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Three Centuries of Dynamics in the Lowland Section, induced by Human Impact – a Sociogeomorphic Approach

Fabian Timofte[A*], **Petru Urdea**[A,B]

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Abstract

This study aims to analyze one of the most dynamic sections in the lower part of the Mureș River, Lipova-Arad sector. The geological and tectonic context influenced the shifts of the watercourse at both a regional scale and a local one. The channelization works have shortened the length of the channel by 1/3 of it. The flood events in the 70s and the mining activity have also influenced the evolution of the river in last decades. Accelerating the geomorphological processes, mostly after the great floods, have narrowed the channel by 35%, and have reduced the total islands surface by almost 80%. In this context, the Mureș River try to reach the dynamic equilibrium state had before the human interventions. Under the anthropic pressure the geomorphological processes have been accelerated and the landscape left behind in Lipova-Arad section, along the Mureș River suffered important changes.

Keywords: meanders; historical changes; channel migration; GIS; sociogeomorphology; Mureș River; Romania

Introduction

The people used the methods for watercourses regulation from ancient times, in order to control both the discharge and water level for settlements supply. At the same time, the minor riverbeds are anthropic affected for the propose of flood protection, easier navigation, irrigation and hydroelectricity or for a better water management (Church, 2015).

The regulation of alluvial channels changes the balance between the discharge and the sediment budget, so considerable changes in the geometry of the cross sections and the planform parameters of course may occur (Petts, 1984). These changes are the response of the river for recovery the dynamic equilibrium state (Andrews, 1986; Carling, 1988). The velocities and direction of the river downstream are changing and the flow is governed by the relative frequency of sediments from tributaries unaffected by regulation (Petts, 1984).

Even if the channelization process based on good intentions, the engineers could not predict the impact on the channel morphology and the intensity of geomorphological processes. The cross section analysis is missing for recent period because of a lack infrastructure. On this line, we focused on the assessment of planform parameters of the minor riverbed. Channel pattern is the view of the river reach from above (satellite, plane, drone etc.). There are three main patterns of the minor riverbed: meandering, braiding and relatively straight channels (Leopold & Wolman, 1957). Rust (1978) refines the classification with anastomosing type and Miall (1977) introduces the wandering channel type.

[A] West University of Timișoara, Department of Geography, Romania, V. Pârvan, no. 4, Timișoara, 300223, Timiș, Romania; fabian.timofte@e-uvt.ro; petru.urdea@e-uvt.ro
[B] Institute for Advanced Environmental Research, West University of Timișoara, V. Pârvan, no. 4, Timișoara, 300223, Timiș, Romania
[*] Corresponding author: Fabian Timofte, e-mail: fabian.timofte@e-uvt.ro

The Mureș River is one of the biggest fluvial link between Transylvanian and Pannonian basin. For millennia, this path was used to carry natural resources to Tisa River (as an intermediate stop), and then further to central Europe and Balkan Peninsula (Kovach, 1980).

The flow direction of the Mureș River frequently changed during the Quaternary and this fact is reflected in its symmetrically arranged alluvial fan, and in the huge number of paleomeanders from the Pleistocene-Holocene period (Mike, 1991). Swamps and extensive wetlands have surrounded the meandering sectors, and the river have flooded large areas every year. The floods sometimes lasted for months, until the lateral depositional structures facilitated the evacuation of excess water (Sipos et al., 2012). The geotechnical works emerged as a strategy for fixing this problem, in order to facilitate an optimum navigation.

The scientific purpose of this study was born as a need for quantifying at a local scale the changing rates of the Mureș River channel in his depositional area. Compared to other previous studies (Timofte et al., 2016; Timofte, 2019), the temporal analysis scale was doubled and the spatial scale have been reduced, focusing on the most dynamic sector in Mureș lowland section - Lipova-Arad sector. The main findings of the previous papers regarding the analysis of some morphometric parameters for the Romanian part of alluvial fan.

Study area

The catchment of the Mureș River is 29.767 km^2 (Ujvari, 1972), of which 28.310 km^2 in Romania - 11.7% of the country's surface (A.B.A.M., 2015) - which represents 94% of the surface of the entire basin. The highest point of the basin is 2509 m above sea level, Peleaga Peak in Retezat Mountains, and the lowest point is 82 m a.s.l., located on the confluence point with Tisa River in the area of Szeged city (Sipos et al., 2012). As much as the river basin surface and its multiannual average discharge, 186 m^3/s, (A.B.A.M., 2015), the Mures river is on second position in Romania, after Siret with 36083 km^2 and 222 m3/s (Diaconu & Zăvoianu, 1983).

The lowland section of the river is located from the apex (to the west of Lipova) to Szeged, in the south-western part of Panonian Basin. The total length of the watercourse is around 175 km. In this area Mureș river built-up a huge alluvial fan (Kiss et al., 2104). The average slope for Lipova-Nădlac sector is 0.28 m/km.

Study area covers the eastern part of the deposition area (Fig.1), between Lipova city (123 m, 46° 05' N, 21° 41' E) and Arad city (105 m, 46° 09' N, 21° 20' E). The entire segment is a part of Arad County. A simple visual analysis of the cartographic representations shows off that this part is one of the most dynamic portion from the entire lowland section. The floodplain outline is obvious, especially on the left side, where the contact with the high plain of Vinga is made by a terrace level. On the right side, the contact with tabular plain of Arad is quite smooth (Posea, 1997).

