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DESCRIPTION OF THE CHARACTERISTIC SOIL PROFILES AND INDICATION OF THE DEGREE OF SHEET EROSION IN VERPELÉT

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Abstract

In the administrative area of Verpelét settlement, we excavated 22 soil profiles in July and August of 2014 to show what soil types build up the area, as well as the extent of soil erosion in each profile. The description of the soil profiles was carried out based on the methods of the FAO (2006) and Novák's Soil Practicality (2013). In the study area, we found chernozem brown forest soils (Chernozems), alluvial meadow soils (Fluvisols), humous sandy soils (Arenosols), humous alluvial soils (Fluvisols), meadow chernozem soils (Chernozems), Ramann brown forest soils (Cambisols), and brown forest soils with clay illuviation (Luvisols). We examined the sheet erosion in the vicinity of Verpelét using three methods: (1) GIS method considering slope category values, (2) examining the geomorphological character of the environment around the soil profiles, and (3) determining the sheet erosion within the specific soil profiles using the methods of Kerényi (1991) and Kerényi and Martonné Erdős (1994). The first method did not indicate any erosion-prone areas in the Verpelét vicinity; however, we were able to detect greater soil erosion in the excavated soil profiles. Using the second method, 32% of the excavated soil profiles were strongly eroded, 36% were moderately eroded, 4.5% were weakly eroded, and 27.5% showed accumulation conditions. However, our third method, which focused on specific soil profiles, indicated that 32% of the excavated soil profiles were strongly eroded, 63.5% were moderately eroded, and only 4.5% were weakly eroded. The question arises as to what causes this significant difference between the various methods, and where the significant sheet erosion in the examined profiles in Verpelét actually originates from. In order to investigate this question, we examined the 1st, 2nd, 3rd Military Survey Maps, the topographic map from 1990, the CLC18 satellite imagery and the 2023 version of Google Earth. The previously forested areas on these maps were already characterized by extensive arable land, and later by arable and vineyard areas. Today, Verpelét has become predominantly an actively cultivated agricultural landscape. Therefore, the significant sheet erosion can be attributed to the spread of inappropriate land use methods and significant anthropogenic impacts (β-euhemerobic level).

Keywords: soil erosion, land cover categories, military survey maps, Verpelét, North Hungary

INTRODUCTION

The soil is a crucial element of the ecosystem, a necessary resource for satisfying human needs, and the basis for agriculture (Amundson et al., 2015). According to the Global Soil Partnership report (2016), globally $75*10^9$ tons of soil erodes annually, leading to significant reductions in productivity (Koppitke et al., 2019; Sonderegger and Pfister, 2021). Globally, erosion has resulted in the loss of 33.7 million tons of agricultural products, accounting for 0.41% of global agricultural production (Sartori et al., 2019).

Erosion caused by water is often considered a natural phenomenon, but changes in land use and increasing anthropogenic impacts can have a serious impact on soil erosion processes (Borelli et al., 2017; Cimusa Kulimushi et al., 2023; Chaisa et al., 2024; Van Rompaey et al., 2001, 2002; Kim et al., 2013; Yang et al., 2003). Among the factors explaining the intensity of soil erosion, vegetation cover and land use are considered the most important (Thornes, 1990; Kosmas et al. 1997; Garcia-Ruiz, 2010). It is estimated that nearly 60% of soil erosion is caused by human activities, and with the expansion of agricultural land over the past century, potential soil erosion has increased by about 17% (Yang et al., 2003).

The negative impact of improper land use on soil erosion is discussed in numerous global and local studies. While some researchers have found that changes in land use are not the main cause of accelerated soil erosion (Borelli et al., 2022; Gordon et al., 2001; Bettoni et al., 2022), changes in land use cause geomorphological reactions that lead to the expansion of areas exposed to intensive erosion (Pelicani et al., 2008).

Kidane and colleagues (2019) established the relationship between land use changes and erosion through the RUSLE model and sediment yield analyses. Their studies showed that with the decrease in forested areas, soil loss increased by close to 20% between 1973 and 2015, and sediment yield follows land use changes at river mouth of the watershed. In southern Brazil, a similar relationship is observable, although the impact is primarily seen on steep slopes, with less pronounced effects on moderate slopes (Vanacker et al., 2019). Field experiments by Zoakib and Naser (2011) confirmed that runoff and soil loss varied among different land use parcels. The lowest soil loss was observed in pasture lands, while the highest was recorded in degraded parcels (Zoakib and Naser, 2011). Donovan (2022) found clear differences in erosion rates among different land uses across all of New Zealand. Surface erosion rates in winter storage paddocks were significantly higher than in grasslands, woodlands, and natural soil production methods. Simulations conducted in four typical agricultural regions in Europe (Amendoeire, Portugal; Leutaret, France; Lagadas, Greece; Hageland, Belgium) showed that reducing land use intensity over the past 50 years has significantly reduced erosion. This reduction is often strengthened by turning erosion-prone land use practices into less erosion-prone land uses on steeper slopes (Bakker et al., 2008), for example when the arable lands become forested areas.

However, some sources suggest that the relationship between land use and erosion is not unidirectional, as abandoning cereal cultivation is associated with soil degradation caused by erosion, and land use in the examined cases shifted from arable lands to pasture lands (Kosmas et al., 2000; Marathianou et al., 2000; Bakker et al., 2005).

Assessing soil erosion and determining its extent requires field data collection, which is of paramount importance. The current soil surveying and classification procedures vary significantly. The Genetic Based Soil Classification System developed in the 1960s defined 39 soil types based on similar soil-forming factors that result in soils with similar morphogenetic properties (Stefanovits, 1963; Szabolcs, 1966). In contrast, the WRB is based on a diagnostic approach, containing 30 reference groups determined by the presence, sequence, or properties of diagnostic levels, features, and materials (IUSS Working Group WRB, 2006).

In our article, we excavated soil profiles in Verpelét, Northern Hungary, to use field data to identify main soil types, soil types, and soil subtypes based on both WRB reference groups and the Hungarian Soil Classification System (Stefanovits, 1981; Szendrei, 1998; Michéli et al., 2006; Novák, 2013; Pásztor et al. 2018), as well as determine the extent of sheet erosion in the soil profiles. We sought to uncover the causes of significant sheet erosion in the village, investigating not only soil erosion in the soil profiles but also changes in land use systems and the intensity of anthropogenic impacts in our study area.

STUDY AREA

Verpelét is located in the Tarna Valley between the Mátra and Bükk Mountains, as shown in Figure 1. The area serves as a transition between the low mountains, foothills and valley areas, and this characteristic is reflected in both its geological and geomorphological features (Pelikán, 2005; Kocsis, 2018). The surroundings of Verpelét are composed of volcanic and sedimentary rocks. The areas to the northwest and northeast of Verpelét are characterized by rocks from the Miocene Nagyhársas Andesite Formation, the Lower Miocene Tari Dacite Tuff Formation and the Upper and Lower Miocene Sajó Valley Formation (Pelikán, 2005).

The foothill areas in the Mátra Mts. are made up of the Miocene Kozárdi Formation. To the east and south of Verpelét, the foothill areas of the Bükk Mts. are covered with Upper Pleistocene aeolian loess and slope loess, while between Verpelét and Feldebrő, Pleistocene and Holocene periodic water flow deposits appear. The alluviums of the Tarna Stream and major streams are built up by Holocene alluvial deposits (gravel, sand, silt, clay).

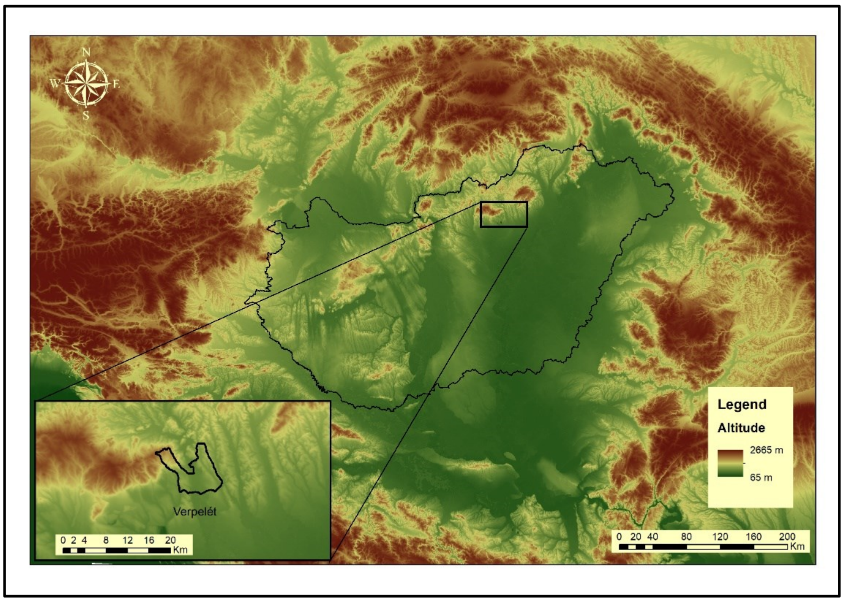

Fig.1 The topographical location of the study area, Verpelét situated between the Mátra and the Bükk Mts. (own structured, cource: NASA Shuttle Radar Topography Mission (SRTM) 2013.)

Geomorphologically, the volcanic areas feature volcanic landforms and the Verpelét Castle Hill as a stratovolcano (Székely, 1997; Dobos and Schmidt, 2005; Dobos et al., 2005), while the foothills of the Mátra and Bükk Mountains are characterized by older and younger dissected pediments (Pinczés et al., 1993). Streams accompanied by valleys with Pleistocene fluvial terraces (Pinczés et al., 1993; Dobos, 2002). Derasional, erosional-derasional valleys and landslides occur on the slopes.

