RELATIONSHIP BETWEEN CHANGES IN HYDROLOGICAL CONDITIONS AND BANK EROSION ALONG THE UPPER RÁBA RIVER IN HUNGARY

SUMMARY OF PH.D. THESIS

by
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Budapest
2024

DOI: 10.15476/ELTE.2024.225

1. Introduction and objectives

Lateral erosion is a basic process governing the channel dynamics of meandering rivers. Free or partially regulated meanders can have significant lateral erosion of up to several metres per year. Bank erosion contributes to the dynamic meander development of rivers (Bertalan et al. 2016), the maintenance of alluvial sediment household (Nagy and Kiss 2020), and the reworking of floodplains (Kiss et al. 2022). At the same time, depending on its spatiality and intensity, bank erosion can cause severe damage to agricultural lands or infrastructure (Das et al. 2012).

The Hungarian section of the Upper Rába River offers an excellent opportunity to study the spatial and temporal changes in bank erosion and meander development. The high slope (42–106 cm/km) of the Rába River accelerates the fluvial processes, which allows for significant changes in bank erosion rate, channel migration, meander shape and meander development within a short time.

The main objective of my research is to investigate the rate of bank erosion and sinuosity changes of the channel and their influencing factors along the Upper Rába (216.3-86.6 rkm) in Hungary. The aim is to quantify the spatial and temporal varations in bank erosion and sinuosity development, and to analyse the effects of some selected environmental factors influencing bank erosion. Since the main factor influencing bank processes is the hydrological characteristics of a river (e.g. duration of floods, flooding rate, length of low stages, seasonality of floods), my main objective is to assess the hydrological changes affecting the evolution of the studied reach. I also aimed to analyse the semi-anthropogenic processes triggered by engineering works (e.g. revetment and dam constructions), which, in addition to the material, height and vegetation of the banks, can also have a significant influence on the bank erosion of certain sections. The ultimate aim of the research is to use long-term (1844-2022) and short-term (2022-2024) spatial data to identify sections most affected by recent bank erosion and meander development, to outline the general evolutionary path describing the dynamics of horizontal changes in the channel, and to assess the fluvial response to spatial and temporal changes in environmental factors.

2. Materials and Methods

As a first step, the hydrographic data of the water gauges along the Upper Rába in Hungary (Szentgotthárd, Körmend and Sárvár) were collected. The hydrological database for the studied section was provided by the West-Transdanubian Water Directorate (NYUDIVIZIG), which included daily water stage (1901-2024) and water discharge (1970-2024). Based on these data, I calculated and analysed the hydrological parameters relevant for bank erosion (e.g., annual highest, medium and lowest water levels, frequency of given water stage and water discharge values, return period of floods and slope between two gauging stations).

For the analysis of the different morphometric parameters of the channel and bank erosion 17 maps (1844, 1878, 1951, 1955, 1960, 1983, 1996), aerial photographs (1967, 1972) and orthophotos (2000, 2005, 2008, 2012, 2015, 2018, 2021, 2022) taken at different dates were used. Spatial data from different sources with different formats and different projections, were processed using QGIS software (3.28/Firenze). After defining the bankline on the spatial data sources, the bank erosion rate between two dates were measured using the NNjoin module of QGIS. Furthermore, the morphometric channel parameters (i.e., reach length, sinuosity and channel width) were calculated to characterize the long-term changes in the channel morphology.

In the Upper Rába, 14 units were identified based on the degree of channel and floodplain regulation works and the dynamics of bank erosion.

For a more detailed assessment of bank erosion, repeated at-a-site bank erosion measurements using an RTK-GPS were carried out every 4 months from April 2022 to April 2024. The surveys were performed along the most intensively developing meanders (20). Boreholes were drilled at the eroding banks of each meander to determine the grain size composition of the bank material and to evaluate the effect of the bank material on bank erosion.

