biggest river from southwest of Romania, the Jiu river has its springs in Southern Carpathians and after 339 km it reaches to the Danube (Atlasul Cadastrului Apelor din România, 1992). In the upper course, Jiu river seems to be more stable, but while it flows towards is lowest point the situation change drastically, and what we want is to undersatand why this is happening.

The analyzed river section starts North of Craiova city at 23°42'26.436"E and 44°21'57.61"N and ends South of Zăval village, at 23°48'41.115"E and 43°46'48.409"N.

This section corresponds to a part of the Jiu middle course, which flows through the South part of the Getic Piedmont, but the interest of the research goes especially to the lower course, which crosses the central axis of the Oltenia Plain.

Some can observe that in its lower section the Jiu river has created meanders and from place to place it course is braided. But the most impressive thing is that the Jiu moved its riverbed many times. By analysing the pattern in its evolution we want to answer to some questions: "why those things happened? why the Jiu river meanders an moves its course? can we predict its future evolution?".

Method

The Jiu river fluctuation over time were identified based on four cartographic supports. Therefore, we used the following maps: Szathmári's Map of Southern Romania (Charta României Meridionale, 1864), sheets IV – 7 and IV – 8, at scale 1:57.600, georeferenced in the STEREO_70 projection system. The second map was an Austrian map from 1910, at scale 1:200.000, also projected in STEREO_70. The third map correspond to the Soviet maps sheets: L-34-132-C, L-34-144-B, L-34-144-A, from 1970, at scale 1:50.000. Those map sheets were georeferenced in the STEREO_70 projection system. For 2018 we used an Open Street Map sheet, which is an open source data project. The main operations were to extract by vectorization the Jiu historical and present channels and to create a GIS database in order to to facilitate measurements, ordering and comparisons. We have also calculated the distance between the Jiu river channels from 1864 to 2018 in 41 sections, chosen after we analyzed the cartographic data. To understand that the lateral migration of the Jiu river had an impact on its length, we calculated the sinuosity coefficient in order to identify what type of channel Jiu river has and to catch its main evolution tendencies. The mathematical formula for calculating this coefficient (Cs) involves dividing the real length of the river course (Rl), between two points, to the straight-line length (Stl) between the these points (Cs= Rl/Stl). Values less than 1.5 suggest that the river sector is sinuous and values greater than or equal to 1.5 are associated with the meandered river sectors (Leopold, Wolman, 1957).

Results and Discussion

This Jiu river's section is one of the most dynamic, suffering from intense lateral oscillations over time, with an impact on the morphology of the floodplain that the river crosses, as well as on the agricultural practices. The late antropic intervention on the course allowed to the Jiu river to travel freely through its floodplain. Its lateral migration was also possible due to the small slope of the thalweg, or beause of the neotectonic movements and the meteo-hydrological events. Of course, the transported sediments and the banks resistance to erosion played a key role in Jiu's evolution. Another possible explanation of Jiu lateral oscillation is related to the alluvial fans, created by the tributary streams, which are pushing aside the main channel. This situation happenes when Dâlga stream flows into the Jiu river, bending its course (Boengiu et al, 2011).

The analysis we carried out revealed that there were some changes in length between Jiu-Amaradia and Jiu-Danube confluences. If in 1864, the straight line between the two outlets was 70.3 km, in 2018 the distance has decreased to 65.3 km.

The changing of the length of the Jiu course, in the sense of decreasing, was a consequence of river rectification, a situation highlighted by the values of the sinuosity coefficient. The obtained value showed that sinuosity coefficient dropped from 1.91 in 1864 to 1.55 in 1910. In 1970 the sinuosity coefficient was 1.47, value registered also in 2018. Leopold and Wolman suggested in 1957 that values less than 1.5 are specific to a sinuous rivers and values greater than or equal to 1.5 are associated with the meandered bedside sectors. Therefore, Jiu river evolved from a meandered bed in 1864 to a sinuous one in 2018.