The settlement is administratively located in the North Hungarian Region, in Heves County, in the Eger District. Its area is 53.18 km^2, its population is 3709 people (January 1, 2023, KSH) and its population density is 71.46 people/km^2.

METHODS

During our research work, we excavated 22 soil profiles on our study area in Verpelét between 21st of July, 2014 and 1st of August, 2014 (Dobos et al., 2014). When designating the topographic location of the soil profiles (Fig. 2), we took into account the geological and geomorphological characteristics of the settlement and aimed to uncover the most characteristic soil profiles at the settlement level. For the description of the soil profiles, we applied the methods of FAO (2006), Novák (2013), Stefanovits (1981) and Szendrei (1998). In the description, using the field and tabular methods of the FAO, we revealed the depths of the soil layers in the individual soil profiles, named the genetic soil horizons, examined the horizon boundary, the soil colour with the Munsell Soil-Color Charts, the mottling, the moisture condition, soil texture, soil structure, consistency, cementation and compaction and the carbonate content of the horizons (FAO, 2006; Novák, 2013). In the Environmental Laboratory of EKCU, we determined the thickness of the topsoil layer, pH value, CaCO3 content, and the Arany's plasticity index of the soil horizons of each soil profiles (Dobos et al., 2014; Table 2). After investigating the soil properties, we named the WRB reference group of the soil types uncovered in the individual soil profiles (Michéli et al., 2006; Novák, 2013), and then named their soil taxonomy main type, type, and subtype based on the Hungarian Soil Classification System (Stefanovits, 1981; Murányi et al., 1989; Michéli et al., 2006; Novák, 2013; Pásztor et al., 2018). The sheet erosion observable in the study area and the soil profiles was investigated using three methods: (1) GIS method (SURFER 13 version) considering the slope category values of the settlement, (2) considering the geomorphological characteristics and processes of the environment of the soil profiles (FAO, 2006), and (3) examining the sheet erosion that can be calculated based on the specific data of each profile (Kerényi, 1991; Kerényi and Martonné, 1994; Novák, 2013). In the latter method, we compared the thickness of the humus layer to the total thickness of the soil profile. Subsequently, we were able to determine the specific sheet erosion value using a tabular method (>110%: accumulation; 90-110%: not eroded; 70-90%: slightly eroded; 30-70%: moderately eroded; <30%: strongly eroded). Since the three methods showed that the topographical characteristics did not justify the significant sheet erosion values indicated by the data of the specific profiles, we also examined the changes in the land use categories of the settlement from the 1700s to the present day. We examined the First, Second and Third Military Survey Maps (Institute and Museum of War History of Hungary ARCANUM Database Ltd., 2006, Biszak et al., 2007), the topographic map from 1990 (Cartography, 1990), the CLC18 satellite image and the Google Earth 2023 version. The maps were structured using the ArcGIS 10.4.1. for Desktop and SURFER 13 and 25 programs. The diagrams were created using the Microsoft Excel program.

RESULTS

Results of Soil Description

We exposed and described 22 soil profiles in Verpelét in 2014 to examine the soil types and the extent of sheet erosion in the area (Fig. 2). In the western part of the village, Cambisols were found, Fluvisols on the alluvium along the Tarna and Kígyós Stream, Arenosols in the central, southern and southeastern parts of the village, Cambisols on the eastern foothills, Luvisols near the hilltops, and occasional Chernozems in the southern part of the village. The soil profiles were exposed using the soil survey methods of FAO (2006), Novák (2013) and Stefanovits (1981). Based on the identified soil properties, we categorized the soil profiles into the WRB reference groups and named them according to the Hungarian Soil Classification System with main types, types, and subtypes of soils (Table 1).

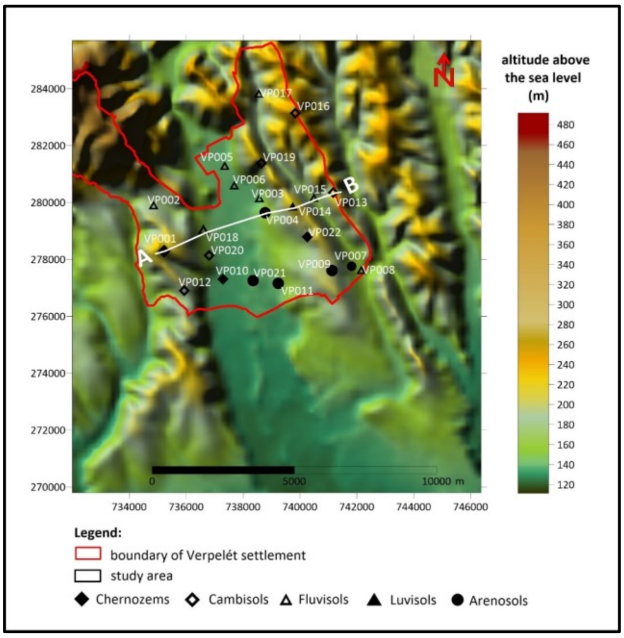

Fig.2 The topographical location of the soil profiles investigated in Verpelét and the cross section of characteristic soil profiles (A – B)

Table 1. The Classification of genetical soil types based on FAO and Hungarian Soil Classification Systems in case of surveyed soil profiles in Verpelét (Dobos et al., 2014.)

Code for soil profile Verpelét (VP)	WRB Reference group (FAO, 2006)	Main soil type	Soil type	Soil subtype	The rate of soil erosion (Kerényi, 1991; Kerényi and Martonné, 1994; Novák, 2013)
		based on Hungarian Soil Classification System (Stefanovits, 1981; Murányi et al., 1989; Novák, 2013)			
VP 001	Chernozems	Brown forest soils	Chernozem brown forest soils	Carbonate Chernozem brown forest soil	strongly eroded
VP 002	Fluvisols	Meadow soils	Alluvial meadow soils	Carbonate alluvial meadow soil	medium eroded
VP 003	Fluvisols	Meadow soils	Alluvial meadow soils	Alluvial meadow soil	medium eroded
VP 004	Arenosols	Stony soils	Humous sandy soils	Humous sandy soil	strongly eroded
VP 005	Fluvisols	Alluvial and slope soils	Humous alluvial soils	Carbonate humous alluvial soil	strongly eroded
VP 006	Fluvisols	Meadow soils	Alluvial meadow soils	Carbonate alluvial meadow soil	medium eroded
VP 007	Arenosols	Stony soils	Humous sandy soils	Layered humous sandy soil	medium eroded
VP 008	Fluvisols	Meadow soils	Alluvial meadow soils	Carbonate alluvial meadow soil	weakly eroded
VP 009	Arenosols	Stony soils	Humous sandy soils	Humous sandy soil	strongly eroded
VP 010	Chernozems	Chernozems	Meadow Chernozem soils	Carbonate meadow Chernozem soil	medium eroded
VP 011	Arenosols	Stony soils	Humous sandy soils	Humous sandy soil	strongly eroded
VP 012	Cambisols	Brown forest soils	Ramann brown forest soils	Ramann brown forest soil	medium eroded
VP 013	Cambisols	Brown forest soils	Ramann brown forest soils	Ramann brown forest soil	medium eroded
VP 014	Luvisols	Brown forest soils	Brown forest soils with clay illuviation	Non podzolic brown forest soil with clay illuviation	strongly eroded
VP 015	Fluvisols	Meadow soils	Alluvial meadow soils	Carbonate alluvial meadow soil	medium eroded
VP 016	Cambisols	Brown forest soils	Ramann brown forest soils	Ramann brown forest soil	medium eroded
VP 017	Fluvisols	Alluvial and slope soils	Humous alluvial soils	Layered carbonate humous alluvial soil	medium eroded
VP 018	Fluvisols	Meadow soils	Alluvial meadow soils	Carbonate alluvial meadow soil	medium eroded
VP 019	Cambisols	Brown forest soils	Ramann brown forest soils	Ramann brown forest soil	medium eroded
VP 020	Cambisols	Brown forest soils	Ramann brown forest soils	Ramann brown forest soil	medium eroded
VP 021	Arenosols	Stony soils	Humous sandy soils	Humous sandy soil	strongly eroded
VP 022	Chernozems	Brown forest soils	Chernozem brown forest soils	Carbonate Chernozem brown forest soil	medium eroded

4% of the exposed soil profiles belonged to Luvisols, 23% to Cambisols, 23% to Arenosols, 36% to Fluvisols, and 14% to Chernozems of WRB reference group (Fig. 3).

Taking into account the Hungarian Soil Classification System (Stefanovits, 1981; Michéli et al., 2006; Novák, 2013), the exposed soil profiles reflected the geological and geomorphological characteristics, the transitional nature of the area can also be nicely observed here (Fig. 3). *Brown forest soils* typical of the mid-mountains and foothill areas appeared in 36% of the exposed soil profiles. *Meadow soils* indicating river terraces and *alluvial and slope soils* appeared in proportions of 27% and 9% respectively. In the southern part of Verpelét, *stony soils* represented 23% of the sand dunes area, while the share of fertile *chernozem soils* was the smallest, at 5%.

At the soil type category level, the higher, medium-altitude and foothill areas were represented by *brown forest soils with clay illuviation* (4%), *Ramann brown forest soils* (23%), and *chernozem brown forest soils* (9%) (Fig. 3). The terraced valleys and alluvial plains were indicated by *meadow soils* (27%), *humous alluvial soils* (9%), and *meadow chernozem soils* (5%). In the sand dunes, *humous sandy soils* (23%) were characteristic.

