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SPATIOTEMPORAL CHANGES IN MORPHOLOGY AND BED MATERIAL BUDGET ALONG THE LOWLAND SECTION OF RIVER MAROS

Theses of Ph.D. dissertation

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Szeged
2018

1. Introduction, aims

Besides natural processes, river morphology and sediment regime are highly influenced by anthropogenic activities which have increasing impact on fluvial systems. Due to these interventions dynamics and spatial extent of fluvial processes can change, which can result in environmental and social conflicts. Therefore, the assessment of the influencing factors and the determination of the preliminarily risks are important. Due to the bedload, composed mainly of sand and gravel, and high slope, River Maros can change rapidly. Previously river regulations, nowadays gravel and sand quarrying from the riverbed are the major anthropogenic interventions on the river. However, the impact of mining activity on river morphology and bedload sediment regime is less known. Based on the above mentioned, the main goal of the research is to determine the bed material budget using hydromorphological surveys along the Hungarian and Romanian lowland sections of River Maros, where intensive sediment quarrying can significantly influence natural processes.

To reveal the above mentioned problems the following aims were identified:

- assessment of the longer-term alterations in riverbed morphometry on the entire lowland section in the past century, investigation of the impact of quarrying on the changes of centerline and channel width
- surveying methodology development to monitor longer-term bed material budget changes
- determination of short term changes in riverbed morphology, quantification of bar development along the longitudinal section
- evaluation of different riverbed dynamics observed along the longitudinal section in terms of the effects of sediment extraction

2. Study area

The study area is the lowland section of River Maros, having a length of 175 km, from which 22 km is the common Hungarian-Romanian border; 28 km river section is located in the territory of Hungary and 125 km in Romania. River Maros has a relatively high slope, even on the whole lowland section (10-40 cm/km). Along the longitudinal section of the river, and also on the investigated section, incision and depositional sections vary (Török 1977, Andó 2002, Molnár 2007).

There are usually two main flooding periods on the river: the first one occurs in early spring due to snow melting, the second one is due to the late spring or early summer rainy weather. The floods proceed rapidly within even 20 days; longer floodings are characteristic near the river mouth due to the backwater effect of River Tisza. Flood recurrence interval was between 5 and 15 years in the past 40 years (Andó 2002, Urdea et al. 2012). After floods low water is characteristic for the rest of the year, and low-water periods can last for 10-11 months. Mean and bankfull water level is 36 cm and 310 cm at Makó gauge station, respectively. The highest and the lowest water levels were 625 cm and -113 cm, respectively. The mean and bankfull discharges of the river at Makó are 160 m^3/s and 850 m^3/s, respectively. At floods the discharge can reach 1600-2400 m^3/s, while at low-water periods it is approximately 20-30 m^3/s, thus the river fluctuates considerably (Sipos és Kiss 2003, Fiala et al. 2007, Urdea et al. 2012). River Maros transports significant amount of suspended (8.3 million t/year) and bedload (28 000 t/year) sediment (Bogárdi 1971). River regulation in the 19-20th centuries greatly affected the river development and as a result of the 33 cutoffs the length of the lowland section decreased from 260 km to 175 km between Lipova and Szeged. A positive result of the interventions was the decreasing duration of flooding, however, in parallel slope and stream power of the regulated river increased. Incision processes and later increasing channel width due to lateral erosion were observed, however, nowadays, the channel is narrowing, and the bar and island formation is still characteristic (Fiala et al. 2006, Urdea et al. 2012). Following the river regulation works, the intensive sand and gravel quarrying from the riverbed is the most import driver of morphological changes. The mining activity has been characteristic on the waterflow since the 1970-1980s, and it became very significant on the section upstream of Arad from the 2000s (Urdea et al. 2012).

In the research the assessment of longer-term alterations was performed on the whole lowland section of River Maros, the investigation of the hydromorphological changes was carried out on 5 smaller study areas. The surveyed areas were adjusted to the river section between Mândruloc and Cicir, mostly affected by in channel mining. The first site at Lipova is located in a meander upstream of the major sand exploitation on the river. The second site at Arad is directly downstream of the excavations. The other sites at Pecica, Seitin and Apátfalva are located at increasing distances from the main exploitation area. The length of the investigated sections was between 1.2 and 2 km. Their morphology is similar in the sense that each includes a riffle section (a complex of bars and/or islands) and an adjacent pool section above and below.

