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ACCUMULATION STUDIES AT SPECIFIC SAMPLING AREAS OF THE ACTIVE FLOODPLAIN IN THE UPPER-TISZA REGION

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Abstract

In this paper the rate of accumulation was studied along four VO floodplain cross sections of the Upper-Tisza region between 1974 and 2014. VO floodplain cross sections are based on a mapping base-point grid (established in 1890), and they are located a few kilometers from each other. Furthermore, the roughness changes of different surface types, crossed by the VO floodplain cross-sections, were also determined between 1965 and 2015. The accumulation studies were extended to include the accumulation rates of the cut off meanders located along and/or close to the VO cross-sections. The roughness values increased in all four floodplain VO cross-sections since 1965; in two of them it reached or approximated 100 %. The average accumulation along the VO cross-sections was between 28 and 47 cm (0.73–1.23 cm/year) during the 38-year period. However, its areal distribution showed large differences. The highest values (169–309 cm, i.e. 4.44–8.13 cm/year) were found at the lowest points of the cut off meanders and swales in every case. The accumulation rate of the examined three cut off meanders near the floodplain cross-sections (140 and 1570 meters from the river bed) was lower (0.84–2.5 cm/year), but the study period was significantly longer (154 and 161 years, respectively). Comparing the values of the two periods, it is obvious that the accumulation of the active floodplain accelerates, presumably due to the significant increase of surface roughness.

Keywords: Upper-Tisza, active floodplain, accumulation, cross-section, floodplain roughness

1. Introduction

The accumulation studies in the Hungarian floodplain regions became popular in the last two decades. At the turn of the millennium, the attention of geographer and hydrographical experts turned to the topic due to the record-size, levee breach floods of the Tisza River and its tributaries (Kiss and Fejes 2000, Gábris et al. 2002, Schweitzer et al. 2002, Oroszi 2005, Kiss and Sándor 2009, Kiss et al. 2011). The early works mostly determined the accumulation rate with different methods in the areas of the middle and lower course of the Tisza River. The active floodplain of the Upper-Tisza was first investigated by the researchers of the University of Debrecen, using heavy metal, isotope, sedimentation and geoinformation methods (Borsy 1972, Braun et al. 2003, Szabó et al. 2004, Szabó and Posta 2008, Vass 2007, Dezső et al. 2009, Szabó et al. 2012).

In the present study the floodplain roughness and its changes during the investigated period were determined along four different VO cross-sections, based on aerial photographs representing the areas between two settlements of the Upper Tisza (Tarpa and Jánd) in 1965-66 and 2014 (VO is a mapping base-point grid that crosses the floodplain. The acronym 'VO' is the shortened name of Department of Hydrography in

Hungarian language. This department was the part of the Hungarian Royal Ministry of Agriculture in the 1890's). In addition, the altitude values of the points photographed in 1976 and 2014 were also studied along the VO cross-sections. Then, the results were compared to the accumulation rates – determined by sedimentation studies – of the cut off meanders crossed by or close to the VO cross-sections.

2. Study area

The floodplain area designated for the accumulation studies is located between 709-689 river km of the Upper-Tisza (Fig. 1.). Traces of the levees - which are very similar to those of today – that mark the width of the floodplain area can be found even on the first military maps (dated 1784); however, they were built mostly by local initiatives, and their exact altitude is unknown (Lászlóffy 1982). Field-works began with the foundation of the Company for Flood Protection and Control of Bereg County in 1846. The continuous levees were finished between 1849 and 1856 in the concerned section (Vázsonyi 1973). Almost simultaneously with the flood protection works, river regulation also began. The majority of the work (nine cut-offs) was carried out between 1855 and 1867, and the last cut-off at Jánd – between the 26th and 27th VO cross-sections – was executed after 1905 but before 1914 (Fig. 1.) (Vázsonyi 1973; Lászlóffy 1982). In the investigated area between Tarpa and Jánd, 8 of 9 cut-offs developed into active main channels.