During the research work, detailed descriptions of all uncovered soil profiles were completed (Dobos et al., 2014). In our article, we present the characterization of the most characteristic soil profiles that appeared along the designated cross-section or catena in the central part of Verpelét (Fig. 2 and 4).

Description of characteristic soil profiles in Verpelét

Along the designated cross-section (Fig. 2), we uncovered soil profiles of VP001 (Chernozems), VP018 (Fluvisols), VP004 (Arenosols), VP014 (Luvisols), VP015 (Fluvisols) and VP013 (Cambisols) (Fig. 4 and Table 2).

VP001 soil profile (*Chernozems / Carbonate Chernozem brown forest soil*)

The **Ap horizon** is located at a depth of 0-17 cm, with a clear horizon boundary and a transitional layer of 2-5 cm in width, its topography is wavy. The colour of this horizon is dark gray (10YR 4/1), with no visible mottling. The moisture status of soil is dry and slightly moist. The material of this horizon is clay and fine gravels. The soil texture is clay. The soil is moderately structured, with nutty subangular blocky (medium and coarse/thick: 10-20 and 20-50 mm) and granular (fine/thin: 1-2 mm) soil

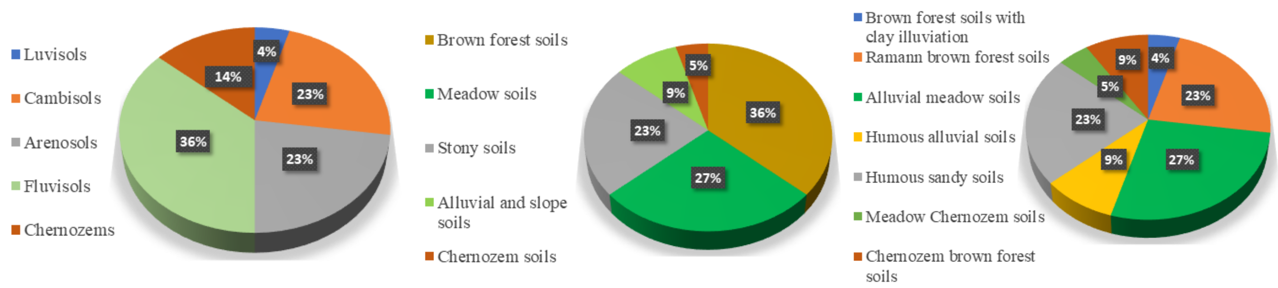

Fig.3. The distribution of WRB reference groups (left), main soil types (middle) and soil type categories (right) (based on the Hungarian Soil Classification System) in case of investigated soil profiles (%) in Verpelét

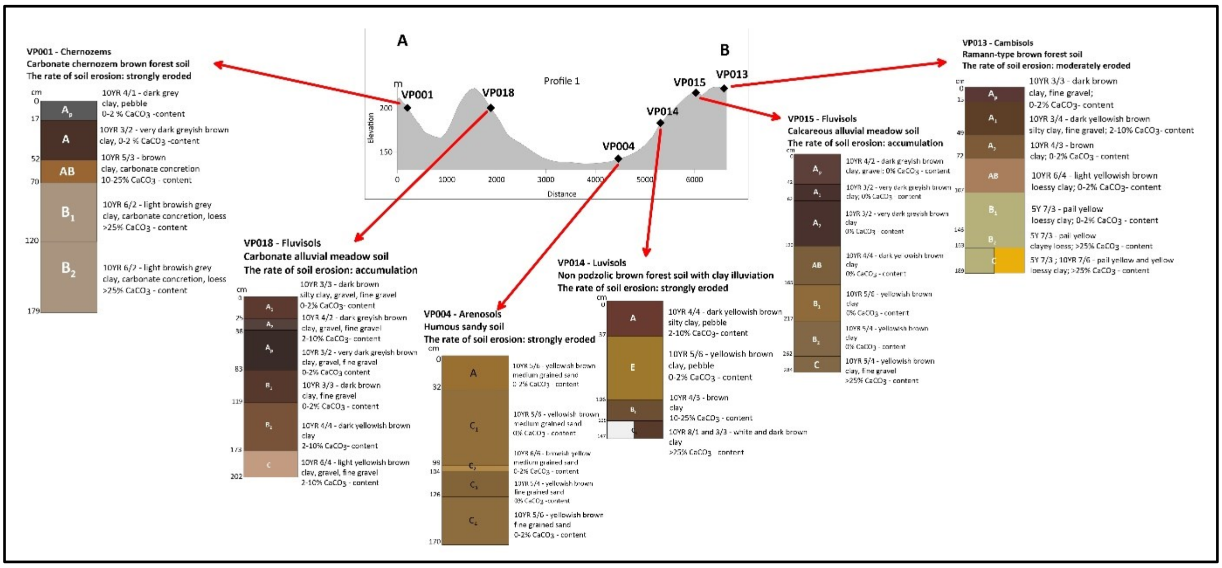

Fig.4 The cross section of main characteristic soil profiles in Verpelét
(A – B cross section, Fig. 2.)

Table 2. Summarized data for the characteristic soil profiles in Verpelét (Dobos et al., 2014)

Profile						
VP 001	Thickness of humus layer:	52 cm	Rate of soil erosion:	strongly eroded	Parent material:	clay, loess
	Horizons	Code of horizon	pH	pH categories	$CaCO_3$ (%)	Arany's plasticity index
	0-17 cm	Ap	7	neutral	0-2 %	80%
	17-52 cm	A	7	neutral	0-2 %	89%
	52-70 cm	AB	8	slightly basic	10-25 %	69%
	70-120 cm	B_1	8	slightly basic	>25 %	73%
	120-179 cm	B_2	8	slightly basic	>25 %	72%
	179-	(? C)				

Profile						
VP 004	Thickness of humus layer:	32 cm	Rate of soil erosion:	strongly eroded	Parent material:	sand
	Horizons	Code of horizon	pH	pH categories	$CaCO_3$ (%)	Arany's plasticity index
	0-32 cm	A	7	neutral	0-2 %	29%
	32-99 cm	C_1	7	neutral	0%	25%
	99-104 cm	C_2	7	neutral	0-2 %	26%
	104-126 cm	C_3	7	neutral	0%	25%
	126-170 cm	C_4	7	neutral	0-2 %	27%

Profile						
VP 013	Thickness of humus layer:	72 cm	Rate of soil erosion:	medium eroded	Parent material:	loessy clay
	Horizons	Code of horizon	pH	pH categories	$CaCO_3$ (%)	Arany's plasticity index
	0-15 cm	Ap	7	neutral	0-2 %	53%
	15-49 cm	A_1	7	neutral	2-10 %	50%
	49-72 cm	A_2	8	slightly basic	0-2 %	50%
	72-107 cm	AB	8	slightly basic	0-2 %	57%
	107-146 cm	B_1	8	slightly basic	0-2 %	57%
	146-163 cm	B_2	8	slightly basic	> 25 %	56%
	163-189 cm	C	8	slightly basic	> 25 %	61%

Profile						
VP 014	Thickness of humus layer:	37 cm	Rate of soil erosion:	strongly eroded	Parent material:	clay, loess
	Horizons	Code of horizon	pH	pH categories	$CaCO_3$ (%)	Arany's plasticity index
	0-37 cm	A	7	neutral	2-10 %	56%
	37-106 cm	E	8	slightly basic	0-2 %	59%
	106-129 cm	Bt	8	slightly basic	10-25 %	59%
	129-147 cm	Ck	8	slightly basic	> 25 %	57%

Profile						
VP 015	Thickness of humus layer:	120 cm	Rate of soil erosion:	accumulation	Parent material:	clay, little gravel
	Horizons	Code of horizon	pH	pH categories	$CaCO_3$ (%)	Arany's plasticity index
	0-42 cm	Ap	8	slightly basic	0%	49%
	42-62 cm	A_1	8	slightly basic	0%	50%
	62-120 cm	A_2	8	slightly basic	0%	52%
	120-165 cm	AB	8	slightly basic	0%	61%
	165-217 cm	B_1	8	slightly basic	0%	61%
	217-262 cm	B_2	8	slightly basic	0%	60%
	262-284 cm	C	8	slightly basic	> 25 %	63%

Profile						
VP 018	Thickness of humus layer:	83 cm	Rate of soil erosion:	accumulation	Parent material:	clay, little gravel, gravel
	Horizons	Code of horizon	pH	pH categories	$CaCO_3$ (%)	Arany's plasticity index
	0-25 cm	A_1	8	slightly basic	0-2 %	59%
	25-38 cm	A_2	8	slightly basic	2-10 %	60%
	38-83 cm	Ap	8	slightly basic	0-2 %	80%
	83-119 cm	B_1	8	slightly basic	0-2 %	77%
	119-173 cm	B_2	9	basic	2-10 %	68%
	173-202 cm	C	9	basic	2-10 %	69%

structure type. The soil is loose, uncemented, and non-compacted, with a weak carbonate content (0-2%).

The **A horizon** is located at a depth of 17-52 cm, with a gradual horizon boundary and a transitional layer of 5-15 cm in width, its topography is wavy. The colour of this horizon is very dark grayish-brown (10YR 3/2), with no visible mottling. The soil is slightly moist and consists of material from fluvial clay. The soil texture is clay. The soil is moderately structured, with nutty subangular blocky and blocky subangular (medium: 10-20 mm) soil structure type. The soil is slightly compacted and uncemented, with a thin clay compaction present in

5-15% of the horizon. The carbonate content of the soil is weak (0-2%).

