Riverbank erosion in Hungary – with an outlook on environmental consequences

Zoltán SZALAI[1,2], János BALOGH[1] and Gergely JAKAB[1]

Abstract

In the 19th century deforestation in the Carpathians and the growing population made flood control and river regulation an urgent task in the Carpathian Basin. As a result of shrinking active floodplains and cut-offs, the natural sedimentation/erosion equilibrium have been upset over the Hungarian Plain. The modified conditions have also changed the erosion patterns on minor floodplains. The present paper will outline the necessity for flood control, its effects and consequences for bank erosion. The present conditions and forms of bank erosion along the Hungarian rivers are considered and an overview is provided on the most important factors affecting bank protection with their socio-economic consequences in Hungary.

Keywords: riverbank erosion, floodplain, flood control, flood wave, heavy metals, remobilisation, Danube, Tisza

Introduction

The Danube and Tisza rivers have always played an essential role both in natural landscape evolution and in national life in the Carpathian Basin. These rivers and their tributaries wandered across the major part of this basin during the past 500,000 years (Borsy, Z. 1991). Both rivers and their tributaries have often altered their channels (although the Danube less frequently), so the river meanders have a relatively short evolution from their emergence till natural cut-off (Borsy, Z. 1991; Somogyi, S. 2001). In the 19th century socio-economic development called for effective flood control. While the deforestation of Carpathians caused higher and higher flood waves, the growing popula-

[1] Geographical Institute, Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences, H-1112 Budapest, Budaörsi út 45. E-mails: szalaiz@mtafki.hu, baloghj@iif.hu, jakabg@mtafki.hu

[2] Department of Environmental and Landscape Geography, Faculty of Science, Eötvös Loránd University, H-1117 Budapest, Pázmány P. sétány 1/C.

tion required more and more protection for settlements and farming. Parallel with these the industrial development also demanded waterways providing safe navigation.

Flood control and water regulation measures started in the middle of the 19th century along the Tisza and Danube rivers and subsequently were extended to their tributaries. These activities have continued up to our days and can be classified into three groups:

1. building of dyke system and implementing cut-offs,
2. bank protection;
3. construction of hydraulic power plant systems (Erdélyi, M. 1994; Fejér, L. 2001; Somogyi, S. 2001).

The dyke system had been completed along the most important rivers by the early of 20th century parallel with cutting off meanders (*Figure 1*). Rivers have been shortened and their stream gradient increased (*Table 1*).

Although the early phase of channel regulation protected the settlements against the rising flood peaks and provided new (previously not cultivated) fields for agriculture, it did not reduce bank erosion (Julian, J. and Torres, R. 2006). On the contrary, bank erosion rates and meander evolution increased and undercut the existing dykes and abutments along the Tisza River and its tributaries (Károlyi, Z. 1960). The construction of new dykes continued in the late 20th century, but by now the strengthening and rising of

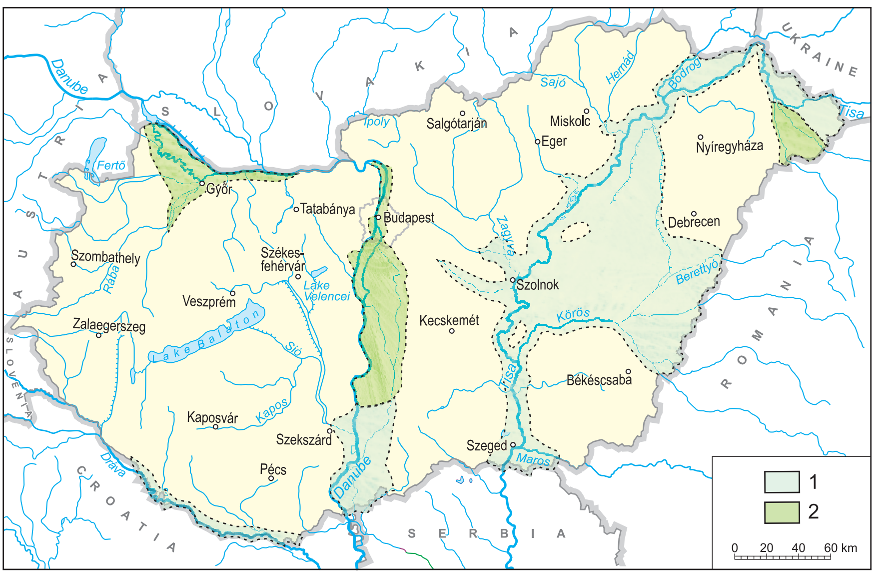


Fig. 1. Inundated areas before flood control in Hungary. – 1 = inundated areas during floods; 2 = inundation period was longer than three months per year (On the basis of National Atlas of Hungary)

Table 1. Properties of the most important rivers in Hungary before and after flood regulation (after Somogyi, *S. 1974)*

River	Length, km		Average stream gradient, cm/km	
	before	after	before	after
	flood regulation			
Danube	494	417	5.0	8
Tisza	1,419	966	3.7	6
Dráva	409	232	7.5	12
Maros	191	121	14.0	28
Hármas-Körös	234	91	2.0	5
Rába	132	84	32.0	47

the already existing embankments had become the most important activity in the field of flood control.

