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FLOODPLAIN AGGRADATION ALONG THE LOWLAND SECTION OF RIVER MAROS

Thesis of Dissertation

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Szeged, 2009

1. Introduction, Aims

River Maros is the fourth largest river in the Carpathian Basin considering its catchment area (30 332 km^2) and maximum discharge (2450 m^3/s). The 19th century river regulations and levee constructions on the Hungarian Great Plain have altered the watercourse of the Maros. The geomorphologic evolution of the floodplain and the flood-protected area has been separated, thus modified along the lowland section of the river. The pattern of the river was altered from meandering to straight and sinous, thus the rate of channel migration decreased dramatically, especially downstream from Makó. Floodplain aggradation became the most important geomorphological process on the floodplain, because the considerable suspended sediment discharge of the river caused increased accumulation on the artificially narrower floodplain. Accelerated accumulation of the investigated Hungarian floodplain section were also influenced by its relative position to the alluvial fan, and by the increased channel slope and bed scour, and decreased lateral erosion. These modified processes were enhanced by vegetation changes. The cultivation of the nutrient rich floodplain areas became cumbersome in consequence of the changed social and financial needs. Therefore nowadays mainly forests and dense adventive vegetation types are typical on the former intensively used orchards and pastures. The above mentioned factors resulted in intensive accumulation near the channel and in the deeper parts of the floodplain (cut-offs, pits etc.). The aggradation induces serious problems from the viewpoint of the flood-hazards through raising the flood levels.

The following main research aims were addressed:

1. How did the long-term floodplain aggradation rate change along the lowland section of the River Maros? How did the aggradation rate vary in space and time since the mid 19th century levee construction works?
2. What are the main influencing factors of the deposition?
3. What is the role of the different geomorphological landforms in aggradation process?
4. How has the landscape and vegetation altered for 150 years along the River Maros? How does the vegetation influence the alluviation of the floodplain?
5. Are the pollen grains of adventive plant species applicable to date the sediment and to estimate the rate of overbank sedimentation?

2. APPROACH AND METHODS

The research was carried out using a multiscale and multitemporal analysis, applying various methods on different study areas. It was aimed to assess such a long reach of the river as possible, therefore the measurements were carried out on four different floodplain areas: near the village Apátfalva, two sites by Makó (Csordajárás and Zugoly site) and one site was chosen at Vetyehát, near to the confluence with the River Tisza.

2.1 Assessment of the landscape changes since the 19th century regulation works until the mid-20th century

Early characteristics of the Maros floodplain were evaluated using a historical dataset, hydrological and military survey maps. Based on this data the general way of landscape changes before and after the channelization and levee construction works were analysed. Simultaneously, these data supported the application of palynology in determination of long-term accumulation rate.

2.2 Landuse change analysis since 1953

Detailed assessment of landuse change was carried out with the help of aerial photograph series (1953, 1964, 1981, 1991 and 2000). As fare as the financial background did not make possible to buy aerial photographs for the whole Hungarian section of the River Maros, two floodplain areas were chosen to evaluate landuse changes. The Csordajárás site (3 km^2) is characterised by continuous agricultural use and on the Vetyehát site (13,2 km^2) silviculture was dominant. Geo-correction of the photos was made under Erdas Imagine 8.4 software, landuse patches were defined under ArcView 3.2 (minimum mapping unit was 15 m^2). Ten different landuse categories were separated: water surface, marsh, arable land, forest, pasture, orchards, reed, scrub, non-cultivated area, artificial surface. Constant-analysis was carried out and category transition matrix was also produced between 1953 and 2000 to define the main types of changes on the floodplain and assess the steady-state condition of the patches.

