Gullies of two Hungarian regions – a case study

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Abstract

Gully erosion plays a decisive role in removing the fertile layer of the soil and it has an important long term effect in relief formation. The objective of this paper is to compare gully development and distribution in two pilot areas in Hungary and to reveal the factors controlling gully formation. The pilot areas are natural micro-regions, i.e. the Börzsöny Mountains and the Zselic hills. The results presented in this paper are based on the data of a nation-wide gully cadastre recently under compilation by the authors. The cadastre contains the gullies shown on digital maps (1: 10,000), gully lengths, mean gradients, land use and main properties of parent materials and soils. The results point to the development and formation of significantly different gullies in the pilot areas as a consequence of different environmental conditions. The most important result is the introduction of the concept of equivalent gully length characterizing the gullies of the given category. Topography is the main driving force in gully formation followed by land use type, parent rock and soil properties.

Keywords: gully erosion, gully cadastre, Zselic, Börzsöny

Introduction

Soil erosion is one of the most important agents in contemporary landscape formation. This statement applies also for the subhumid regions of Central Europe. Soil erosion attacks the uppermost, fertile soil layer and the eroded soil contains valuable nutrients (Farsang, A. *et al*. 2011; Borcsik, Z. *et al*. 2011). If the eroded soil will be transported into lakes eutrophication will be accelerated (Csathó, P. *et al.* 2007). Sheet erosion processes affect extended areas, the result is, however, a relatively slow change in topography. Gully erosion appears on relatively limited portions of the surface but it leads to the removal of a huge amount of soil and it makes rapid and remarkable change in surface topography (Pécsi, M. 1955; Kertész, Á. 2009). Both sheet and gully erosion contribute to relief formation (Jakab, G. *et al*. 2009). Gully erosion is a threshold

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phenomenon (Poesen, J. *et al.* 2003) but the identification of the threshold value is a very complex procedure (Poesen, J. *et al.* 2003; Kirkby, M. and Bull, L. 2000). The occurrence of gully, or sheet erosion may change also periodically. The glacial periods are presumed to have been ruled by gully erosion while the interglacials characterized by sheet erosion (Pécsi, M. 1997). Climate is not the only environmental condition that regulates soil erosion (Kertész, Á. 2006; Smolska, E. 2007) the role of soil properties, parent material (Buzek, L. 2007), topography and land use is also important (Kertész, Á. 2008). Many authors refer to the significance of land use changes (Grace, J.M. 2004; Gábris, Gy. *et al.* 2003; Galang, M.A. *et al.* 2007; Centeri, Cs. *et al.* 2009). The development of an already incised gully can only be stopped by radical changes and it is extremely expensive to remove it from the landscape (Kirkby, M. and Bracken, L.J. 2009)

Gullies develop mainly on loose, unconsolidated sediments such as loess and loess-like deposits (Poesen, J. *et al.* 2003; Zglobicki, W. and Baran-Zglobicka, B. 2011) as well as on marine sediments in the Mediterranean (Poesen, J. *et al.* 2006), and on sandstones (Hegedűs, K. *et al*. 2008) etc. Gullies developed on unconsolidated volcanic rocks represent a special type (Pintér, Z. *et al*. 2009). An example is the badland developed on rhyolite tuff in Kazár, Hungary (Horváth, G. *et al.* 2010).

Gully erosion has received less attention due to the complexity and difficulty of its investigation (Valentine, C. *et al.* 2005), nevertheless adequate gully susceptibility prediction would be necessary to control soil loss (Conforti, M. *et al.* 2010). There is no soil type, rock type, land use or topography which could alone launch gully initiation. The interaction of the factors controlling gully erosion is needed for gully formation (Muńoz-Robles, C. *et al*. 2010).

The aim of this study is to identify the spatial properties of gully erosion in two pilot areas in Hungary with the analysis of the recently compiled gully cadastre. The hypothesis to be tested is whether different environmental conditions (topography, land use, parent material and soil) generate distinct spatial patterns and distributions of gully systems. An additional goal is to identify the relationship between gully formation and land use change.

The study sites

In this study two pilot areas are compared, one from a mountain range and another from a hilly country, namely from the Börzsöny Mountains and from the Zselic hills, respectively. The Börzsöny Mountains are of volcanic origin, forested, with steep slopes and with high relative relief values. This area is selected because results of previous research are available from here (Madarász, B. 2009; Madarász, B. and Jakab, G. 2009).

Most of the Zselic hilly country pilot area is covered by loess and cultivated. Detailed investigations have been carried out in the Somogy hilly country for almost two decades (Jakab, G. 2008; Jakab, G. *et al*. 2005, 2009, 2010a) so the reason for choosing the nearby Zselic was to have a new sample area similar to the Somogy hills.