3. Methods

In my research the assessment of longer-term changes was carried out for the alluvial Maros. Mean channel width and centerline length changes were investigated after the river regulations, which can be highly affected by anthropogenic interventions and the resulted semi-anthropogenic processes. 4 map series from 1910, 1953, 1960 and 1982 and aerial photograph series from 2006 were applied for the evaluation. Based on the digitalised bank lines centerlines were obtained using an ArcGIS model. Based on the centerline, cross-sections at 100 m distances were inserted on the centerline using a PostGIS based SQL script that I modified. The cross-sections were cut off by the bankline to determine river width at the given points. The assessment of the changes of the cross-sections and the centerline was carried out for 1km long sections assigned based on the river directions before the river regulation works.

Hydromorphological surveys were carried out at 5 study areas (Lipova, Arad, Pecica, Seitin and Apátfalva) to determine the current tendencies. Surveying was performed after a high-water period in spring and a low-water period in autumn each year. At Apátfalva further measurements were also carried out within a period to assess the impact of smaller flood waves. Cross-sections were allocated to represent variable morphology within a site and the distance between two cross-sections did not exceed the half of the river width. The average distance between cross-sections was 40 m. During the further surveys the same longitudinal and cross-sections were remeasured. The tracking of cross-sections was carried out with Trimble Juno navigational GPS with a spatial accuracy of 2-5 m. For surveying underwater sections a light weight motor boat equipped with a Rio Grande ADCP was used, and for tracking geodetic GNSS receiver was applied. Depth data was recorded at 1.5 m in average at the given speed of the boat. In low-water periods exposed parts of the channel were surveyed with total station at every 5 meters. Data processing had more steps. Raw data were normalised to the same reference level. Data from the total station did not require further processing, since they reflected the absolute height of the riverbed. Depth data from ADCP measurement had to be converted to absolute height data using the surface coordinates provided by the RTK GPS. Digital elevation models (DEM) were set up for all study areas in ArcGIS, serving the base for further evaluation. Based on the final DEMs morphological changes of the study sections were assessed and volume deviations were computed based on the subset of the relevant models to quantify erosion and accumulation. The resulted volumetric difference was considered as a net change, which demonstrates if erosion or accumulation occurred on the investigated section. Since erosion or accumulation results in bed material budget changes, thus the overall or absolute change determined the amount of minimum transported bed sediment. The mean height of the cross-sections was determined to reveal the variability of the river bed morphology.

4. Results

4.1 Longer-term channel development

1. The most significant increase in centerline length can be observed in case of the meanders downstream of Pecica, where the river did not follow the direction of the cutoffs. It started meandering and it has been continuously developing. For the end of the investigated period, section length increased by 16% here. Centerline length increased more significantly in case of meanders near the river mouth, at Lipova and Mondorlac (+200 - +600 m/sector). The change is due to natural reasons in the first two cases, however, in the latter one mostly the mining activity contributed to the more rapid development due to the weakening of river banks.
2. The decrease of the centerline length was characteristic for only shorter river sections, mostly related to the cutoffs of the meanders. For these meanders, the assessment revealed a decrease of approximately 500 m.
3. Between 1910 and 2006 centerline length increased continuously on the whole lowland section. It has changed from 164.8 km to 174.5 km, which means an approximately 6% increase. The main reason for the changes is the active development of the meanders, the rate of which exceeded the shortening due to the anthropogenic cutoffs.
4. The increase of channel width on the lowland section of River Maros was the most significant in case of the sections downstream of Pecica and Arad, and in the sector near Mondorlac. The reasons for the changes are the active development of the meanders and the extraction of the bank material. The increase of some investigated sections exceeds the rate of change for the whole lowland section by 200% on average.
5. The decrease of the mean channel width was characteristic for the Hungarian and near-border morphological units of the lowland section, where the rate of change was 80% higher compared to the whole lowland section on average. Further channel narrowing occurred at Mondorlac morphological unit at the end of the investigation period, and the rate of

change is similar to the above mentioned increase (200%). The main reason for the significant decrease can be the declining gravel and sand quarrying.