The course of the Jiu, during the analyzed period, suffered visible lateral changes (Fig. 1).

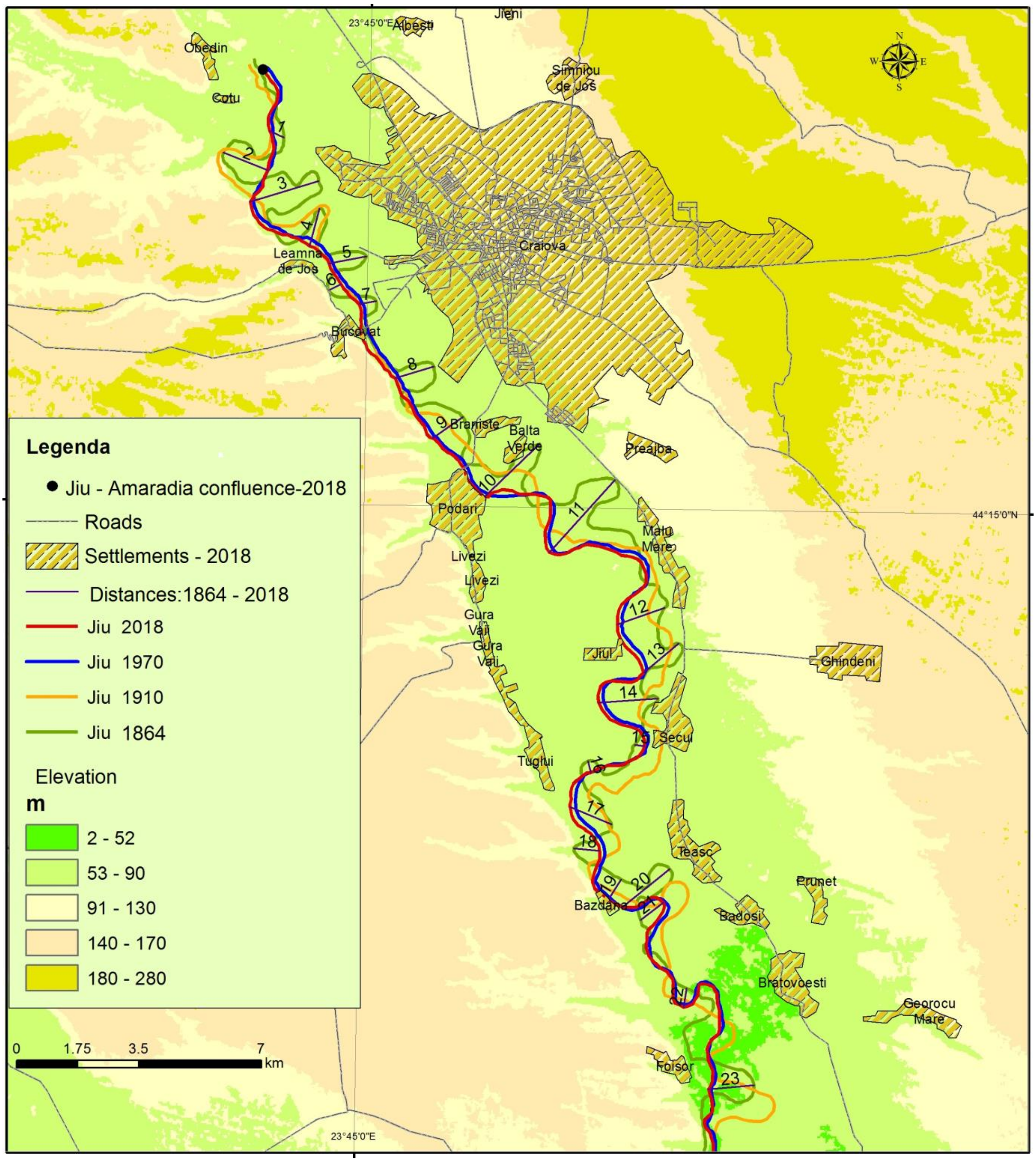

Fig. 1: Jiu river changing between 1864 and 2018: a –Amaradia – Foișor sector

In order to highlight these changes, distance measurements between the Jiu course from 1864 and 2018 were made in 41 sections (Table 1).