The transitional **AB horizon** is located at a depth of 52-70 cm, with a clear horizon boundary and a transitional layer of 2-5 cm in width, its topography is wavy. The colour of this horizon is brown (10YR 5/3), with strong/many mottling (15-40%) and stripes measuring 2-6 mm. The soil is slightly moist, with a clay texture and soft concretions of secondary carbonates. The soil is moderately structured, with nutty subangular blocky and columnar (medium: 20-50 mm) soil structure type. The soil is compacted, weakly cemented, with a carbonate compound as the cementing material, in the form of soft concretions with a frequency of 15-40%. The carbonate content of the horizon is strongly carbonate-rich (10-25%).

The **B$_1$ horizon** is located at a depth of 70-120 cm, with a gradual horizon boundary and a transitional layer of 5-15 cm in width, its topography is wavy. The colour of this horizon is light brownish-gray (10YR 6/2), with a very high degree of mottling (>40%) in the form of stripes and patches measuring 2-6 and 6-20 mm. The soil is slightly moist, with a clay and loam soil texture (with carbonate content). The soil is weakly structured, with blocky subangular (fine/thin: 5-10 mm) and prizmatic (medium and coarse/thick: 20-50 and 50-100 mm) soil structure type. The soil is compacted, weakly cemented, with a carbonate compound as the cementing material, in the form of soft concretions and pore fillings. The frequency of carbonate is 40-80% in the soil. The soil is extremely carbonate-rich (>25%).

The **B$_2$ horizon** is located at a depth of 120-179 cm, with a gradual horizon boundary and a transitional layer of 5-15 cm in width, its topography is wavy. The colour of this horizon is light brownish-gray (10YR 6/2), with a very high degree of mottling (>40%) in a patchy and striped pattern. The soil is slightly moist, with a clay and loam soil texture (with carbonate content). The soil is weakly structured, with granular (fine/thin:1-2 mm), blocky subangular (fine/thin and medium: 5-10 and 10-20 mm) and prizmatic (medium: 20-50 mm) structural elements. The soil is compacted and weakly cemented, with a carbonate compound as the cementing material. Manganese coating and carbonate content can be seen in the form of soft concretions and pore fillings. The frequency of manganese is 0-2%, while the frequency of carbonate content is 40-80%. The soil is extremely carbonate-rich (>25%). The drilling ended at a depth of 179 cm, and the profile was not further expanded.

VP018 soil profile (*Fluvisols / Carbonate alluvial meadow soil*)

The **A$_1$ horizon** lies between 0 and 25 cm depth, with a clear horizon boundary, transitional zone width of 2-5 cm, with a wavy shape. The soil colour is dark brown (10YR 3/3), not mottled. The soil is dry, with a material of silty clay, gravel, and pebbles. The soil texture is silty clay. The soil structure is moderate, with prismatic (size: medium, 20-50 mm and coarse/thick, 50-100 mm) and blocky subangular (size: fine/thin, 1-2 mm) structural elements. The soil is compacted and not cemented, with weak carbonate content, 0-2%.

The **A$_2$ horizon** is located between 25 and 38 cm, with a gradual transition and a wavy shape. The soil colour is dark grayish brown (10YR 4/2), lightly mottled, with a patchy pattern, fine patches smaller than 2 mm. The soil moisture content is slightly moist. The soil material is fluvial clay, gravel, and fine gravel. The soil texture is clay. The soil structure is moderate, with blocky subangular (size: very fine/thin, less than 5 mm and fine/thin, 5-10 mm) and granular (size: fine/thin, 1-2 mm and medium, 2-5 mm) structural elements. The soil is compacted and weakly cemented, with the cementing material being carbonate compound. Carbonate occurs in soft nodules, with a frequency of 15-40%. The soil carbonate content is moderate, 2-10%.

The **Ap horizon** is found between 38 and 83 cm deep, with a gradual transition and a wavy shape. The soil colour is very dark grayish brown (10YR 3/2), moderately mottled, with a patchy pattern, fine patches smaller than 2 mm. The soil moisture content is slightly moist, with a texture of clay. The materil soil horizon is fluvial clay,, gravel, and fine gravel. The soil structure is moderate, with prismatic (size: fine/thin, 10-20 mm) and blocky subangular (size: fine/thin, 5-10 mm) structural elements. The soil is compacted and cemented. The carbonate content in the soil is weak, 0-2%.

The **B$_1$ horizon** lies between 83 and 119 cm, with a gradual horizon boundary and a wavy shape. The soil colour is dark brown (10YR 3/3), moderately mottled, with a patchy pattern, fine patches smaller than 2 mm. The soil moisture content is slightly moist, with a soil texture of clay. The material of soil horizon is fluvial clay and gravel. The soil is structureless. The soil is strongly compacted and not cemented. The soil carbonate content is weak, 0-2%, with carbonate occurring in soft nodules and hard concretions, with a frequency of 2-5%.

The **B$_2$ horizon** can be identified between 119 and 173 cm, with a gradual horizon boundary and a wavy shape. The soil colour is dark yellowish brown (10YR 4/4), heavily mottled, with a patchy pattern, fine patches smaller than 2 mm. The soil moisture condition is slightly moist, with a texture of clay. The soil structure is moderate, with blocky subangular (size: fine/thin, 5-10 mm and medium, 10-20 mm), granular (size: medium, 2-5 mm), and prismatic (size: medium, 20-50 mm) structural elements. The soil is compacted and not cemented. The soil carbonate content is moderate, 2-10%, with carbonate present in the soil in the form of hard concretions, with a frequency of 15-40%.

The **C horizon** is present between 173 and 202 cm deep, with a soil colour of light yellowish brown (10YR 6/4), very heavily mottled, with a striped pattern, fine patches smaller than 2 mm. The soil moisture condition is slightly moist, with a texture of clay. The material of this horizon is fluvial clay, gravel, and fine gravel. The soil has a weak structure, with granular (size: fine/thin, 1-2 mm and medium, 2-5 mm) structural elements. The soil is compacted, weakly cemented, with the cementing material being carbonate compound. The soil carbonate content is moderate, 2-10%, with carbonate occurring in the form of hard concretions and fracture fillings in the soil, with a frequency of 15-40%.

VP004 soil profile (*Arenosols / Humous sandy soil*)

The **A horizon** is located 0 to 32 cm deep, with a clear horizon boundary, the transitional band is 2-5 cm wide, and has a wavy shape. The soil colour is yellowish brown (10YR 5/6), highly mottled, with patchy patterns and medium-sized patches measuring 6-20 mm. The soil is dry, with a medium sand texture. The soil structure is moderate, with blocky granular (size: medium, 2-5 mm), granular (size: very small/thin, Ø <1 mm) and single grain (size: medium, 10-20 mm) structural elements. The consistency of the soil is loose, uncemented, and not compacted. The soil is mildly calcareous, with a carbonate content of 0-2%.

The **C_1 horizon** is located 32 to 99 cm deep, with an abrupt transition, the transitional band is 0-2 cm wide, and has a smooth topography. The soil colour is yellowish brown (10YR 5/6), highly mottled, with patchy patterns and fine-sized patches measuring 2-6 mm and coarse, with a Ø >20 mm. The soil is dry, with a medium sand texture. The soil is weakly structured, with blocky subangular (size: very small/thin, Ø <5 mm), granular (size: medium, 2-5 mm) and single grain (size: very small/thin, Ø <1 mm) structural elements. The soil is slightly compacted, uncemented, and not calcareous.

The **C_2 horizon** is located 99 to 104 cm deep, with an abrupt horizon boundary and a smooth topography. The soil colour is yellowish brown (10YR 6/6), not mottled. The soil moisture content is slightly moist, with a medium sand texture. The soil is moderately structured, with columnar (size: medium, 20-50 mm), blocky subangular (size: medium, 10-20 mm) and single grain (size: very small/thin, Ø <1 mm) structural elements. The soil is slightly compacted, uncemented. The soil has a weak carbonate content of 0-2%.

The **C_3 horizon** is identified at 104 to 126 cm deep, with a clear horizon boundary, the transitional band is 2-5 cm wide, and has a wavy shape. The soil is yellowish brown in colour (10YR 5/4), not mottled. The soil moisture content is slightly moist, with a fine sand soil texture. The soil is weakly structured, with blocky subangular (size: very small/thin, Ø <5 mm) and single grain (size: very small/thin, Ø <1 mm) structural elements. The soil is slightly compacted, uncemented, and not calcareous.

The **C_4 horizon** is found at 126 to 170 cm deep, with a colour of yellowish brown (10YR 5/6). The soil is highly mottled (15-40% surface ratio), with patchy patterns, fine-sized patches (2-6 mm) and coarse (Ø > 20 mm). The soil moisture condition is slightly moist, with a fine sand soil texture. The soil is moderately structured, with blocky subangular (size: medium, 10-20 mm), single grain (size: fine/thin, Ø=1-2 mm) and granular (size: very small/thin, Ø <1 mm) structural elements. The soil is slightly compacted, uncemented, with a weak carbonate content of 0-2%.

VP014 soil profile (*Luvisols / Non podzolic brown forest soil with clay illuviation*)

The **A horizon** lies between 0 and 37 cm deep, with a gradual horizon boundary and a transitional zone width of 5-15 cm, with a wavy shape. The soil is dark yellowish brown in colour (10YR 4/4), not mottled. The soil moisture state is slightly moist. The soil texture is silty clay. The material of this horizon is silty clay and fine gravel. The soil is weakly structured, with columnar (size: medium, 20-50 mm and coarse/thick, 50-100 mm), granular (size: fine/thin, 1-2 mm and medium, 2-5 mm) and blocky subangular (size: medium, 10-20 mm) structural elements. The soil is slightly compacted and not cemented. The carbonate content of the soil is moderate, at 2-10%. The calcium carbonate is present in the form of soft nodules in the soil at a rate of 2-5%.