In order to reduce bank erosion building of protection works have been started along the endangered bank reaches. Four methods have been used mostly: 1. groynes, 2. revetments, 3. retaining walls, 4. bluff reinforcement. The first and second is of common use along all big rivers for maintaining the shipping and protecting bridges and hydraulic works. The third method is used along river sections in the cities (Bariteau, L. *et al.* 2013) and the fourth one is widespread along the Danubian loess bluffs (Kleb, B. and Schweitzer, F. 2001; Stancikova, A. 2001). Adequate bank protection is capable of reducing bank erosion to a considerable extent.

The reduced floodplains and protected riverbanks have accelerated alluvial processes (e.g. sedimentation on sensitive areas) and changed the quality, amount and pattern of riverbank erosion.

Riverbank erosion: forms and processes

In convex and flat floodplains different processes control riverbank erosion (Butzer, K.W. 1976). These variations between the processes result in various erosion forms and patterns. A convex floodplain is typical of the majority of Danube sections. Under natural conditions channel shifting is slower over convex than flat floodplains. Thus the amount of the transported sediments is also lower in general. The most important erosion forms can be found on the natural levees both along riverbanks and the banks of islands. Erosion forms on natural levees depend mainly on vegetation structure and land use pattern. Under geomorphic conditions close to natural two kinds of bank erosion processes prevail: piping, which results in a spongyform structure in the near-surface part of natural levee and transverse crevasses across natural levees.

Piping is typical along those natural levees where the sediment is sandy loam or finer sediments. Pipe formation occurs on the falling limb of the flood hydrograph and it is driven by water escape. When water levels are falling, the external pressure is decreasing until it is equal to atmospheric pressure, i.e. lower than the internal (groundwater) pressure. The outflow of groundwater on the bank face is freed from this pressure difference and it starts on the bank face. These flows mostly emerge along lines where the sandy layers are exposed on the natural levee. The outflow partly runs on the bank surface and partly flows in a pipe network near to the surface (*Figure 2*).

The pipe network is enlarged by outflowing groundwater and mostly formed along the root network (Hubble, T.C.T. *et al.* 2010) and thus parts of the bank face where the interparticle force of cohesion is less than the average. The mean diameter of these pipes is around 5–9 cm (*Photo 1*). The majority of pipes collapse during subsidence. The rate of collapse depends on that of drying and rewetting. Finally, this process causes a very slow bank retreat and 100–200 m^3/km/year material losses from natural levees in the Hungarian Danube sections. Kiss, T. *et al.* (2002) reported higher bank erosion rate (9.2–44.5 cm/year) along the Tisza River (between 212 and 216 river kms), which approximately means 140–700 m^3/km/year material losses from natural levees.

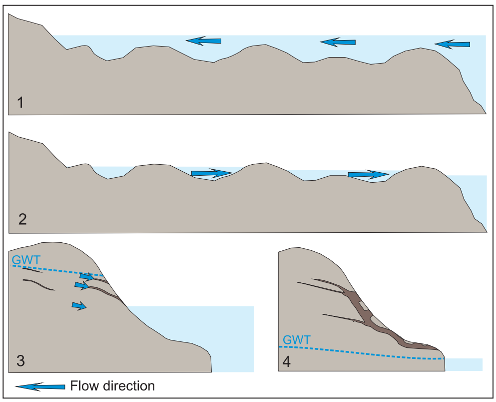


Fig. 2. Pipe forming in natural levee. – 1 = inundation of active floodplain, natural levee saturated during the flooding; 2 = the level of the floodwater on the floodplain is higher than the water level during falling; 3 = initial phase of pipe forming: the outflow starts to cave pipes in the natural levee due to the pressure of floodwater; 4 = after flood-wave pipe system starts to collapse; GWT = ground water table

The crevasses on the natural levee are developed during of 6–10-year floods. These crevasses play an essential role in the inundation of floodplains, stretching beyond the levees because flood water should not overtop the natural levee during inundation (Pizutto, J. *et al.* 2010). Crevasses can be attributed to both natural and anthropogenic processes. A crevasse can form at sites where the bank face is lower than the average. Along some river sections the dredged and dumped sediments can raise natural levees. These raised banks also accentuate the crevasses. Crevasses across the natural levees have an ambivalent role in bank erosion because they contribute to accretion behind the levees during floods (crevasse splays) and locally intensify bank erosion (*Figure 3*).

Photo 1. Pipe outflow (the Danube River, Háros Isle) (Photo by Szalai, Z.)

