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# THE EVOLUTION OF MUREȘ CHANNEL IN THE LOWLAND SECTION BETWEEN LIPOVA AND NĂDLAC (IN THE LAST 150 YEARS), ASSESSED BY GIS ANALYSIS

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**Abstract**: Mureș River is a natural resource both for Romania and Hungary. The lowland section of this river was influenced by regulation works in the 19th century and it is affected nowadays by other human interventions like mining activity (especially in the upper part of the study area). The aim of this work is to quantify the changes induced by humans in the last 150 years in the Romanian section (between Lipova and Nădlac). For that we have used GIS software and integrated tools to automate the analysis. After regulation works, the slope of the river has increased on some sectors and this enhanced the fluvial processes. The sinuosity coefficient (based on changing in length) dropped and the water velocity increased the erosion. The width of the course and the island's surfaces were affected by the mines which extracted sediments directly from the channel. In the future is suitable to monitor in addition the sediment budget and the 3D profile of the river because it will for sure unveil many enigmas.

**Key words**: channelization, channel migration, GIS, sand mines, Mureș River

## 1. INTRODUCTION

Fluvial geomorphic system is linked with other natural or anthropic systems, but the main evolution of the channel is controlled by discharge. In the last few centuries the human impact on rivers evolution increased considerably to avoid catastrophic floods and to enlarge the agricultural fields.

The changes of channel parameters are discussed in many geomorphological and hydrological studies (Schumm, 1977; Knighton, 1998; Bridge, 2003; Charlton, 2007). Alterations of horizontal profiles and lateral channel changes are researched all over the world especially to examine the sedimentary riverbeds in lowland areas (Wolman, 1959; Schumm & Lichty, 1963; Brooks, 2003; Kiss et al., 2008). The influences of hydro technic works on channels are investigated in several geomorphological studies to evaluate the resulted imbalance on local fluvial systems after dams' construction (Friedman et al., 1998; Brandt, 2000; Petts et al., 2005) and regulation works (Shields, 1989; Church, 1995; Hooke, 1995; Surian, 1999; Abizaid, 2005).

In Romania, the quantitative approach of fluvial processes was done especially for the rivers in Eastern Carpathians such as: Prut, Moldova (Rădoane et al., 2008; Chiriloaei et al., 2012), and also for Someşul Mic river in Transylvania (Perșoiu & Rădoane, 2011) Prahova River from Southern Carpathians (Ioana-Toroimac et al., 2010) and Jiu River (Ionuș, 2014). These approaches have distinguished the main channel characteristics for each river category.

Mureş River is one of the Carpathian rivers intensively affected by human interventions in XIX-XX centuries. Based on the analysis of historical maps and ortophotos the main channel parameters can be calculated in order to see both temporal and spatial evolution of the river.

In Romanian part the recent evolution of Mureș was investigated by Pandi & Horváth, (2012). The authors have correlated some morphometric parameters with the river flow. There is a study that covered both Romanian and Hungarian part of the river lowland section called FUTUMAR, a cross border project which tried to reconstruct the river evolution for the Holocene period (Sipos et al., 2012). Some papers is tackling in detail the paleo reconstruction of alluvial fan (Kiss et al., 2014; Sümeghy & Kiss, 2011) and some of papers is approaching the river response to anthropic interventions - mostly of these studies for Hungarian part (Sipos et al., 2007; Kiss et al., 2011).

The Romanian section of the river between Lipova and Nădlac was not investigated in detail in terms of recent changes and this is a good reason to research on this river sector. Main goal of this work is to quantify the changes in the lateral channel evolution induced both by human interventions during the last centuries and the nowadays mining activities. We hope the results will allow better understanding the regional characteristics of this reach and the river response to anthropic influences.

## 2. STUDY AREA

Mureș River (Maros in Hungarian) is a Carpathian river that springs from Hăşmaşu Mare Mountains (Eastern Carpathians) and flows from east to west. It outlet is in Tisa in Hungary near Szeged. Its total length is 766 km and the lowland section from Lipova to Szeged is approximately 175 km length. Nearby Lipova is located the apex of the alluvial fan (covering around 10.000 $km^2$), one of the most extensive landform in the western part of Romania. The catchment of the Mureş River is 29.767 $km^2$ (Ujvari, 1972), located mostly in Romania (94%). The highest point of the basin is Peleaga Peak in Retezat Mountains (2019 m), and the lowest is located on the confluence point with Tisa River which has 82 m (Sipos et al., 2012).

The investigations were made along its channel between Lipova (123 m, $46^0$ 05’ N, $21^0$ 41’ E) and Nădlac (88 m, $46^0$ 09’ N, $20^0$ 42’ E) (Fig 1). This area divides the historical regions of Banat and Crișana and played a key role in the historical times because it served for salt trade and light navigation. Three hydrological stations (Lipova, Arad and Nădlac) record discharge data daily, but suspended load can be recorded only in Arad.

The oldest cartographic representations of the river were compiled in the 15th and 16th centuries (e.g. Fra Mauro Camalduleb map in 1459 and Lazarus map in 1528). On many maps the river is called Marisius, Merisch or Marisch (Mureșan, 2011).

First detailed representations of the river are from 18th century, on these maps the river paleochannels, meanders and islands can be identified (The map of Mikoviny’s disciple from 1750, Hubert’s map from 1775 and Joseph Spatsek’s map from 1789).

