LAND-USE CHANGES AND THEIR EFFECT ON FLOODPLAIN AGGRADATION ALONG THE MIDDLE-TISZA RIVER, HUNGARY

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Received 29 January 2009; accepted in revised form 2 September 2009

Abstract

Land-use changes and their effect on overbank sediment accumulation were investigated on the floodplain of Middle-Tisza River. Military survey maps (1783, 1860, 1883 and 1890) and aerial photos (1950, 1965, 1980 and 2000) were used to evaluate land-use changes and to calculate the vegetational roughness of the area. To determinate the rate of overbank sedimentation sediment samples were collected from a pit, the grain-size, content of organic matter, heavy metal content (Pb, Cu, Zn, Ni and Cd) and pH were measured. Until 1950 meadows and pastures were typical on the floodplain, gallery-forest was along the river, the oxbow-lake and the artificial levee. Notable land-use changes were detected in the second half of the 20th century, as the aerial photo taken in 1965 shows extensive forestry in the area. These land-use changes affected the average vegetational roughness, as it has been doubled since the disappearance of grasslands. Land-use changes highly affect the aggradation, as the increased roughness decreases the flood velocity on the floodplain, causing accelerated aggradation. Using Pb marker horizons and grain-size changes the studied sediment profile was compared to dated profiles (Braun et al. 2003), thus, the sediment accumulation rate could be determined for the periods of 1858-1965 and 1965-2005. According to our measurements the accumulation rate was doubled since 1965, very likely in connection with the doubled vegetational roughness.

Keywords: land-use change, roughness, sediment accumulation, Tisza, floodplain

1. Introduction

As the result of the 19th c. river regulation works the area of floodplains was drastically decreased along the Tisza River. On the narrower floodplain the rate of fluvial processes were altered. Several studies present flood conductivity decrease (Kozák and Rátky, 1999, Török, 2000; Rátky and Farkas, 2003), but its cause have not been discussed yet. Simultaneously with the fluvio-morphological changes the land-use of the floodplain also transformed. The type and density of vegetation altered (invasion of exotic plans), smaller artificial levees and buildings were constructed. These land-use and vegetation changes increase the roughness of the floodplain, decreasing its flood conductivity. The process plays important role in increasing flood levels during the last decade (1998, 1999, 2000 and 2006).

As the land-use change affects the roughness of the floodplain, the flood velocity and thus the rate of aggradation also alter, resulting worse flood conductivity conditions on the floodplain. However, on the Tisza no study was made on the relationship between land-use change and aggradation rate. The rate of floodplain accumulation could be measured after a single flood event (i.e. Steiger and Gurnell, 2003, on the Tisza: Kiss et al. 2002), whilst other researchers calculate the mean rate of aggradation based on longer term sedimentary record (i.e. Walling and He, 1998, on the Tisza: Nagy et al. 2001, Schweitzer, 2001, Gábris et al. 2002, Braun et al. 2003).

The rate of accumulation is highly determined by the distance from the river (Oroszi et al. 2006), and its pattern is influenced by the geomorphology of the floodplain (Mariott, 1992, Asselman and Middelkop, 1995, Gábris et al. 2002), by the local currents (Borsy, 1972; Walling and He, 1998) and land-use (Steiger and Gurnell, 2003; Rátky and Farkas, 2003; Sipos et al. 2008). But none of the studies aimed to evaluate the spatial and temporal changes of these factors, and how do these changes influence the aggradation of the floodplain. At the same time some studies emphasized the role of vegetation, as through its influence on aggradation it also determines the chemical distribution (i.e. heavy metals) of the aggraded sediment through its grain size distribution (Szabó et al. 2008ab). According to Török (2000) especially in case of Tisza River the land-use is a very important factor in altering the flood conductivity of the floodplain, though such relationship was not found on the Danube and other Hungarian rivers.

The aim of the presented study is to evaluate (1) the land-use changes of a floodplain section in the Middle-Tisza region, north of Szolnok and (2) the influence of land-use changes on the rate of long-term aggradation.

2. Study area

The studied floodplain area is situated in the Middle Tisza Region, east of Szolnok (339.2-340.7 fkm), on the right floodplain side of the Tisza *(Fig. 1)*. It is bordered by the Millér Irrigation Canal and the Feketevárosi Ox-bow Lake. The width of the studied floodplain section varies between 285 and 2550 m. During the regulatory works three cut-offs were made in the area in 1858, increasing the slope of the river, and probably altering the grain-size of the sediment. The relative relief of the study area is under 3 m (83-86 m a.s.l.), the active natural levees and the point bars are the highest surfaces.

