UNIVERSITY OF SZEGED
Faculty of Science
Doctorate School of Earth Sciences
Department of Physical Geography and Geoinformatics

FLOODPLAIN AGGRADATION ALONG THE MIDDLE- AND LOWLAND SECTION OF RIVER TISZA

Thesis of Dissertation

ANDREA SÁNDOR

Supervisor: Dr. Tímea Kiss
Assistant Professor

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1. Introduction, aims

Record flood stages have became more frequent in the last decades within the catchment of the Tisza River. The causes of the rising flood stages are different: they are in connection with the environmental and landuse changes of the catchment and the local natural and human induced processes along a river section. These processes may occur separately, or they might intensify each others effect.

The natural fluvial processes of Tisza River were mostly altered by river regulation works in the 19-20th centuries. Since the artificial levee construction the fluvial processes have been confined to the narrow artificial floodplain. As the result of channel regulation the evolution of the meanders has became slower or in same cases it has terminated. As the result of the limited lateral erosion the role of overbank aggradation in floodplain geomorphology has increased. Its rate is controlled by several changing environmental factors (e.g. flood hydrology, vegetation, relief).

The primary aim of the research is to measure the overbank floodplain accumulation since the river regulation works (long-term) and after a single flood event (short-term) along the Middle and Lower Tisza River. The following questions were addressed: What is the long-term rate of accumulation on different morphological forms? How did the accumulation rate change spatially and temporally? Which physical and chemical parameters of the deposited sediment could be applied during the comparison of sediment profiles and defining its age? How does the spatial pattern of the deposited sediment change during a single flood (short-term). As the rate and pattern of accumulation change in space and time, it was important to evaluate its influencing factors. Therefore, water stage data of Tisza River, land-use changes, and the resulting vegetation roughness were analyzed and flow velocity was measured on the floodplain. The final objective is to evaluate the drainage capacity reduction of the floodplain caused by accumulation.

2. Methods

The studied floodplain sections are located in the Middle- and Lower Tisza Region. The spatial and temporal changes in long- and short-term overbank sedimentation were studied applying different methods.

2.1. Long-term overbank accumulation

2.1.1. Sample collection and preparation

To evaluate the overbank accumulation since the river regulation works, sediment samples were collected from points where (1) the grain-size of the sediment changed as the result of river regulation works and (2) the overbank accumulation was continuous for hundreds of years. To find connection between these two sites marker-layers were identified and thus the rate of accumulation could be determined.

Altogether 5 sediment-pits were dug in the study areas (Nagykörű: 2; Feketeváros-cutoff: 1; Mártély: 2). Sediment samples were collected at 2 cm intervals. The following properties of the samples were defined: grain-size, organic matter content (%), heavy-metal content (Cd, Ni, Zn, Cu and Pb in ppm) and pH values. On some sediment profiles magnetic susceptibility measurements and X-ray tests were carried out at the University Of Wolverhampton School Of Applied Sciences. The measurements were visualized by TILIA and TILIA Graph software. Based on the cluster-analysis of the samples they were grouped into zones. A shorter-term (5 years) accumulation was also studied applying the same methods in an artificial flood-passage (Árapasztó) at Szolnok, where two pits were dug.

2.1.2. Characterization of flood hydrology

In order to study the hydrological background of the long-term accumulation daily water stage data were analyzed. The data of the Szolnok gauging station (334,6 fkm) were analyzed for the period of 1876-2010, whilst at the Mindszent gauging station (217,8 fkm) they are available just from 1901. The annual maximum flood level and the annual length of floods were analyzed.

2.1.3. Long-term changes in landuse and vegetation roughness coefficient of the floodplain

The maps of the I-III. Military Surveys and topographic maps were used to determine the long-term changes in roughness coefficient caused by vegetation. The maps and aerial photos (1950, 1965, 1981, 1991 and 2000) were geo-corrected under ERDAS Imagine 8.6 software, then the total area of landuse categories was calculated under Arcview 3.2. A Manning's roughness coefficient was linked to each landuse category, then the area proportional vegetation roughness of the area was calculated.