The stream gradient in the investigated area between Tivadar and Jánd is 12 cm/km. In this part of the Upper-Tisza the dominant type of particles moving at the bottom of the river is fine, middle-sized sand grain. The suspended load is averagely 139 g/m^3 at Tivadar, while according to the literature, the maximum value is 11000 g/m^3 (Lászlóffy 1982). This is less than half of the maximum 28377 g/m^3 value found in the evaluated database. The quantity of the suspended load is approximately one thousand times more than the traction load.

Position of the VO cross-sections

The highest, 18th VO cross-section crosses the Tisza at 708 river km. Starting from the

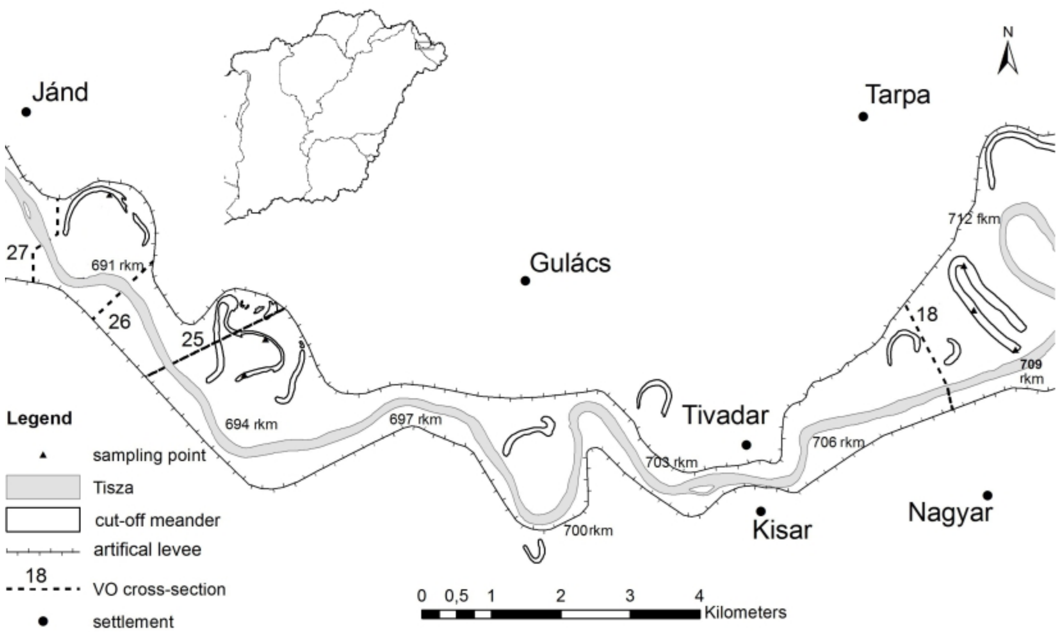

Fig. 1. Location of the studied VO cross-sections and the sampling points

left-side levee, it crosses the floodplain to the right-side levee 1680 m long (Fig. 1. and 2.). The meander parallel to the cross-section at about 1000 meter far was cut off in 1855 (Fig. 1. and 2.). Today it is heavily accumulated; continuous water coverage can be found only in a small radius curve that is farthest (1600 m) from the Tisza. Based on the land use of the cut off meander it can be concluded that the closer to the Tisza, the accumulation rate of the riverbed is growing, because the formerly planted poplar groves are being replaced by agricultural land use. Three deposit sampling points (140, 965 and 1570 meters away from the active riverbed, respectively) were determined in the meander in order to define the areal pattern of the accumulation.

The full length of the 25th VO cross-section at 693 river km is 2210 m (Fig. 1. and 2.). At the bottom of the left levee a borrow pit and a formless alluvial area lies, and on the right bank of the Tisza it crosses its overbank. The section crosses the meander (that was cut off in 1855), and its point bars and overbanks twice (Fig. 2.). During our previous studies two bore points were created in the meander, 300 and 500 meter from the VO cross-section.