The **E horizon** is located between 37 and 106 cm, with a clear horizon boundary and a transitional zone width of 2-5 cm, with a wavy shape. The soil is yellowish-brown in colour (10YR 5/6), strongly mottled (15-40% surface area), with a striped pattern, and patches of medium size, 6-20 mm. Soil moisture state is slightly moist, with a clay soil texture. The material of this horizon is fluvial clay and fine gravel. The soil is moderately structured, with columnar (size: coarse/thick, 50-100 mm and medium, 20-50 mm) and blocky subangular (size: fine/thin, 5-10 mm and medium, 10-20 mm) structural elements. The soil is compacted and not cemented. Iron nodules are observed in the soil with a frequency of 2-5%. The carbonate content of the soil is weak, at 0-2%.

The **B_t horizon** is identified between 106 and 129 cm, with a gradual horizon boundary and a wavy shape of the transition. The soil is brown in colour (10YR 4/3), strongly mottled, with a striped and patchy pattern, with very fine patches smaller than 2 mm and fine patches between 2-6 mm. Soil moisture content is slightly moist, with a clay soil texture. The soil is moderately structured, with blocly subangular (size: medium, 20-50 mm), columnar (size: fine/thin, 10-20 mm) and granular (size: medium, 2-5 mm) structural elements. The soil is compacted, weakly cemented. Calcium carbonate is present in pore spaces and cracks in the soil at a frequency of 2-5% on the surface. Soft nodules can also be observed in some areas. The soil is highly carbonated, with a carbonate content of 10-25%.

The **C_k horizon** is identified between 129 and 147 cm. The soil colour is white and dark brown (10YR 8/1 and 10YR 3/3), very heavily mottled, with a reticulate pattern, and very fine patches smaller than 2 mm. Soil moisture state is slightly moist, with a clay soil texture. The soil is moderately structured, with columnar (size: medium, 20-50 mm and coarse/thick, 50-100 mm), blocky subangular (very fine/thin, Ø < 5 mm; fine/thin, 5-10 mm and medium, 10-20 mm) and granular (medium, 2-5 mm) structural elements. The soil is heavily compacted, weakly cemented. The cementing material is carbonate, which is visible in the filling of cracks at a frequency of 40-80%. The soil is extremely carbonated, with a carbonate content greater than 25%.

VP015 soil profile (*Fluvisols / Carbonate alluvial meadow soil*)

The **Ap horizon** is observed between 0 and 42 cm, with a clear horizon boundary and a transitional band width of 2-5 cm, with a wavy shape. The soil is dark gray-brown in colour (10YR 4/2) and not mottled. The soil moisture condition is dry, with a clay soil texture. The material of this horizon is fluvial clay and gravel. The soil is moderately structured, with blocky subangular structural elements (sizes: medium, 10-20 mm and very small/thin, Ø< 5 mm). The soil is compacted, non-cemented, with no carbonate content.

The **A_1 horizon** lies between 42 and 62 cm, with a gradual horizon boundary and a wavy shape. The soil is very dark gray-brown in colour (10YR 3/2) and not mottled. The soil is dry, with a clay soil texture. The soil is moderately structured, with blocky subangular (sizes: medium, 10-20 mm and very small/thin, Ø< 5 mm) and granular (sizes: medium, 2-6 mm) structural elements. The soil is compacted and non-cemented, with no carbonate content.

The **A_2 horizon** is found between 62 and 120 cm, with a gradual horizon boundary and a wavy shape. The soil is very dark gray-brown in colour (10YR 3/2) and not mottled. The soil moisture condition is slightly moist, with a clay soil texture. The soil is moderately structured, with blocky subangular structural elements (sizes: coarse/thick, 20-50 mm and small/thin, 5-10 mm). The soil is slightly compacted, non-cemented, with no carbonate content.

The **AB horizon** lies between 120 and 165 cm, with a gradual horizon boundary and a wavy shape. The soil has a dark yellow-brown colour (10YR 4/4), is very strongly mottled, with fine patches, 2-6 mm in size. The soil moisture condition is slightly moist, with a clay soil texture. The soil has not got carbonate content.

The **B_1 horizon** is found between 165 and 217 cm, with a gradual horizon boundary and a wavy shape. The soil is yellow-brown in colour (10YR 5/6), strongly mottled, with fine patches, 2-6 mm in size. The soil moisture condition is moist, with a clay soil texture. The soil is unstructured, slightly compacted, non-cemented. The soil contains lime concretions, with a frequency of 15-40%.

The **B_2 horizon** lies between 217 and 262 cm, with a clear horizon boundary and a transitional band width of 2-5 cm, with a wavy shape. The soil is yellow-brown in colour (10YR 5/4), moderately mottled (with a surface ratio of 5-15%), striped, with fine patches, 2-6 mm in size. The soil moisture content is moist, with a clay soil texture. The soil is unstructured, slightly compacted, non-cemented. The soil contains manganese coatings, with a frequency of 5-15%. The soil has no carbonate content.

The **C horizon** is found between 262 and 284 cm, with a yellow-brown colour (10YR 5/4). The soil is strongly mottled, with striped patterns and fine patches, 2-6 mm in size. The soil moisture condition is moist. The soil texture is clay. The material of this horizon is fluvial clay and gravel. The soil is unstructured, slightly compacted, and slightly cemented. The cementing material is carbonate, filling the cracks, with a frequency of 5-15%. The soil is extremely carbonate-rich, with a carbonate content of over 25%.

At a depth of 284 cm, the water table was reached, so further deepening of the profile was not conducted.

VP013 soil profile (*Cambisol / Ramann-type brown forest soil*)

The **Ap horizon** lies between 0 and 15 cm deep, with a gradual horizon boundary and wavy shape. The soil colour is dark brown (10YR 3/3), slightly mottled, with a speckled pattern and very fine spots, smaller than 2 mm. The soil is dry, with a clay soil texture. The material of this horizon is fluvial clay and gravel. The soil has a moderate structure, with blocky subangular (size: small/thin, 5-10 mm), granular (size: small/thin, 1-2 mm and medium, 2-5 mm) structural elements. The soil consistency is loose, not cemented, not compacted. Iron content can be found in the soil, with a frequency of 0-2%. The soil is slightly calcareous, with a lime content of 0-2%.

The **A_1 horizon** lies between 15 and 49 cm deep, with a gradual horizon booundary and wavy shape. The soil colour is dark yellowish brown (10YR 3/4), the soil is not mottled. The soil is slightly moist in moisture content, with a silty clay soil texture. The material of this horizon is fluvial clay and gravel. The soil has a moderate structure, with blocky subangular (size: very small/thin, Ø < 5 mm and small/thin, 5-10 mm), nutty subangular blocky (size: medium, 10-20 mm), granular (size: very small/thin, Ø < 1 mm and small/thin, 1-2 mm) and prismatic (size: medium, 20-50 mm) structural elements. The soil is compacted but not cemented. The soil exhibits soft nodular carbonate content, with a frequency of 2-5%. The soil is moderately calcareous, with a carbonate content of 10-25%.

The **A_2 horizon** is detected between 49 and 72 cm deep, with a clear horizon boundary and wavy shape. The soil colour is brown (10YR 4/3), heavily mottled (15-40% surface area ratio), with a speckled pattern and fine spots, 2-6 mm. The soil is slightly moist in moisture content, with a clay soil texture. The soil has a moderate structure, with blocky subangular (size: medium, 10-20 mm) and prismatic (size: medium, 20-50 mm) structural elements. The soil is slightly compacted, not cemented, with a weak carbonate content of 0-2%.

The **AB horizon** appears between 72 and 107 cm, with a gradual horizon boundary, a transitional zone width of 5-15 cm, and a wavy shape. The soil is light yellowish brown (10YR 6/4), moderately mottled, with striped pattern and fine spots, 2-6 mm. The soil is moist, with a loamy clay texture. The soil has a moderate structure, with blocky subangular (size: medium, 10-20 mm and small/thin, 5-10 mm) and prismatic (size: medium, 20-50 mm) structural elements. The soil is slightly compacted and not cemented, with a weak carbonate content of 0-2%.

The **B_1 horizon** lies between 107 and 146 cm deep, with a clear horizon boundary and wavy shape. The soil colour is pale yellow (5Y 7/3), not mottled. The soil is moist, with a loamy clay texture. The soil has a moderate structure, with blocky subangular (size: very small/thin, smaller than 5 mm; small/thin, 5-10 mm and coarse/thick, 20-50 mm) and nutty subangular blocky nodular (size: medium, 10-20 mm) structural elements. The soil is slightly compacted, not cemented, with a weak carbonate content of 0-2%.

The **B_2 horizon** is located between 146 and 163 cm deep, with a clear horizon boundary and a wavy shape. The soil colour is pale yellow (5Y 7/3), highly mottled, with fine patches and a size of 2-6 mm. The soil moisture content is moist, with a clay loam texture. The soil has a weak structure, with blocky subangular (coarse/thick, 20-50 mm and fine/thin, 5-10 mm) and granular (fine/thin, 1-2 mm, medium, 2-5 mm) structural elements. The soil is slightly compacted, weakly cemented, with the cementing material being carbonate compounds. The soil contains soft concretions and pore filling of carbonate inclusions, with a frequency of 15-40%. The soil carbonate content is extremely high, exceeding 25%.