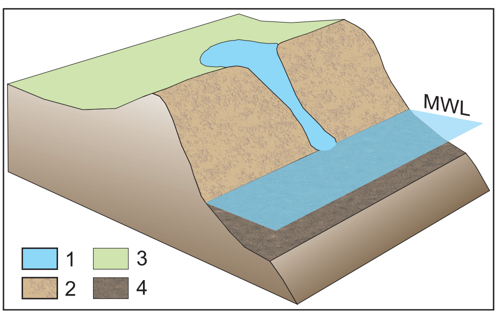


Fig. 3. Transverse crevasses in natural levees. – 1 = crevasse; 2 = natural levee; 3 = floodplain; 4 = storage bar; MWL = mean water level

During inundation a large amount of suspended load can reach the floodplains behind the levees where normally there is no sedimentation. During the retreat of floods the drop of the water level is much more rapid in the channel than over the floodplain and the difference between the water level in the channel and the floodplain can reach 5–10 m. The retreating water on the floodplain is less turbid than during flooding because the vegetation adsorbs suspended sediments. This filtration is accelerated by micro-topography. The water outflow from the floodplain has high energy because the suspended sediment concentration is low and the relative relief is high. This temporary high-energy flow forms V-shaped crevasses (Anderson, M.G. *et al*. 1996).

The amount of material eroded from the riverbank can be high locally, while the total amount of material loss from crevasse on riverbank remains low. The bank-derived sediment is moved into a temporary storage and thus material becomes available for transport during the following flood. In the adjacent and dead channels the crevasses incise into this bar. The dredging in adjacent channels accelerates the bank erosion processes, because the temporary storage bars are destroyed and finally the bank slope angle increases. Moreover, near-bank dredging results in bluffs caving in along these sections (*Photo 2*).

The willow groves might reduce bluff instability temporarily. After three-four flood events undercutting can cause 1–2 m bank retreat and a new

Photo 2. Near-bank dredging caused caving bluff along the Danube (Photo by Szalai, Z.)

storage bar forms simultaneously. During a repeated near-bank dredging the material of renewed temporary storage disposed again into the natural levee.

In the Middle Danube Valley the convex floodplain and its landforms are combined with loess bluffs. Karácsonyi, S. and Scheuer, Gy. (1972) identified three types of loess bluff (*Figure 4*) along the Hungarian sections of Danube:

– The first type is where the Danube washes away the debris from the foreland of bluffs during the floods groundwater is released from the loess without completely saturating it (*Figure 4, A*). The loess becomes saturated only during the flood events and this can cause landslides, but the alluvium accumulated in the foreland protects it against undercutting. This kind of bluff is relatively stable, landslides and gully incision are the most important bank erosion processes.

– The second type a directly undercut bluff, where lateral erosion of the river is the main agent (*Figure 4, B*). Along these sections it is the caving in that can lead primarily to erosion processes and forms (Schweitzer, F. 1999).

– The third type of bluff is characterised by debris slopes and, as a rule, it is situated in the foreland of a steep bank (*Figure 4, C*). It is typical in some river sections of the Middle Danube Valley. This debris protects the bluff against the lateral erosion of Danube as a buttress, but it also impounds groundwater in the loess (Lóczy, D. *et al*. 2008). The backwater level can reach the top of the debris slope and it is one of the most important reasons of landslides along this section of the Danube (Schweitzer, F. 2001).

Human activities (e.g. inflow of municipal and industrial wastewater in lack of a sophisticated sewerage system) cause serious problems along loess bluffs through increasing bluff instability and landslide hazard Growing population and industrial development impose a positive feedback on these processes. Visy, Zs. (1988) estimated bank retreat between 1778 and present. He reported 2.5–12.5 m/100 years retreat (*Figure 5*).