The 1345 m long 26th VO cross-section crosses the active floodplain at 691.5 river km. (Fig. 1. and 2.). The section crosses a series of point bars at the left-side of the floodplain, while on the right-side it reaches the borrow pit through a formless area near the levee. The 1200 m long 27th VO cross-section crosses the Tisza at 690 river km. On the left side of the floodplain it crosses a meander in addition to the borrow pit and the formless areas; the cut-off of the meander is unknown. The right-side section runs through a form-deficient area to the borrow pit at the bottom of the levee. Between the 26th and 27th VO cross-sections – the distance between them is 1300 m – there is a meander that was separated in the early 1910s (Fig. 2.). In the inner curve of the meander (approximately 650 m radius) a series of point bars were formed that reach the active channel.

3. Methods

The roughness of the active floodplain and its change were determined along the VO cross-sections based on the FÖMI (Institute of Geodesy Cartography and Remote Sensing) archives, using the black and white aerial photographs taken in 1965 and 1966,

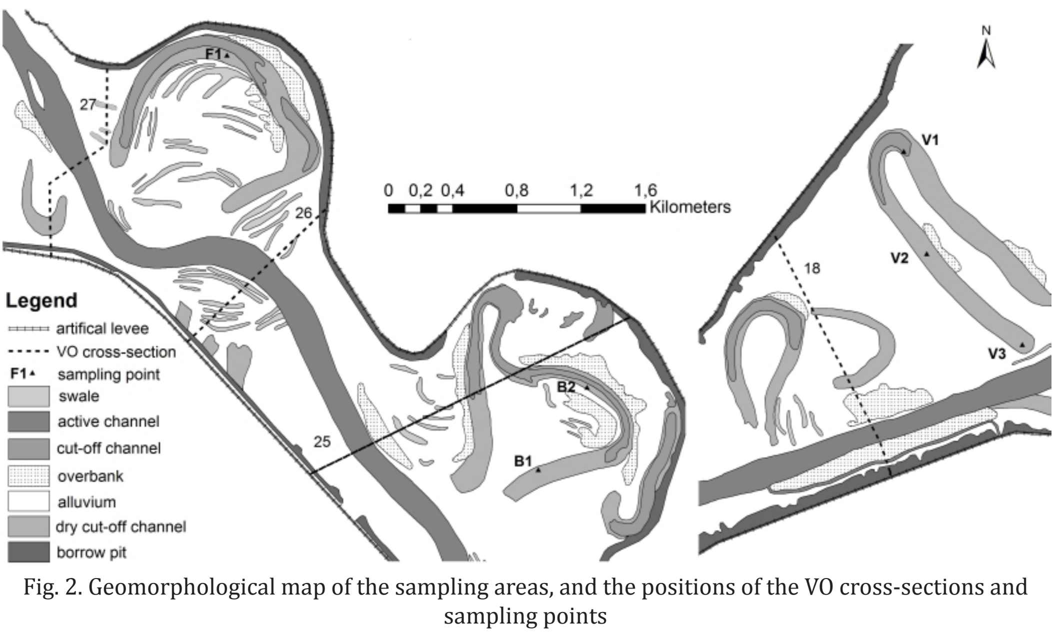

Fig. 2. Geomorphological map of the sampling areas, and the positions of the VO cross-sections and sampling points

and the Google Earth database mainly from 2014. During the evaluation the roughness factors defined by Chow (1959) were applied to the different surface and vegetation types. The land use types were mapped along the VO cross-sections, and weighted roughness values were calculated by multiplying their lengths with the relevant roughness factors. Surface heights were determined by levelling along the VO-section in 1976, while the new survey was conducted with LiDAR (Light Detection And Ranging) technology. LiDAR' accuracy make possible to discriminate fluvial floodplain forms having only a few dm difference in their heights (Szabó et al. 2015, Szabóet al. 2017). During the evaluation we used the altitude values of those parts of the VO cross-sections, which were not affected by either the lateral erosion of the river or the anthropogenic effect on the accumulation. In addition, the whole section of the active channel was neglected from the comparison. The starting points of the VO cross-sections were always located at the left artificial levee, and continued to the right levee.

An F-type bore head was used for the sediment sampling. Samples were taken from every 10 cm, and in each case we attempted to reach the former riverbed sediment that would indicate the bottom of the cut off meander.