3. Results and theses

The results of the doctoral research are summarised in the following theses:

1) The hydrological conditions in the Hungarian reach of the Upper Rába changed fundamentally between 1901 and 2024, which was divided into periods. **The Hungarian section of the Rába was in hydrological equilibrium until 1980, but later the hydrological parameters changed significantly, indicating a hydrological dis-equilibrium.** The annual highest water levels have become more extreme. For example, difference between the annual highest water levels was 484 cm between 2001 and 2005, but it increased to 576 cm between 2021 and 2024 at Szentgotthárd. The mean annual highest water level for each period has decreased (Szentgotthárd: 1996–2000: 390 cm; 2016–2020: 299 cm). Meanwhile, the duration of the lowest stages (≤0 cm) has increased dramatically: it characterized 52–81% of a year between 1901 and 1980, but it increased to 91–97% between 1981 and 2024. The water discharges associated with given water levels have almost doubled, indicating channel incision.

The intra-annual pattern of the hydrology also changed. Early spring (March) floods were common in the 20th century, but they became absent or occurred in a form of a much smaller flood in February (at Körmend) in the 21st century. Formerly, early summer floods were also frequent, but nowadays they shifted to early autumn (August–September). These regime changes could be associated to climate induced changes in runoff, as summer and early autumn rainfalls became heavier and more frequent.

2) The bends of the studied reach eroded intensively between 1844 and 2022 (mean bank erosion rate: 3.5 m/y; max: 29 m/y). However, the bank erosion was not uniform, as there are significant differences between periods and channel segments (units). The bank erosion of the Rába was particularly rapid in certain periods (1955–1959, 1960–1966, 1967–1971 and 1996–1999), when the mean bank erosion was 4.9–6.1 m/y. However, after these periods, the bank erosion declined sharply (2.1–2.4 m/y). The lowest rate of bank erosion (1.6–2.8 m/y) were measured in 1878–1950, 1972–1982, but it became more common in the 21st century, in 2000–2004, 2005–2007, 2015–2017, 2018–2020 and 2021–2022.

The hydrological dis-equilibrium and changes in hydrological parameters partly explain the changes in bank erosion rate. However, the short-term field measurements (in every 4 months) gave a more detailed insight into the relationship between hydrology and bank erosion. Flood waves reaching or exceeding the bankfull level play a prominent role in bank erosion, as they directly erode the banks, and after their termination mass movements were triggered. Successive, large (200–400 cm) flood waves caused significant (2.8 m/4 months) bank erosion along the entire length of the reach, but in some bend this could be as high as 10–19 m/4 months. However, not only flood waves at or above the bankfull level are associated with bank erosion, but virtually any water level, just to different degrees. During low stages, when small flood waves (50–150 cm above the low water stage) appeared, the mean bank erosion rate was <1 m/4 months. During low stages the accumulated bank material at the bottom of the bank could impede or significantly reduce bank erosion.

3) The channel development of some sections of the studied Upper Rába was significantly influenced by local management works implemented between 1977 and 1981. Based on the degree of human impact and channel development, the studied section of the Rába was divided into 14 units.

The identified units were classified into three groups ("natural", "slightly modified" and "heavily modified"). Bank erosion was highest in the "natural" units (mean: 4.3 m/y), it slightly reduced in the "slightly modified" units (mean: 3.3 m/y) and the bank erosion was minimised in the "heavily modified" units (mean: 2.0 m/y).

4) The position of the bank with the highest bank erosion varied in the bends. In most of the bends, the greatest bank erosion took place downstream of the bend apex. However, there were also some bends where, due to local geomorphological conditions (e.g., development of islands or mid-channel bar modifying the thalweg), the most significant bank degradation occurred upstream of the bend's apex. Some meanders developed into compound bends, as secondary bends developed on them. Lastly, the development of some of the bends was greatly hampered by the presence of high banks.