In the section between Breasta and Bucovăţ, more precisely near the Roșieni village, the Jiu course suffered between 1864 and 2018 a lateral modification of 2.04 km. An approximately equal distance (2.1 km) was also measured near Podari hydrometric station. Between Podari and Malu Mare, the Jiu river migrated 2.8 km from East to West. In the Jiul village (also known as Vîrâţi), located just 300 m from the river bank, the Jiu river migration occurred on a distance of 1.44 km from East to West. Between the settlements of Secui and Ţugului, the migration of the river on a distance of 1.7 km from East to West forced the inhabitants of the second village to move their houses from the immediate vicinity of the minor bed of the Jiu river at a distance ranging from 700 m to 3 km from the current river bed.

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Table 1: The distances between Jiu river's channels from 1864 and 2018 and medium slope

Section	Dist. km	Slope (°)	Section	Dist. km	Slope (°)
1	0.44	9.38	22	0.56	2.50
2	1.37	2.84	23	1.31	4.89
3	2.04	5.68	24	0.72	3.30
4	1.11	2.65	25	1.86	5.73
5	1.08	2.59	26	1.14	2.73
6	0.40	3.84	27	1.77	3.88
7	0.50	2.86	28	0.68	6.42
8	1.15	3.28	29	0.59	3.04
9	1.06	3.61	30	0.70	5.11
10	2.10	2.18	31	0.49	5.29
11	2.80	3.31	32	0.50	5.44
12	1.44	4.27	33	0.73	6.04
13	1.31	4.48	34	0.82	4.35
14	1.70	4.64	35	1.29	1.67
15	0.27	4.35	36	0.45	4.12
16	0.34	2.16	37	0.46	6.20
17	1.28	3.63	38	5.32	3.98
18	0.73	3.88	39	5.56	4.44
19	0.69	5.73	40	6.45	3.45
20	1.73	5.36	41	11.22	2.55
21	0.83	3.81			

South of Foişor, a village located within Drănic commune, the meander that existed in 1864 was cut and the Jiu river became more straight-lined, migrating 1.31 km from East to West (Fig.1).

In the vicinity of the villages Drănic and Padea, the Jiu river did not turn its stream, and it still has a very strong meandering course, the wave length of the meanders varying from 2826 m to 2879 m and the amplitude of the meanders also varies from 1855 m to 633 m (Ionuș, 2013). The distance within meander curvature that existed in 1864 and the current one varies between 1.14 km and 1.86 km

Beyond the cartographic evidence that the Jiu river has changed its course, a number of abandoned meanders can be seen on the terrain, such as those from Popoveni, Malu Mare, Podari, Bratovoeşti - Rojişte, between Tâmbureşti and Căciulăteşti, Sadova etc. The sectors between past and present courses are covered with a dense floodplain vegetation.

Changes in the course of the Jiu in the section from the confluence with Amaradia to the Danube were caused, among other factors, by the low water velocity (below 1 m / sec) and by the decreasing slope. It was noted that as the slope decreased, the distance between the 1864 and the 2018 course increased (Table 1).

We have also calculated the annual migration rate (Fig. 2) by dividing the migration amount by the number of years in the time period (154 years).