6. A 18% decrease of the mean channel width can be observed for the whole lowland section on average comparing the maps from 1953 and 2006. Increase occurred only on smaller river sections e.g. downstream of Seitin, at Pecica or at sections significantly modified by the mining activity.

7. Based on the rate of change in centerline and mean channel with, the entire Hungarian section, the border section, the near-border section in Romania and the morphological units upstream of Pecica can be considered more stable, characterised by slight changes. Dynamic sections, characterised by moderate changes are the meandering section downstream of Pecica, the section upstream and downstream of Arad and some sectors near Seitin.

8. Based on the current tendencies, the decline of the channel width and the increase of the centerline length, mainly due to the meandering character after the cutoffs, can continue in the future. However, the speed of the processes can be influenced by anthropogenic activities. As a result of the decreased sediment amount due to gravel and sand quarrying, the active meander development is accelerated by the lateral erosion.

4.2 Short term changes in morphology and bed material budget

9. Measurement and evaluation uncertainty was assessed using repeated measurements on representative sections of River Maros. The deviations of bed material budget, normalised to 1 river km (rkm), were 600 m^3/rkm and 1462 m^3/rkm at Apátfalva and Arad, respectively, while at Pecica and Lipova the deviation was more than two times higher (3600 m^3/rkm). Considering all studied sections mean volumetric deviation was 2300 m^3/rkm. Thus, it can be regarded as the overall uncertainty of surveys at the present environment and measurement setting due to improper tracking of survey lines and the measurement inaccuracy of the applied devices.

10. Based on the repeated measurements on representative sections, the mean horizontal difference of survey tracks was 3-4 m, which is in correspondence to the accuracy of the navigational GPS (2-5m). Measurement accuracy was smaller using ADCP compared to RTK GPS, which can also cause differences (average +/- 7 cm) in the mean elevation of the same profiles. The reasons for the higher volumetric differences are primarily the sections located at near-bar position. Therefore, the most accurate tracking is of high importance. Furthermore, ACDP has to be installed on the motor boat in the same way during the consecutive measurements, the weight distribution on the boat has to be kept in balance and the survey speed has to be the same.

11. Bed morphology at the Lipova study section can be considered stable; the bar size changes only slightly and the alterations have a periodic character. The mean width of the mid-channel bar and the length of the point bar do not change in the whole studied period. The changes in mean bar length and width are 15 m between two measurements; the mean bar top migration is 50 m.

12. Among study areas Lipova showed one of the slightest bed material budget changes (29 000 m^3 on average). Its reason is that the river can form the bed armour less effectively in case of a smaller flooding; furthermore, less sediment is likely to come from upper areas compared to other study sections. In the case of surveying in high water periods usually sediment surplus, while in low water periods erosion is characteristic. Besides the slight changes in width and length of bars, even a smaller flooding can cause a more significant mean height change (50 cm) in a cross section.

13. Although significant changes could be observed at Arad study section between the investigated periods, the main morphological character of the section is permanent. The mean length change of the mid-channel bars and point bars were 60 m between the two surveys, while the alteration of the mean width was 10 m on average and the mean bar top migration was resulted as 30 m. The total bar area periodically changed.

14. The bed material budget change was higher at Arad (49 000 m^3 on average) compared to Lipova section. The sediment surplus, observed in the first two years, later showed a continuous decline surveying at low or even high water periods. The possible reason for the decrease is the less amount of sediment arriving from upper areas, which causes the river to erode the area. A further reason can be that there were no relatively large channel-changing floods, characterised by high sediment transporting capacity, in the investigated period, thus bed armour could form. Furthermore, a major factor can be the continuous sand and gravel quarrying from the river bed upstream of Arad, as a result of which the amount of transported sediment also decreases in the river, thus erosion potential increases. This change is demonstrated by the above mentioned bed material budget opposed to Lipova, since in high water periods erosion is characteristic, not accumulation.

15. The morphological character of the Pecica study section is considered stable based on the assessments. Thalweg is located along the left bank, while side bars can be found along the right bank; their length and width changes continuously in the studied period. The mean length and width change was 40 m and 5 m between the two surveys, the mean bar top migration was 30 m.