The pilot areas were identified according to the Inventory of Natural Micro-regions of Hungary (Dövényi, Z. ed. 2010). The Börzsöny pilot area covers 447 km^2 and is situated in the northern part of Hungary *(Figure 1).* It is a paleo-volcano formed in the Miocene between 16.5 and 13.5 Ma B.P. (Pécskay, Z. *et al.* 1995; Karátson, D. 2007). The older volcanic rocks of are mostly covered by younger volcanic deposits, however, at the margins of the mountain at some spots older deposits outcrop. During the Pliocene and Quaternary times erosion and tectonic movements were the main landscape forming agents in the Börzsöny (Láng, S. 1955). The recent surface and valley system was formed by the erosion of the nearly 800 m thick volcanic strata (Karátson, D. 2007). The elevation of the study area varies between 120 m and 939 m a.s.l. The characteristic surface forms are debris flows as well as elongated and steep hillsides dissected by relatively young V-shaped valleys. Relative relief values gradually decrease towards the periphery of the mountains, from 350–370 m km^{-2} to 100–150 m km^{-2} (Madarász, B. 2009). Most of the slopes are exposed to west–north-west and to east–south-east. The study area belongs to the cool and wet climate domain. Mean annual temperature does not exceed 8–8.5 °C with only 7–8 °C in the highest region. Annual precipitation varies between 600 and 800 mm with higher values in the peak region (Dövényi, Z. ed. 2010).

The Zselic hills (1170 km^2) are situated in the southern part of the Transdanubian Hills macro-region *(Figure 1).* It is a relatively plane area with gentle slopes similar to a pediment (Sebe, K. *et al.* 2008). Almost the whole area is covered by loess, mainly of Wurm origin, and can be classified mostly as slope loess (Kapronczay, J. 1965). At some deeper lying spots sandy Pannonian sediments occur on the surface (Lóczy, D. and Gyenizse, P. 2003). Forest management was the traditional main occupation and income source in the area (Gyenizse, P. *et al*. 2008) supported by a rather high amount of annual precipitation (700–750 mm, Kapronczay, J. 1966). With the expansion of arable fields soil erosion became an increasingly serious problem after Second World War (Lóczy, D. and Gyenizse, P. 2003). The area can be characterized as fragmented from geological and social aspects.

Methods

The gullies of the study areas were digitized using the 1:10,000 scale maps of the Unified National Map System (EOTR). A GIS was organized which con-