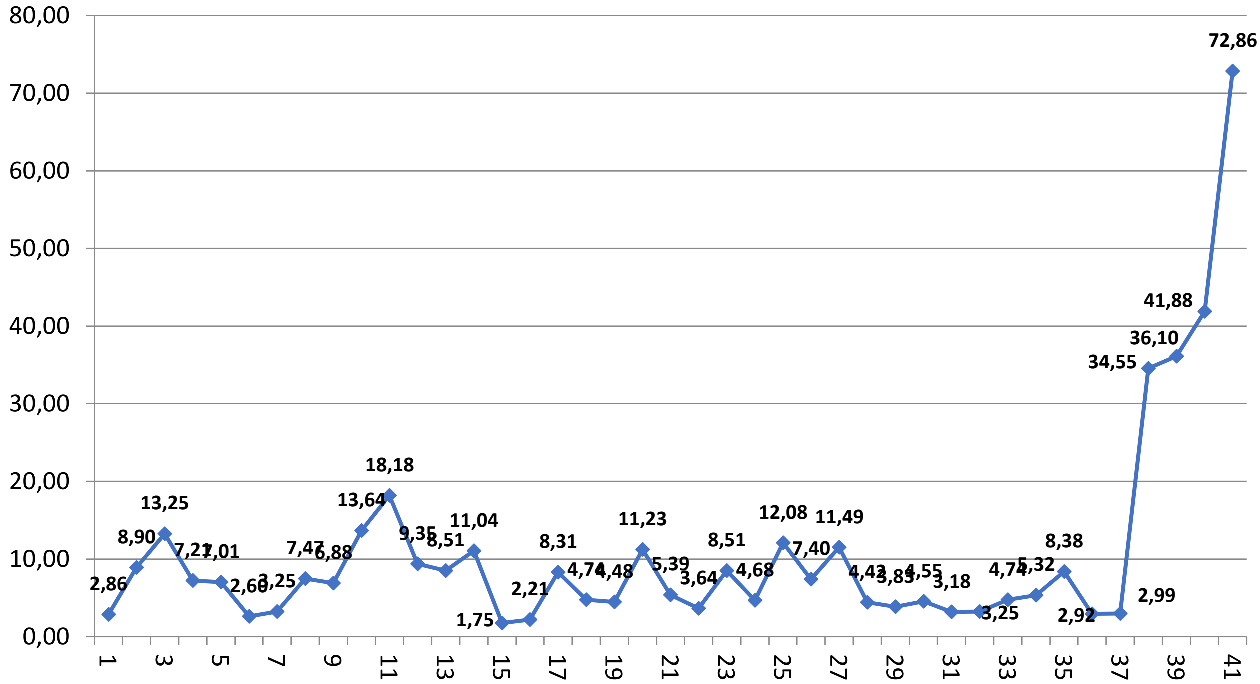

Fig. 2: Migration rate (m/yr)

The migration rate was measured in meters per year and the biggest value corresponds to the last section. Here the migration rate was 72 m/year. High migration rates have been recorded in the 38th, 39th and 40th sections. In this sections the lateral migration rate per year was above 34m/yr. Those section corresponds the the lower sector of the Jiu river course. High migration rate were registered at Podari and on the line between Podari and Preajba (18.1 m/yr). From the 28th to the 37th section the lateral migration rate per year was less than 8m/yr, with the lowest value of 2,29 m/yr registered south of Gângiova. The lowest migration rate was recorded near Secui village, and it was less than 2 m/yr (1.75 m/yr).

As the Jiu river flows towards the Danube, the distance between its channel from 1864 and 2018 increases. Thus, from the south of Gângiova, the difference between the two channels gradually increases from 460 m to 11.22 km in the confluence area with the Danube (Fig. 3).