4. Results

Change of roughness along the VO cross-sections

The biggest change along the 18th VO cross-section can be observed in the extension of the forests and arable lands. According to the status in 1965, no wood-covered area of the 0.1–0.14 roughness range was found in the cross-section; however, approximately one third of the investigated area (590 m) fell into this category in 2014. In addition, the extension of 0.03 roughness category arable lands reduced from 1170 to 730 meter. As a direct result of the significant changes in agricultural cultivation, the weighted roughness doubled during a 49-year period (Table 1.). In the floodplain, in the left side of the cross-section there were no significant changes during the examined period.

In case of the 25th VO cross-section, small changes were observed; the main reason is that afforestation at the expense of agricultural activities was almost negligible. Furthermore, even at the beginning of the studied period a significant part of the area was covered by orchards of 0.1 roughness category.

The 26th VO cross-section also showed significant changes in the size of forest-covered and arable lands. At the beginning in 1966 a 340 m of the cross-section was arable land; however, this cultivation type was reduced to 50 m by 2014. In this case, the ratio of the forests also increased significantly, from 425 m to 720 meter. Accordingly, the weighted roughness increased by approximately 25 % (Table 1.).

In the 27th VO cross-section the extension of arable lands decreased to a quarter of the original size, while the forest-covered part increased from 270 m to 620 m. In this case the weighted roughness values showed the highest (more than 100 %) increase between the two dates (Table 1.).

The altitude changes measured in VO cross-sections

At the left side of the 1660 m long 18th VO cross-section the altitude of 11 points were measured along an 80 meter section, while 1308 m of the right side was studied. At first, the differences of the average altitudes along the cross-section measured in two years (1976 and 2014) were determined (Table 2.). According to the measurements, the average altitude of the studied points increased by 35 cm (Table 2., Fig. 3.) during 38 years. The left- and right-side riverbanks showed 44 and 33 cm accumulation, respectively. The significant difference occurred owing to the fact that the sampling points on the left-side are much closer to the active channel and the accumulation is more intensive there

Table 1. Roughness changes along the VO cross-sections.
(* the product of roughness categories multiplied by their length)

VO cross-section	length (m)	**weighted roughness***	**roughness increase (%)**
18 (1965)	1660	55.6	83
18 (2014)	1660	**101.6**	
25 (1965)	2210	88.6	4.5
25 (2014)	2210	**92.6**	
26 (1966)	1345	68.1	33
26 (2014)	1345	**91.0**	
27 (1965)	1200	50.2	103
27 (2014)	1200	**102.6**	

(Sándor and Kiss 2006). Furthermore, the average altitude of the left-side area in 1976 was 78 cm lower than that of the right-side bank. Due to its lower position, theoretically the area suffered much more floods, and its water coverage could be more permanent. In the right-side, the cross-section crosses a cut off meander twice (at 843 m and at 1228 m), and in its lowest points quite significant accumulation (2.58 and 3.09 meter, respectively) was observed (Fig. 3.). Studying the cut off meander about 1000 meter to the east of the cross section, in the sampling points (1570 m (V1), 965 m (V2) and 140 m (V3) from the active channel) 200 cm, 230 cm, and 400 cm sediment accumulation was measured, respectively. From cutting off the loop in 1855 until 2016 the accumulation rates in the sampling points were as follows: V1: 1.2 cm/year, V2: 1.4 cm/year, V3: 2.5 cm/year. The accumulation rate of the cut off meander in the VO cross-section was found to be considerably higher: 6.7 and 8.13 cm/year. The accumulation rate changes over the surveyed 38-year period are obviously related to the significant increase of roughness in the area.

A 243 m long section in the left side of the 2210 m long 25th VO cross-section was examined, based on 7 points; while in the right side the studied section was 1638 m long (Fig. 1. and 2.). The average altitude values in this case were also observed to be higher in 2014 (Table 2.). Evaluating the left and right side of the floodplain, we found that the accumulation rate was higher on the left-side area (closer to the active channel): 83 cm (left side) and 36 cm (right side). In 1976, the average altitude values of the points studied at the left side were 40 cm lower than on the right side, but in 2014 this tendency reversed: the average left-side altitude values were 10 cm higher. The most significant accumulation was observed in the cut off meander which is crossed twice by the cross-section (at 1190 m and 1424 m). The largest accumulation (1.69 m; rate: 4.4 cm/year) was noticed at the 1424 m point, while the accumulation was lower at 1190 m (0.46 m; rate: 1.2 cm/year) (Fig. 3.). According to our previous investigations