The **C horizon** is located between 163 and 189 cm. The soil colour is pale yellow (5Y 7/3) and yellow (10YR 7/6). The soil material is very mottled (>40%), with patchy patterns and medium-sized patches (6-20 mm) and large patches (>20 mm). The soil moisture content is moist, with a loamy clay texture. The soil has a weak structure, with blocky subangular (very fine/thin, less than 5 mm; fine/thin, 5-10 mm, and medium, 10-20 mm), granular (fine/thin, 1-2 mm, medium, 2-5 mm) and prismatic (fine/thin, 10-20 mm) structural elements. The soil is slightly compacted and weakly cemented, with carbonate compounds as the cementing material. The soil contains soft concretions of iron compounds, with a frequency of 15-40%. The carbonate content is present in soft concretions and pore filling, with a frequency of 15-40%. The soil carbonate content is extremely high, exceeding 25%.

The examples presented here indicate that based on a very detailed soil profile description, we can determine the WRB reference group and the Hungarian Soil Classification System of individual soil profiles (Table 1).

Results of the rate of the soil erosion

Results of the rate of soil erosion risk based on GIS method

The level of erosion risk was examined in the study area (Fig. 5). The slope category map of the study area was prepared using the SURFER 13 program, where the slope category value was adjusted to the erosion risk levels (Várallyay and Fórizs, 1966; Novák 2013). It can be seen that in Verpelét, north of it, and towards Feldebrő in the Tarna Valley, there is no soil erosion expected with slope category values of 0–5% or 0–3°. On the slopes bordering the valley, or in steeper side valleys, small to medium soil erosion can be detected, where the slope category is 5–12% or 3–7°. High soil erosion risk is expected in the higher volcanic areas of the Mátra Mts. in the northwestern part of the study area.

Results of the rate of sheet erosion based on FAO (2006) method

During the description of soil profiles, there was an opportunity to identify both sheet erosion and linear soil erosion (FAO, 2006). The on-site soil survey record in the book named as „Guidelines for soil description" asks about the specific characteristics of the soil surface and the type of erosion. Therefore, during the description of the soil profile, it is possible to determine both linear and sheet erosion based on the knowledge of geomorphological processes occurring in the vicinity of the soil profile. In our study area, we were able to detect sheet erosion in the surroundings of the soil profiles.

If we apply this research method to the exposed soil profiles, it can be seen from Figure 6 that moderate sheet erosion (VP007, VP012, VP013, VP016, VP019) is detected at the hillfoot surfaces and younger fluvial terraces. At the soil profiles north and south of the built-up area of Verpelét (VP003, VP006, VP021), moderate soil erosion is also observed. On the edge of the Tarna Valley and on the alluvium of the Kígyós Stream,

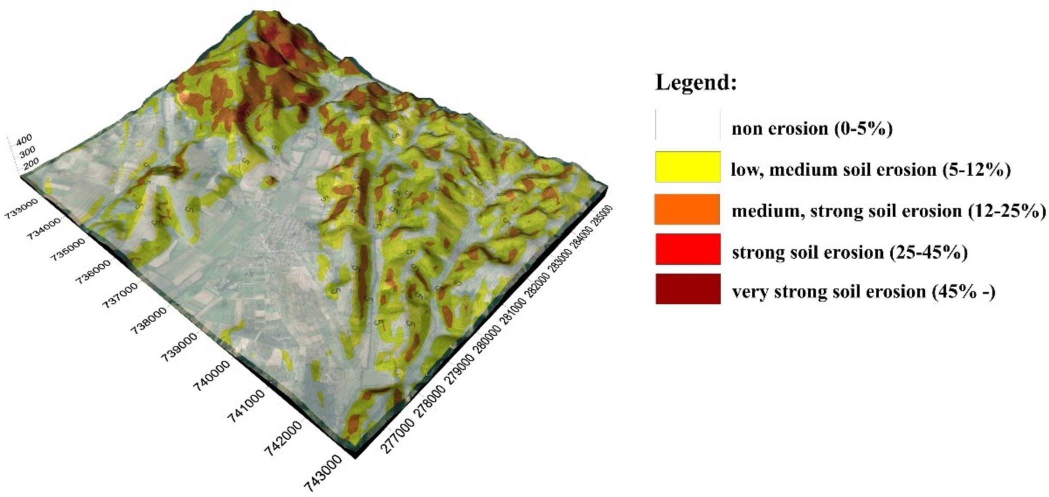

Fig.5 The rate of soil erosion risk based on slope steepness in Verpelét based on GIS method (A) (source: Google Earth Map, 2023)

accumulation tendencies can be observed (VP002, VP008, VP010, VP015, VP017, VP018). We were able to identify strongly eroded soil profiles on the top level and slopes of the young pediment surface (VP001, VP014, VP022). Unexpectedly, strongly eroded soil profiles are also found in some areas on the alluvium or lower fluvial terraces based on field conditions (VP004, VP005, VP009, VP011).

Results of the rate of sheet erosion based on Kerényi (1991), Kerényi and Martonné Erdős (1994) method

As a third method, for the evaluation of sheet erosion, we compared the thickness of the humus-rich topsoil horizon to the total thickness of the sample profiles (%) (Kerényi, 1991; Kerényi and Martonné Erdős, 1994). When examining the specific soil profiles, the previous results varied (Fig. 7). Most of the exposed soil profiles fell into the moderately eroded category (VP002, VP003, VP006, VP007, VP010, VP012, VP013, VP015, VP016, VP017, VP018, VP019, VP020, VP022). Among these soil profiles, there are mixed profiles located either in the hilltop levels, slopes, or on the Tarna alluvium. The remaining soil profiles were mostly classified under the strongly eroded category (VP001, VP004, VP005, VP009, VP011, VP014, VP021). Among these, reference groups of Arenosols, Fluvisols, and Chernozems were found. In one soil profile (VP008), a weakly eroded category was detected.

Results of investigating land use changes by Military Survey Maps, topographic maps and satellite imagery

As can be seen, the first method does not indicate soil erosion risk near the built-up area of Verpelét. However, the second and third research methods revealed significant sheet erosion in the vicinity of the soil profiles and in the specific soil profiles themselves. The question arose as to what could have caused this significant sheet erosion in the area of Verpelét. In searching for the answer to this question, we also examined the changes in the previous land use system of the settlement. During the Pleistocene and Holocene periods, until the time of river regulations, our study area was continuously forested (Kocsis, 2018). Therefore, huge forests characterized the environment of Verpelét in the past. However, during the 1st military survey (1782-1785), extensive cultivated fields were already present in the vicinity of Verpelét (Fig. 8A). North of the settlement, we only find vineyards in small areas. Along the Tarna Stream, floodplain gallery forests accompanied the course of the water flow, and meadow management took place on the floodplain.

Forest areas have been reduced to smaller areas, primarily in the Mátra region. Verpelét and Feldebrő appeared as built-up areas with a basic street network.

During the 2nd military survey (1819-1869), the proportion of arable land increased, with arable land extending to the Nagy Szántóföld, Ilka tető, Dohány föld, and Nagy part (Fig. 8B). The fields were

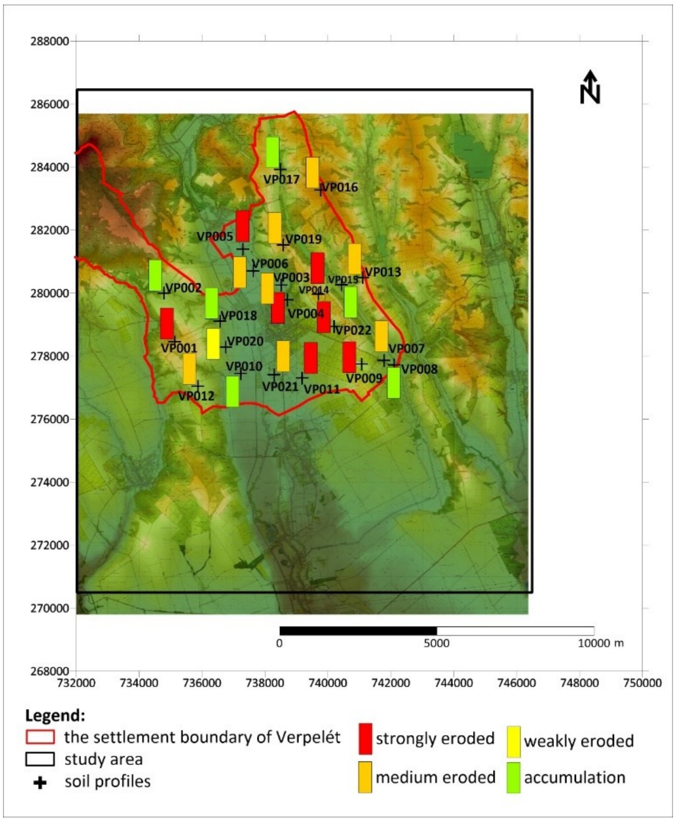

Fig.6 The rate of sheet erosion investigated the surroundings of soil profiles (FAO, 2006) (based on topographic map, Cartographia, 1990)

segmented by smaller to larger eroded valleys with tree branch patterns, as well as numerous gullies. The widespread occurrence of gullies raises the possibility of climate change (the appearance of warmer, humid periods) or the expansion of more intensive agricultural cultivation. The vineyard area situated in northeast of Verpelét was destroyed, replaced by scrubland. The Tarna alluvium (Hosszú-rét) was entirely characterized by meadow management. North and west of Három határ, the previous forests were cut down and replaced by scrubland. The former forests remained in the Felső Cserhát region or on the side slopes of steeper erosional side valleys. The proportion of built-up areas increased.

During the 3rd military surveys (1869-1887), only patches of forested areas remained (Fig. 8C). The landscape was dominated by extensive arable lands. The arable lands extended down to the lower floodplain of the Tarna Stream, into the area of the Lower Meadow (Alsó-rét). The arable lands were increasingly fragmented by pronounced erosional side valleys and gullies. Smaller series of gullies can be found on the steeper slopes (on the slopes of Kígyós Stream, west of the Lower and Upper Meadows), while the areas east of Verpelét were divided by longitudinal valleys, indicating more intense soil erosion processes. North of Feldebrő, the sandy hilly areas also begin to appear. This area was previously represented as a unified terrain on old maps. Eolian surface shaping may have also become more active during this period. The built-up areas grew to a lesser extent, mainly in the southeastern part of Verpelét.