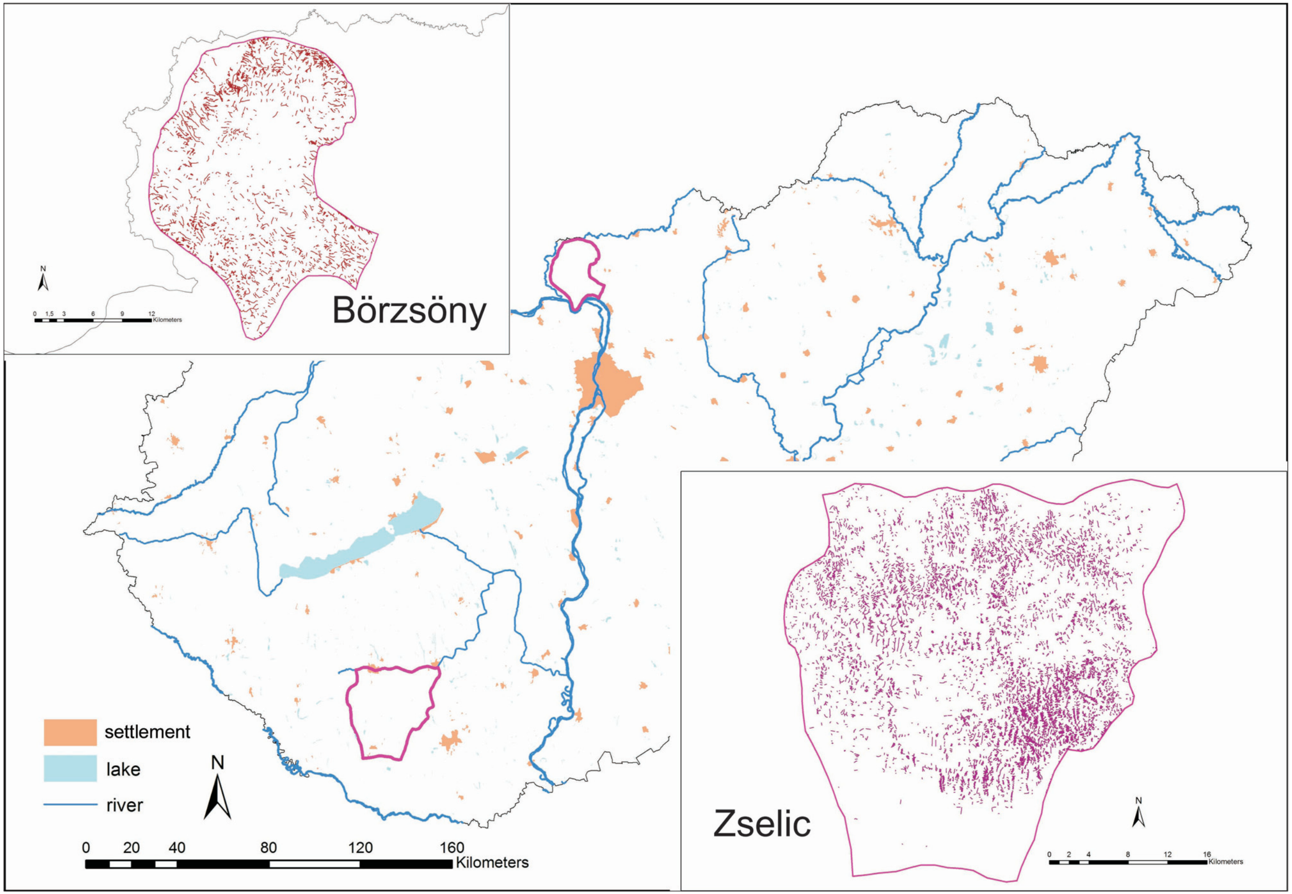

Fig. 1. Location of the study sites with the surveyed gullies

sisted of the digital map of the gullies, the map of soil properties, the land use map and the topographic map of the pilot areas. The map of soil properties is a map series derived from the AGROTOPO map at a scale of 1:100,000 (RISSAC 1991). This database contains information on soil type, parent material, texture, clay mineral composition, hydrology, pH, soil organic matter (SOM) and soil depth. The land use map was compiled on the basis of the CORINE Land Cover database (1:50,000) (Büttner, G. *et al*. 2002). Gully sections with intermittent or permanent water flows were excluded.

The original CORINE database has more than 60 land use types which had to be generalized for the purposes of the pilot study. As a result six land use types were created focusing on soil conservation, ranked according to their endangerment by soil erosion, i.e. cultivated area including arable land, vineyard and orchard followed by permanent vegetation, forest and wetland/scrubland. Elevation data are taken from SRTM (Shuttle Radar Topography Mission, Rabus, B. *et al.* 2003). The resolution is 90 m. The soil gradient map with five category classes (see e.g. Pécsi, M. 1991) was derived from the elevation model.

Soil, land use and topographic data are given for each gully. If a gully extends over two or more pixels then the gully is identified with the value/property occupying the largest area in the gully. Concerning numerical data the gully is identified with the arithmetical mean of the values of the pixels in question.

Results and discussion

The distribution of soil parent material and soil type is shown in *Table 1*. The Börzsöny is dominated by volcanic rocks mainly covered by Luvisol. On the remaining area Cambisol and Phaeozem are to be found. Phaeozem stands for a special type of soil developed on volcanic rocks named "erubáz soil" in

Table 1. Soil type and parent material distribution

Area	Soil type (%)					Parent material (%)			
	Phaeozem	Luvisol	Cambisol	Chernozem	Gleysol	Glacial and alluvial deposits	Loess	Tertiary and older deposits	Andesite, basalt, rhyolite
Börzsöny	4	81	15	0	0	0	1	33	66
Zselic	–	63	19	5	13	13	87	1	–