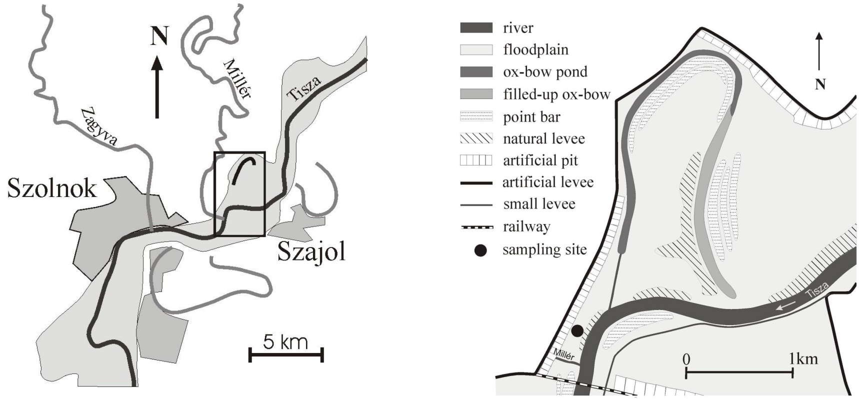

Fig. 1. Location of the study area and its geomorphological features. The sediment sampling site is situated near the Millér Irrigation Canal

3. Methods

To evaluate the land-use changes topographical maps were used covering the last 300 years: I. Military Survey Map (1783), II. Military Survey Map (1860), III. Military Survey Map (1883), survey made by Lányi (1834-64), the survey map of the Tisza (1890) and four aerial photographs (1950, 1965, 1981 and 2000). The geo-correction of the photos was made under ERDAS Imagine 8.6, then the area of land-use categories was calculated by Arcview 3.2 software.

Based on the land-use categories the vegetational roughness was determined. Citing the normal roughness values (*Table 1*) published by Chow (1959) the average roughness at a given date was calculated using the following equation:

$$n_{average} = \frac{n \times t}{T}$$

where $n_{average}$ is the average roughness of the area, n is the normal roughness coefficient, t is the area of a given land-use category and T is the total area of the studied floodplain section.

To determinate the rate of accumulation since the 19^{th} century such sampling point had to be chosen, which was undisturbed since the cut-off and artificial levee construction. Finally the sampling was made north of the Millér Irrigation Canal *(Fig. 1)*, where the width of the floodplain decreases to 300 m, and the area is covered by natural riparian forest (sampling is not possible in planted forest, because during the plantation the soil is ploughed and mixed in 50-80 cm depth). This point represents the sedimentary history of the whole study area, however it is close to the channel, thus, the rate of aggradation is higher than the average of the floodplain (Oroszi et al. 2006).

Table 1. Values of the roughness coefficient calculated for floodplains by Chow 1959

Land-use	***Roughness coefficient (n)***		
	minimum	***normal***	***maximum***
Planted forest	0.1	0.12	0.2
Riparian forest	0.11	0.15	0.2
Bushes (medium density)	0.045	0.07	0.16
Clearance	0.03	0.05	0.08
Grassland	0.025	0.03	0.05
Garden	0.03	0.04	0.05
Uncultivated	0.02	0.035	0.05

Sediment samples were taken from a pit at every 2 cm. The following parameters of the samples were defined: grain-size distribution (by Köhn-pipetten method and wet-sieving), pH (by electrometrics), content of organic matter (by spectrophotometry) and heavy metal content (digestion in aqua regia and measurement by AAS).

4. Results and discussion

Land-use changes since the 18th century

At the end of the 18th century the deeper lying, regularly flooded areas were covered by swamps and marshes, the higher surfaces were covered by meadows *(Fig. 2/a)*. By the mid-19th century smaller groves appeared along the riverbed, *(Fig. 2/b)*. The map made in the second half of the 19th century *(Fig. 2/c-d)* show larger forests along the channel and also on the floodplain. The location of the cut-off was also signed, as a narrow channel. The topographical names (*Kisrét*: small meadow, *Tenyő puszta*: steppe) on the 1890's map indicates the existence of large grassy areas *(Fig. 3/d)*.