Table 2. Altitude values measured in the VO cross-sections, their differences, and the changes in roughness

VO	average altitude (m) 1976	average altitude (m) 2014	average altitude difference (m)	change in roughness (%)	rate of accumulation (cm/year)
18	111.18	111.53	0.35	83	0.92
25	109.01	109.36	0.35	4.5	0.92
26	108.90	109.18	0.28	33	0.73
27	108.76	109.13	0.47	103	1.23

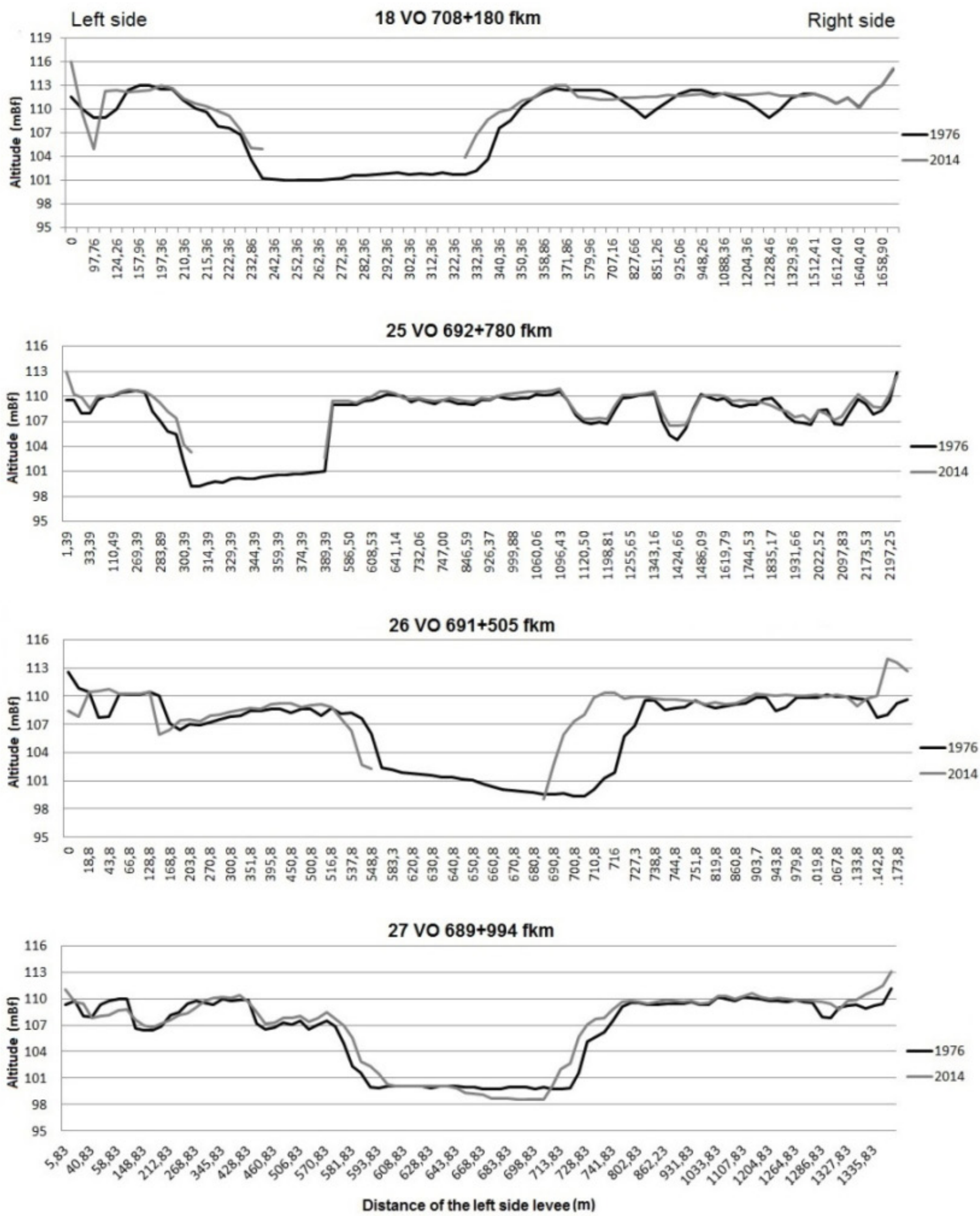

Fig. 3. Altitude values measured along the VO cross-sections

(Szabó et al. 2012; Vass 2014), based on the bore-points in the meander cut off in 1855, in the past 154 years the accumulation rates were as follows: B1: 0.84 cm/year, B2: 0.58 cm/year. Comparing the two periods, the increase of accumulation can be observed in this case, as well, that can also be related to the increase of roughness.

The lowest accumulation rate during the studied 38 years was found along the 1345 m long 26th VO cross-section (Table 2.), since only point bars and swale surfaces can be observed along the cross-section, instead of sharp, deep forms. The accumulation of the bank sides were even: the right side of the floodplain had only 7 cm higher accumulation. The reason for this is probably that the length of the studied sections and their farthest point from the active channel was nearly identical (left-side section: 469 m, right-side section: 405 m). Extreme values were noticed at the swales that have lower bottom-level, at 451 m (0.94 m; rate: 2.74 cm/year) and 943 m (1.61 m; rate: 4.31 cm/year) points of the section. Strong correlation is presumable between the relatively weak accumulation and the 25 % – also relatively small – increase in roughness.

Examining the studied cross-sections, the largest accumulation was found along the 27th VO cross-section (Table 2.). The accumulation rates of the left and right side were found to be completely identical; this can be explained by the reasons mentioned above at the 26th VO cross-section. In the left side of the floodplain, in the cut off meander at 148.8 m the accumulation was 0.88 m (rate: 2.31 cm/year) (Fig. 3.). The biggest observed accumulation in the right-side section that crosses the swale series was found at 1286 m (2.04 m; rate: 5.36 cm/year). According to our bore samples (F1) in the cut-off meander between the 26th and 27th VO cross-sections, in the period between the cutting off in the 1910s and 2009, 100 cm i.e. ~1 cm/year accumulation was measured. The reason for the bigger accumulation compared to the other VO cross sections, observed at the 27th VO cross-section is clearly related to the 103 % increase of the roughness in the area.