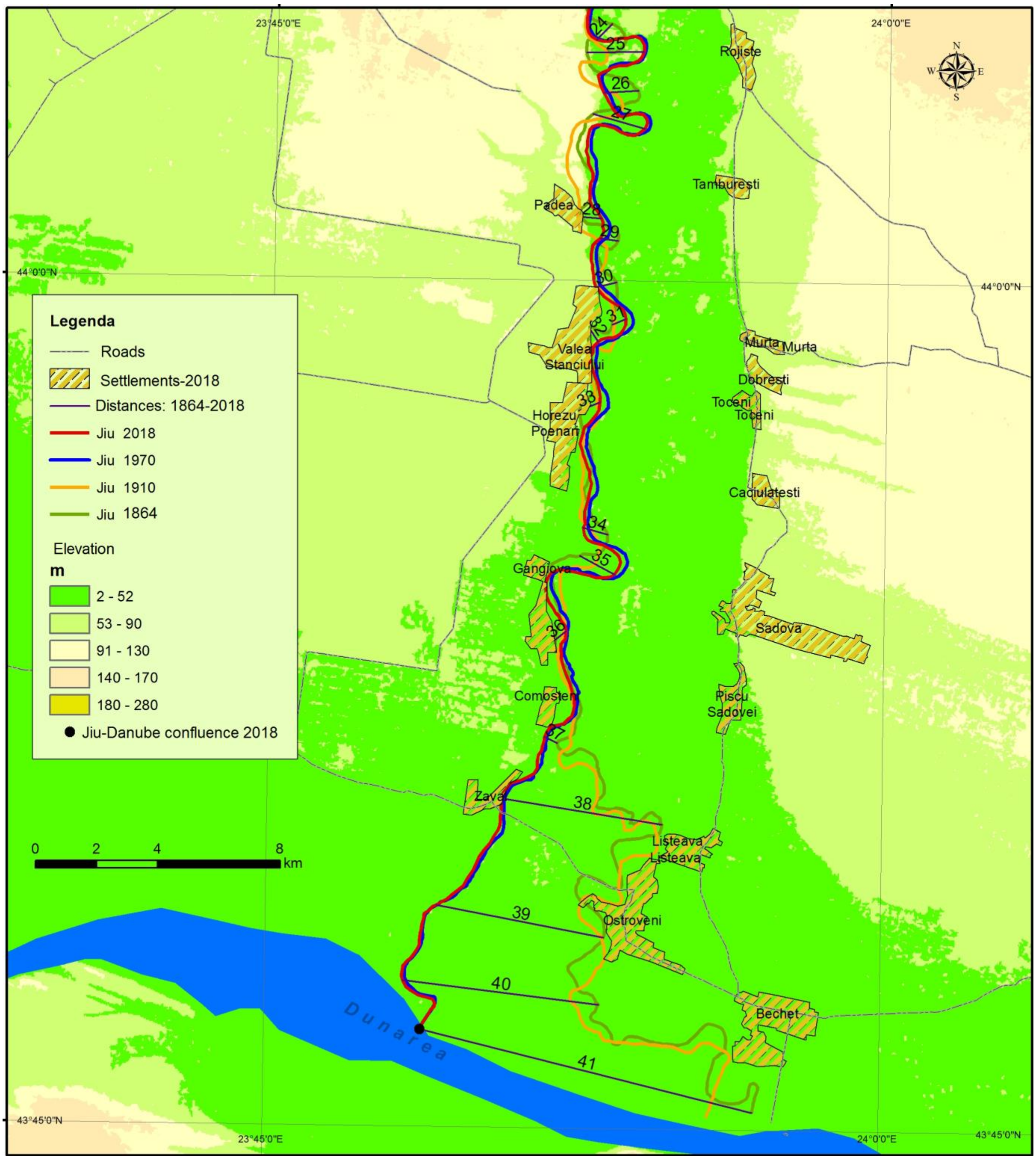

Fig. 3: Jiu river channel migration between Gângiova and Danube confluence – 1864 - 2018

The sandy bottom of the bed, its too wide breadth, as well as the spring and autumn high waters were considered responsible for the course change (Nicolescu, 1932).