5) The bank material of the studied meanders is highly variable; therefore, the bank erosion of the bends varies even under the same hydrological conditions. Most of the bends (except bends *O*, *P* and *U*) are characterised by an increasing silt-clay content in the bank material towards the surface. Thus, there is a sandy-gravely layer the bottom of the banks, promoting more intensive bank erosion than on other rivers. Both in the short and long term, bank erosion rates are moderate (1.75±0.42 m/y) in the meanders embedded into silty floodplain sediments. However, bank erosion rates are higher and highly dispersed (3.0±2.16 m/y) in the meanders with high sand content (80-90%).

6) Bank erosion is a periodic process, but due to changes in environmental factors, the rate of bank erosion gradually decreased during the period under study (1844–2024).

According to the conceptual model (*Figure 1*), in the mid-20th century (1950–1972), the bankfull water levels created suitable conditions for intense bank erosion. Due to the widening of the channel, the following period (1972–1996) can be considered as a relaxation period. During this period, no intensive bank erosion could be detected, despite successive and regular flood waves. The bank erosion cycle restarted between 1996 and 2000, but with a lower magnitude. This erosion cycle was also completed by a relaxation period of limited bank erosion (2000–2008). In the last (third) bank erosional cycle (2008–2012), the bank erosion increased slowly, but was not as intense as in the previous cycles. The last decade (2012–2024) could be evaluated as the end of the third erosional cycle (relaxation time) or as a beginning of a completely new development phase. During these periods, the bank erosion rate gradually decreased.

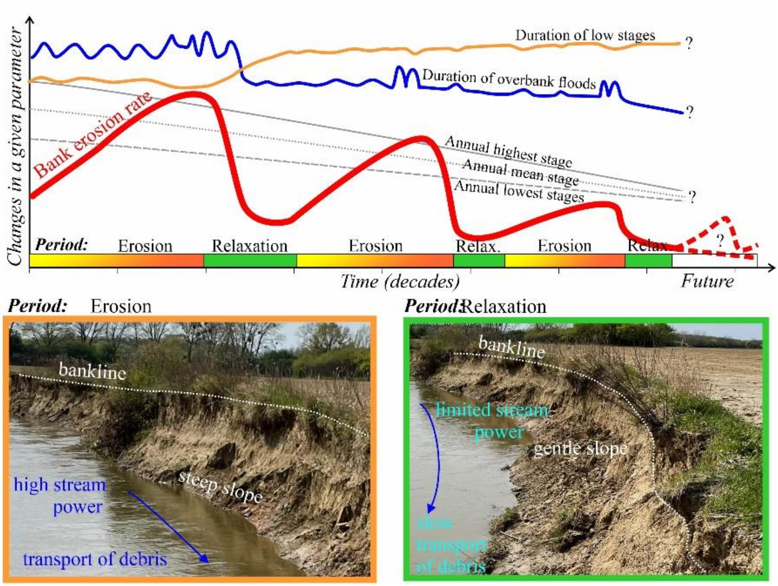

Figure 1. Conceptual model of declining bank erosion driven by hydrological changes.

4. References

Bertalan, L., Szabó, G., & Szabó, S., (2016). Soil degradation induced by lateral erosion of a nonregulated alluvial river (Sajó River, Hungary), in: Zapletalová, J.; Kirchner, K. (Ed.), *Aktuální Environmentálni Hrozby a Jejich Impakt v Krajiné (Current Environmental Threats and Their Impact in the Landscape Brno).* (pp. 8-9). Sbornik Abstraktu Z Mezinárodniho Workshopu. Ústav geoniky AV CR, ISBN: 978-80-86407-65-4

Das, A.K., Sah, R.K., & Hazarika, N., (2012). Bankline change and the facets ofriverine hazards in the floodplain of Subansiri-Ranganadi Doab, Brahmaputra Valley, India. *Nat. Hazards* 64, 1015- 1028. DOI:10.1007/s11069-012-0283-5

Kiss, T., Sipos, Gy., & Vass, R. (2022). Alluvial ridge development and structure: Case study on the Upper Tisza, Hungary. *Geographica Pannonica 26(3)*, 230-240, DOI:10.5937/gp26-38365