5. Discussion

Deposit accumulation rates were determined in four VO cross-sections of the active floodplain of the Upper-Tisza River, between 1976 and 2014. Meanders were also examined near the sections from the date of their cut off until 2016, between 709 and 689 river kilometres. In addition, the surface roughness of the active floodplain from 1965, 1966 to 2014 was compared and analysed. The highest accumulation rates (1.2–8.1 cm/year) were found in the meanders, but a considerable 5.36 cm/year rate was observed in the swales, as well. The average accumulation calculated for the whole length of the VO sections was 0.73–1.23 cm/year, which is similar to the 1–1.6 cm/year accumulation value at Tiszabercel (Károlyi 1960). A slightly higher value, 1.6–2.1 cm/year accumulation rate was found at the active floodplain of the Szamos River at Tunyogmatolcs (Borsy 1972). Accumulation rates in the active floodplain along the Middle-Tisza River were lower, 0.6–0.8 cm/year (Kiss-Sándor 2009). Accumulation rates in the cut off meanders varied between 0.84–2.5 cm/year. The accumulation process close to the active channel was found to be twice intense than at a sampling point 1570 meter farther. The cut off meanders in the active floodplain of the Maros River showed similar, 1.2–2.5 cm/year accumulation rates (Oroszi 2009; Kiss et al. 2009). Regarding all four VO cross-sections, the increase of surface roughness in the active floodplain was demonstrable; in two cases it reached almost 100 %. The measured accumulation rate during the last 38 years was observed to be twice or even three times higher than the value based on the sedimentation studies determined from the beginning of river regulations to the present day. Consequently, the rate of accumulation has accelerated significantly during the last few decades; this can be definitely correlated to the increase of surface roughness.

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