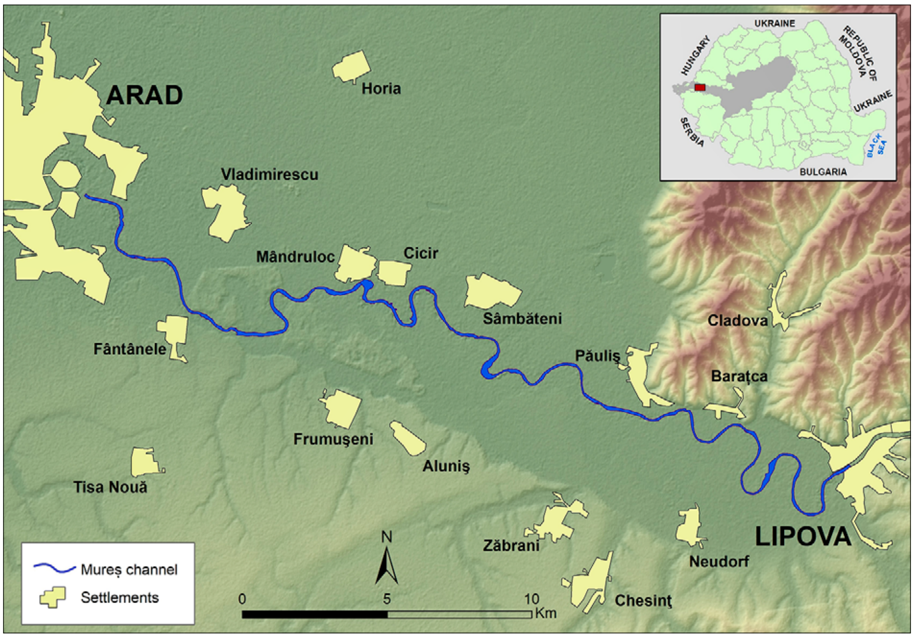

Figure 1. Location of the study area

Geological and geomorphological framework

The Quaternary evolution of the lower Mureş area is connected to the tectonic and geomorphological dynamic of this contact area between Carpathian orogen and Pannonian Basin, a large back-arc basin formed in Middle Miocene on a structural basement of the Carpathian type (Polonic, 1985). In the lower Mureş area are recognize the presence of a complex faults systems, at the level of the Pannonic basement, being individualized horsts and grabens, disposed from East to West, Caransebeş Graben, Buziaş-Battonya Horst, Sînnicolau Mare-Szeged Graben, fragmented by transverse faults, Jimbolia–Lipova fault and Sînnicolau Mare-Arad fault, all covered by Neogene sedimentary deposits (Visarion & Săndulescu, 1979). In detail, the Sînnicolau Mare-Szeged Graben is presented as two half-grabens, Szeged half- graben and Makó half-graben, in fact with the asymmetric tectonic trough character (Balázs et al., 2017). The continuous neotectonic subsidence, with varying speed, remained active in the Quaternary time, which explains the thickness of 600-700 m of the Quaternary deposits in Szeged area (Timár & Rácz, 2002).

The entire evolution of the lower Mureş sector from Midle Pleistocen to the Holocen is connected to the organization of the drainage system in the south central Tisa valley, coupled with Tisa graben evolution and with subsidence rates, flow direction, discharges and load dynamics in the Tisa-Criş-Mureş fluvial system (Kiss et al., 2015). In addition, the channel river spatial evolution was connected to the formation of an extensive alluvial fan, with a radial length of 80-100 km and 9000 km2 area, with a high density of paleochannels, in a tectonic active area. The successive courses of paleo-Mureş were driven by the local erosional base represented by the floodplain area of Criş and Tisa rivers in variable conditions of slope. The water discharges – between 2600-2700 m^3/s, 9,6 ± 1.3 ka and 680 m^3/s, 1.6 ka -, and loads, with effect on the behavior of the river, with the predominance of anastomosing, meandering or braiding, marked in the appearance of sectors with distinct paleochannel pattern (Kiss et al., 2014). The active tectonic area Mako-Szeged played a decisive role in fixing the course on the E-W axis, with the confluence point in the Szeged area at 1.6 ka (Kiss et al., 2014).

For entire area the contemporary tectonic activities are characterize by a high contrast between negative and positive vertical movements and opposite of horizontal velocity, which maintains the seismicity of the area, with polikinetic earthquakes with a magnitude of over 5 (Oros et al., 2018). For the extremely lower Mureş section, in the confluence Tisa-Mureş area the recent subsidence movements has values of 3 - 4.1 mm/y (Cornea et al., 1979; Joó, 1992), which plays an important role in maintaining a certain status for the local erosional base.

Geotechnical works and sociogeomorhpology

Our analysis of the Mureş evolution in the last three centuries highlights the fact that, in the last two centuries human intervention has been, for certain sectors, essential for adjusting the drainage in the flooding regime and, last but not least, for alluvial plain morphology reconfiguration, for the channel migration zone. This situation imposed a kind of approach compatible with the specific of sociogeomorphology, after which the geomorphic landscapes is seen as the result of interactions between physical and human processes (Ashmore, 2015). Both physical and human processes are critical for explaining how rivers have evolved and how they might adjust in the future. So, we find that in the case of the lower Mures, from a sociogeomorphological perspective, the human and physical processes, as well as interactions between these processes, drive and/or inhibit river adjustment (Mould et al., 2018), specific for a socio-natural system with human and physical components.