2.2. *Short-term overbank accumulation*

2.2.1. Sample collection and preparation

The depth of the sediment deposited by a single flood event was studied along cross-sections after the floods of 2005 and 2006. The leaf-litter layer of last autumn and artificial surfaces served as reference levels, therefore the depth of the newly deposited sediment could be precisely measured. (The different colour and structure of the fresh sediment made the measurement easier.) Based on the hundreds of point-data a map was created showing the spatial pattern of the overbank accumulation. At the points where the depth of the sediment was deeper than 3 mm, samples were collected and their grain-size distribution was determined.

2.2.2. *Flow velocity measurements*

In order to establish a connection between the flood flow velocity and the rate of aggradation a propeller type current meter (GR-21) was used. Unfortunately the date of the measurements were determined by the local authorities, therefore at Nagykörű in 2005 only 14 points were measured, but in 2006 at the Feketeváros study area 35 points along 6 cross-sections and at Mindszent 87 points along 12 cross-sections were measured. At each point the flow velocity was measured at 90 cm depth from the water surface. At some points the vertical profile of flow velocity was also measured to reveal the role of vegetation in altering the flow.

2.2.3. *Calculation of vegetation roughness coefficient*

In 2006 simultaneously with the mapping of fresh sediment depths the vegetation was surveyed on all study areas. The arboreous (mainly invasive) vegetation density was defined in 3x3 m quadrates, by counting the number of the trees and bushes and by measuring the periphery of their trunks. Based on the newly invested "vegetation index" the separation of quadrates with low vegetation roughness coefficient (some large old trees with thin underwood) and high coefficient (dense, but thin Amorpha bushes) was possible.

The field survey and the aerial photo (made in 2000) were used to create a landuse map of the study sites under ArcView 3.2 software. The vegetation classes were connected to the Manning's roughness factor, then the territory of the different vegetation roughness categories were calculated based on the landuse map.

2.2.4. Calculation of floodplain's drainage capacity

The deposited sediment reduces the cross-sectional area of the floodplain, thus it decreases its flood drainage. Using 1:10 000 scale topographical maps the total cross-sectional area of the floodplain (up to the top of the artificial levees) was calculated. This area represents the water drainage capacity without accumulation and vegetation. The cross-sectional area of the fresh sediment was measured, so the reduction of the floodplain's water drainage capacity (%) was calculated.

3. RESULTS

3.1. Characteristics of long-term overbank floodplain accumulation

3.1.1. Characteristics of floods

Between 1876 and 2010 the length of the floods and their highest stage increased on the Middle and Lower Tisza too. However, since the 1960-70's the floods became increasingly higher and longer at the Middle Tisza than at the Lower Tisza. These hydrological tendencies accelerate the overbank accumulation.

3.1.2. Long-term landuse changes

3.1.2.1. In the 18th century the mean vegetation roughness coefficient of the floodplain was low (n=0.03), and it slightly had changed until the end of the 19th century. At the time of the river regulation works gallery-forest appeared on the banks, in front of the artificial levee and in the wide floodplain sections. The forests increased the mean roughness coefficient (n=0.034-0.04).

3.1.2.2. The landuse of the floodplains hardly changed until the 1950's, though along the artificial levee the area of willow and poplar forest became greater than before, increasing the roughness coefficient. In the first half of the 20th century the vegetation roughness doubled (n=0.06-0.09).

3.1.2.3. After 1950's the floodplains became the area of intensive forestry, whilst the small gardens and arable lands were abandoned, invasive plants species spread and holiday houses were built. By 2000 the floodplain average vegetation roughness coefficient reached n = 0.11-0.15. This dense vegetation could decrease the flood velocity, thus it could significantly influence the rate of floodplain accumulation.