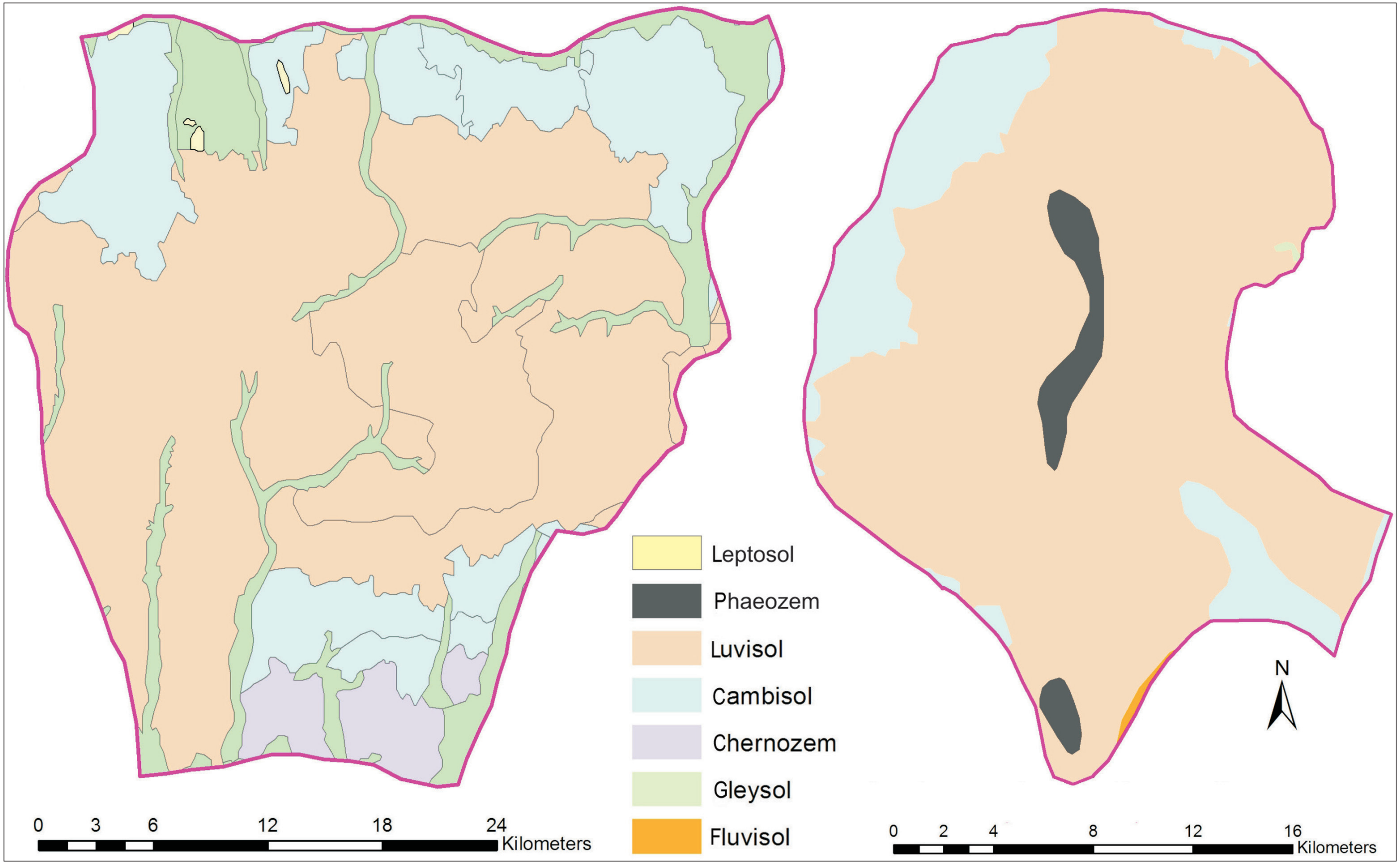

Fig. 2. Main soil types of the Zselic (left) and Börzsöny (right) study areas

the Hungarian nomenclature, see Madarász, B. 2009. In the valley bottoms and near the Danube Fluvisol occurs *(Figure 2).*

In the Zselic area loess is the dominant parent material. Texture and organic matter distribution data are shown in *Table 2*, soil depth in *Table 3*.

The Phaeozems of the Börzsöny site are shallow (soil depth < 40 cm), other soil types are thicker, up to 70 cm *(Table 3).* Presumably, deep gullies cannot be formed on volcanic rocks covered by shallow soils. There are gullies developed on this soil types, too. During the field campaigns there were detected deep gullies with steep slopes cut into the hard volcanic rock. These gullies can be older, developed presumably during the Pleistocene. There are also shallow gullies running parallel with each other and brought about by man induced activities (e.g. roads used for wood transport or for military training).

The central part of the Börzsöny was used by the army as a training area in the second half of the last century. These shallow gullies are not shown in the digital maps.

The Zselic pilot area has deep soils. Their high proportion (95%) can be explained by map generalization, the data are taken from the AGROTOPO map series (1:100,000). Small spots of Leptosol, however, could be observed all over in the area. The deep soils are mainly colluvia accumulated by erosion. Due to the porous parent rock it is hard to determine the boundary between the rock and the soil, especially in case of arable fields.

The two study sites have distinct land use structure (*Table 4* and *Figure 3*). The Börzsöny is almost completely covered by forest. The Zselic has large arable fields and the forest spots are fragmented. The average land area of the individual land use categories show similarity in the two pilot

Table 2. Texture and organic matter (OM) distribution

Area	Texture (%)		OM content distribution (%)				
	Loam	Clay loam	50–100 t ha^{-1}	100–200 t ha^{-1}	200–300 t ha^{-1}	300–400 t ha^{-1}	400 < t ha^{-1}
Börzsöny	23	77	0	96	4	–	–
Zselic	100	0	63	24	1	7	5

Table 3. Soil depth distribution

Area	Soil depth (%, cm)			
	20–40	40–70	70–100	100 <
Börzsöny	4	62	–	34
Zselic	0	–	5	95