The first aerial photo was made in 1950 (*Fig. 3/a*). It showed very similar land-use pattern to the 1890's map, as most of the studied floodplain section was covered by grassland *(Fig. 3/b)*. Forests occupied much smaller areas along the Tisza and the ox-bow lake, and a strip of trees was planted along the artificial levee to protect the levee from greater wave action. The photo, which was made in 1965 showed a robustly changed land-use pattern *(Fig. 3/c)*. Already 60 % of the study area was covered by forest, and forestry was followed afterwards. According to the subsequent aerial photos (1981 and 2000) forestry was intensively practiced in the area, clearances then new plantations appeared *(Fig. 3/d)*.

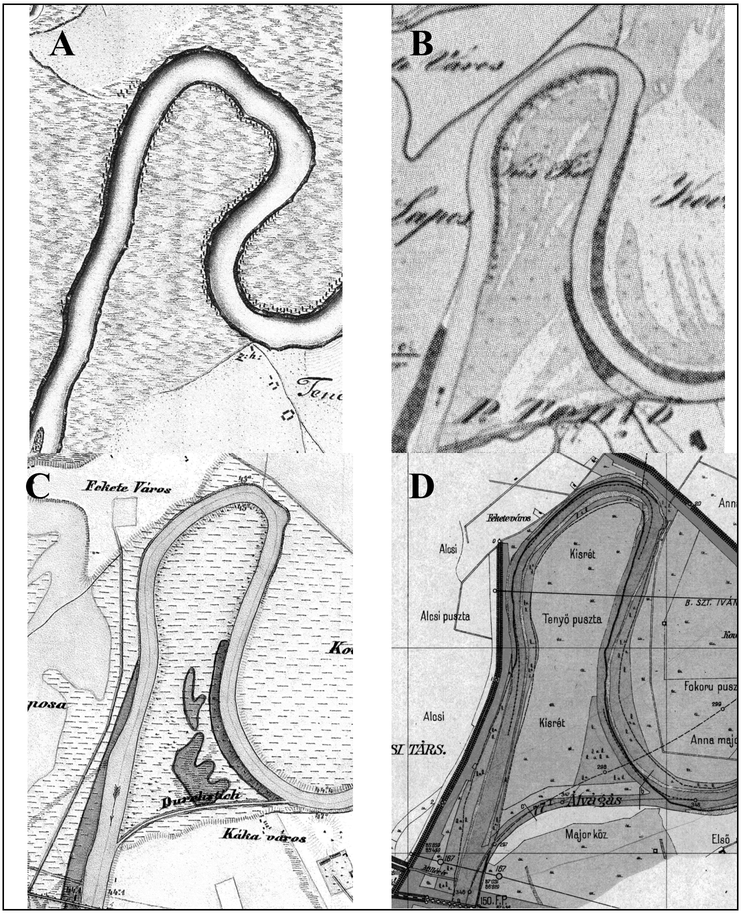

Fig. 2. The study area on different historical maps. A: I. Military Survey (1783); B: Map made by Lányi (1834-64); C: II. Military Survey (1860); D: Map of the Tisza Survey (1883)

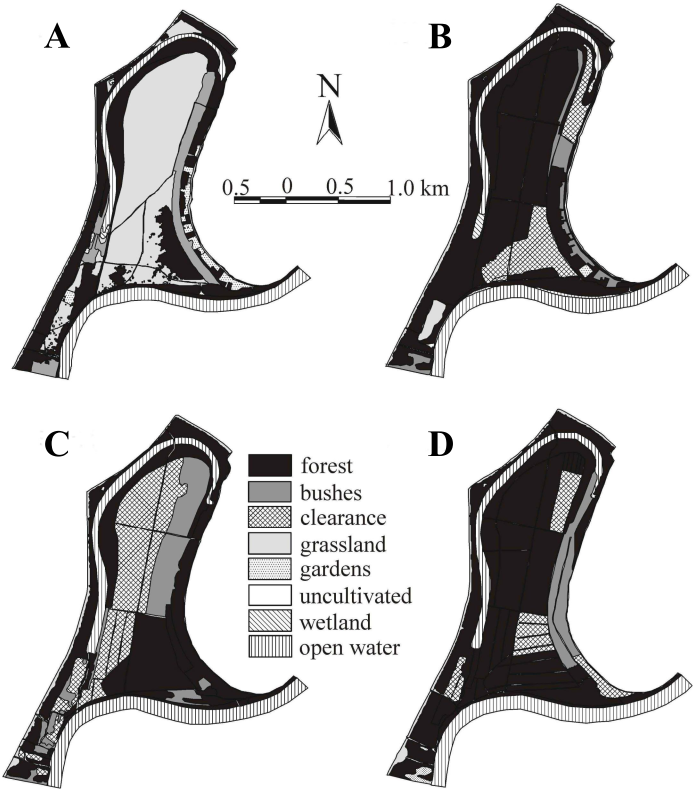

Fig. 3. Spatial distribution of the different land-use categories between 1950 and 2000 based on aerial photos. A: 1950; B: 1965; C: 1981; D: 2000.