2.3 Investigation of the floodplain's hydraulical roughness

Hydraulic roughness caused by vegetation was analysed using the empirical tables composed by Chow (1959), Szribnij (in Németh 1959) and Werner et al (2005). Minimum, normal and maximum hydraulic roughness values were defined for each landuse category to reflect seasonal and other differences (density, flexibility etc.) of the vegetation. Hydraulical roughness was investigated on the whole Csordajárás and Vetyehát sites and on 100 meter wide zones in line with the riverbed. The analysis was based on the area (%) of landuse types and their hydraulical roughness to specify the change in roughness since 1953.

2.4 The measurement of short-term accumulation caused by single flood events

The thickness of freshly deposited sediment was measured at Apátfalva (on 34 and 101 points) and at Vetyehát (on 349 and 456 points) after the spring floods in 2005 and 2006. Sampling was carried out along cross-sections perpendicular to the active channel. Sampling was denser near the active channel, as exponential decrease with increased distance was expected, as it was suggested in earlier studies (Middelkoop and Asselmann 1998, Simm and Walling 1998, Steiger et al. 2001, Kiss T. et al. 2002). Three cross-sections in 2005 and two added in 2006 were recorded at Apátfalva (Ap). At the Vetyehát site measurements were made along 12 cross-sections on the northern side of the floodplain (Vj) and 6 on the southern floodplain section (Vb). In 2006 further short (20 m) sections were investigated near the active channel at Vetyehát, as I wanted to get clearer picture on the increased accumulation near the active channel. The thickness of fresh deposit was defined based on its different colour and texture and on the thin „marker" layer of fallen leaves from the previous year. The thickness of point samples were measured three times at each point, with the acuracy of 1.0 mm, vegetation type surrounding the sampling point was also documented. Along three cross-sections and on some typical sampling points (i.e. in cut-off) the grain-size of newly deposited sediment was measured by Köhn's silting and dry sieving method. Interpolated sediment accumulation raster maps were generated with Minimum Curvature method under Surfer8 software, grid size were set for 5 meters. Residuals of the surface were calculated with the same method after an „error decreasing iteration" published by Geiger (2002). One-variable analysis and simple regression analysis on the resulted sediment accumulation and residual raster maps were used under Statgraphics Plus 5.1 software.

2.5 Assessment of long term floodplain aggradation since the 19th century regulation works

To determinate of long-term floodplain aggradation rate samples were collected from characteristic parts of the floodplain, where (1) marked change occured in grain-size of the sedimets due to the river regulation (i.e. sandy surface of pre-regulation natural levee was covered by finer sediments as the active channel was relocated); (2) where sedimentation was continuous (i.e. in backswamp area). The deposition since 1950 was also studied on the rough sandy surface of a former bar on the low-floodplain at Apátfalva. Here, along cross-sections perpendicular to the active channel five borings were made to determine the limit between sandy bar sediments and silty and clayey overbank deposits. The precise relief of the floodplain and the bore-holes was also recorded by a Sokkia SET310 workstation.

Sampling was carried out on the bar surface by Edelman-type hand auger, while in the case of the cut-offs Földvári-type hand auger was applied, and samples were collected from every 10 cm depth. Sediments of the backswamp area and the former natural levee were sampled in 2 cm intervals using a pit. Grain-size of the collected samples (Apátfalva 42, Csordajárás 43, 54 and 55, Zugoly 41, Vetyehát 39 samples) was analysed applying dry sieving and a Köhn Pipetten method, carbonate content was measured by Scheibler-type calcimeter, organic content was measured by spectrophotometry after a threatment in $K_2Cr_2O_7$ digestion (Tyurin's method). Due to the short timescale (150 years) the classical ^{14}C dating could not be applied, therefore, the pollen grains of invasive plant species were used to date the sediments of former oxbow lakes and to measure the rate of accumulation. Samples were collected for pollen analysis (Csordajárás 43, Zugoly 41 and Vetyehát 39 samples). Zólyomi-Erdtman's zinc-chloride acetholysis method was applied. Pollen grains were identified under 400-600 magnification. The pollen of the most abundant invasive plant species were collected from the Maros floodplain and photographs were downloaded from Internet databases to create a special pollen identification data set. Charcoal content of the samples was evaluated on a five-grade scale. Graphical lay-out of the results was produced under Tilia and Tilia-Graph softwares. The prepared absolute pollen diagrams contained the pollen grains of invasives in separate groups to make the evaluation easier.