The human interventions on the main channel through regulation works were done in order to control the transport and to protect the settlements. We could not find out yet the information about the moment in time when each meander was regulated, but a situation plan highlights the fact that the meander from Arad was incised after 1815 according to Johann Mihalik's plan (Sipos et al., 2012). For all that, we suppose the channelization locally started in the end of 18th century, not before 1776[1], because the map from that year shows an unaltered channel. An extra argument is the map from 1792 that shows three fresh paleomeanders near Lipova and Mândruloc[2]. A number of six bigger meanders were incised before the second part of 19th century (Fig. 2), the information is available on the second topographic survey of Habsburg Empire map (1860-1865). After few decades, the meander incision process has been resumed in the end of 19th century, but with a less intensity (Kiss et al., 2011).

A vision of this kind, which, from another point of view, has a relevance for the history of riverbeds and alluvial plain mapping, we find in a situation plan at a scale of 1: 7.200, made by the Austrian engineer, Fried Braun in 1793 for a sector of Mureş (Fig. 3), downstream of Lipova. A detailed mapping marks

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[1] https://maps.hungaricana.hu/en/MOLTerkeptar/1707/?list=eyJxdWVyeSI6ICJtYXJvc2NoIn0

[2] https://maps.hungaricana.hu/en/MOLTerkeptar/29235/?list=eyJxdWVyeSI6ICJtYXJvc2NoIn0

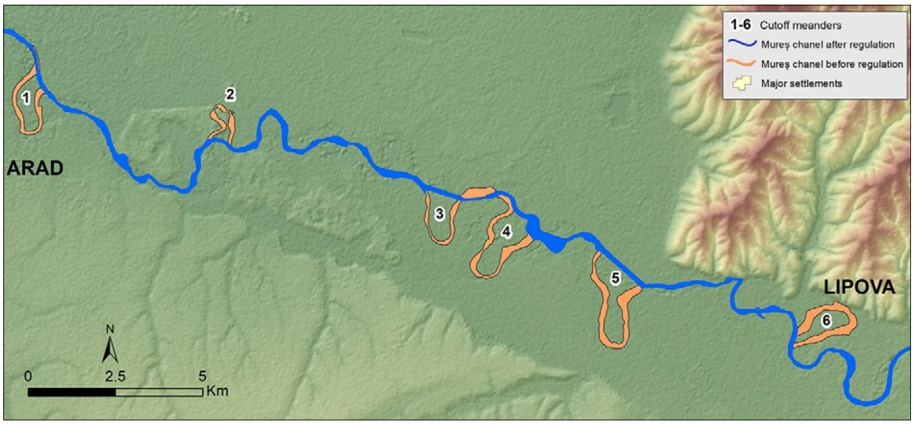

Figure 2. Meanders incised before the second part of the 19th century

the banks of the minor riverbed with their change in the floods of 1790 - indicated in a separate note -, by a dotted line the thalweg, as well as the rapids of the riverbed "*Treppelweeg*". Alluvial point bars, islands, river tributaries, abandoned meanders „*alte Todt Marosch*", and the accumulation of ice floes with the formation of an ice jam are also mapped, explaining the specific situation, even 4 weeks of each winter. In correlation with the economic component - agricultural terrains and industrial use (sand quarries, tiling, etc.) -, and the cadastral classification, represented by characteristic colors, the correction of the meander loop with a more accentuated dynamics is marked „*Neuer durchschnitt*". For geomorphological mapping, this way of cartographic approach is a remarkable one for that period, the genetic-thematic cartography of the relief being sketched only towards the end of the 19th century (Passarge, 1912).

The floods from 70s

This is the generic name used to describe the events that affected the carpathian rivers in 1970 and 1975. For most of them, the discharged reached the historical maximum. The flood wave of Mureș River exceeded 2300 m^3/s at Arad hydrological station (Fig. 4) and covered the whole floodplain.