16. The amount of reworked sediment at Pecica is similar to Lipova study section (29 000 m^3 on average). In addition, similar changes to Arad study section were observed in the second part of the studied period: the initial periodic changes are replaced by a continuous erosion, which is also reflected by the alteration in morphology and mean height of the cross sections. A significant difference compared to the previously presented study areas is that the river reworks here not only the sediment arriving from upper areas, but in the lack of bed armour it also disrupts the channel bed along the thalweg, which leads to incision. The possible reason for this is the finer grain size of the sediment compared to Arad or Lipova. Without significant, bankfull floods further erosion is likely to occur in the future.

17. The section near Apátfalva shows higher variability compared to the other study sites. Among the examined river sections, the most significant morphological changes occurred here. The development of side bars is continuous in the whole investigated period, and the mean bar top migration is 75 m. The change of mean bar length is 60 m, while mean width is 15 m between two surveys. As a result of the continuous migration and replacement of bars the direction of the thalweg also changes.

18. Based on the morphological changes in the study section the amount of reworked bed material is also significant (63 000 m^3 on average) at Apátfalva. Accumulation can be detected in low water periods and after surveys following floods, while erosion can be experienced until low water survey after floods. In the case of consecutive floods occasionally erosion or accumulation prevails, however, the average change shows similar values. The absolute amount of reworked bed material is the highest in low water period or in case of consecutive floods. The changes have a cyclic character, thus erosion is usually followed by accumulation. This process can be fostered that the finer grain size of sediment, characteristic for this section can be transported by the river in case of smaller floods, furthermore, if appropriate amount of sediment from upper areas is available.

4.3. Temporal changes of bed material budget

19. The assessment of the channel dynamics along a longitudinal section revealed that a continuous change is characteristic for the sections at Lipova, Arad and Pecica, and its rate is constantly increasing by applying wider temporal scale, which is not influenced by the hydrological conditions (e.g. water level). The direction and rate of the changes reflect slight incision or accumulation on all river sections. Based on the morphological changes and the bed material budget Lipova faces rather accumulation, while on the contrary incision is characteristic at Pecica and Arad.

20. On the study area near Apátfalva the assessment of the absolute bed material budget revealed a cyclic rearrangement, thus, a dynamic

balance is characteristic for the section. The duration of the maximal rework within the sediment cycle is approximately 18 months, which reflects the return period of the significant bankfull floods. A cycle, involving erosion and accumulation processes, has an average duration of 38-40 months.

4.4. Spatial changes of bed material budget in relation with the gravel and sand quarrying

21. The assessment of the absolute bed material budget along the longitudinal section revealed that the amount of reworked sediment, normalised to 1 rkm, was the slightest at Lipova (~ 15 000 m^3), followed by Arad and Pecica (~ 25 000 m^3) and Seitin (~ 38 000 m^3) and the highest values were observed at Apátfalva (~ 65 000 m^3). Based on the resulted data and the morphological changes mainly accumulation occurred on the study section at Lipova, however, in case of Arad and Pecica erosion could already be detected. It is likely that gravel and sand quarrying upstream of Arad has significant impact on bed material budget due to the experienced significant erosion processes downstream the extraction. It can also be observed on the section downstream of Pecica resulting in accelerated meander development, where based on the results of the longer-term change assessments erosion is also significant (estimated 150 000 m^3/y between 2006 and 2010). All these contribute to increasing sediment amount on the lower parts of the lowland section, evolving a dynamic, cyclic change in the bed material budget, which is also followed by a morphological change.

22. Based on the results of the short-term hydromorphological assessments the similar development of the Lipova section is likely to occur in the future. Arad and Pecica study sections can be significantly influenced by the quarrying. In the middle part of the lowland section erosion, observed at Arad and Pecica in the second part of the investigation period, can continue, which can be further intensified by the large scale gravel and sand quarrying on the upper sections. If the river can not provide enough sediment from the upper and middle sections towards the lower sections, the decreased amount of sediment can contribute to the termination of the

current dynamic balance. Therefore, further monitoring of the area and change tracking are of high importance, which can be achieved by the measurement and data processing methodology developed within this research.

Publications in relation with the dissertation

TamásPrávetz, György Sipos, Zsuzsanna Ladányi 2017. Assessment of possible uncertainties arising during the hydromorphological monitoring of a sand-bedded large river. *Journal of Environmental Geography* 10:(3-4) pp. 27-33.