3. RESULTS

3.1 Changes in landuse and the hydraulical roughness of the floodplain

3.1.1 Based on the historical dataset and and former geographical names the changes in environmetal conditions and landuse in the surroundings of the river was analysed. The hydrological and vegetational changes of the former and present-day active floodplain were studied. For example at Csordajárás site pastures have dominated since 1804. On the other hand at Vetyehát site before the regulations marshlands and pastures were mentioned, while nowadays forests dominate, which were mentioned 1862 at the first time.

The old maps gave data also on geomorphological changes, as at Csordajárás the meander was cut-off in 1846, but by 1899 it was silted up such an extent, that permanent water-supply was not awailable any more. The same thing happened few kilometers downstream at Zugoly site between 1864-72 and 1914.

3.1.2 Since 1953 the extension of previous pastures at Csordajárás site decreased and they were replaces by arable lands and forests. Later parts of arable lands were unutilized. At Vetyehát forests became prevailing in contrast with the arable lands. On the investigated sites opposite trends were revealed: simultaneously with the decrease of mean patch size (from 1.4 to 0.9 ha) patch density duplicated at Csordajárás site. At Vetyehát site at the same time, insreasing mean patch size (from 1.6 to 3.4 ha) resulted decreasing patch density. It is important to mention, that mean patch size can cover great deviations. Patch shapes were very simply (rectangular) on both sites and it changed slightly during the investigated period. Shannon's diversity index increased at Csordajárás site and decreased at Vetyehát. These changes were not absolutely advantageous. Since the reason of increasing diversity value was the spreading of arable lands at Csordajárás, while at Vetyehát decrement experimented due to forests plantation on the expense of arable lands.

3.1.3 Landuse did not changed on 40 % of the territory of Csordajárás based on the category-transition analysis between 1953 and 2000. Main transition types were pastures-arable lands (on 20 %) and also the pasture-forest transition (11 %). Besides, the expansion of uncultivated pastures (6.5 %) and arable lands (7.1 %) was also considerable, together with floodplain forests planted on arable lands (3.8 %). Concerning Vetyehát site the structure of landuse transformed significantly. Only on 17 % of the site was cultivated with the same method in 2000 as in 1953. Nowadays more than a half (51.5 %) of the territory is used as forest instead of arable lands. Large extent (5.1 %) of arable lands became non-cultivated since 1953 and the spreading of scrubs on arable lands was documented on 1.2 % of the total area. On 2.8 % of the area the pastures were replaced by forests, and only 2.6 % is used in the same way.

3.1.4 The hydraulical roughness increased definitely on both study sites. Normal roughness values were the smallest in 1953 (Csordajárás: 0.044, Vetyehát 0.045). The same values later differentiated, as roughness increased on Vetyehát site ($n_{norm2000}$=0.096) due to the intensive forest plantations and by 2000 it became double of the roughness estimated on Csordajárás ($n_{norm2000}$=0.059). Maximum value of roughness also increased considerably at Csordajárás ($n_{max1953}$=0.072; $n_{max2000}$=0.102), though at Vetyehát this tendency was more expressed ($n_{max1953}$=0.072; $n_{max2000}$=0.175) during the assessed time period.

3.1.5 Change in hydraulical roughness was adverse along the active channel in the investigated 100 meter wide zones. Considering the highest values of the near-channel zone at Csordajárás ($n_{max2000}$=0.140) and Vetyehát ($n_{max2000}$=0.189) also increased hydraulical roughness is measured. Mainly these are the territories exposed to increased accumulation during floods.