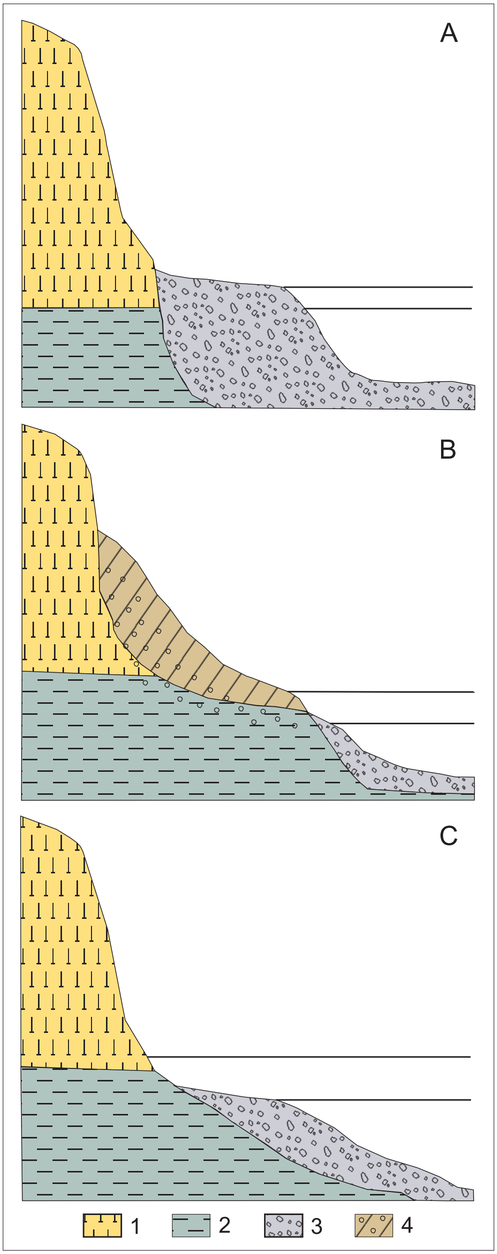


Fig. 4. Loess bluff types in the Middle Danube Valley (after Karácsonyi, S. and Scheuer, Gy. 1972). – 1 = loess; 2 = pannonian clay; 3 = gravel bed; 4 = debris slope

Lóczy, D. *et al.* (1989) determined erosion rates due to various agents. They have identified three bank retreat rates: 1. an overall rate on a geological timescale (1–2 m/100 years); 2. periods of active undercutting (2–10 m/100 years); 3. natural retreat enhanced by human intervention during the last hundred years (10–100 m/100 years). This means that the human activities of the last hundred years have multiplied the rate and the amount of bank retreat in comparison with the active undercutting periods (*Figure 6*).

The amount of the removed material per landslide event has increased as well. Landslides along the Danubian loess bluff affect 10,000,000 m^3/km sediment per on an average event during the second half of 20th century (Lóczy, D. 1997; Schweitzer, F. 1999).

One of the most important man-induced impacts on riverbank evolution in convex floodplains is bank accretion with industrial hazardous waste. The most important embankments can be found in the river sections of the Danube near Mosonmagyaróvár and Almásfüzitő (Northwest Hungary), where red mud reservoirs are found behind natural levees. The riverside dykes of the reservoir have been built upon the natural levees from slag. There is virtually no vegetation cover on the red mud and the dykes of reservoir and when it rains (especially during rainstorm events) huge

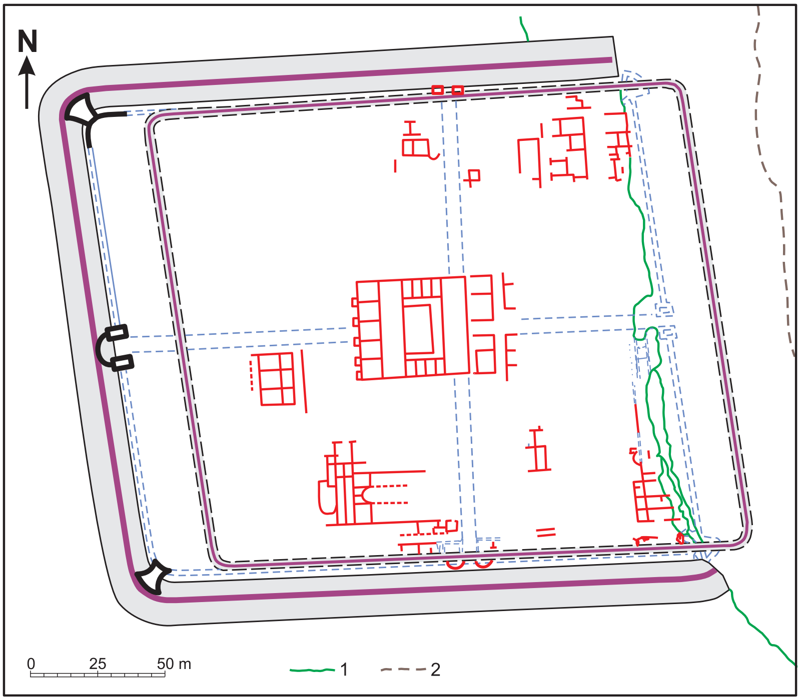


Fig. 5. Bank retreat along the Dunaújváros section of the Danube River on the basis of the Roman castrum Intercisa (Dunaújváros). – 1 = recent loess bluff; 2 = hypothetic line of the loess bluff (495 AD)

amounts of hazardous material are eroded into the channel. Piping here is replaced by rill erosion features. During the 6–10-year floods the floodwater surrounds the reservoirs and washes hazardous materials into the channel (Viczián, I. 2004; Schweitzer, F. and Szeberényi, J. 2011).

Flat floodplains are typical for most of the reaches of the Tisza River and for the majority of its tributaries. There are also some reaches of flat floodplain along the Danube near to the southern national border as well. The most important erosion process of flat floodplains is the lateral erosion of meandering rivers. The rate of meander evolution and lateral erosion has been changed fundamentally by cutoffs, reducing active floodplains and by channelization (Somogyi, S. 2001). The cut-offs with a bank protection have decelerated bank erosion dramatically. In some places lateral erosion has been reduced by 75% *(Table 2)*.