The first aerial photo (1950) represents very similar land-use conditions to the period of the late 19th century when the regulation works were carried out. The rate of changes could be measured comparing the first (1950) and last (2000) photos *(Fig. 4)*. The most striking, sudden change happened between 1950 and 1965, when intensive forestry started in the area replacing the grasslands by forest. Now the grasslands occupy just 5 % of their original area. At the same time the proportion of uncultivated areas increased from 1.2 % to 3.8 %. The area of bushes did not change considerably, because it is very difficult to separate them on aerial photos from the young forest stands. However, the clearances can be considered as bushy areas, because within the year of the clearance the invasive *Amorpha fruticosa* usually appears in quite dense stands. This bush started to invade the floodplain in the second half of the 20th century, appearing in clearances, light forests, uncultivated gardens and grasslands (Mihány and Botta-Dukát, 2004). According to our earlier measurements it increases the vegetation density so drastically, that during floods no flood velocity can be measured in its stands (Sándor and Kiss, 2007).

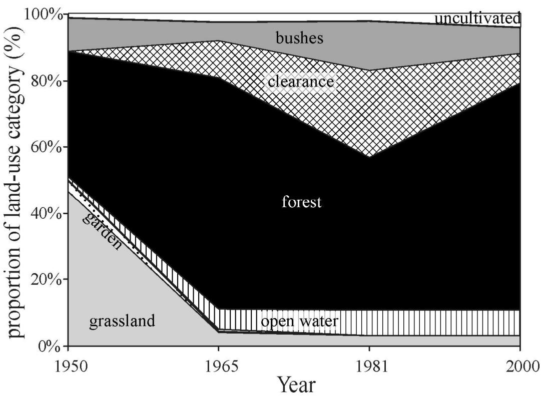

Fig. 4. Land-use changes between 1950 and 2000

Vegetational roughness changes since1950

The above described land-use changes have altered the roughness of the study area (*Fig. 5*). The average roughness values for the different dates indicate significant increase in vegetational roughness of the floodplain since the 1950's. It is mostly resulted in the considerable enlargement of land-use categories with great roughness value, therefore the roughness was doubled in the second half of the 20th century. As the vegetational roughness influences the overbank flow velocity, we supposed, that aggradation rate will change simultaneously.

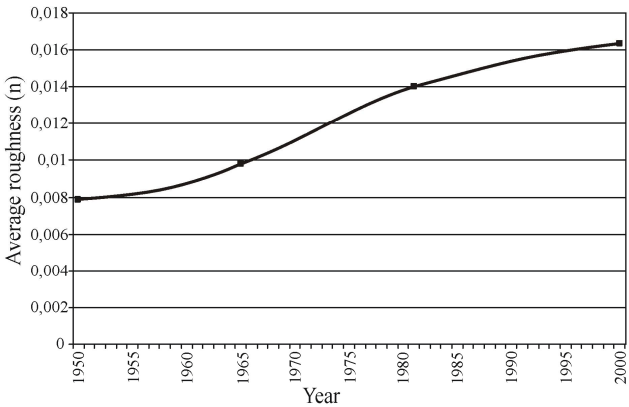

Fig. 5. Changes in vegetational roughness values of the study area between 1950 and 2000

Aggradation rate since the mid 19th century

The samples were grouped into zones based on the similarities of their physical and chemical parameters *(Fig. 6)*. The lowermost zone (Zone I., 108-125 cm) is characterised by finer material and more organic material. In fluvial environment the high organic content is in connection with moderate overbank sedimentation, whilst the large amount of coarse and inorganic material indicates high energy floods (Oroszi and Kiss, 2005). In the upper zones the sediment is coarser, with less organic material. Zone I. represents the sediments deposited before the regulation, when floods had smaller energy. In the middle zone the appearance of coarse sand indicates high transport velocity. This could be the result of the cut-offs, which are located at the sampling site and upstream of it, made in 1858. They increased the slope and the transport capacity of the river. Unfortunately, no sediment load data are available from this period, but according to the description of Iványi (1948) intensive bar formation has started after the regulatory works of the Tisza River.