3.1.3. Spatial and temporal changes in long-term accumulation

3.1.3.1. The physical and chemical parameters enabled us to determine the long-term accumulation rate. On the sites, where the distance from the active channel changed considerably due to the river regulation works, the grain-size change of the sediment-layers could be used to define the exact time of the cut-offs within the sediment profile. The magnetic characteristics of the samples were useful to divide the intensive overbank aggradation periods from the flood-free soil-formation periods. At the given pH conditions the lead concentration was the most useful as a marker-layer. In the sediment profiles it was possible to calculate the overbank accumulation rate before 1960 and after 1975, using a well-defined lead-peak.

3.1.3.2. In the Middle Tisza Region at Nagykörű the sampling points represents a point-bar of the pre-regulation channel (N1) and a floodplain-bottom (N2).

Based on the analysis of this two sediment profiles the average rate of overbank sediment accumulation rate is 0.36-0.39 cm/y. The N2 profile is located in a flood-passage zone, its existence is indicated by its coarser grain-size distribution.

3.1.3.3. At the sampling point of the Feketeváros-cutoff (M) accumulation rate was greater (0.75 cm/y) than at Nagykörű. It can be explained by the location of the sampling point, as it is situated on the concave bank of the river bend close to the thalweg, and downstream of a straightened high gradient section.

3.1.3.4. At the Lower Tisza Region, at Mártély the sediment profiles (T1 and T2) were located at the same distance from the active riverbed of the Tisza, therefore the accumulation was mostly affected by the elevation of the sampling points. On the higher area (T2) the accumulation rate was less (0.29 cm/y), then on the lower lying area (T1) (0.79 cm/y).

3.1.3.5. At the Feketeváros-cutoff along the artificial levee is a chain of a sand-pit, where drillings (Ff1-8) were made, representing relatively lower lying areas. Here the accumulation is greater (0.21-0.46 cm/y) than in the surrounding areas. In the very low-lying flood-passage (Árapasztó: A1-2) near the bank the accumulation rate is very high (8-13.6 cm/y). These high accumulation rates can be explained by near-channel location and that the sampling points are representing such a very low-lying surface which is inundated by water-stages lower than bankfull.

3.1.3.6. Between the sediment profiles a comparison was drawn based on high lead-content marker-layers deposited between 1960 and 1975. The accumulation has accelerated since 1975 at the Middle Tisza Region from 2.7 to 3.7-fold, while at the Lower Tisza Region from 2.3 to 2.8-fold, than it was before. It can be reasoned by the (1) hydrological characteristics, as mainly at the Middle Tisza Region the duration and water stages of floods has increased, (2) floodplain landuse changes increased the mean vegetation roughness coefficient by 300% since river regulation works, and (3) invasive plant species spread on floodplain since 1980's.

3.2. Characteristics of short-term overbank floodplain accumulation

The accumulation caused by single flood events at Feketeváros-cutoff (in 2005 and 2006), and at Nagykörű and Mindszent (in 2006).

3.2.1. Characteristics of the floods

The rate of accumulation was influenced by the flood hydrology and the amount of suspended sediment. The rise of the flood was slower in 2005 (11 cm/d) than of the two flood waves in 2006 (16 and 27 cm/d). The first flood wave in 2006 had a long peak (almost 4 days at Mindszent), followed by rapid fall. During the rising limb of the flood-wave the river might deliver by 90 % more suspended sediment than during the falling limb. However, in 2006 the rising and falling limbs of the second flood wave was characterised by the same suspended sediment discharge. According to the measurements of the Hydrological Directorate (KÖTIKÖVIZIG) the 2006 transported more suspended sediment by 10% than the flood in 2005 (measured at Kisköre). According to their measurements 54% of the suspended sediment was deposited between Kisköre and Szolnok in 2006 referring to intensive overbank floodplain accumulation, while in 2005 46% of the suspended sediment was deposited on the same section. (The measurements may be inaccurate, because the suspended sediment was measured only once a week at Szolnok.)