Recently, 1 m^3 water washes out ca. 1 kg sediment from the riverbank along whole length of the Hungarian section of the Tisza (Károlyi, Z. 1960; Rátóti, B. 1964). Along the reaches of Danube flanked by flat floodplains lateral channel shifting has removed much more material from its bank than from that

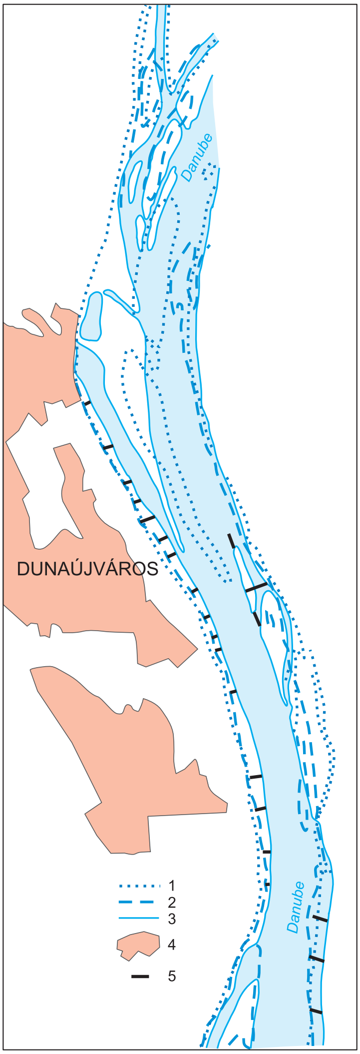


Fig. 6. Changes in riverbanks due to the channel regulation (from the Map Series of Hidrology, 11. Danube 2. – VITUKI, 1970). – 1 = riverbank on the 1884.1829 map (by Huszár, M.); 2 = riverbank after the 1899–1904 survey by the Hydrographic Department of the National Water Construction Authority; 3 = recent riverbank; 4 = built up area; 5 = groyne

Table 2. *Bank erosion rates along the Hungarian sections of the Tisza River (after Károlyi, Z. 1960)*

River sections along the Tisza	Number of shifting meanders	Amount of eroded riverbank	
		before	after
		bank protection, m^3/km/year	
Upper Tisza Valley	109	32,590	11,500
Middle Tisza Valley	21	10,633	2,450
Lower Tisza Valley	12	4,785	3,090

of Tisza. Somogyi, S. (2000) reported on 5–10 times higher values for lateral erosion than along the sections of Tisza River (*Table 3*).

Table 3. *Amount of riverbank erosion along the Danube (after Somogyi, S. 1974. and the measurements of the authors)*

River sections along the Danube	Amount of eroded riverbank	
	before	after
	flood regulation, m^3/km/year	
Sárköz	138,460	70,000
Fajsz-Baja	82,000	53,330
Middle Danube	–	1,200

High bank erosion rates of temporary character can also result from channel regulation. Several cutoffs with an initial channel width around 20 m (Lászlóffy, W. 1982) have widened up to 100–200 m. Thus, after cutoff the sediment yield of bank erosion could reach 40,000 m^3/km for the initial period.

Economic and environmental consequences of riverbank erosion

Although riverbank erosion has decreased, farming, industrial and municipal assets are still imperiled. After channel regulation and bank protection more than 95% of previously endangered settlements are still to be protected. At present the most endangered riverbank section is the Middle Danubian loess bluff. More than 10 settlements are at risk and the highest amount of municipal and industrial infrastructure damage have been recorded there. The total amount of damaged assets and the expenditure on bank protection has not been summarized until now. In Hungary the value of dykes and other hydraulic works is around 1.932 billion EUR. The total value of hydraulic works, for bank protection directly, is estimated around 728 million EUR. Considering the settlements and areas endangered by bank erosion prior to flood control the value of protected assets can reach 20 billion EUR in 2001 (Láng, I. 2001).

A less considered aspect of riverbank erosion is the remobilization of the deposited pollutants. Environmental consequences of this phenomenon have not been investigated yet and now it poses an immense hazard (Vonk, J.E. and Gustafsson, Ö. 2013). The rivers in the Carpathian Basin transport a huge amount of inorganic pollutants. The majority of the emitted non-biodegradable inorganic pollutants (e.g. heavy metals) derive from the neighbouring countries. The main source of these pollutants is the slag and sludge reservoirs of mines, slag reservoirs of non-ferrous metal plants, and the oil refineries (Kerényi, A. and Szabó, Gy. 2002; Kerényi, A. *et al.* 2003; Szabó, Gy. 2002; Szalai, Z. 1998b). These elements accumulated in well-identifiable floodplain sections (Szalai, Z. 1998c; Szabó, Sz. *et al.* 2008). The site of the accumulation mainly depends on the physical form of pollutants and on the shape of the floodplain (Szabó, Sz. and Posta, J. 2008).