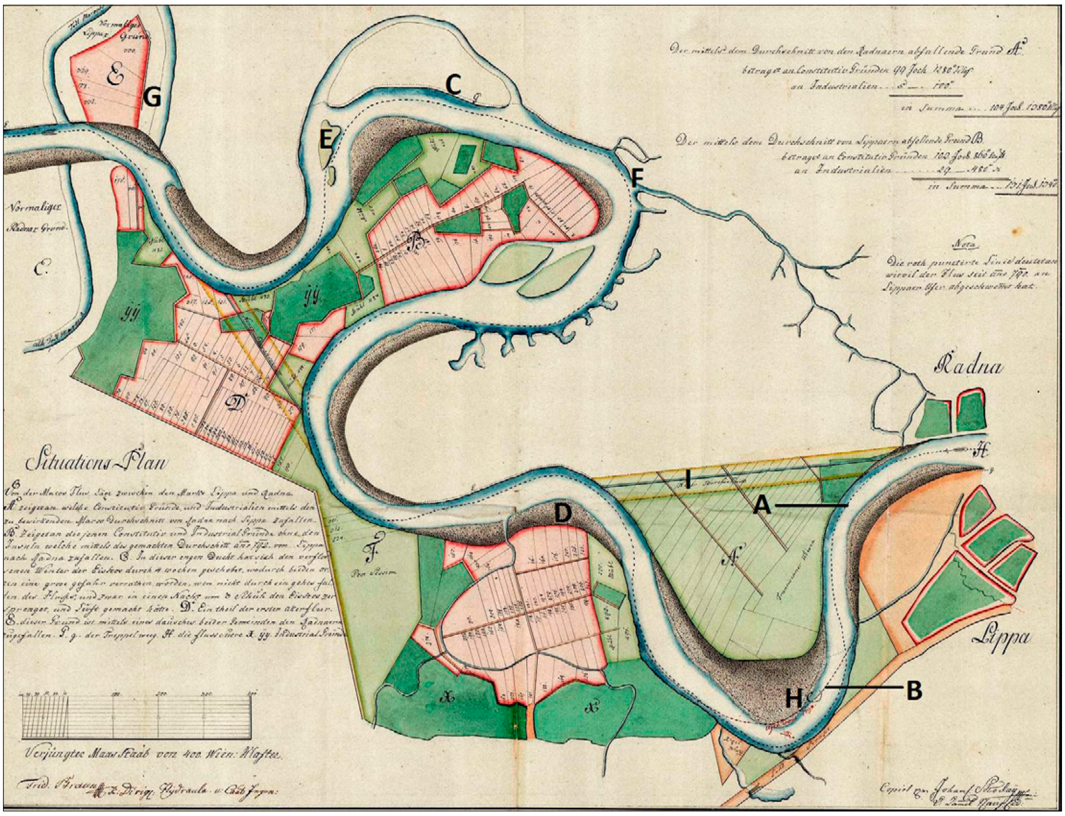

Figure 3. Situation plan of the Mureș River near Lipova city. A – thalweg; B – thalweg during floods; C – rapids; D –point bars; E – central bars; F – river tributary; G- abandoned meander; H – ice floes; I – meander correction. (Data source - https://maps.hungaricana.hu/en/MOLTerkeptar/5333/)

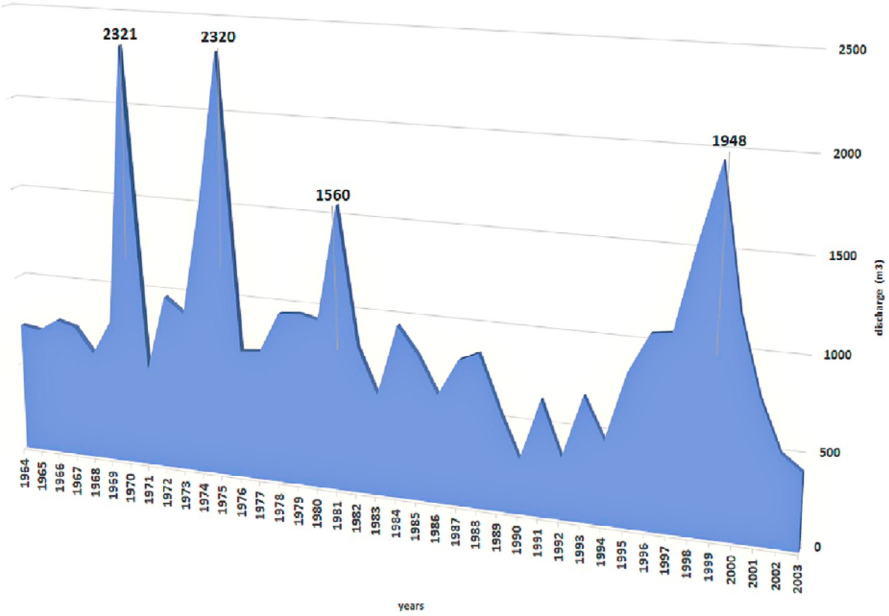

Figure 4. The maximum discharge at Arad hydrological station between 1964 and 2003 (after Zaharie, 2010)

An important consequence of the floods from 70s was related with the geomorphological impact in changing the configuration of the riverbed. For settlements protection the national authority built-up flood embankment: 4.7 km on the left bank in Lipova and 9.86 km on the right bank near Sâmbăteni (Timofte et al., 2016).

Data and methods

In the first instance, we have extracted the primary data for transforming analysis from different cartographic representations (Fig. 5). The first one is the Map of Lippa (Lipova) district that cover the entire section with only one sheet. This map is a base map for a well-known representation called Mercy map. This one portrays the Mureș channel before any geotechnical works. The next three maps are part of Habsburg and Austro-Hungarian military survey missions. Detailed situation plans for some parts of the watercourse supplement the basis maps. Because of coarse scale and cartometric reasons, for the first two sources only the length and sinuosity parameters have been analyzed.

For some representations, the acquisition and drawing period took more than 1 year, only for convention we decided to assign only one year for each cartographic source. The Romanian military and topographic surveys cover the 20th century especially the middle decades, highlighting the impact of the great floods that affected the Mureș drainage basin.

The orthophotos for the present day century are the best resource for evaluating the Mureș channel because of its higher accuracy. In contrast to the maps, orthophotos are untainted data sources; the researcher is free to interpret in his own way the shapes of the landforms and the limits between them.

There are many ways to investigate fluvial landforms, from the in situ methods to the remote ones. The geomorphologists seek all the information that could explain the origin and the evolution of the forms created by flowing waters. We applied a digital analysis in order to characterize the Mureș channel and its surroundings for the last three centuries.