3.2.2. Landuse of the floodplain and the vegetation roughness coefficient

3.2.2.1. On all study sites the arborescent vegetation occupies 50-70% of the floodplain area. At Nagykörű forests cover 69% of the area, 23% of it belongs to the "sparse wooded vegetation" category. At the Feketeváros-cutoff 53% of the study area covered by forest, but only its 14% have sparse woods. At Mindszent 59% of the area occupied by forest, but its 55% belong to the "dense wooded vegetation" category. At Nagykörű and Mindszent large number of the small gardens and arable lands is abandoned, and on these areas *Amorpha* and other invasive plant spaces spread rapidly increasing the roughness coefficient.

3.2.2.2. The vegetation roughness coefficient of the areas varies between 0.03 and 0.2 depending on the type, height and density of vegetation. The vegetation roughness coefficient influences the flood flow velocity on the floodplain. The mean vegetation roughness coefficient in 2006 was the greatest at Nagykörű and Mindszent ($n = 0.15$), whilst at the Feketeváros-cutoff it was slightly lower ($n = 0.11$).

3.2.3. Flow velocity on the floodplain

3.2.3.1. The flow velocity is primarily determined by the morphology of the channel. At the upstream inflection zone of the channel the flood enters to the floodplain with high flow velocity (0.2-0.6 m/s) to the flood-passage zone behind the point-bars. In this zone the water flow velocity is higher (0.29-0.63 m/s) than the surrounding area (decreases to 0 m/s). On the relatively narrow (≤300 m) floodplain sections the entire floodplain function as a flood-passage. In the wider floodplains flood flow velocity was measurable only within 150 m distance from the active channel. At high water-level the oxbow lakes has hardly any role in the water drainage.

3.2.3.2. The flow velocity was lower in forest with dense shrubs and on the abandoned fields covered by invasive *Amorpha* bushes. (The exception was the inflection zone at Mindszent, where the beginning of the flood-passage was also covered by *Amorpha* bushes, but at this point despite of the dense vegetation high flow velocity was measured, though it was probably reduced to a certain extent by the vegetation.) In the inner parts of floodplains lower flow velocities were measured in the forest with highest roughness coefficient (n = 0.2), while higher flow velocities were measured at the areas with sparse (n = 0.03) vegetation, especially in front of the artificial levee. Thus, the vegetation of the area significantly affects the roughness, which defines the water draining capacity of the floodplain.

3.2.4. Spatial and temporal pattern of short-term accumulation

3.2.4.1. During the flood waves of the 2006 flood, the greatest amount of sediment was accumulated at Nagykörű (average depth of sediment 24.4 mm), while less was measured at Feketeváros-cutoff (2005: 3,7 mm 2006: 6,8 mm) and at Mindszent (18.9 mm).

3.2.4.2. The spatial pattern of aggradation depends mostly on the distance from the active channel. Significant part of the sediment was accumulated in a maximum 20-50 m wide zone from the riverbed, independently of the density and type of the vegetation. The deepest sediment (Nagykörű: 240 mm; Feketeváros-cutoff: 109 mm; Mindszent: 500 mm) was accumulated on the natural levees and point-bars.

3.2.4.3. On the floodplain the pattern of the accumulated sediment is modified typical by the horizontal pattern of the river-bed and the morphology of the floodplain.

- In the inflection zone of meanders along the banklines deeper and coarser sediment was accumulated in wider zone (independently of the vegetation). However, in the inflection zone of less developed bends such extreme high sediment thickness was not measured.
- Greater amount of sediment was deposited on the outer side of the natural levee (towards the artificial levee) than on its inner side (towards the river bed), which indicates the widening of the form.
- The amount of accumulation was higher on the natural levee than on the point-bar, suggesting intensive heightening of the natural levee.
- The accumulation is more intensive on the low-lying surfaces than on the surrounding areas. Thus considerable accumulation was

measured in the flood-passage of "Árapasztó", in artificial pits, in the scroll-bars, in the area of ox-bows and crevasses.