Fabian TIMOFTE, Alexandru ONACA, Petru URDEA & **Tamas PRAVETZ** 2016. The evolution of Mures channel int he lowland section between Lipova and Nadlac (int he last 150 yeras), assassed by GIS analysis. *Carpathian Journal of Earth and Environmental Sciences.* Volume 11. No. 2, p. 319 - 330.

Právetz Tamás, Sipos György, 2014. Mederanyag egyenleg változásának vizsgálata hidromorfológiai felmérések segítségével a Maros síksági szakaszán, *Hidrológiai Közlöny.* 94/2, 35-40.

György Sipos, **Tamás Právetz**, Tímea Kiss, Ardelean Florina 2014. Fluvial responses to past and present human impacts on the lowland section of river Maros, Hungary-Romania, British Geomorphological Society Manchester, 1-3. September 2014.

Sipos György, **Právetz Tamás**, Katona Orsolya, Ardelean Florina, Fabian Timofte, Alexandru Onaca, Kiss Tímea, Kovács Ferenc, 2013. A folyamatosan változó Maros - Mure§ul, un ráu mereu in schimbare - The ever changing river. In A Maros folyó múltja, jelene, jövője, Szegedi Tudományegyetem Természeti Földrajzi és Geoinformatikai Tanszék, Szeged (FUTUMAR, ISBN 978-963-306-213-5)

Tamás Právetz, György Sipos, Orsolya Katona, Tímea Kiss, Petru Urdea, Ardelean Florina, Alexandru Onaca 2013. Investigation of bed sediment household ont he lowland section of River Maros, Romania-Hungary. In: Ján Novotny, Milan Lehotsky, Zofia Raczkowska, Zora Machová (ed.) Book of Abstracts and Excursion guide. Carpatho-Balkan-Dinaric Conference on Geomorphology. Geomorphologica Slovaca et Bohemica. Vol. 2013/1, 66.

Sipos György, Kiss Tímea, Petru Urdea, Alexandru Onaca, Florina Ardelean, **Právetz Tamás**, Sümeghy Borbála, Katona Orsolya, Tóth Orsolya, Blanka Viktória 2013. A Maros síksági szakaszának múltbeli és jelenlegi fejlődése a klímaváltozás és az emberi használat szempontjából. Magyar-Román Természetvédelmi konferencia, Körös-Maros Nemzeti Park Igazgatóság, 2013.02.09.

Sipos György, **Právetz Tamás**, Katona Orsolya, Fiala Károly, Seres Tibor 2012. A görgetett hordalék szállítás volumenének vizsgálata hidromorfológiai felmérések segítségével a Maros síksági szakaszán, A VI. Magyar Földrajzi Konferencia, Szeged 2012. szeptember 5-7

Other publications

Boudewijn VAN LEEUWEN, **Tamás PRÁVETZ**, Zoltán Árpád LIPTAY & Zalán TOBAK 2016. Physically based hydrological modelling of inland excess water. *Carpathian Journal of Earth and Environmental Sciences.* Volume 11. No. 2, p. 497-510.

Právetz Tamás, Sipos György, Benyhe Balázs, Blanka Viktória 2015. Modelling Runoff on a Small Lowland Catchment, Hungarian Great Plains. *Journal of Environmental Geography* 8:(1-2) pp. 49-58.

Benyhe Balázs, **Právetz Tamás**, Sipos György, 2014. Hidrológiai modellező szoftverek összehasonlítása egy síkvidéki kisvízgyűjtő esetében. In: Blanka Viktória, Ladányi Zsuzsanna (szerk.) Aszály és vízgazdálkodás a Dél-Alföldön és a Vajdaságban. Szegedi Tudományegyetem Természeti Földrajzi és Geoinformatikai Tanszék, Szeged (ISBN:978-963-306-341-5)

Sipos György, **Právetz Tamás**, 2014. Vízvisszatartásra alkalmas területek lehatárolása térinformatikai módszerekkel a Dong-ér vízgyűjtőjén, In: Blanka Viktória, Ladányi Zsuzsanna (szerk.) Aszály és vízgazdálkodás a Dél-Alföldön és a Vajdaságban. Szegedi Tudományegyetem Természeti Földrajzi és Geoinformatikai Tanszék, Szeged (ISBN:978-963-306-341-5)