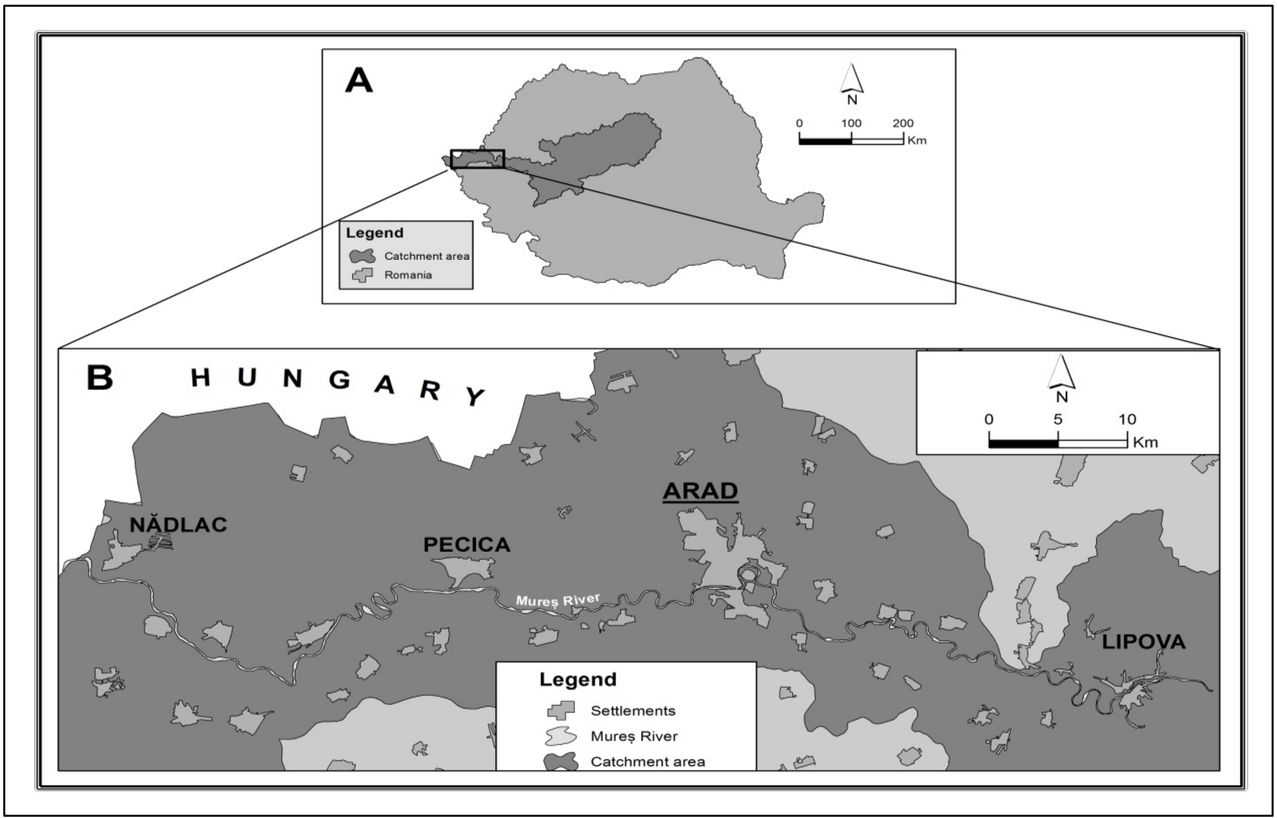

Figure 1. Location of the study area. A. Romania. B. Lipova-Nădlac sector

More recently, the most known maps for this area are the Military topographic maps (three editions) of the Habsburg and Austro-Hungarian Empires from the end of the 18th century to the beginning of the 20th century (Mureșan, 2011).

The analysis of paleoevolution of the river in this lowland section in Holocene revealed the paleodischarge directions and also the morphometric and patterns of the paleochannels based on orthophotos, satellite images and DEMs (digital elevation models) (Kiss et al., 2014). OSL (optically stimulated luminescence) dating was used to achieve the absolute ages for many old channels and meanders (Kiss et al., 2014). Those absolute ages demonstrate that Mureș River drainages first to Crişul Alb river (15 – 20 ka. ago) and then turned to the south. The present-day direction of the river probably exists from Roman Empire around 2 ka. ago (Sipos et al., 2012).

According to Zámolyi et al., (2010), in the Pannonian basin (Little Hungarian Plain) the river's sinuosity was affected by tectonic movements due to lateral erosion of Eastern Alps and Late Miocene faults activity. It is very possible that the Apuseni Mountains and geological structure of the alluvial fan had a certain influence on the main course of the Mureș River. In terms of tectonic structure, the area along the river is built up on inner dacides which compound the Carpathian basement. This structure is crossed by many faults oriented from north-west to south-east (Oros, 2008) which can affect the meanders migration.

The hydrological regime of the Mureș River is characterized by spring and early summer high waters. The mean discharge is 169 $m^3/s$, whereas the maximum recorded discharge was 2088 $m^3/s$ (at Arad) during the floods in 1970 (Lucaciu, 2005). In the 20th century the most destructive hydrological events based on water record levels were in 1941, 1970, 1975 and 2000. In the last decades the floods recurrence was between 5 and 15 years. The sediment budget related to this river is huge, the mean discharge of suspended load is 263 kg/s and bed discharge load is 0.9 kg/s. These values are comparable with recent findings of Tisa`s sediment budget near Szeged (Sipos et al., 2012).