The upper part of the sediment record was correlated to an earlier study made by Braun M. et al. (2003). They analysed the sedimentary record of a nearby natural levee, measuring the absolute date (^{137}Cs) and the heavy metal content of the sediment. Fortunately, they found higher lead content in those samples which were deposited between 1960 and 1975, which accidentally coincide with the land-use changes of the site. Based on the heavy metal marker layers it became possible to correlate the two sites and to determinate the rate of aggradation at our site *(Fig. 7)*. Samples with higher lead content were found at the depth between 42 and 52 cm, which peak was also found in the study of Braun M. et al. (2003), who dated this lead peak to 1960-1975. Therefore, at our site between the regulations and 1960-75 the rate of floodplain aggradation was 0.5-0.6 cm/y, whilst since it increased to 1.0-1.5 cm/y. The latest data correlates well with those studies, which measured the rate of floodplain sedimentation after single flood events, resulting 5-10 mm deep sediment /flood (Oroszi et al. 2006; Sándor and Kiss, 2007; Sipos et al. 2008).

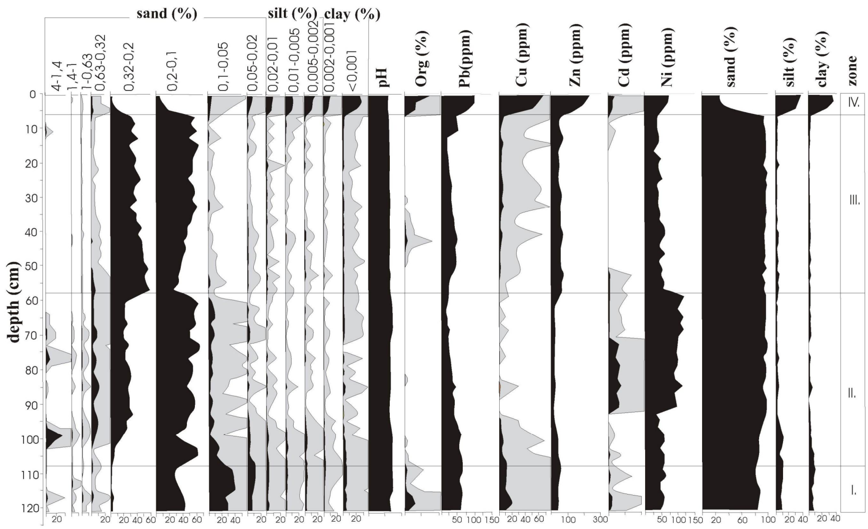

Fig. 6. Physical and chemical properties of the studied profile. The black diagrams show the actual ales, but in case of smaller quantities 10x magnification (grey) was applied

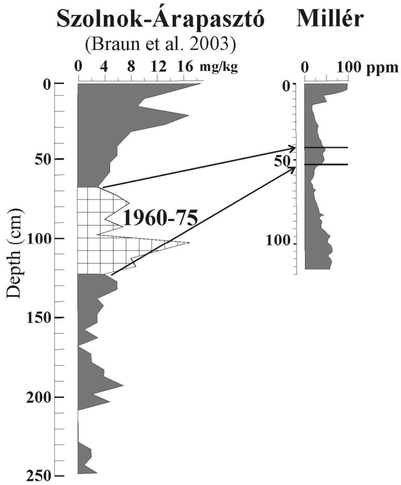

Fig. 7. Comparison of lead content of two sediment profiles. The Szolnok-Árapasztó site was analysed and dated (^{137}Cs) by Braun et al. (2003)

5. Conclusions

The land-use drastically changed on the studied floodplain section since the 19th century regulation works. Grassland with small vegetational roughness coefficient was typical on the floodplain until the mid-1960s. Since that time the plantation of forests and the invasion of dense bushes (like *Amorpha fruticosa*) derived to doubled roughness. As the result of increased friction of the floodplain the fluvial processes altered, and since the vegetational changes the floodplain aggradation doubled from 0.5-0.6 cm/y to 1.0-1.5 cm/y. Therefore, the land-use changes of the floodplain play important role in increasing the flood hazard through (1) the greater roughness, which decreases flood velocity, and (2) increased sedimentation rate, which elevate the surface of the floodplain in an accelerated rate.

Reference

Asselman N.E.M. – Middelkoop H. (1995): Floodplain sedimentation: quantities, patterns and processes. *Earth Surface Processes and Landforms* **20**: 481-499.