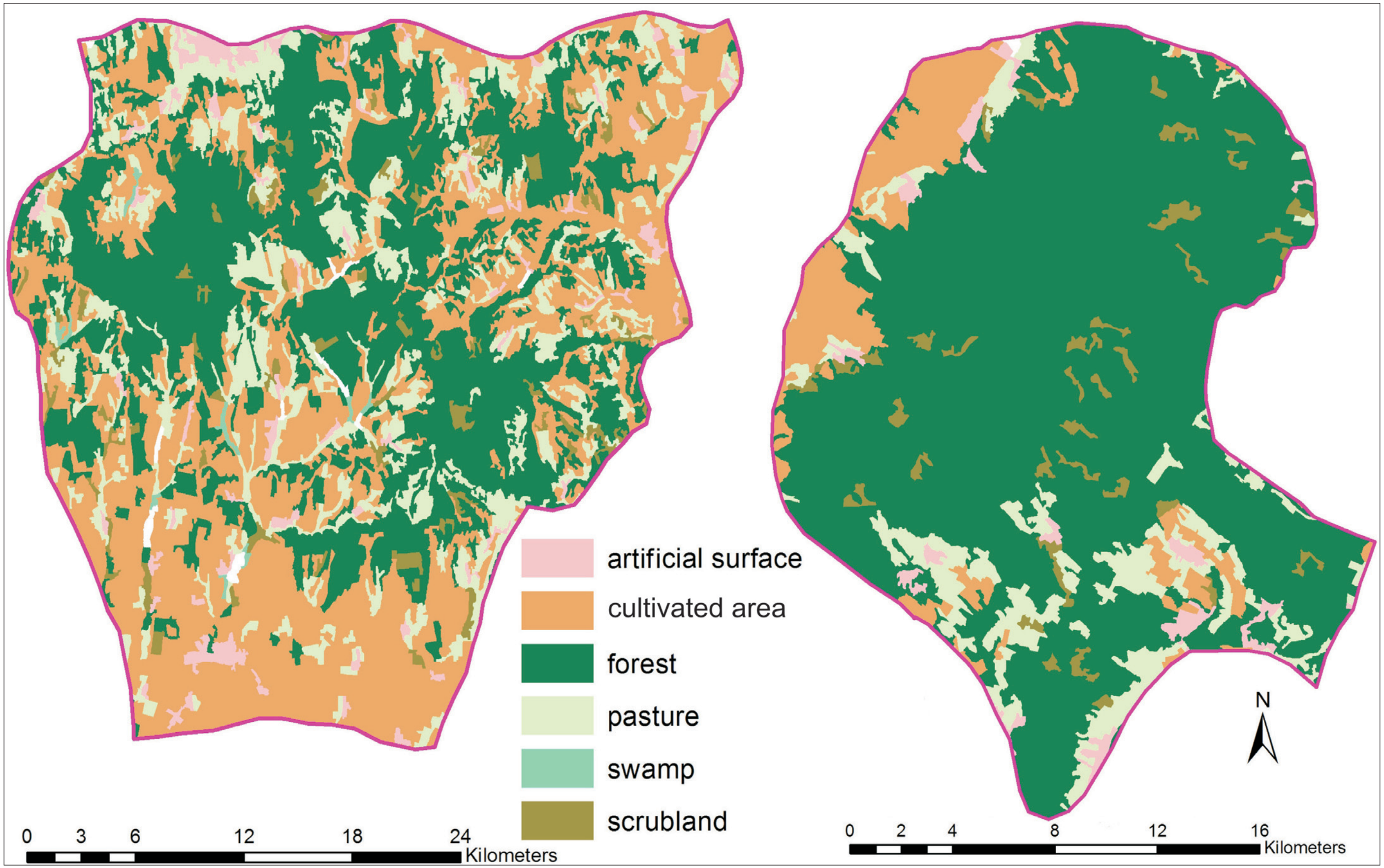

Fig. 3. Simplified land use map of the Zselic (left) and Börzsöny (right) study areas

Table 4. Land use distribution of the study sites derived form the CLC50 (2000) database

Land use	Zselic			Börzsöny		
	Total area (ha)	Rate (%)	Average area (ha)	Total area (ha)	Rate (%)	Average area (ha)
Artificial surface	3,585	3	50	985	2	47
Cultivated area	46,524	40	358	4,235	9	132
Forest	43,688	37	299	33,928	76	1,696
Pasture	19,076	16	64	4,134	9	63
Swamp	340	0	43	1	0	0
Scrubland	3,304	3	49	1,447	3	39

areas except for cultivated area and forest. Artificial areas include built-up areas, open-cast mines etc.

The distinct land use structure of the sites can be explained by different parent materials and relief conditions. In Börzsöny the largest homogeneous areas are covered by forest and they fall into the highest slope gradient class. In Zselic the steepest slopes have a very limited spatial extension, they are covered by forest, but the woodland is fragmented (*figures 4* and *5*).

Gully properties are summarized in *Table 5*. The gully dissection index value is almost the same in the two pilot areas. The average values are three times larger than the lower limit value (0.5) of the highest category of the Hungarian classification underlying the necessity of introducing an additional gully dissection category as already suggested (Jakab, G. *et al.* 2010b).

Average gully length is slightly higher in the Börzsöny. The difference between the average and median values point to the anomalous distribution of the data similar to the case of the Tetves catchment (Jakab, G. *et al.* 2005). The difference between the median values is also very small. The minimum gully length values (2 m, see *Table 5*) do not refer to real gully lengths as they represent only parts of gullies which are longer but they are cut by the border of the natural micro-regions.