Even if the tributaries are missing in this area, from the channel spring two secondary branches, Ier (which rise nearby Păuliș and turns back to main channel in Hungary) and Mureșel (which springs in Arad and turns back 20 km downstream). Nowadays these branches, especially Mureșel are used mostly as sewage.

The river channelization started in the second part of the 19th century with levee construction to prevent major floods. The cumulated length of the levees between Lipova and Nădlac counts 154 km on both river banks (Lucaciu, 2005). Until the end of the 19th century, 33 meanders were cut off in the entire lowland section and the course length decreased with more than 100 km. Some riverbank sectors were modified in order to streamline the navigation on the river, first upstream Arad (from 1865) and then downstream the city (at the end of the 19th century). On concave banks stone revetments were applied and on convex banks brushwood groins were installed (Sipos et al., 2012).

Sand and gravel mining activity represents one of the main problems nowadays. Many pits are located very close to main channel and the natural evolution is disturbed.

## 3. DATA AND METHODS

### 3.1. Data

Spatio-temporal data were obtained from various cartographic sources and orthophots and were used to reconstruct the river channel in the past. The comparison of achieved data from the maps can be done because the difference between map scales is not significant. The only disagreement is because orthophotos resolution depends on zooming.

Table 1. The collection of data we used in this study is listed in table

| Name | Topographic survey*/reambulation**/ acquisition date*** | Scale | Sector covered | RMSE (m) |
|---|---|---|---|---|
| Military maps of Habsburg Empire | 1860 – 1865* | 1:28 800 | Lipova - Nădlac | 21.2 |
| Austro-Hungarian military maps | 1881* | 1:25 000 | Lipova - Nădlac | 42.8 |
| Romanian military survey | 1919-1953* | 1:20 000 | Lipova - Nădlac | 26.4 |
| First Romanian topographic survey | 1952** | 1:25 000 | Lipova - Nădlac | 4.7 |
| Second Romanian topographic survey | 1981** | 1:25 000 | Lipova - Nădlac | 0 |
| Orthophotos | 2005*** | 1:5 000 | Lipova - Nădlac | 2.4 |
| Orthophotos | 2010*** | 1:5 000 | Arad - Nădlac | 2.8 |
| Orthophotos | 2012*** | 1:5 000 | Lipova – Nădlac | 2.1 |

Eligible data for this river sector are only available from the second part of the 19th century. The Habsburg topographic maps (1783 – 1784) were not considered in the analysis, because the georeferencing process of these maps was not possible. The special reference was missing and the map orientation was $5^0$ disturbed (Mureșan, 2011) making these valuable data useless for the GIS based analysis. All the data set (Table 1) extends more than 150 years temporal resolution and covers different sectors within our study area. Root mean square error (RMSE) was calculated to find out the accuracy for each data source (Downward et al., 1994). On this line we measured the location difference between the points (e.g. roads intersection) for each data source. Because the accuracy of maps resulted from Austrian surveys and Romanian military survey is not so good, we used this sources only for quantify the length of the river, the sinuosity coefficient and average slope.

### 3.2. Methods

The analysis of historical maps to assess the channels migration and to quantify the changes rates is a very used procedure in fluvial geomorphology. The majority of the approaches on horizontal channels evolution applied this method because maps from different period of time are suitable for analyzing longer term tendencies (Hooke, 1995).

All the data sets in Table 1 were used to digitize the channel banks in different periods as vector shapefiles. Most of the maps were in analog format and the coordinate systems were different but the workflow help to integrate all these maps in the analyzing process.

Geographical information systems (GIS) software is a powerful tool for every spatial problem and can integrate, analyze and display data and solutions for that problems. Downward et al., (1994) show 5 advantages of adopting GIS based approach to quantify river changes. They have arguments for integrating, processing and representing data and results. GIS software has many integrated tools, but the best thing is that every user can customize and create tools for particular problems.

Firstly we georeferenced the historical maps using ArcMap software to associate the raster images with spatial location in physical space. For resampling we used as base layer maps mosaic from 1981 with 1:25.000 scale whereas the Romanian coordinate system Stereo70 was used.

Next stage was to vectorize the riverbanks and the islands from all the sources. The digitizing scale is very important for orthophotos (Mount & Louis, 2005) because the changing rates have to exceed the measurement errors. According to Liro, (2015), the best scale for vertical orthophotos digitizing of riverbanks is 1:1000 to achieve better results.

In order to quantify the changes we extracted the centerlines of the channels from all the data sets. We used the centerlines to calculate the length variations of the river, the lateral migration and the width lines to rate the channel alteration. In addition some islands parameters (surface, elongation coefficient) were calculated to detect sediment deposition sites and to predict future changes.

The vectors of the main channel and islands were drawn manually, but the other operations were made automatic or semiautomatic. For sinuosity coefficient we used the Python script called „Calculate sinuosity" which is implemented on ArcGIS software by Esri. The sinuosity index value for the straight lines is 1 and it is down to 0 for the sinuous and curved lines. This tool makes the inverse operation, dividing the valley length (the minimum distance) to stream length (real distance). Channel migration toolbox for ArcGIS software has been developed by a team ruled by Nicholas Legg from Oregon State University (Washington Department of Ecology, National Park Service). This toolbox includes 4 tools and helped us to measure automatically the channel migration rates. The first one allowed us to measure the average migration rates for the entire reach in 1952, 1981, 2005 and 2012. The second generates perpendicular transects and we used it to calculate the channel width in the same time periods. We set the distance between transects to 100 m to notice the changes in detail. The other tools calculates the transect channel migration (tool number 3) and transect channel width (tool number 4). For islands analysis we used the Minimum bounding geometry tool implemented in the same ArcGIS software and we calculated the surface and the main axes for each island.