By doing an analysis of the Jiu course, Nicolescu identified in 1932 four stages in its evolution until then. Chronologically, a first course was the one under the terrace on the left, which remained in the literature under the name of "Jiul Bătrân" (Old Jiu), and could be seen from the south of Craiova until the outlet. Then followed the Jieț phase, when the Jiu river was flowing along the line of Murta, Dobreşti, Căciulăteşti, Sadova, Lişteava, Ostroveni and Bechet. Jieț separated from Jiu and now it flows parallel with it from Murta to the Danube. The next phase indicates a Jiu that discharged into the Danube near Bechet, but passed through the commune of Comoșteni and Grindeni. The last phase is that of the Jiu flowing under the right slope, spilling into the Danube near Copanița islet, approximately halfway between the confluence of 1864 and 2018 (Nicolescu, 1932).

Jiu's clear tendency to build its floodplain on the left side and to destroy the right bank through lateral erosion or even regressive erosion on some portions is another proof that Jiu has turned strongly westward (Coteț, 1957).

In an attempt to determine the causes of Jiu's course changes, Nicolescu (1932) questioned the following situation: Jiu was bound by a system of lakes and ponds from the Nedeia (on the right bank of the Jiu) and the Potel (left of Jiu) lakes. Jiu was filling up these lakes, but as much water as it could send to them, they dried out regularly and alternatively. Nedeia lake dried out near the Jiu and increased on the opposite side, and the Potel pond was increasing in the Jiu side and dropped to the opposite side. The author mentioned above said that in some years the situation was going backwards. The phenomena of drying and increasing the water level of the ponds were closely related to the oscillations of the Jiu river bed to the East and West (Nicolescu, 1932). Taking on the ideas of Murgoci, Martonne, Mrazec, Matheiu Draghiceanu and Ionescu Argetoaia, Nicolescu suggested that changes of the Jiu course and also of the entire hydrographic network of Oltenia, were due to the presence of the neotectonic movements (Nicolescu, 1932).

The reactivation of the neotectonic movements in the Pasadena phase, the Pleistocene Medium, reactivated the ascension of the Balş-Leu-Rotunda line, which forced Jiu to deviate south and indicate a slow tendency of deviation to the southwest, the proof being the course from present and development of its floodplain and terraces on the left side (Boengiu et al 2009).

A series of geodetic measurements about the vertical movements of the crust were carried out in the Rast - Lom sector between 1964 and 1986. The speed of the measured movements oscillated between - 12 mm / year and + 0.4 / year on the Calafat - Rast line (Rădulescu, 1996). On the interfluvium between Jiu and Olt, the map of the vertical crustal movements in 1985 showed positive movements of 1 mm / year (Popescu et al, 1987). We can conclude that in the Lom area the subsidence was more intense than the positive movements in this area, and if we add the rise of the interfluvium between the two large rivers in Oltenia, the Jiu river could have diverted to the west, of course if the movements had occurred for a long time.

Oscillations of the Jiu minor bed could have been caused by floods on the river. The flood from 1879 moved the course of the Jiu river with 15 km from east to west. At that moment the river was flowing into the Danube near Bechet and after the flood it changed it course (Savin 1990). Although we cannot always make a correlation between channel changes and floods due to lack of data, we can still note that after building a series of levees in the second half of the last century, the lateral oscillations of the stream bed have diminished. The years in which Jiu floods occurred, recorded by the hydrometric stations, were: 1940, 1953, 1972 at the Podari hydrometric station and 1969, 1972 and 1976 at Zăval (Savin. 1990). The maximum flood flow occurred in 1972 when the Podari station recorded 2000 m3 / s, a value that was recorded in the same year at Zăval. In 1953 at Podari station were recorded 1950 m3 / s, and in 1940 at the same station the maximum flow rate at flood was 1765 m3 / s (Savin, 1990).