Against the background of development of digital platforms, the geomorphology adopted (as the majority of research domains) the resources provided by computational analysis. The software and the tools are special created to fulfill the scientific needs. Also for fluvial geomorphology have been adapted software solutions which integrate the data for a proper analysis.

Specific for meandering rivers is the sinuosity index (the ratio between the total length of the centerline and the straight line that link the heads of the centerline). According to this index, there are three channel types: straight with $Si < 1.05$, sinuous with $Si < 1.5$ and meandering with $Si > 1.5$ (Rinaldi et al., 2016). The length of the channels always correlates with the sinuosity index. The increasing or decreasing in length depends on the analysis scale. It is proven fact that human interventions in meanders correction diminishes the lengthiness of the rivers, but these are not the only causes of length degradation. Largely, the natural processes are also important in channel evolution. It is true that an-

18th Century	19th Century	20th Century	21th Century
Map of Lipova district Publishing year: 1719 Scale: 1 : 144,000	Second military survey of Habsburg Empire Publishing year: 1860 Scale: 1 : 28,800	Romanian military survey Publishing year: 1940 Scale: 1 : 20,000	Orthophotos Publishing year: 2005 Scale: 1 : 5,000
Josephinian Land Survey Publishing year: 1769 Scale: 1 : 28,800	Austro-Hungarian survey Publishing year: 1881 Scale: 1 : 25,000	First Romanian topographic survey Publishing year: 1952 Scale: 1 : 25,000	Orthophotos Publishing year: 2012 Scale: 1 : 5,000
		Second Romanian topographic survey Publishing year: 1981 Scale: 1 : 25,000	Orthophotos Publishing year: 2019 Scale: 1 : 5,000

Figure 5. Cartographic data sources grouped by century

thropic pressure is increasing the intensity of water erosion, but sometimes meander chute cutoffs is influenced by a higher variation in discharge.

The most powerful instrument for digital analysis in the fluvial geomorphology is GIS analysis, included both in proprietary and open source software (Kondolf & Piégay, 2016). Using the ArcGIS software and some especially developed tools, we examined the information from the cartographic sources.

The first part of the analysis was to draw the channel and to extract the islands polygons from all the data sources. After that, we availed the Polygon to centerline tool to generate the centerline based on Thiessen polygons (Dilts, 2015). It was the basis for the almost all the investigation we made upon the minor riverbed. Channel migration toolbox was a good support for calculating the migration rate and particularly the width at a given distance (Legg et al., 2014).

For assessing the islands parameters, we calculated the surface and the elongation index using the Minimum Bounding Geometry tool from ArcGIS with the smallest convex polygon enclosing the input feature.

Results

Watching the Mureș River behavior during the built-up of his alluvial fan, we can say that he changed a lot his own pattern, especially because of climate conditions and through load inputs (Sipos et al., 2012).

The most obvious fact is the Mureș channel in the analyzed sector had a different aspect. The maps from 18th century displayed a much-braided riverbed[3] (even if this one looks very artistic). For sure, the presence of many branches in Păuliș-Vladimirescu (Glogovăț) sector (Fig. 6), which crossed the riparian forest on both sides, imposed a custom channel type, very close to the anastomsing.

Overall, the analyzed section can be assigned to meandering channel class (Fig. 7), the only exceptions being the first examined year and the moment after the end of meanders incision process.

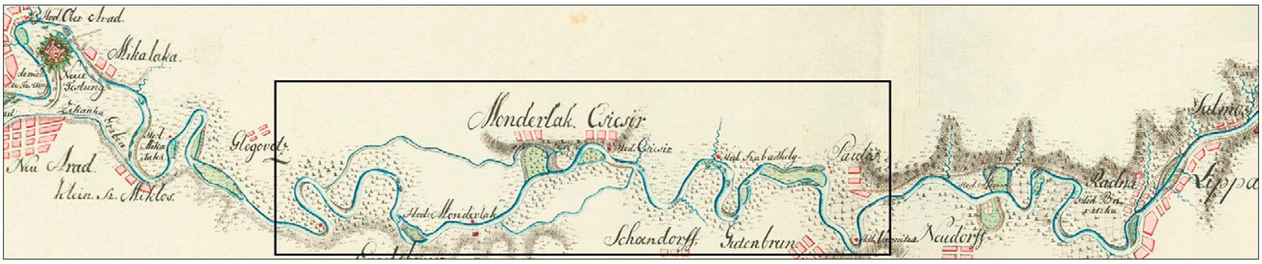

Figure 6. The map of Mureș River in 1805 (https://maps.hungaricana.hu/en/MOLTerkeptar/11020/view/?bbox=13858%2C-3920%2C14989%2C-3459); Păuliș-Vladimirescu sector in the frame

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[3] https://maps.hungaricana.hu/en/HTITerkeptar/2154/view/?bbox=5773%2C-3473%2C11154%2C-1274