We mapped the levees and mines from orthophotos in two different periods (2005 and 2012). The human direct influence on the main course was decisive for anthropic or semi natural evolution of the channel, and the distance factor was calculated to map the anthropic areas of the river.

## 4. RESULTS

The channel configuration before regulation works was very different even for inhabited areas. Thereby the Mureș River at Arad was regulated after 1815 in accordance with Johann Mihalik's plan (Sipos et al., 2012). The channelization effects can be seen in some sectors even in the present because the river's equilibrium state was not reached yet.

### 4.1. The length variation

It is a very important parameter for quantifying the human direct impact (alterations after anthropic cut offs) and the derived one (the future effects). The length variation was obtained by measuring the river centerline in different time periods (Fig. 2). According to RMSE the length value before channelization was 137.7 m and after this process the value was 108.4 m. For the last sources, the length varied with almost 0.16% in 1952, and less than 0.07 in 2005 and 2012 (less than 100 m from total measured length). The suddenly decreasing of total length has determined the slope increasing and accelerating the geomorphological processes on riverbanks and river bed, especially the bed-load transport (Kiss et al., 2008). The average slope of the analyzed sector was calculated based on the altitude at the hydrological stations (Radna and Nădlac) and the river length between these points. Based on the data from Austrian second survey, the river slope in the second part of the 19th century was around 0.24 m/km before the first channelization works in 19th century and 0.31 m/km after those interventions. Nowadays the river gains in length and the mean value is closer to the measurements from the first decades of 19th century (0.27 m/km).

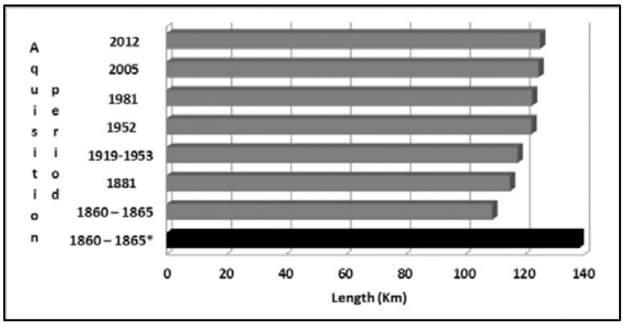

Figure 2. The length variation of the channel. (*1860-1865* - River course before regulation works*)

The sinuosity index calculated for the entire reach varies from 0.7 (around 1.4 if it is used the classical method) on the second Austrian maps to 0.63 on Romanian topographic maps and 0.61 on orthophotos from 2012. Before channelization the coefficient value was 0.55 (around 1.85). According to these values, the Mureș River has evolved into a meandering river from the middle of the last century.

### 4.2. The channel migration

The asymmetry index shows that the right side is more developed (58%) than the left side because the local geology that influenced the flow direction.

Using the centerlines as input data and the channel migration tool to automatize the process we induce the mean rate of lateral migration for some periods. Because the maps from the second Austrian survey could not be very well georeferenced the analysis was made without those maps. Discarding this data, the scale of the analyzed maps was almost standardized at 1:25.000.

The year 1952 was chosen as reference year and it was the starting point for the lateral migration analysis (Fig. 3). Between the centerlines were built polygons for each inflection with different areas. The migration means erosion in the concave part and aggradation in the convex one.

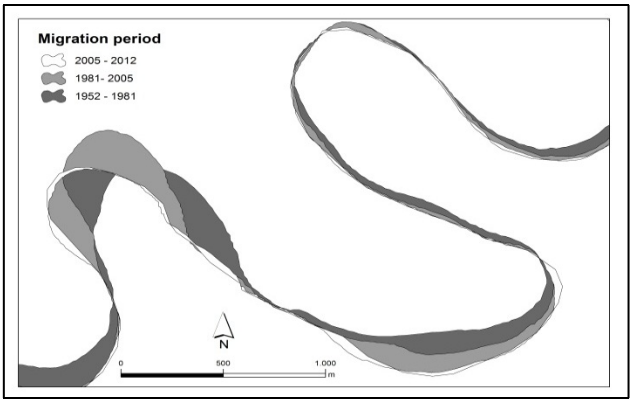

Figure 3. Channel migration between 1952 and 2012

This tool measures the changes in central axe position. If the channel became wider or narrower without alteration only in one side, the centerline will keep the same position. We calculated the lateral modifications for both sides (Table 2) of the river from the Romanian topographic maps and orthophotos. The left side was affected mostly before the flood period from ‘70s and the right side in the next decades.