3.1.6 Evaluation and comparison of the present landuse and the requirements of water authorities resulted, that the proposed grass belt was not implemented for a long time along the riverbank. Earlier (Ihrig 1952) it was defined as a zone two or three times wider than the width of the active channel, later in 2006 a 6.0 meter wide belt was required by the law. Forests have the highest maximal roughness values and change their roughness in the greatest interval (n_{min}=0,06; n_{max}=0,2) among landuse categories. Therefore it is very important to pay attention to the conditions of floodplain forests. They are usually not in accordance with demands of the official bureaus, mainly due to the poplar plantations with a well developed false indigo *(Amorpha fruticosa)* undergrowth. Requirements in the floodplain state became lower since the channelization, because no doubt that they are too difficult to fulfill.

3.1.7 Landuse change influenced hydraulic roughness change shows clearly that drainage properties of the floodplain deteriorated since 1953 along the Maros, indirectly promoting accelerated floodplain accumulation.

3.2 Short-term deposition on the Maros floodplain

3.2.1 Short-term analysis focused on the overbank deposition caused by single flood events. It showed that the thickness of the deposited sediment decreased exponentially from the riverbank to 300-400 meter distance. The most significant aggradation was measured in a 20-50 meter wide zone along the riverbank. On distant parts of the floodplain the amount of accumulation decreased and deposition was influenced mainly by the geomorphology and vegetation. In addition, downstream component of sediment thickness decreased on wider floodplain sections.

3.2.2 Along straight reaches and undeveloped meanders althought accumulation was intensive, but it was restricted to a narrower area. The thickest sediment layer (18 and 26 cm during the floods in 2005 and 2006) was deposited on the convex bank downstream from the apex of the bends. This refer to intensive point-bar development.
In contrary, the investigation of a braided unit (by Apátfalva) the same processes on the flodplain were revealed as Sipos (2006) publicated in relation to the active channel. The greatest accumulation during floods was observed mainly in upstream sections of the braided unit and aggradation decreased downstream. From the three morphological zones (accumulation, transportation and erosion) defined by Sipos, the first one also evolved on the floodplain, just upstream of the islands. Due to the shallow channel the river transported more and mainly coarse (60-77 % sand content) material to the floodplain during overbank flow. As braid unit became narrower downwards the amount of overbank deposits decreased as well.

3.2.3 Increased overbank deposition (2.0-3.5 cm per single flood event) is also typical in distant parts of meanders which were cut-off during the channelization works and silted-up rapidly. During overbank flows they function as secondary flow channels, therefore their sediment supply is continuous. The greater flow velocity was supported by the relatively higher sand content (19-23 %) of the samples collected from old meanders far (more than 1 km) from the active channel.

3.2.4 The pattern of the deposited sediment was modified by natural geomorphological units as well as by artificial objects. Increased accumulation was registered in artificial depressions such as pits and cannals.

3.2.5 Sand content of sediment accumulated during single flood events decreased by distance from the riverbank. Mainly silty material was accumulated 50-80 meter far from the active channel. In the most upstream site (at Apátfalva) coarse sediment with high sand content (60-77 %) was typical, while close to the confluence (at Vetyehát) the physical parameters of the fresh deposits were similar or finer than the riverbank material (fine-sand).

3.2.6 Greater amount of fresh sediment deposited in forests with rare undergrowth, than in forests characterized by dense scrub vegetation such as false indigo *(Amorpha fruticosa)* and box-elder *(Acer negundo)*. The main reason can be the extremely dense vegetation formed high resistance against water flow and flow velocity became so slow that only small amount of suspended sediment was transported into these patches. On the other hand, the used sampling method was not suitable to see clearly how vegetation influences overbank deposition. Other sampling strategy should have been applied to assess the role of vegetation, these measurements should be made on such points of the floodplain where the effects of other influencing factors are the same (eg. distance from the riverbank).