On convex floodplains the majority of particulate pollutants accumulated on natural levees, because the waves of pollution usually coincide with flood waves. Along Danube Zn concentration in sediments ranges between 150–250 ppm, cadmium is around 1 ppm and lead between 50–70 ppm DW (Szalai, Z. 1998a). In the Middle Danube Valley piping remobilizes around 10.5–35 kg/km/year zinc, 0.8–1.4 kg/km/year cadmium, and 3.5–10 kg/km/year lead. Most of the remobilized heavy metals move into the temporary storage and is washed into the bedload of the adjacent channels and dead arms. Since the material transport is minimal in these channels, the pollutants accumulate there, thus becoming available for the aquatic ecosystems.

In the main channels (of gravel-bed rivers) the overwhelming part of remobilized heavy metals remains in suspended load. The eroded material results in 0.1 mg/litre zinc concentration increase per kilometre. The growth of lead concentration remains of the order of μg/litre. In the case of the Tisza, Gosztonyi, Gy. *et al.* (2011) analyzed the remobilization of zinc and iron with DW and HNO_3 treatment. They found that zinc was mobilizable with distilled water in small amount (0.014±0.001 mg/kg) applying 1 week extraction, while iron was not. Furthermore, 0.001M HNO_3 mobilized 2.9±1.4 mg/kg Zn; in the case of iron they experienced rebounding after one week. Heavy metal remobilization from other rivers has not been estimated yet.

Conclusion

Channel regulation and flood control have changed riverbank erosion conditions completely. Bank erosion has been generally reduced along the rivers of the Carpathian Basin. Before flood regulation and bank protection it was the lateral channel shifting that eroded the highest amount of material. Recently these river curves are protected, and, consequently, the share of erosion of natural levees has increased.

While important results have been achieved in the field of bank protection, other human activities are expanding (e.g. near-bank dredging, inadequate land use system on active floodplains) (Lóczy, D. and Dezső, J. 2013).

Riverbank erosion and associated human activities have made an essential impact on economy. The endangered and damaged assets and the maintenance of flood control systems and of bank protection related structures belong to the measurable values of these objects and activities. The remobilised hazardous elements pose immeasurable environmental and public health risk and damage to economy.

Acknowledgement: The authors are grateful to Prof. John Boardman for his remarks concerning the original manuscript and to László Bassa for reviewing drafts of this manuscript.

REFERENCES

Bariteau, L., Bouchard, D., Gagnon, G., Levasseur, M., Lapointe, S. and Bérubé, M. 2013. A riverbank erosion control method with environmental value. *Ecological Engineering* 58. 384–392.

Borsy, Z. 1991. A Tisza-völgy hidrogeológiai viszonyainak fejlődése (Development of hydrogeological properties of the Tisza Valley). In *Széchenyi és a Tisza-szabályozás*. Eds. Dunka, S. and Fejér, I. Budapest, Aqua Kiadó, 9–17.

Erdélyi, M. 1994. *Hydrogeology of the Hungarian Upper Danube*. Budapest, Hungarian Natural History Museum, 115 p.

Fejér, L. ed. 2001. *Vizeink krónikája: A magyar vízgazdálkodás története* (Chronicle of our waters: History of the Hungarian flood management). Budapest, Vízügyi Múzeum, Levéltár és Könyvgyűjtemény, 307p.

Gosztonyi, Gy., Braun, M., Prokisch, J. and Szabó, Sz. 2011. Examination of zinc and iron mobilization with acid treatments and the metal content of maize and stinging nettle in the active floodplain of the River Tisza. *Carpathian Journal of Earth and Environmental Sciences* 6. 25–33.

Hubble, T.C.T., Docker, B.B., and Rutherfurd, I.D. 2010. The role of riparian trees in maintaining riverbank stability: A review of Australian experience and practice. *Ecological Engineering* 36. (3): 292–304.

Julian, J. and Torres, R. 2006. Hydraulic erosion of cohesive riverbanks. *Geomorphology* 76. (1–2): 193–206.

Karácsonyi, S. and Scheuer, Gy. 1972. A dunai magaspartok mérnökgeológiai problémái (Engineering geological problems of Danubian bluffs). *Földtani Kutatás* 15. 71–83.

Károlyi, Z. 1960. *A Tisza mederváltozásai a folyószabályozás tükrében* (Channel shifting of Tisza River regarding to flood control). Budapest, VITUKI, 102 p.

Kerényi, A. and Szabó, Gy. 1999. *Main Environmental Problems in East Central Europe with Special Reflect to Hungary.* Brno, Papers of the 3rd Moravian Geographical Conference CONGEO'99. 111–118.