Table 2. Surface of channel lateral migration

| Period of time | Total changes (km$^2$) | Right side (km$^2$) | Left side (km$^2$) |
|---|---|---|---|
| 1952 – 1981 | [6.95; 4.74] | [2.89; 1.78] | [4.06; 2.97] |
| 1981 – 2005 | [6.05; 4.92] | [2.89; 2.37] | [3.16; 2.55] |
| 2005 – 2012 | [1.45; 1.13] | [0.74; 0.58] | [0.71; 0.55] |

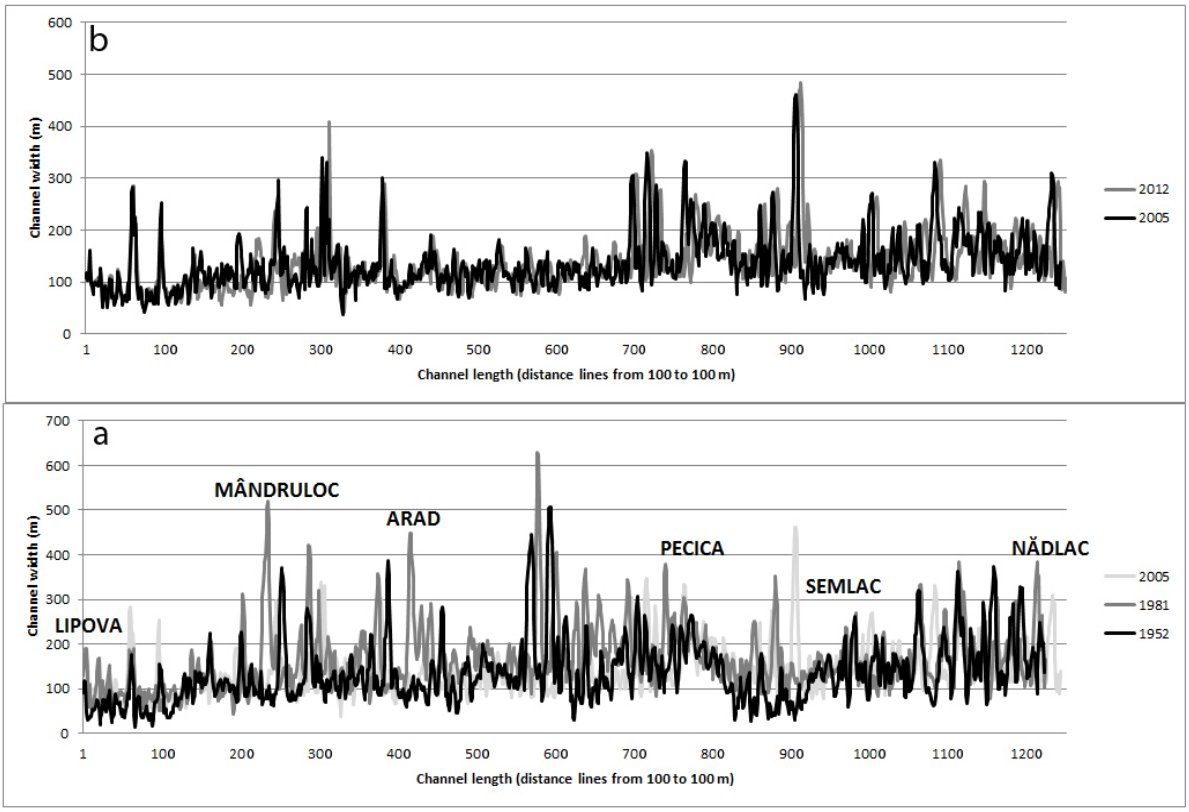

Figure 4. Channel width from different data source

In the last 50 years the Mureș River was very sensitive to anthropic or natural changes and the width was considerably affected. Figure 4a shows by comparison the variation of width for the channel between Lipova and Nădlac. Geomorphic processes affecting the channel left its mark on the width alteration of the river.

Discharge and especially the mining activity have modified the channel width in some sectors. The comparison of channel width in the same period of different years revealed the most affected areas of the river course. Perpendicular lines were generated from 100 to 100 m and then were clipped using the polygon shape of the river. In 1952 the mean width of the channel was 136 m, in 1981 this value increased to 166 m, in 2005 this decreased again to 138 m and in 2012 the mean was 139 m.

Overlapping the width in three different periods we are able to see that the highest values are recorded at the end of ‘70s between Arad and Pecica. We estimate that the main reason is the huge amount of sediments which was deposited during the floods on the middle part of the channel. After that the river course was deepened and sand bars developed along the both banks. For short time comparison we have chosen to analyze the channel from 2005 and 2012 (Fig. 4b) in order to calculate the mean annual changing rate.

### 4.3. Island analysis

The mid-channel bars and islands are distributed in the entire section of the Mureș River both in straight river sections and in meander loops. The islands formation correlates with the huge amount of discharge and with low slopes. The islands surface increased between 1952 and 1981 (Table 3). Also the number of the islands and bars have enriched from 42 in 1952 to 65 in 1981. We assume that the main reason was the floods in the ‘70s which have risen the bar surfaces. New branches occurred after the floods, but in a few years sediments filled the secondary channels and the island surfaces decreased again. The maps and the orthophotos show that the vegetation is installed very quickly and it helps for the island’s stabilization.

Table 3. Island surfaces

| Year | Total surface ($km^2$) | Mean surface ($km^2$) |
|---|---|---|
| 1952 | [2.01; 1.66] | [0.05; 0.04] |
| 1981 | 2.15 | 0.03 |
| 2005 | [1.53; 1.36] | [0.03; 0.025] |

The relation between longitudinal and transversal axes of the islands is expressed by elongation coefficient (Fig. 5). This index changed in the last years and the longer islands developed within Mureș channel. The older islands were attached to the banks and thus the width of the channel has decreased in the next period of time.