Comparing maximum gully lengths of the pilot areas the value of Zselic is twice as large (16 km) as that of the Börzsöny. The explanation is the porous parent material and smaller gradient values in the Zselic area.

Table 5. Main gully properties

Indicator	Börzsöny	Zselic
Number of gullies	2,260	6,579
Dissection index (km km^{-2})	1.43	1.45
Total length (m)	638,309	1,693,374
Average length (m)	282	258
Minimum length (m)	2	2
Maximum length (m)	7,308	16,220
Median (m)	126	133

Comparing *tables 6* and *7* a conspicuous observation can be made, i.e. looking at the properties (e.g. soil type, land use etc.) there are only small differences between the percentage values calculated from the number of gullies, com-

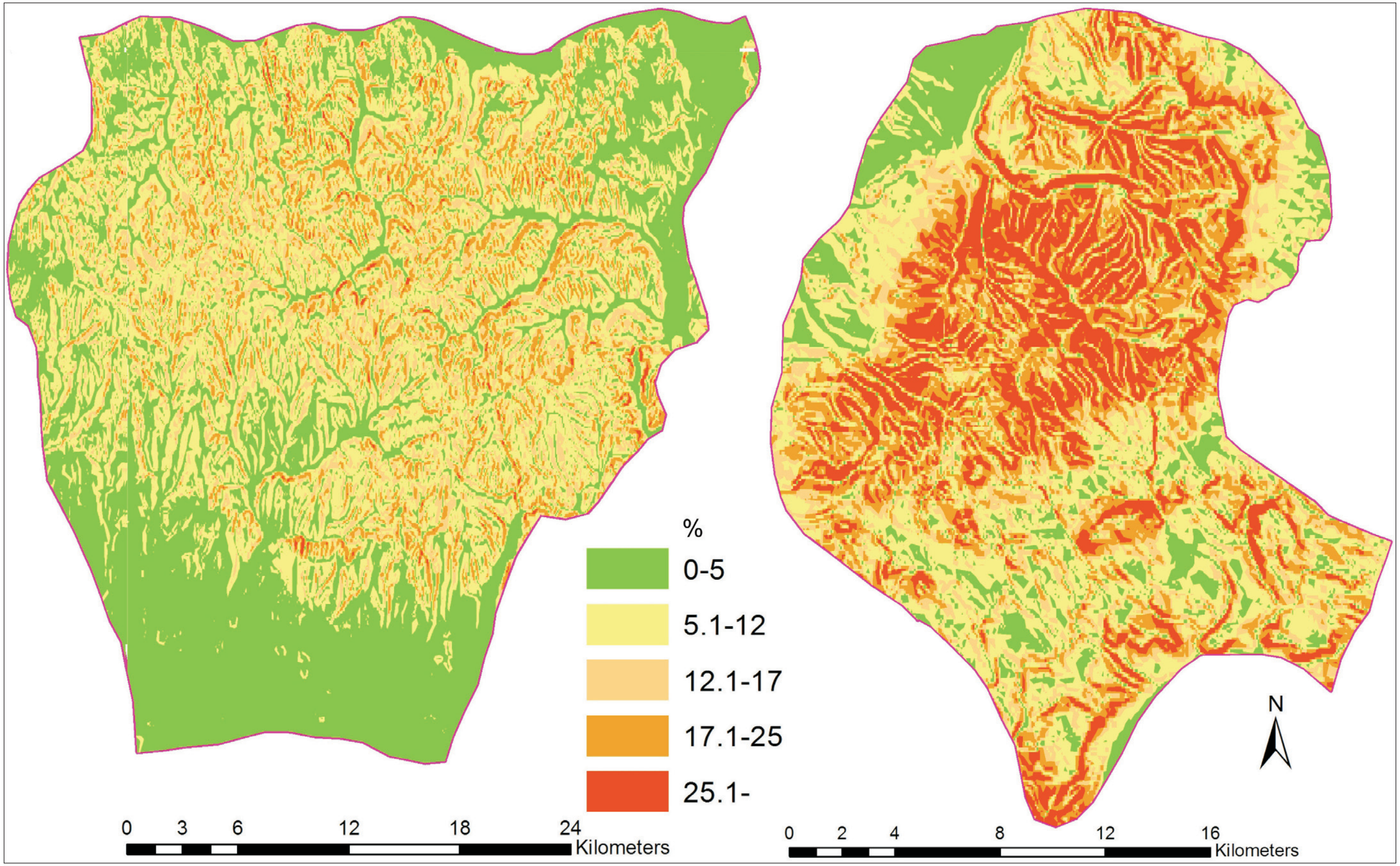

Fig. 4. Slope gradient distributions of the study areas derived from the SRTM database (Rabus, B. *et al.* 2003)