Kerényi, A., Szabó, Gy., Fazekas, I. and Szabó, Sz. 2003. Környezeti problémák és megoldási lehetőségek (Environmental problems and possible solutions). In *A Tisza és vízrendszere 2.* Ed.: Telpák, I. Budapest, MTA Társadalomkutató Központ, 179–202.

Kiss, T., Sipos, Gy. and Fiala, K. 2002. Recens üledék-felhalmozódás sebességének vizsgálata az Alsó-Tiszán (Investigation of recent sedimentation along Alsó-Tisza). *Vízügyi Közlemények* 84. 456–472.

Kleb, B. and Schweitzer, F. 2001. A Duna csuszamlásveszélyes magaspartjainak településkörnyezeti hatásvizsgálata (An environmental assessment of landslide hazardous Danubian loess bluffs). In *Risk factors in geosciences and geo-processes*). Ed.-in-chief.: Glatz, F. Budapest, Hungarian Academy of Sciences, 169–193.

Láng, I. 2001. *Vízgazdálkodás* (Water management). EVI, Budapest, 121 p.

Lászlóffy, W. 1982. *A Tisza. Vízi munkálatok és vízgazdálkodás a tiszai vízrendszerben* (The Tisza River. Hydraulic works and water management in catchment of Tisza River). Budapest, Akadémiai Kiadó, 610 p.

Lóczy, D. 1997. Human impact on rivers in Hungary as reflected in changes of channel planform. *Zeitschrift für Geomorphologie* 110. 219–231.

Lóczy, D. and Dezső, J. 2013. Groundwater flooding hazard in river valleys of hill regions: example of the Kapos River, Southwest-Hungary. *Hungarian Geographical Bulletin* 62. (2): 157–174.

Lóczy, D., Balogh, J. and Ringer, Á. 1989. Landslide hazard induced by river undercutting along the Danube. *Física e Dinamica Quaternaria* 11. 5–11.

Pizzuto, J., O'Neal, M. and Stotts, S. 2010. On the retreat of forested, cohesive riverbanks. *Geomorphology* 116. (3–4). 341–52.

Rátóti, B. 1964. Néhány érdekes térszíni formavizsgálata a Tisza árterén (Investigation of some interesting forms on floodplain of the River Tisza). *Hungarian Geographical Bulletin / Földrajzi Értesítő* 13. (2): 205–212.

Schweitzer, F. 1999. Danubian caving loess bluffs and their relationship with settlements (in Hungarian) In *Changing environment*. Eds. Tóth, J. and Wilhelm, Z. Pécs, Janus Pannonius University – Centre of Regional Studies HAS, 300–315.

Schweitzer, F. 2001. A magyarországi folyószabályozások geomorfológiai vonatkozásai: folyóink hullámtereinek fejlődése, kapcsolatuk az árvizekkel és az árvízvédelmi töltésekkel (Geomorphological aspects of river regulation and flood control measures in Hungary). *Hungarian Geographical Bulletin / Földrajzi Értesítő* 50. (1–4): 299–310.

Schweitzer, F. and Szeberényi, J. 2011. Cianid- és nehézfém-szennyezés a Tisza vízgyűjtőjén (Cyanide and heavy metal pollution in the catchment of the River Tisza) In *Katasztrófák tanulságai. Stratégiai jellegű természetföldrajzi kutatások.* Ed. Schweitzer, F. Elmélet–Módszer–Gyakorlat 67. Budapest, Geographical Research Institute HAS, 49–68.

Somogyi, S. 1974. Meder- és ártérfejlődés a Duna sárközi szakaszán az 1782–1950 közötti térképfelvételek tükrében (Channel and floodplain development along the Sárköz section of the River Danube between 1782 and 1950). *Hungarian Geographical Bulletin / Földrajzi Értesítő* 23. (1): 27–36.

Somogyi, S. 2000. A folyóhálózat kialakulása és természetes fejlődése (Development and evolution of river system). In *A XIX. századi folyószabályozások és ármentesítések földrajzi és ökológiai hatásai Magyarországon.* Ed. Somogyi, S. Budapest, Geographical Research Institute HAS, 57–80.

Somogyi, S. 2001. Természeti és társadalmi hatások a Duna mai vízrendszerében (Natural and social impacts in catchment of Danube). *Hungarian Geographical Bulletin / Földrajzi Értesítő* 50. (1–4): 299–310.

Stancikova, A. 2001. A Duna szabályozása (Regulation of River Danube) *Vízügyi Közlemények* 83. 451–472.

Szabó, Gy. 2002. Anthropogen Effects on Soils in Hungary. *Oldenburger Geoökologische Studien* 5. 188–200.

Szabó, Sz. and Posta, J. 2008. A földtani közeg nehézfémtartalma és a feltöltődés sebessége a tiszai hullámtéren (The heavy metal content of geological deposits and the rate of sedimentation). In *Tanulmányok a geológia tárgyköréből dr. Kozák Miklós tiszteletére.* Ed. Püspöki, Z. Debrecen, Debreceni Egyetem, 85–90.