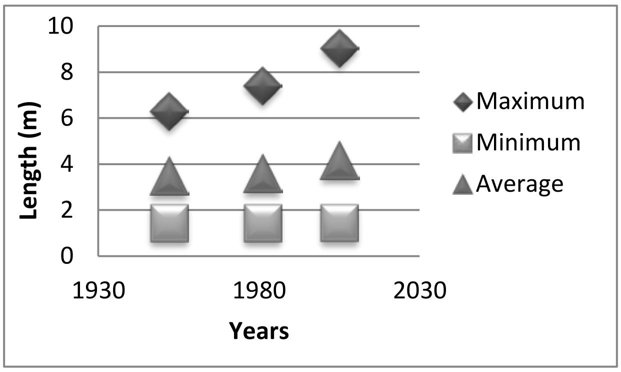

Figure 5. Islands elongation parameters

### 4.4. Anthropic vs. semi natural evolution

The levees length and the number of sand extraction mines along the course play a key role in the evolution of reaches. The distance factor is the main criteria for this analysis. We have calculated the distance between the levees and the channel from 2012. To find out the range we have created points from 100 to 100 m and established the maximum, the minimum and the average distance (Table 4) for each dyke section.

Most of these levees were built up in the 19th century especially at west of Arad city (Felnac – Cenad, Pecica, Șeitin and Năclac). After the floods from ‘70s, a new dyke system was built to protect the settlements (e.g. around Lipova, Păuliș, Sâmbăteni, Vladimirescu etc.). We have analyzed only the levees which are parallel with the channel.

The natural migration of the channel was stopped in some areas by these levees, whereas the river’s tendency was to affect the thalweg.

The islands’ migration and changing in morphological parameters indicate the river energy. If the changing rate is not so visible it is a good indicator of channel stability.

In the last few years the mining activity increased upstream of Arad because of the growing need for building materials.

Even if the river produces an important sediment budget, the channel is not monitored enough and nobody knows yet how much sediment can be removed without further consequences.

The root mean square error seems to have appropriate values for this type of study and we think a better georeferencing operation can increase the quality of the results.

More than 75% of mines are seated upstream of Arad because downstream of this city is located the „Mureș River meadow” natural park a protected area with habitats for many species of plants and animals. In the area of this park only 3 mines extract the sediments from the channel or from vicinity.

Between Lipova and Arad a number of 15 mines were mapped on the orthophotos from 2005 and 16 on the images from 2012 (Fig. 6). We can mention that 10 of them have the same location during all this time. The channel is permanently subjected to a great pressure from this activity even if almost every flood fills up the pits created during the extraction. The nearest mines from the Mureș course are located on the left bank in Lipova (15 m), Cicir (74 m) and Mândruloc (22 m).

## 5. DISCUSSION

Human interventions on river channels accelerate fluvial processes, shifting the channel configuration and the sediment budget. The intensity and changing rate was not the same for entire analyzed section, some sectors being more affected (e.g. Păuliș-Fântânele, Pecica-Semlac) then others (e.g. Arad – 3rd Island and Semlac-Periam Port).

Table 4. The levees sectors and the distance to the river channel

| Section name | Length (km) | Max_dist. (m) | Min_dist. (m) | Ave_dist. (m) |
|---|---|---|---|---|
| Left bank Lipova | 4.7 | 376.2 | 12.7 | 103.8 |
| Left bank Arad | 9.4 | 654.9 | 14 | 168.2 |
| Left bank at Aradu Nou | 1.96 | 436 | 24.4 | 132.3 |
| Left bank Bodrog | 2.12 | 864.1 | 164.5 | 486.4 |
| Left bank Periam Port - Felnac | 22.45 | 2008.1 | 68.7 | 760.5 |
| Left bank Cenad - Periam | 23.19 | 997 | 44 | 390.8 |
| Right bank Nădlac - Șeitin | 17.5 | 881.5 | 74.1 | 346.9 |
| Right bank Semlac (city belt) | 1.31 | 745.2 | 131.7 | 445 |
| Right bank Pecica (city belt) | 6.73 | 2572.9 | 147.4 | 860 |
| Right bank Pecica -Vladimirescu | 37 | 4223.2 | 10.6 | 1285 |
| Right bank Sâmbăteni - Păuliș | 9.86 | 1251.5 | 19.3 | 344.2 |