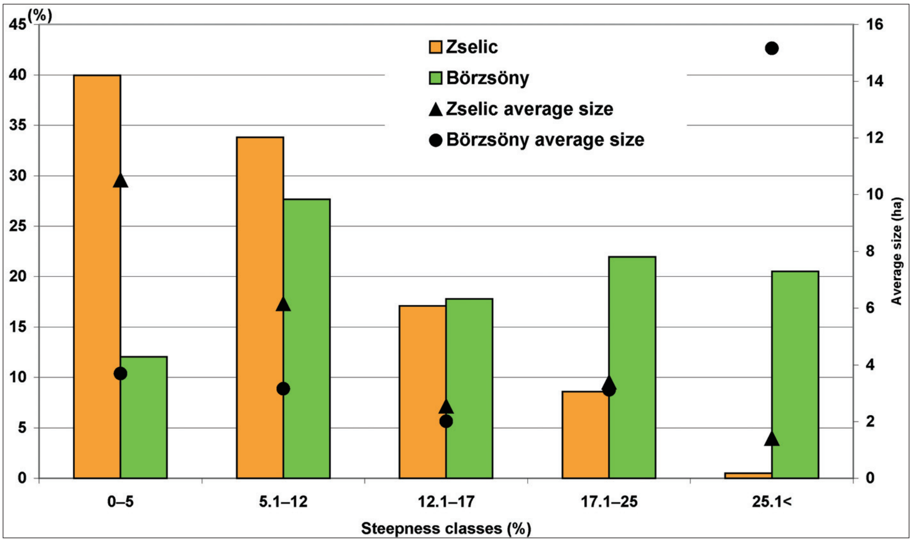

Fig. 5. Slope gradient classes of the Zselic and the Börzsöny study sites

Table 6. Average properties of the surveyed gullies in the Börzsöny

Property	Rate according to the number of gullies (%)	Rate according to gully length (%)	Average gully length (m)
Soil type			
Phaeozem	1.1	0	118
Luvisol	86.9	88	283
Cambisol	11.5	11	279
Chernozem	0.4	1	808
Parent rock			
Loess	1.9	3	441
Tertiary and older deposits	36.4	31.0	241
Volcanic rocks	61.7	66.0	302
Soil texture			
Sandy loam	0	1	110
Loam	30	26	242
Clay loam	70	73	297
OM content t ha^{-1}			
100–200	98.9	100	284
200–300	1.1	0	118
Soil depth (cm)			
20–40	1	0	118
40–70	61	66	305
> 100	38	34	251

Table 7. Average properties of the surveyed gullies in the Zselic

Property	Rate according to the number of gullies (%)	Rate according to gully length (%)	Average gully length (m)
Soil type			
Luvisol	79	81	265
Cambisol	18	17	236
Gleysol	3	1	195
Parent rock			
Glacial and alluvial deposits	2	2	224
Loess	96	97	260
Tercier and older deposits	2	1	144
Soil texture			
Loam	98.3	99	259
Clay loam	1.0	1	144
OM content t ha^{-1}			
50–100	79	81	264
100–200	20	18	232
> 400	1	0	191
Soil depth (cm)			
70–100	1	0	191
> 100	99	99	258

pared to those from gully length, e.g. the percentage of gullies on Luvisol is 86.9% versus 88.0%.

Analyzing the distribution of gullies according to soil types of the Börzsöny the first interesting phenomenon is that there are relatively few gullies on Phaeozem. The reason for this is the shallow soil on solid parent rock as mentioned above. Another reason may be the geomorphological position of these soils, i.e. they develop on the highest parts of the mountain, at the caldera fringe which is not a favourable location for gully formation because of the lack of sufficient catchment area. It is striking that the percentage of Luvisol is slightly higher than the percentage of its area. Compared with Cambisol the share of the latter is less than its territorial percentage. Luvisol is more resistant to gully erosion than Cambisol (Nachtergaele, J. and Poesen, J. 2002). The difference can be explained by the morphological position of the gullies.

Analyzing the role of soil texture the problem has to be dealt with that the AGROTOPO texture data give only one single value for the total soil profile and textural differences between the soil horizons are not taken into account. Loam is overrepresented, with a higher ratio of gullies on it than the territorial distribution of loam.

In Zselic the percentage of gullies on Luvisol is also high (*Table 8*) compared with the areal representation of this soil type. The reason for this

Table 8. Land use type distribution of the gully areas in 1985

Indicator	Börzsöny			Zselic		
	Arable land	Pasture	Forest	Arable land	Pasture	Forest
Total length (m)	11,343	76,619	550,347	45,032	135,941	1,512,401
Total length (%)	2	12	86	3	8	89
Number of gullies	37	266	1,959	201	867	5,512
Ratio of gullies (%)	2	12	86	3	13	84
Average length (m)	307	290	281	226	157	274
Median length (m)	161	131	124	184	110	135
Minimum length (m)	14	22	2	2	2	2
Maximum length (m)	2,558	6,990	7,308	1,235	2,430	22,124

is the same as in the Börzsöny, i.e. the morphological position of the gullies. The share of gullies developed on Cambisol is proportional with the territorial extension. On Gleysol and Chernozem there are hardly any gullies. This is normal concerning Gleysol but there should have been more gullies on Chernozem. This soil type is used as arable land where ephemeral gullies develop being not always shown on topographic maps (Jakab, G. *et al.* 2010a).