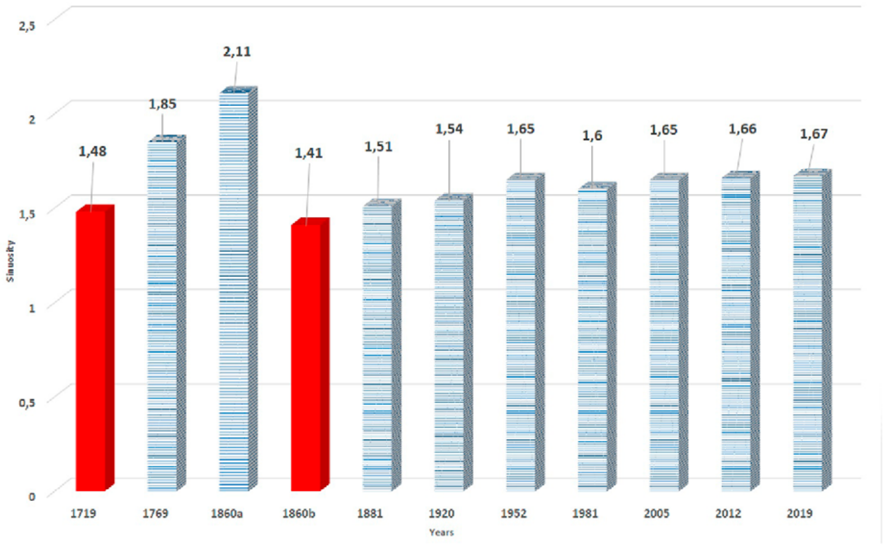

Figure 7. Sinuosity index evolution: 1860a-before incision; 1860b-after incision

Even if the general tendencies of this index are for increasing, some events in the history of evolution can drop down the values of sinuosity. A lower value for the end of the 20th century is associated with the floods that affected the Mureş River catchment.

Length variation

The main events that affect the length of Mureş River in Lipova-Arad sector are connected with the channelization in the end of the 18th century and in the first part of the 19th, the total length dropped down with almost 20 km. The graph below (Fig. 8) shows the difference in length for a base value of 41419 meters in 1719. For each period, we calculated the fluctuation in relation to previous stage.

The great floods from the 1970 and 1975 changed the configuration for some meanders, especially the meander near Sâmbăteni. The total length dropped after that hazard by almost 1.5 km. Due to intensification of geomorphological processes, river tendency is to increase his channel length, mostly in the meandering areas, in the last two periods the increasing rate is more than 150 m.

Channel migration

A specific fluvial activity is related with channel migration. The lateral erosion is related with specific avulsion processes. Based on centerlines from 4 periods we have calculated the total and average migration (Table 1). The first column of the table depicts the surface of the polygons created by the watercourse on the both sides. For the first two periods, the shifted surface is around 300 ha (which means almost 10 ha/year and 13 ha/year), and the values for the last two in-

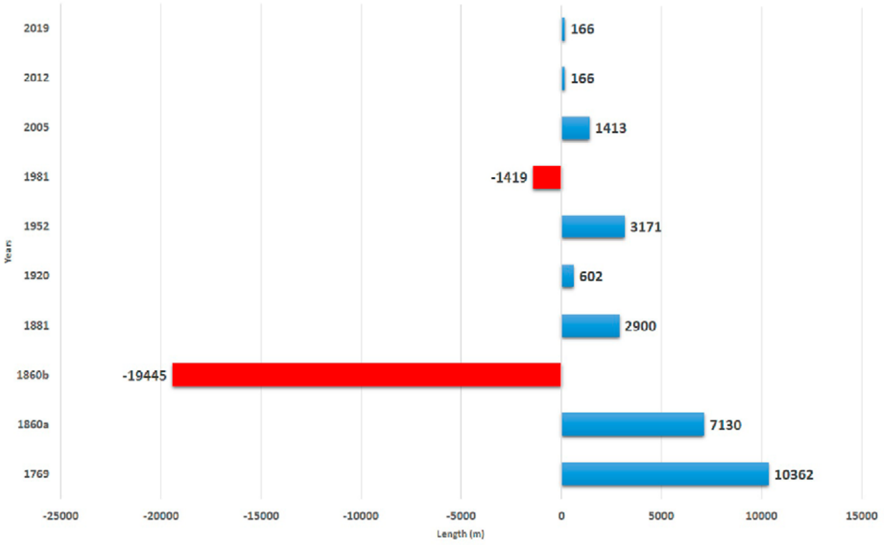

Figure 8. The differences in length for each consecutive analyzed period: 1860a-before incision; 1860b-after incision

tervals is ± 60 ha (around 10 ha/year and 7 ha/year). A less anthropic pressure gives the difference for the last period, for in the last few years mining activity has a lower impact on the channel. The second column of the table is the ratio between the migration area and the length of the centerline in order to correct the values based on channel length.

Table 1. Channel migration results

Analyzed period	Migration shape area (ha)	Length average migration (m)
1952-1981	286.06	62
1981-2005	308.55	66,87
2005-2012	68.56	14,86
2012-2019	54.04	11,71

Width variation

The channel width is in close contact with the transport and deposition activity of the rivers, especially with load amount. Perpendicular lines to the centerlines with 100 m distance was drawn in order to quantify the width of the Mureș course in Lipova-Arad sector. There are important differences especially for the maximum width in each period (Fig. 9), because of development of the mid-channel bars and islands. After the floods from 70s, the characteristics of the channel have changed and width as well. The watercourse width mean values are quite close (around 100 m) except the period of 80s, when the rate is close to 150 m. The minimum values are located in the upper part (between Lipova and Păuliș), where the slope is a little bit higher than in the rest of the analyzed surface.