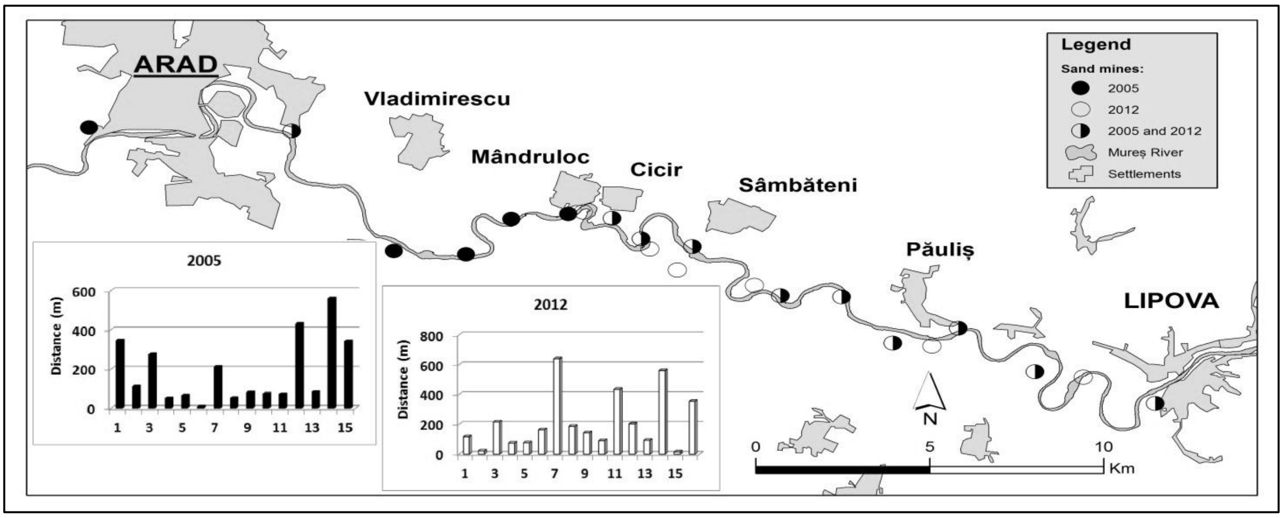

Figure 6. Mines distribution along the Mureș course and the distance to the main channel

The results can be integrated into some scenarios to show the future evolution. Even if the accuracy of the findings depends on input data we must assume that topographic maps and orthophotos can be integrated despite of the scale (for the maps) and the resolution (for orthophotos) does not fit.

The incertitude of this study is also related to the water level at the moment when the maps were drawn. We noticed that downstream of Lipova the channel on the topographic maps from 1952 looks too narrow.

Table 5. The Mureș River morphological sectors between Lipova and Nădlac

| Morphological sectors | Name | Length (km) | Average slope (m/km) |
|---|---|---|---|
| **I** | Lipova - Păuliș | 16,6 | 0,39 |
| **II** | Păuliș – Fântânele | 22,1 | 0,47 |
| **III** | Fântânele – Arad | 7,7 | 0,41 |
| **IV** | Arad – 3rd Island | 11,7 | 0,13 |
| **V** | 3rd Island – Felnac | 11,5 | 0,18 |
| **VI** | Felnac – Pecica | 12,4 | 0,24 |
| **VII** | Pecica – Semlac | 13,3 | 0,3 |
| **VIII** | Semlac – Periam Port | 7,3 | 0,06 |
| **IX** | Periam Port – Nădlac | 22,7 | 0,33 |

The intensity of the changes is not the same for the entire reach because some sectors are more affected than others. For a better quantifying of the results, the channel was divided in nine morphological sectors (Table 5). The channel in every sector is affected by different slope conditions, particular geological structure and in some degree by human interventions.

Looking on the data (Fig. 7) it can be easily estimated which is the most affected sector. The second one (Păuliș – Fântânele) has the greatest mean slope (0.47 m/km) among all the zones and the most number of mines (8, both in 2005 and 2012). This one is located very close to the apex of Mureș alluvial fan and the channel in this area looks very disorderly. The flow direction is from east to west and the settlements are located very close to the channel.

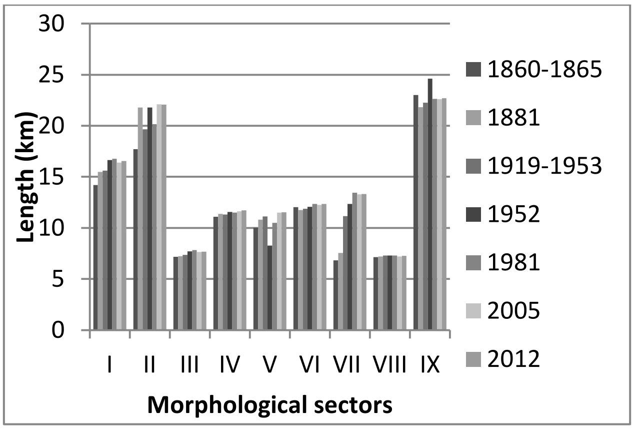

Figure 7. Length variation for morphological sectors

There are 5 meanders and the second one in this section is the most developed one and its amplitude have changed a lot in the last half century (more than 2000 m). Sand mine is located nearby this meander and the width of the course is permanently changing. Many paleochannels along this sector printed on orthophotos validate the great changes in the last centuries. The channel's average width has decreased from 160 m in 1981 to 122 m in 2012 because the anthropic activity controls the suspended load.

The VII$^{th}$ sector between Pecica and Semlac is not so long but the meanders have permanently developed after anthropic cut-offs. The flow direction is northeast to southwest and because of the sedimentary rocks the water has carved a meandering channel with a higher sinuosity coefficient. The mean slope for this area is steeper

(0.3 m/km) comparing to the slope for its neighbor sectors because some meanders were cut off downstream of this sector, in the southern part of Pecica city and the river energy increased considerably. The tectonic structure greatly influenced the morphology and the channel was sudden deviated by the tectonic faults with north-south orientation. Both channel length and width increased in the last 60 years and also the islands have changed its surface. The intensity of human impact is not so high because of the protected area “Mureș River meadow” and the great distance to the levees. This area is a good example of semi natural channel evolution especially in the last century.

The average width for every sector (Fig. 8) reveals that the changing in channel’s length does not influence the changing in channel’s width. The fluvial processes have affected not only the straight channel sectors but also the meandering ones. The Vth sector is very affected because some islands (e.g. the 3rd Island) were attached to the riverbanks (the side channel was silted up in the ’80s).

The anthropic levees are very important for Mureș fluvial system concerning the natural evolution. The banks of these sectors are stable because of the constructions, but it is very possible the thalweg and cross section to be seriously affected (especially the IVth sector). The low slope and the reduced human interventions have made the river reach the natural equilibrium for some sectors (both sectors between Semlac and Nădlac).