- At Mindszent behind the point-bar a thinner but coarser sediment was accumulated; referring to the existence of a flood-passage zone, where the flow velocity is high enough to prevent intensive aggradation.
- Where the flow velocity was greater (in forest clearances and in flood-passage zones), coarser sediment accumulated.

3.2.4.4. The role of vegetation in sediment accumulation is secondary, because the geomorphologic factors overwrite it. However, in the inner part of the floodplain, in the dense *Amorpha* stands the vegetation roughness coefficient is so high, that the flow velocity is reduced to zero, therefore during floods the suspended sediment could not be transported into this area. Thus, under very dense vegetation patches the aggradation is very limited.

3.2.4.5. In the inner parts of the floodplain, further from the active channel the grain-size of the sediment became finer. The proportion of silt and clay in the freshly deposited sediment became dominant at 40-90 m distance from the channel. The coarsest sediment (sand-content >90%) accumulated on the natural levee and the point bar.

3.2.4.6. At Feketeváros-cutoff in 2005 and 2006 the pattern of accumulation of sediment was different, highlighting the role of different hydrological situations. In 2006 the amount of deposited sediment was greater, as it was indicated by the contour-lines of the accumulation map: the same contours got further from the river-bed than in 2005. It could be explained by the rate of flood-rising and the amount of the transported suspended sediment.

3.2.4.7. The Nagykorű and Mindszent-Mártély study areas are quite similar in their landuse characteristics, as their mean vegetation roughness was similar (n=0.15). However, the coefficient was lower (n=0.11) at Feketeváros-cutoff because of active forest management. At Mindszent the greatest flow velocity (max. 0.67 m/s) was measured, whilst slightly lower at Feketeváros-cutoff (max. 0.57 m/s) and the lowest was at Nagykörű (max. 0.37 m/s). In the study areas changes in flow velocity were similar to the changes in roughness coefficient: greater flow velocity was measured in the flow-passage zones and near the river bed, and lower at the vegetation patches with high roughness.

3.2.5. Changes in flood drainage capacity

The flood drainage capacity of the floodplain is reduced by accumulation, this reduction was 0.21-0.46% in 2006. The reduction was the greatest on the narrow floodplains (0.66-1.44%) and in the inflection zones (1.35%).

But in the wide floodplain sections the rate of flood drainage capacity reduction was less (0.05-0.1%), although along a 150-200 m wide zone of the river a very intensive aggradation was measured.

3.3. Final conclusions

3.3.1. The average overbank accumulation rate of a single flood was greater than of the long-term aggradation. It could be explained by the altered hydrological parameters of Tisza River (increasing duration of floods and water stages) and by the increased vegetation roughness coefficient of the floodplain. The differences in overbank accumulation caused by single floods are highly depended on the amount of suspended sediment.

3.3.2. Spread of invasive plant spices results additional increase of vegetation roughness, which can cause greater overbank accumulation, because the dense vegetation decreases the flow velocity and the suspended sediment accumulates. However, the very dense *Amorpha* bushes can reduce the flow velocity to zero, and instead of increasing the rate of overbank accumulation, it prohibits the process (double-threshold).

3.3.3. There are flood-passage zones behind the developed river bends. Their continuous maintenance would be useful to reduce flood hazard.

3.3.4. On the river banks point-bars and natural levees develop, increasing the elevation of the banks, while the inner parts of the floodplains become plane and uniform as the result of intensive aggradation of the low-lying areas. Pre-regulation natural forms and even the anthropogenic forms are disappearing due to accumulation. As the result of the elevated near-bank zones (point bar, natural levee), the floodplain is inundated by higher water stages (though my field experiences suggest, that the accumulated sediment on the river bank can get back to the river bed by landslides).

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