Changes can already be observed on the 1:10,000 scaled topographic map from 1990. The forests have returned to the lower part of the Mátra region in the steeper erosive side valleys and at higher altitudes. East of Verpelét towards Eger, vineyards have also been replanted following the phylloxera epidemic (Fig. 8D). The landscape is still dominated by active arable land in the outskirts of Verpelét, in the floodplain of the Tarna Stream, and in areas characterized by lower fluvial terraces. The sandy hilly areas between Verpelét and Feldebrő have also been brought under agricultural cultivation. The signs of sheet erosion are visible to the naked eye in the vineyard areas east of Verpelét, in the sandy areas between Verpelét and Feldebrő, and on the Tarna alluvium in the 2023 Google Earth images (Fig. 8E).

Results of land use changes in different historical times

We also analyzed the changes in land use that took place in different historical periods using the Landuse Database of the Eszterházy Károly Catholic University (Balogh, 2017) (Fig. 8). The database contained the digitalized data of the 1st, 2nd and 3rd Military Survey Maps (1782-1785, 1819-1869, 1869-1887), EOTR (1990) and CLC18 (2018) land use categories (Fig. 9). In Verpelét, the discontinuous urban fabric areas continuously expanded (1% - 5.04%) during the period under review. The non-irrigated arable land had the largest spatial ratio in the settlement (47.49% - 53.01% - 40.17%), but its spatial ratio halved by 2018 (24.6%).

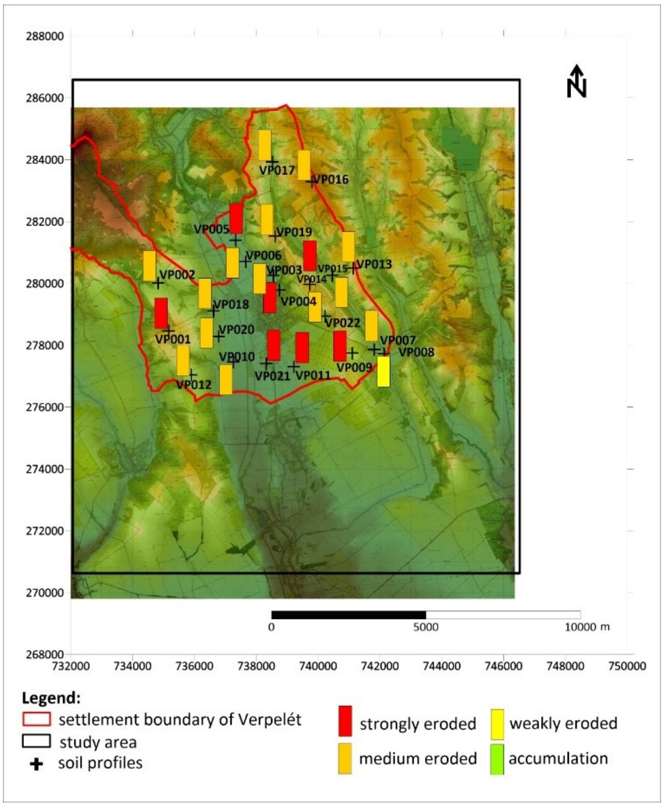

Fig.7 The de facto pointed out sheet erosion rate in the investigated soil profiles (calculated by using Kerényi, 1991; Kerényi and Martonné Erdős, 1994 method) (based on topographic map, Cartographia, 1990)

The spatial ratio of land principally occupied by agriculture, with significant areas of natural vegetation category continuously decreased (18.18% - 12.73% - 7.74% - 2.30%). The vineyard area showed a spatial ratio of 2.44% or 2.41% during the 1st, 2nd and 3rd Military Surveys, then doubled by 1990 due to the phylloxera epidemic and new vineyard plantations (7.47%), and again by 2018 (15.35%). The pastures area increased from 0.63% to 12.31% in the last period. The broad-leaved forest category initially decreased from 26.82% to 17.69% and 18.34%, then in 1990 it was already 28.28% and by 2018 it decreased again to 22.75%. The coniferous forest had a spatial ratio of 1.13% by 2018, while the mixed forest was 1.07%. The natural grassland category increased from 4.07% to 15.1% in the 1860s, then it was 13.39% in 1990 and 0% in 2018. The transitional woodland-scrub category increased to 13.1% by 2018 after 1990.

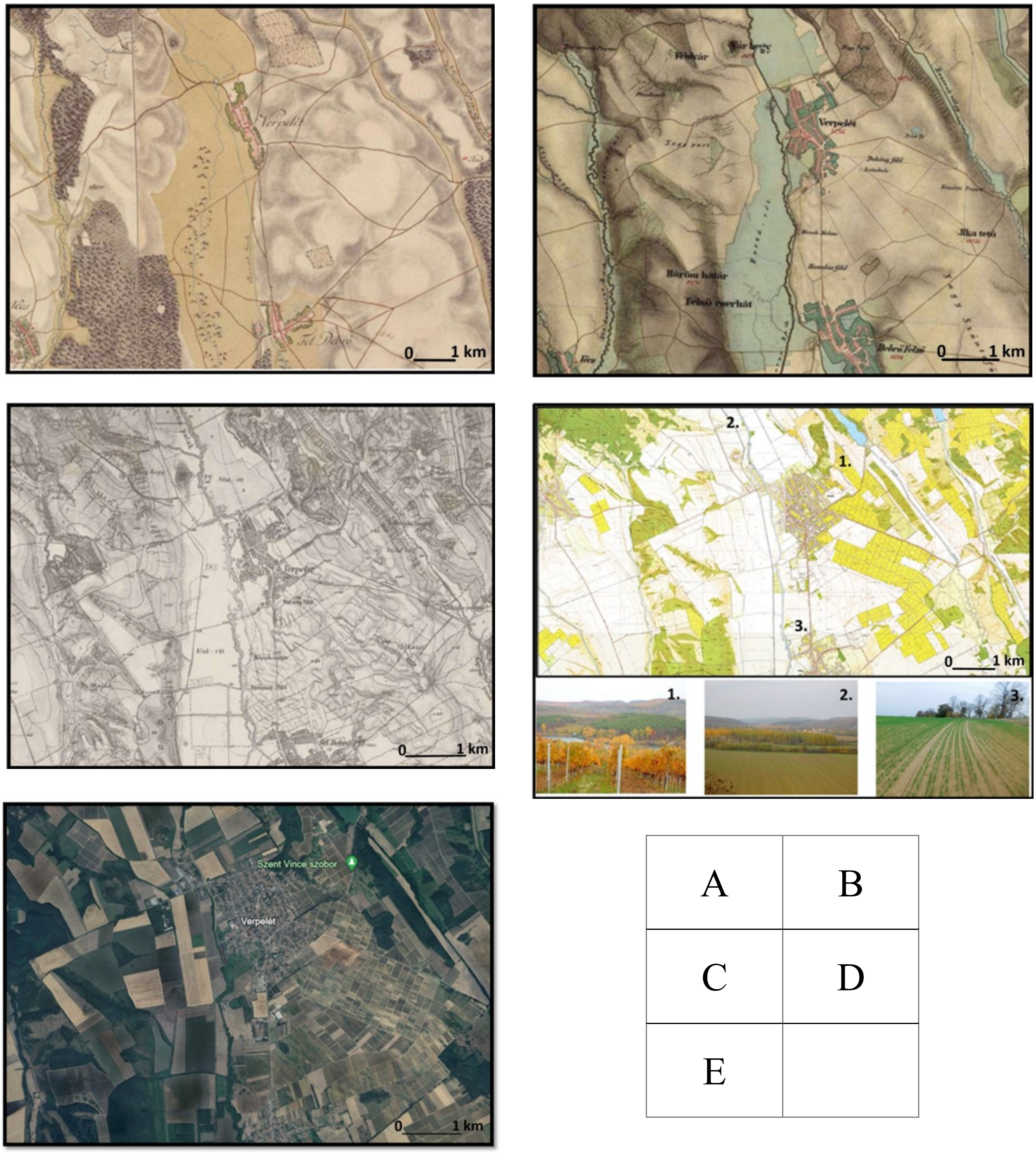

Fig.8 The 1st Military Survey Map (1782-1785) (A) (https://maps.arcanum.com/hu/map/firstsurvey-hungary/)
The 2nd Military Survey Map (1819-1869) (B) (Institute and Museum of War History of Hungary, 2006)
The 3rd Military Survey Map (1869-1887) (C) (Biszak et al., 2007)
The topographic map from 1990 (D) (Cartographia, 1990)
The Google Earth Map around Verpelét (E) (Google Earth, 2023)

Summarized results of the rate of soil erosion and the land use changes

In the method used for determining sheet erosion during our research (Table 3), we can see that the degree of sheet erosion identified by the GIS method shows significantly different values and categories compared to the other two methods. This can be explained by the fact that the first method uses general slope category data, while the other two methods calculate the degree of sheet erosion based on specific profile data. In the case of these last two methods, we found 59% agreement in categories (see green colour in Table 3).