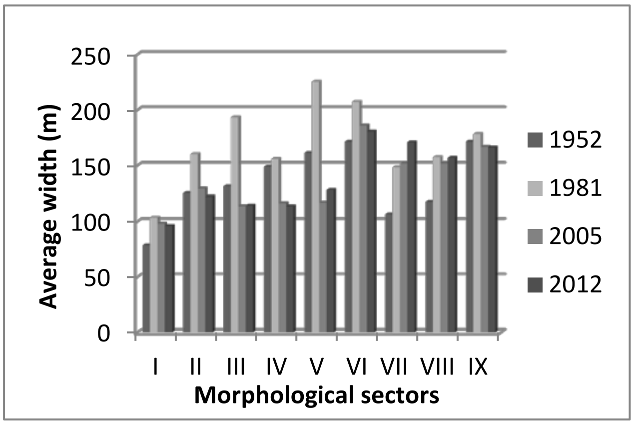

Figure 8. Width variation for morphological sectors

Mureș River was very active in the past and it still remains one of the most active rivers in the Carpathians basin because the extending of sand bars and mid channel bars surfaces. Looking on the data before channelization we realized that in natural conditions, the river evolves as a meandering stream. Before the regulation works the river has developed many meanders especially in sectors where the slope is very low. In the future we believe that in semi natural areas the channel will develop meanders. For the zones with human impact (bank stabilizations, levees, and mining activity) we suppose that the thalweg will be very affected because of erosional processes.

Our aim was not to calculate the migration or other morphometric parameters of the meanders (e.g. wave length, meander amplitude, radius of curvature etc.) because our attention was concentrated on the entire section and morphological sectors. In the Hungarian part of the river, the authors obtained almost same results but different values (because of the length section which is around 25 km). The length of Mureş River in Hungarian part decreased very much after channelization (43% of total). The sinuosity index decreased from 1.82 to 1.20 for the entire section (this value is greater in upper section – 1.38 than lower section – 1.02). The values for sinuosity index in Romanian part are close to values for upper section in Hungarian part of the river. The mean width of the course in Hungary increased after regulation works until the middle of the 20th century, from 150 m to 177 m and decreased after that (156 m in 2000). The sector near to Romanian border (upper sector) is wider (163 m) and it is comparable with the data in our study area (Sipos et al., 2007).

In terms of climatic aspects, some studies were done in order to predict the hydrological evolution for entire catchment (Sipos et al., 2014) and for upper and middle sector of the river (Lobanova et al., 2015). The prediction was done until 2100 and based on these models the temperature will increase with $2^0$ C in the next 30 years and with $3,5^0$ C until the end of this century. (Sipos et al., 2014). On the other hand the mean annual precipitations will decrease with 20 to 50 mm until 2100. The discharge will be influenced by these changes and it is expected that the spring and summer floods magnitude to be lower. For the upper and middle sector of Mureş River the authors believe that the mean discharge will increase in winter months and will decrease in late spring months because of the climatic changes in the next decades (Lobanova et al., 2015). If the entire regime of the river will be changed we think that the river in the future will develop a narrower channel with many lateral structures like sand point bars and natural levees.

Mining activity influenced the course shifts especially in the last 20-30 years. We are hoping that, in the future, we will have additional data to integrate in our analysis for a better interpretation of the results.

Concerning the results and the scenarios related to the river we are sure that only actions based on sustainable development can be profitable both for river evolution and for settlements protection against floods. For this the load should be investigated in detail to know which the optimal sediment amount that can be exploited is. The defense system against floods should be optimized, the distance from the channel to levees have to be greater than 200 m and the drainage channels (e.g. Ier and Mureșel) have to be unclogged.

## 6. CONCLUSIONS

Mureș River shaped a huge alluvial fun in the western part of Romania and in the south-eastern part of Hungary. Based on a great energy, the river has graven a meandering channel in the lowland section.

The evolution of the main course is influenced by the anthropic interventions through regulation works from 19th century. Many meanders were cut-off and the length of the channel suddenly decreased (with 21% of total length) and the intensity of erosion increased.

Special tools integrated in GIS software are appropriate for this type of analysis. The channel geometric parameters can be automatically derived from the channel shapefile. In this way the human induced errors will drop, and the results will gain in accuracy.

Human impact modified all the channel parameters, the sinuosity index decreased very much (from 1.85 before channelization to 1.4 after that). The channel was very dynamic even in the last 50-60 years. Between 1952 and 1981, the total lateral migration was around 5.8 km$^2$ and between 1981 and 2005, the migration was around 5.5 km$^2$. For short time period (2005-2012), the lateral migration was almost 1.3 km$^2$.

The consequences of mining activity influenced the sediment budget especially upstream part of Arad. Between Lipova and Arad are localized 80% of total mines (16 in 2012). The islands and mid channel bars surfaces decreased from 2.2 km$^2$ to 1.3 km$^2$ in 24 years (between 1981 and 2005). The natural evolution of the channel is obstructed by levees, these structures being built-up very close to the course (minimum distance is less than 100 m for almost all sectors).

Based on climatic scenarios the river discharge will decrease affecting the hydrological regime. The channel will become narrower, highlighting the lateral and the mid structures of the river. The river will try to reach the equilibrium state that had before channelization and it is sure that without any interventions, the length of the channel will increase.

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