Gully distribution data on various parent rocks reflect the well known fact that gully development favours loess environment (Poesen, J. *et al.* 2003, 2005; Valentin, C. *et al.* 2005). Comparing the areal percentage of parent rocks with the percentage occurrence of gullies on them we can see that loess is overrepresented while glacial and alluvial deposits are underrepresented.

Analyzing the role of organic matter the well known positive effect of organic matter in preventing gully erosion can be recognized, i.e. with low OM content more gullies develop.

There is a close relationship between gully erosion and land use (*Table 8*). In both pilot areas most of the surveyed gullies were in the forest when the map was prepared. If gullies are deeply incised arable cultivation must be stopped and these gullies will not be classified into arable land any more (Jakab, G. 2006). These gullies will soon be covered by forest.

The overwhelming area of Börzsöny is covered by forest, but the proportion of gullies outside the forest area is higher than in the forest. In the Zselic most of the gullies are located in the forest (90%) in spite of the fact that the percentage of forests is less. Gullies on cultivated land generally are longer as shown by Vanwalleghem, T. *et al.* (2003).

Differences in average gully length among the land use categories in the Börzsöny are negligible, in the Zselic area they are bigger.

Land use types of the gullies in 2000 are presented in *Table 9*. Since 1985 the percentage of the number of gullies on arable land had increased in both areas, in Börzsöny from 2 to 6%, in Zselic from 3 to 8% and average gully length from 2 to 13% and 3 to 22%, respectively.

Table 9. Land use type distribution of the gully areas derived from the 2000 CLC50 database

Indicator	Börzsöny				Zselic			
	Cultivated area	Forest	Pasture	Scrubland	Cultivated area	Forest	Pasture	Scrubland
Total length (m)	82,968	455,933	81,718	6,247	370,862	1,088,531	197,872	30,491
Total length (%)	13	73	13	1	22	64	12	2
Number of gullies	126	1,812	242	33	1,128	4,398	847	165
Ratio of gullies (%)	6	82	11	1	18	67	13	3
Average length (m)	658	252	339	189	329	248	234	185
Median length (m)	265	119	150	115	180	108	143	103
Minimum length (m)	22	2	17	20	2	2	6	18
Maximum length (m)	6,990	5,561	7,308	1,078	16,220	8,237	3,081	2,531
Dissection index (km km^{-2})	2.0	1.3	2.0	–	0.8	2.5	1.0	–

Intensive land use increases the rate of both sheet and gully erosion (Centeri, Cs. 2002; Gábris, Gy. *et al.* 2000). A similar trend is connected with changing land use, i.e. with the transformation of the former forest and pasture into arable land.

The dissection index values vary between 0.8 and 2.3. Arable land and pasture have similar values in both areas. Much higher values should have been on arable land. The reason why this is not the case is that ephemeral gullies are not surveyed as mentioned above (Jakab, G. *et al*. 2010b) The forest can also be dissected due to the dirt roads running in them and because of the effect of rill and gully erosion taking place in the arable field upward the slope (Jakab, G. *et al.* 2010a).

Analyzing the trends of changes the following statements can be made. In Zselic 66% of the gullies which were classified as forest in 1985 had become arable land by 2000, in the Börzsöny this value is 50%.

It is difficult to evaluate the effect of gradient on gully formation as an elongated form of sometimes more than 10 km length is characterized by only one gradient value. Average gradient in the Börzsöny Mountains is 2.98, in the Zselic hills it is 2.69.

Conclusions

Two pilot areas were analyzed and compared in detail. As it was expected the gullies and gully systems of the pilot areas were different. It is difficult to assess the effects of the environmental factors because they are interrelated, not independent from each other, i.e. they constitute a complex system and this system as a whole controls gully development. Being aware of this statement it is assumed that soil properties exert the smallest impact on gully development. This conclusion is confirmed by the high share of gullies formed on Luvisol and it is known that Luvisol is resistant to gully erosion. The role of parent material in the process is very important. High gully erosion rate can be found on loess as the parent material. Relief and land use play the most important role in gully development. The effects of these two environmental factors cannot be treated separately, except in very small areas. In accordance with the results of Menéndez-Duarte, R., *et al.* (2007) the effect of topography is more decisive of the two because it controls also land use. The methodology of gully identification is not perfect as such formation is classified as a gully in the forest even if a considerable part of its catchment is on arable land. The method applied in the paper for the identification of gully gradient is suitable in small scale only.

In the Börzsöny Mountains very deep gullies can be found that have developed into valleys in some cases. They must be of Pleistocene, early Holocene origin as they are deeply cut into hard rock.

The analysis of the two pilot area revealed important characteristics of the gullies and pointed to some features of gully development. Future research will be devoted to the classified survey of gullies in the country (i.e. a detailed country-wide survey of ephemeral gullies).

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