Szabó, Sz., Posta, J., Gosztonyi, Gy., Mészáros, I. and Prokisch, J. 2008. Heavy metal content of flood sediments and plants near the Tisza River. *Acta Geographical Debrecina Landscape and Environment* 2. 120–131.

Szalai, Z. 1998a. Nyomelem-eloszlási típusok természeteshez közeli állapotú ártéri területek talajaiban és üledékeiben (Distribution of trace elements in sediments and soils of quasi-natural floodplains). *Hungarian Geographical Bulletin / Földrajzi Értesítő* 47. (1–2): 19–30.

Szalai, Z. 1998b. Nehézfémek ülepedésének meghatározása talaj- és növényminták elemzésével – Budapest, Háros-sziget (Determination of heavy metal deposition through the analysis of soil and vegetation samples – Háros Isle, Budapest). *Hungarian Geographical Bulletin / Földrajzi Értesítő* 47. (3–4): 515–523.

Szalai, Z. 1998c. Trace metal pollution and micro-topography in a floodplain. *Geografia Física e Dinamica Quaternaria* 21. 75–78.

Viczián, I. 2004. Az almásfüzitői vörösiszap-zagytározók környezetgeomorfológiai viszonyai (Environmental geomorphological conditions of red mud depositories at Almásfüzitő). *Hungarian Geographical Bulletin / Földrajzi Értesítő* 53. (1–2): 85–92.

Vissy, Zs. 1988. *The Pannonian limes in Hungary*. Budapest–Stuttgart, Corvina–Theiss, 149 p.

Vonk, J.E. and Gustafsson, Ö. 2013. Permafrost-carbon complexities. *Nature Geoscience* 6. (9): 675–676.

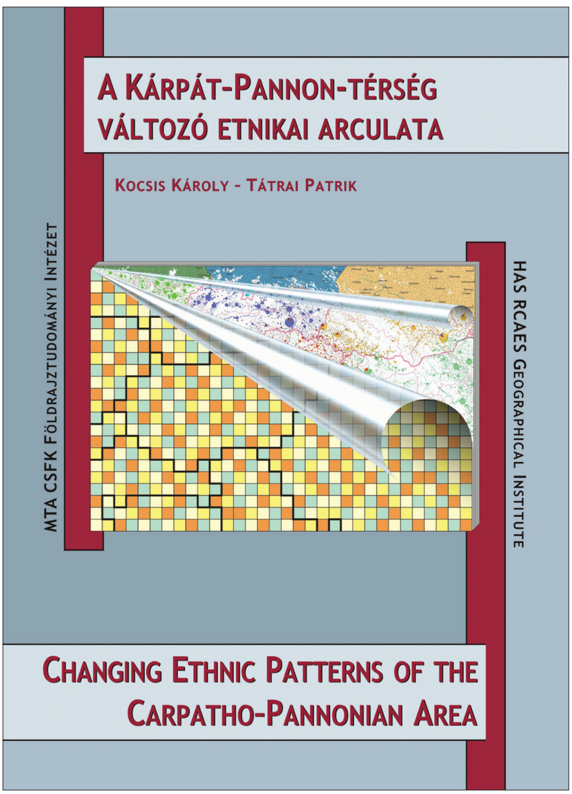
Changing Ethnic Patterns of the Carpatho–Pannonian Area from the Late 15th until the Early 21st Century

Edited by
Károly KOCSIS and Patrik TÁTRAI

Hungarian Academy of Sciences, Research Centre for Astronomy and Earth Sciences
Budapest, 2012.

This is a collection of maps that visually introduces the changing ethnic patterns of the ethnically, religiously, culturally unique and diverse Carpathian Basin and its neighbourhood, the Carpatho-Pannonian area.

The Hungarian and English volume consist of three structural units. On the main map, pie charts depict the ethnic structure of the settlements in proportion to the population based on census data et the millennium. In the supplementary maps, changes of the ethnic structure can be seen at nine dates (in 1495, 1784, 1880, 1910, 1930, 1941, 1960, 1990 and 2001). The third unit of the work is the accompanying text, which outlines the ethnic trends of the past five hundred years in the studied area.



The antecedent of this publication is the „series of ethnic maps" published by the Geographical Research Institute of the Hungarian Academy of Sciences from the middle of the 1990's, which displayed each of the regions of the Carpathian Basin (in order of publication: Transylvania, Slovakia, Transcarpathia, Pannonian Croatica, Vojvodina, Transmura Region, Burgenland, Hungary). This work represents, on the one hand, the updated and revised version of these areas, and, on the other hand, regions beyond the Carpathian Basin not included on previous maps. Thus, the reader can browse ethnic data of some thirty thousand settlements in different maps.