Borsy Z. (1972): Sedimentological and geomorphological investigations on the Szatmár plain after the great flood of 1970. *Földrajzi Közlemények* **41**: 87-101. (in Hungarian)

Braun M. – Szalóki I. – Posta J. – Dezső Z. (2003): Estimation on the rate of floodplain aggradation, in case of Tisza River. MHT XXI. Vándorgyűlés CD-kiadvány (in Hungarian)

Chow, V.T. (1959): Open-channel hydraulics. McGraw-Hill Book Company, New York, 680.

Gábris Gy. – Telbisz T. – Nagy B. – Belardinelli E. (2002): Floodplain aggradation of the Tisza River and its geomorphological background. *Vízügyi Közlemények* **84**: 305-322. (in Hungarian)

Iványi B. (1948): Channel regulation on Tisza River. *Vízügyi Közlemények* **30** (2): 131-159. (in Hungarian)
Kiss T. – Sipos Gy. – Fiala K. (2002): Aggradation rate of recent sediment along the Lower Tisza. *Vízügyi Közlemények* **84**: 456-472. (in Hungarian)
Kozák M. – Rátky I. (1999): The effect of the width and land-use of the floodplain on flood levels. *Vízügyi Közlemények* **81** (2): 311-317. (in Hungarian)
Marriott S. (1992): Textural analysis and modelling of a flood deposit: River Severn, U. K. *Earth Surface Processes and Landforms* **17**: 687-697.
Mihány B. – Botta-Dukát Z. eds. (2004): Biológiai inváziók Magyarországon Özönnövények Természetbúvár Alapítvány Kiadó Bp. pp. 187-206.
Nagy I. – Schweitzer F. – Alföldi L. (2001): The point-bar. *Vízügyi Közlemények* **83**: 539-564. (in Hungarian)
Oroszi V. – Kiss T. (2005): The analysis of sediment accumulation and silting-up of a cut-off channel on River Maros near the city of Makó. *Acta Geographica* **38**: 27-39.
Oroszi V. – Sándor A. – Kiss T. (2006): Aggradation caused by the 2005-flood along the Maros and the Middle Tisza Rivers. In Kiss A., Mezősi G., Sümegi Z. (szerk): Táj, környezet és társadalom. Ünnepi tanulmányok Keveiné Bárány Ilona professzor asszony tiszteletére. pp. 551-561. (in Hungarian)
Rátky I. – Farkas P. (2003): The effect of vegetation on the flood conductivity of the floodplain. *Vízügyi Közlemények* **85** (2): 246-265. (in Hungarian)
Sándor A., Kiss T. (2007): The rate and influencing factors on aggradation caused by the 2006-flood along the Middle Tisza River, near Szolnok. *Hidrológiai Közlöny* **87** (4): 19-25. (in Hungarian)
Schweitzer F. (2001): Society and environment: new levees or heightened ones. In: Keményfi R. –Ilyés Z. (szerk.): A táj megértése felé. Debrecen pp. 95-103. (in Hungarian)
Sipos Gy. – Ilyés E. – Kiss T. (2008): The effect of morphology, hydrology and vegetation on island development in the Maros River, near Apátfalva. IV. Magyar Földrajzi Konferencia Kiadványa, Debrecen, pp. 140-147. (in Hungarian)
Steiger, J. – Gurnell, A.M. (2003): Spatial hydro-geomorphological influences on sediment and nutrient deposition in riparian zones: observations from the Garonne River, France. *Geomorphology* **49**: 1-23.
Szabó Sz. – Molnár L. Sz. – Juhos K. – Prokisch J. (2008b): The heavy-metal contamination of a floodplain section in the Upper Tisza Region. In: Orosz Z. – Szabó V. – Molnár G. – Fazekas I. (szerk): IV. Kárpát-medencei Környezettudományi Konferencia I. kötet. Debrecen, pp. 283-288. (in Hungarian)
Szabó Sz. – Molnár L.Sz. – Gosztonyi Gy. – Posta J. – Prokisch J. (2008a): Heavy metal pollution in the neighbourhood of an ox-bow lake, Upper Tisza River. In: Demeter G. (edt): Geografia generalis et specialis. Debrecen, pp. 255-260. (in Hungarian)
Török I.Gy. (2000): The role of lowland floodplans. In: Pálfai I. (szerk.): A víz szerepe és jelentősége az Alföldön. Békéscsaba, pp. 125-132. (in Hungarian)
Walling, D.E. – He, Q. (1998): The spatial variability of overbank sedimentation on river floodplain. *Geomorphology* **24**: 209-223.