Mid channel bars

The image of the river in the lower part reflects all the processes from the entire catchment. Islands and channel bars formation is conditioned by the discharge and load. The numerical evolution of these forms is closely related with the general conditions for channel development. The number of depositional landforms in the watercourse doubled from 1920 to 1981 (Table 2) due to great floods events: 1924, 1927, 1932, 1940, 1942, 1970, and 1975 (Timofte, 2019). The mining activity and the sand and gravel extraction directly from the channel determined an accelerated linear and lateral erosion, which led to a regression of mid-channel bars and islands as well.

Obvious differences can be distinguished when the surface of islands is examined. A double num-

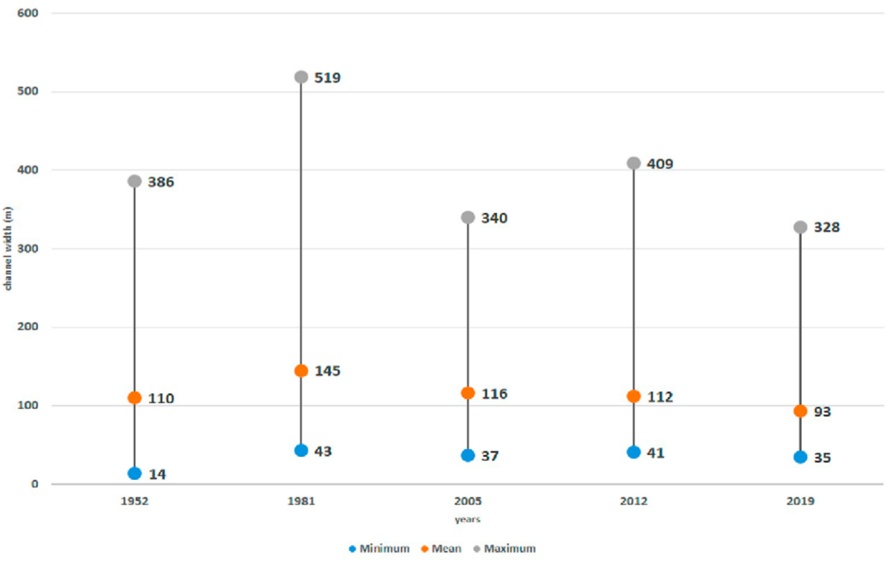

Figure 9. The width channel variation between 1952 and 2019

Table 2. The number and surface of mid-channel bars in the last century

Analyzed year	Number of mid-channel bar	Total surface (m²)	Max. surface (m²)	Mean surface (m²)	Min. surface (m²)
1920	11	607837	176319	55257	4373
1952	13	536150	135554	41242	6828
1981	24	805626	184284	33567	251
2005	18	233246	72459	12958	430
2013	17	208888	70509	12287	278
2019	13	164147	77592	12626	669

ber of forms does not mean a double surface of them. In the first part of 20th century, the islands and mid-channel bars had large surfaces (especially the small ones) while in the last 50-70 years the surface decreased, because some islands were attached to the banks.

Discussion

The lowland Mureş (which overlaps the alluvial fan) can be analyzed at different scales with multiple evaluation possibilities. The first scale is the entire section of the river, the second could be only the Romanian (or Hungarian) territory crossed by the river, the third scale is represented by the sections with accentuated dynamics and the fourth is the scale for morphological sectors imposed by the configuration of the river channel.

The Mureş channel in the study area can be divided in 3 morphological sectors according to planform configuration (Timofte et al., 2016). The first sector, Lipova-Păuliş, 16.6 km length, has three meanders, the second, Păuliş-Fântânele, 22.1 km length, has seven meanders and the last one is Fântânele-Arad sector with 7.7 km has two meanders. Likewise, the slope values are quite different for each morphological sector: 0.39 m/km for the first, 0.47 m/km for the second and 0.41 m/km for the third (Timofte et al., 2016). Dividing the section into morphological sectors is important for quantifying the local shiftings.

The second meander from the Păuliş-Fântânele section is the most interesting meander in terms of evolution (the central bend in the Fig 10). The first flow path followed by the river (before incision) was the south direction. With a straight channel, the flow direction changed to the north, until the floods from 70s, when the huge discharge favored the meander chute cutoffs. From that moment, the old path to the south was reactivated. The meander shape was extracted for the earliest periods not only from cartographic sources, but from the prints on the ortophotos. Total amplitude of the meander was 3015 meters in the last three centuries.

Pauliş-Fântânele seems to be the most dynamic sector in the entire study area. This fact is due to the intensive mining activity. In the last decades at least 15 sand and gravel pits was located in this area, mostly the alluvium being extracted directly from the channel (Timofte et al., 2016). In this way is very hard for the river to reach the state of dynamic equilibrium. In that manner the variation in length will be unexpected, even if the river tendency is to permanently increasing its length.

The water velocity modifies the riverbed parameters. In-channel deposits are a good indicator for the changes that occur in flow regime. The area and the form of the mid channel bars/islands are not so dependent on each other (Fig. 11), because the most developed forms are not the most elongated. For the maximum and minimum surface and elongation, the value of regression coefficient is around 0.12. Local conditions like the presence of water currents in the channel is important for the genesis and evolution of these bars/islands. That fact will affect the width of the channel.