3.2.7 According to my opinion, there was no reason to differentiate in width of the restricted use along the riverbanks of Danube, Tisza, Drava, Körös and Bodrog Rivers agains other larger rivers (21/2006 Governmental Decree). Along the mentioned rivers 10 metres was provided as a near-bank unvegetated zone, but in case of Maros it was determined as 6 metres. Results of my investigation showed that most of the sediments deposited in a much wider, 20-50 m wide zone during overbank flows. The question of the restricted zone width should have to assess from the aspects of economy and nature protection.

3.3 Long-term floodplain aggradation after the river regulationworks

3.3.1 Elevation changes and distance from the riverbank were proved the most important influencing factors of deposition during the last 50-55 years on the former bar surface at Apátfalva. On higher areas closer to the active channel accumulation rate was 1.4 cm/y, farther it decreased to 0.4 cm/y. In former chutes of the bar surface accumulation rate was the same as in cut-off meanders (1.9 and 2.6 cm/y).

3.3.2 Accumulation rate depended on elevation (i.e. duration and energy of inundation, water depth) of geomorphological units. Significant change in grain-size characteristic of sediments was noticed at the depth of 98 cm on the backswamp area of Csordajárás. On a former natural leveee the same process (sand turned into silt and clay) was observed at the depth of 35 cm. Both refer to the relocation (cut-off) of the active channel, in other words to the time of river regulations. On various geomorphic units different aggradation was measured: on backswamp area accumulation rate was 0.63 cm/y, while on inactive natural levee 0.23 cm/y.

3.3.3 Floodplain accumulation was the greatest in the case of oxbow lakes, but there were also differences, caused by the different date of their regulation (Csordajárás 1846, Zugoly 1864-72, Vetyehát 1858), their different position in relation to the alluvial fan and to the confluence with River Tisza. The accumulation rate is also influenced by the position of sampling points within the old meanders and the distance from the active channel. These factors explain the variance of aggradation rate in the three assessed meander (Csordajárás 2.45 cm/y, Zugoly 1.3 cm/y and Vetyehát 1.8 cm/y). Changes of aggradation rate were determined by pollen grains (spreading of ash-leaved mapple and false indigo in 1880’s, and ragweed in 1960’s) and military maps. Aggradation was rapid during the juvenile phase of oxbow-lake development and later became slower. Except at Csordajárás site, where agriculture became more intensive during the last 40-50 years causing significant erosion processes along the former river banks by agricultural machines.

3.4 General conclusions

3.4.1 The long-term development of the Maros floodplain tends to uniformisation with accelerated aggradation of deeper areas (old meanders, canals and pits) and slower deposition on elevated surfaces (former natural levees and point bars). Abandonement of former geomorphic units, equalization of elevation differencies were partly compensate by anthropogenic interventions (establishment of canals and pits), and by natural intensive point bar and natural levee development, as it was observed during short-term investigations.

3.4.2 Determined short and long-term accumulation rates – which were the same or greater than it was experienced in case of Tisza river (Gábris et al. 2002, Kiss et al. 2002, Balogh et al. 2005, Sándor and Kiss 2006b, 2007) – supported that it is also important to recon with aggradation of the Maros floodplain in terms of flood protection and flood hazard.

3.4.3 The examined Maros floodplain sections belong to Nanson and Croke's (1992) B3b (lateral migration, scrolled floodplains), B3c (lateral migration, backswamp floodplains) and C1 (laterally stable, single-channel floodplains with low natural levee and backswamps) orders and suborders, based on their specific stream power, channel pattern before and after the channelization, and decreased lateral migration followed river regulation. In its present state the Maros describes order C1 mainly. All three but in highest degree C1 order fulfill significant overbank deposition.

3.4.4 Results obtained from exotic pollen based chronology demonstrate that only few species were applicable from the numerous adventive plants of the flora of the Maros floodplain. This type of investigation should be based mainly on ragweed *(Ambrosia artemisiifolia)*, due to its wellknown spreading, its significant pollen productivity and easy identification of ragweed pollen grains. Exotic pollen grains occuring merely just in one or two samples are not suitable for longsighted conclusions. This method secures reliable results only together with other investigations.

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