Nagy, J., & Kiss, T. (2020). Point-bar Development Under Human Impact: Case Study on the Lower Tisza River, Hungary. *Geographica Pannonica 24,(1)*, 1-12. DOI:10.5937/gp24-23011

5. Publications related to the PhD research

Pusztai–Eredics, A., & Kiss, T. (2024). Declining Bank Erosion Rate Related to Climate-Change Driven Hydrological Alteration of a Small Sub-Alpine River. *Hydrology* 11(8), 1-16. DOI:10.3390/hydrology11080114

Pusztai-Eredics, A., Kovács, G., Tóth, G., Lenner, T., & Kiss, T. (2024) Lateral meander migration of a medium-sized lowland river: case study on the Rába River, Hungary. *Geogr. Pannonica* 28(3), 169–181. DOI:10.5937/gp28-49989

6. Other publications

Pusztai-Eredics, A., & Tóth, G. (2019). Feliszapolódási vizsgálatok a Rába-folyó árterén ^{137}Cs-izotóp gamma-spektrometriai elemzése alapján. *Hidrológiai Közlöny* 99(3), 23-29.

Kovács, G., **Pusztai-Eredics, A**., & Varga, N. (2024). Településfejlődési vizsgálatokhoz (is) használható topográfiai adatforrások Magyarországon: 1950 előtti topográfiai térképművek. *Településföldrajzi Tanulmányok 13(1)*, 224-237.

Kovács, G., **Pusztai-Eredics, A**., & Varga, N. (2024). Településfejlődési vizsgálatokhoz (is) használható topográfiai adatforrások Magyarországon: 1950 utáni topográfiai térképművek In: Horváthné Molnár K, Fűzfa B (Eds.), *Teremtő tudomány*. (pp. 80-94). Szombathely: Savaria University Press.

Pusztai-Eredics, A., Varga, N., & Kovács, G. (2024). Településfejlődési vizsgálatokhoz (is) használható topográfiai adatforrások Magyarországon: modern topográfiai és térinformatikai adatforrások. *Savaria Természettudományi és Sporttudományi Közlemények* (2630-9653): 21, 49-70.

7. Conference publications related to the PhD research

Pusztai-Eredics, A. (2020). *Alkalmazható vizsgálati módszerek a feliszapolódás mértékének meghatározására*. In: Pozsgai, A., Puskás, J. (szerk.): XVIII. Természet-, Műszaki- és Gazdaságtudományok alkalmazása Nemzetközi konferencia, Szombathely, Magyarország, 111-122.

Pusztai-Eredics, A. (2021). *Történeti térképek felhasználhatósága a földrajzi kutatásokhoz: A kanyarulatfejlődés meghatározása a Rába folyó Alsószölnök és Sárvár közötti szakaszán.* In: Novák, R., Kardos, L., Pipics, J., (szerk.): Természet és társadalom. Az ELTE SEK Történeti Diákműhely Történet- és Természettudományi Hallgatói Konferenciáján (2021. május 17.) elhangzott előadások kivonatai. Szombathely, Magyarország, ELTE SEK Történeti Diákműhely, 37-41.

Pusztai-Eredics, A., Kovács, G. (2021). *Method of dynamic river bed analysis of the Rába River* In: Природничі науки: проєкти, дослідження, перспективи = Natural Sciences: Projects, Research, Prospects: Матеріали II Міжнародної науково-практичної конференції Старобільськ, Україна, 21-22. XII. 2021р. = Materials of the IIst International Scientific-Practical Conference Starobilsk, Ukraine, December 21-22, 2021, 65-67.

Pusztai-Eredics, A., Kovács, G (2021). *A kanyarulatfejlődés meghatározása és okainak feltárása a Rába folyó Alsószölnök és Sárvár közötti szakaszán* In: Karátson, D., Nagy, B., (szerk.): X. Magyar Földrajzi Konferencia absztrakt kötet. Budapest, Földgömb Alapítvány, 29-29.