From the cartographic analysis, we can see that over the last 50 years the Jiu course did not suffer any major lateral change. This situation can be explained, as suggested above, by raising levees. Thus, in 1962, the defense levee between Secui and Bratovoeşti (14,4 km, 1,7 m H) were put into operation, in 1972 between Rojişte and Murta (13,6 km, 1,5 m H), but also between Murta and Lişteava (15.8 km, 1.5 m H), in 1976 the levee that defended Lişteava (5.7 km, 3 m H) and in 1979 the levee between Podari and Ţuglui (14.5 km, 1.7 m H) was put into operation (PMRI, ABA Jiu, 2015). The levees prevented Jiu from spreading sideways through its floodplain, stabilizing the course.

Conclusion

Currently, the Jiu channel may seems stable, but, knowing its bedside oscillations over the historical time, we can consider it a very dynamic river. Maybe this river will continue to change its path as long as floods will take place, as long as its river banks are not consolidated and as long as slow or high tectonic movements are happening in this area.

The high roughness of the riverbanks, the building of the levees will moderate Jiu's lateral migration and in the future we will try to write a paper about how rough are the Jiu river banks.

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References

Boengiu, S., Avram,. S., (2009), Bălăcița piedmont. A model of formation and evolution", Zeitschrift fur Geomorphologie - Annals of Geomorphology, Suppl. 2, Vol. 53, Stuttgart, 106 p., DOI: 10.1127/0372-8854/2009/0053S3-0101.

Boengiu, S., Vîlcea, Cristiana, Licurici, Mihaela, (2011a), Landslides in the Plain Sector of the Jiu Valley, Revista de Geomorfologie, nr. 13, ISSN 1453-5068, Editura Universității din București, p.75-81.

Callander, R.A. 1969: Instability and river channels. Journal of Fluid Mechanics 36, 365-480.

Coteț, P., (1957), Câmpia Olteniei – Studiu geomorfologic (cu privire asupra Cuaternarului), Editura Științifică, București.

Hooke, J.M., 2013. River meandering. In: Shroder, J. (Editor in Chief), Wohl, E. (Ed.), Treatise on Geomorphology. Academic Press, San Diego, CA, vol. 9, Fluvial Geomorphology, pp. 260–288.

Ionuș, Oana (2014) Preliminary data on the Jiu River meanders in the lower course (South-West Romania), Forum geografic. Studii și cercetări de geografie și protecția mediului, Volume XIII, Issue 1 (June 2014), pp. 18-24 (7), http://dx.doi.org/10.5775/fg.2067-4635.2014.026.i.

Leopold, L.B., Wolman (1957), River Channel Patterns - Braided, Meandering and Straight, United States Geological Survey, Professional Paper 282B.

Nicolescu, E. I., (1932) Contribuțiuni la hidrografia Olteniei – Bazinul Jiului, Scrisul Românesc S. A., Craiova.

Popescu, M., N., Drăgoescu, I., (1987) Maps of recent vertical crustal movements in Romania: Similarities and differences, Journal of Geodynamics 8(s 2–4):123–136.

Rădulescu, F., Mocanu, V., Nacu, V., Diaconescu Camelia, (1996), Study of recent crustal movements in Romania: A review, Elsevier Science Ltd., Journal of Geodynamics 22(1-2):33-50•September, Great Britain.

Rhoads, B.L., Welford, M.R., (1991), Initiation of river meandering. Progress inPhysical Geography 15(2), 127–156.

Savin C., (1990), Resursele în apă ale Luncii Jiului, Editura Scrisul Românesc, Craiova.

Planul de Management al Riscului la Inundaţii Administraţia Bazinală de Apă Jiu, accesat:http://www.rowater.ro/dajiu/EPRI/Planul%20de%20Management%20al%20riscului%20la%20Inundatii.aspx.

xxx Atlasul Cadastrului Apelor din România (1992).

https://www.openstreetmap.org/#map=11/44.0907/23.2131

http://www.charta1864.ro/charta.html

http://www.geo-spatial.org/download/harile-austriece-1910-reproiectate-in-stereo70

http://digitalarchive.mcmaster.ca/islandora/object/macrepo%3A9659.

http://www.geo-spatial.org.