The flow regime depends on climatic conditions that will influence the geomorphological processes in the future. According to Sipos et al., 2014, some climatic predictions for the Mureş catchment area show that the temperature will increase in the spring season that means a suddenly melting of snow. The precipitation amount will also increase in the next 30 years and the discharge will be directly influenced. The flood risk will increase, that will accentuate the erosion processes.

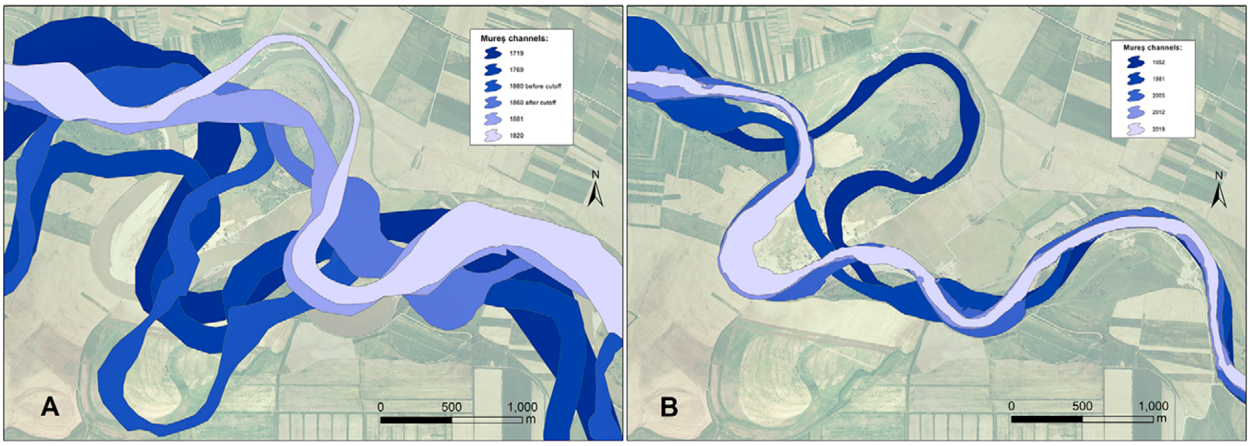

Figure 10. The meander near Sâmbăteni in two periods: 1719-1920 (A) and 1952-2019 (B)

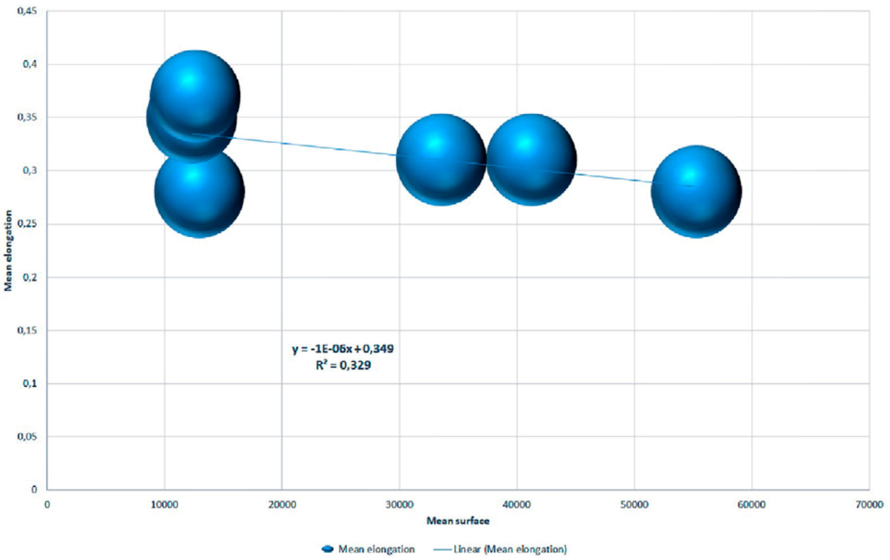

Figure 11. The regression between the mean surfaces of the mid channel bars/islands and mean elongation index

Conclusions

Connected to the manner of sociogeomorphology approach, the scale parameter is very important in landforms analysis. We chose to focus on e regional scale for the first sector of Mureş lowland section (Lipova-Arad) and the obtained results are quite different. Taking into account the specificity of the contemporary tectono-geological and general geomorphological landscape evolution, in relation to the other previous studies, we increased the temporal scale and reduced the spatial one.

Analyzing some channel parameters of Mureş River in a sector of lowland section, we can say without any hesitation that the Mureş River evolved in accordance with anthropic pressure (regulations, mining activity). The geotechnical works modified the planform parameters of the channel: the length have shortened by ⅓ whilst the slope increased, accelerating the erosion. However, the length parameter, with only one exception, has been calibrated by a continuously increasing. Through a constantly anthropic pressure imposed by the mining activity, the width has been altered, from 145 m in 1981 to 93 m in 2019. The channel bars surface changes are aligned with the changes of width parameter, from 80.5 ha in 1981 to 16.4 ha in 2019. Also the number of these microforms decreased from 1981 due to a new channel configuration.

The channel pattern changed during the analyzed period, from a braided and anastomosing in the 18th century to a relatively straight (for some sectors) in the 19th century (only after regulation works) and a meandering in the 20th and 21th centuries. Based on sinuosity index, we can say that Mureş River is still seeking the equilibrium estate had before the anthropic interventions.

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