In landscape use analyses, we could also identify trends in land use change (Table 3). Deforestation has already occurred in the western soil profiles located at higher elevations as early as the 1800s, and the area was put under cultivation for arable farming (VP001, VP002). The afforestation of arable land is observable in the areas of soil profiles VP004, VP012, and VP017. Due to the favorable landscape conditions, continuous arable farming is taking place on alluvial land and lower terraces (VP005, VP006, VP010, VP011, VP018, VP020, VP021). In the floodplain next to the stream beds, or in the higher-lying young pediments, agricultural cultivation has been abandoned in some places, and today we find pastures in these areas (VP007, VP008, VP015). In Verpelét, following the phylloxera epidemic of the 1880s, the young pediments transitioned away from arable farming and were planted with vineyards (from the 1990s: VP013; from the early 2000s: VP009). In several locations, we can observe that the land use around a particular soil profile has changed multiple times over the centuries. At the VP003 soil profile, we can detect a change in categories from arable land – pasture – arable land at the boundary of alluvium. We also frequently encounter the periodic alternation of the categories arable land – vineyard – arable land – vineyard (VP014, VP019). In certain areas, previous forestry practices have been replaced by arable land, pasture, or viticulture (VP016). In the vicinity of the VP022 soil profile, we can observe the application of categories such as arable land – pasture – arable land – pasture – meadow.

DISCUSSION

Based on our research results, it can be seen that we were able to achieve realistic results in assessing the extent of soil erosion using the third method that processes specific field data. Our data also showed that the soil erosion risk map based on slope category values did not indicate any soil erosion in the immediate vicinity of Verpelét. Our map, as well as our second method, did not indicate any significant soil erosion trends in Verpelét that would justify the observed significant soil erosion tendencies.

Therefore, the intensive changes in land use, deforestation, the decline of grassland management areas, and the rapid expansion of arable and vineyard areas can explain the intense soil erosion conditions. Military surveys and other maps examined faithfully depict this situation. Our results support the claims of researchers who argue that changes in land use and increasing anthropogenic impacts can have serious effects on soil erosion processes (Borelli et al., 2017; Cimusa Kulimushi et al., 2023; Chasia et al., 2024; Van Rompaey et al., 2001, 2002; Kim et al., 2013; Yang et al., 2003). Our research in Verpelét has proven that the presence of vegetation cover mitigates intensive soil erosion, thus choosing the appropriate land use category can reduce the extent of soil erosion (Thornes, 1990; Kosmas et al. 1997; Garcia-Ruiz, 2010). The situation in the 2nd military survey, with the appearance of numerous gullies, also confirmed that land use changes can initiate geomorphological processes that lead to the growth of areas exposed to intensive erosion (Pelacani et al., 2008). The land use categories appearing in individual parcels influence the extent of soil erosion (Zoakib and Naser, 2011).

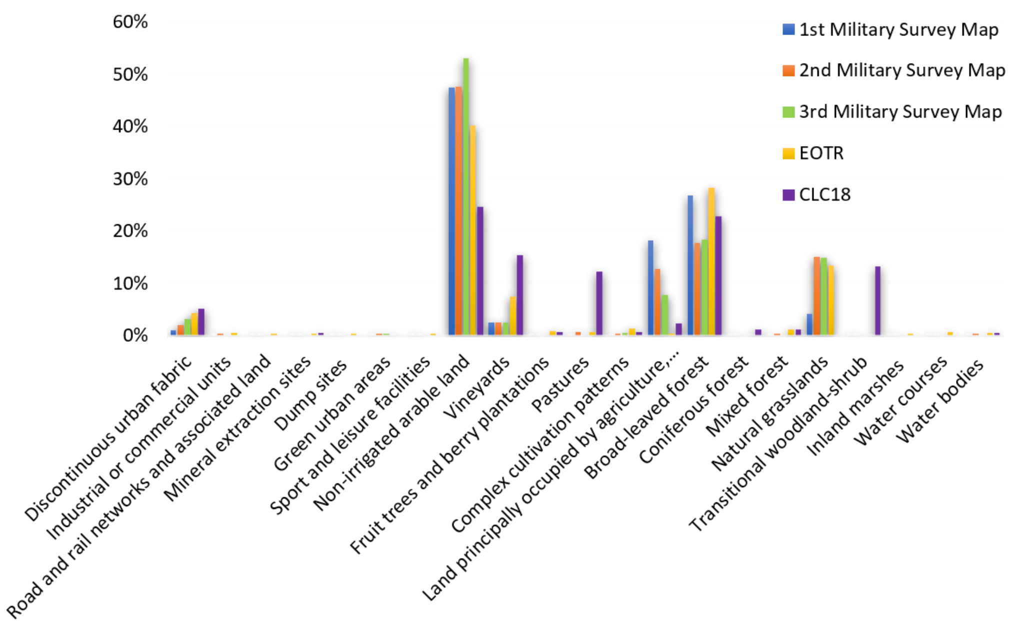

Fig.9 Land use changes from 1st Military Survey Map to CLC18 (2018) (source: Balogh et al., 2017)

Table 3. Summarized data for the rate of soil erosion and land use changes in Verpelét

Code of soil profiles	The rate of soil erosion based on GIS method (slope category map)	The rate of soil erosion based on FAO (2006)	The rate of soil erosion based on Kerényi (1991), Kerényi and Martonné (1994); Novák (2013)	Land Use Categories				
				1st Military Survey Map (1782-1785)	2nd Military Survey Map (1819-1869)	3rd Military Survey Map (1869-1887)	EOTR, Military Map (1990)	Corine Land Cover (CLC) 2018
VP001	no erosion	strongly	strongly	Deciduous forest	Non-irrigated arable land	Non-irrigeted arable land	Non-irrigated arable land	Non-irrigated arable land
VP002	no erosion	accumulation	medium	Deciduous forest	Non-irrigated arable land	Non-irrigated arable land	Non-irrigated arable land	Non-irrigated arable land
VP003	no erosion	medium	medium	Non-irrigated arable land	Non-irrigated arable land	Natural lawns	Non-irrigated arable land	Non-irrigated arable land
VP004	no erosion	strongly	strongly	Non-irrigated arable land	Non-irrigated arable land	Non-irrigated arable land	Deciduous forest	Mixed forest
VP005	no erosion	strongly	strongly	Primarily agricultural areas with significant natural formations	Primarily agricultural areas with significant natural formations	Primarily agricultural areas with significant natural formations	Non-irrigated arable land	Non-irrigated arable land
VP006	no erosion	medium	medium	Primarily agricultural areas with significant natural formations	Primarily agricultural areas with significant natural formations	Natural lawns	Non-irrigated arable land	Non-irrigated arable land
VP007	low, medium	medium	medium	Non-irrigated arable land	Primarily agricultural areas with significant natural formations	Non-irrigated arable land	Non-irrigated arable land	Pasture
VP008	low, medium	accumulation	weakly	Non-irrigated arable land	Primarily agricultural areas with significant natural formations	Non-irrigated arable land	Non-irrigated arable land	Pasture
VP009	no erosion	strongly	strongly	Non-irrigated arable land	Non-irrigated arable land	Non-irrigated arable land	Non-irrigated arable land	Vineyard
VP010	no erosion	accumulation	medium	Primarily agricultural areas with significant natural formations	Primarily agricultural areas with significant natural formations	Non-irrigated arable land	Non-irrigated arable land	Non-irrigated arable land
VP011	no erosion	strongly	strongly	Non-irrigated arable land	Non-irrigated arable land	Non-irrigated arable land	Non-irrigated arable land	Non-irrigated arable land
VP012	low, medium	medium	medium	Non-irrigated arable land	Natural lawns	Non-irrigated arable land	Non-irrigated arable land	Transitional shrub forest areas

Code of soil profiles	The rate of soil erosion based on GIS method (slope category map)	The rate of soil erosion based on FAO (2006)	The rate of soil erosion based on Kerényi (1991), Kerényi and Martonné (1994); Novák (2013)	Land Use Categories				
				1st Military Survey Map (1782-1785)	2nd Military Survey Map (1819-1869)	3rd Military Survey Map (1869-1887)	EOTR, Military Map (1990)	Corine Land Cover (CLC) 2018
VP013	low, medium	medium	medium	Non-irrigated arable land	Non-irrigated arable land	Non-irrigated arable land	Vineyard	Vineyard
VP014	low, medium	strongly	strongly	Non-irrigated arable land	Non-irrigated arable land	Vineyard	Non-irrigated arable land	Vineyard
VP015	medium, strong	accumulation	medium	Non-irrigated arable land	Non-irrigated arable land	Primarily agricultural areas with significant natural formations	Non-irrigated arable land	Pasture
VP016	medium, strong	medium	medium	Deciduous forest	Non-irrigated arable land	Natural lawns	Non-irrigated arable land	Vineyard
VP017	no erosion	accumulation	medium	Primarily agricultural areas with significant natural formations	Primarily agricultural areas with significant natural formations	Non-irrigated arable land	Wetlands	Transitional shrub forest areas
VP018	no erosion	accumulation	medium	Non-irrigated arable land	Non-irrigated arable land	Non-irrigated arable land	Non-irrigated arable land	Non-irrigated arable land
VP019	no erosion	medium	medium	Non-irrigated arable land	Vineyard	Vineyard	Non-irrigated arable land	Vineyard
VP020	no erosion	weakly	medium	Non-irrigated arable land	Non-irrigated arable land	Non-irrigated arable land	Non-irrigated arable land	Non-irrigated arable land
VP021	low, medium	medium	strongly	Primarily agricultural areas with significant natural formations	Non-irrigated arable land	Non-irrigated arable land	Natural lawns	Non-irrigated arable land
VP022	no erosion	strongly	medium	Non-irrigated arable land	Natural lawns	Non-irrigated arable land	Natural lawns	Pasture

The appearance of more intensive, inappropriate land use categories in Verpelét also meant a more intense human intervention, as the expansion of arable and vineyard areas already indicates a level of hemeroby at the α-euhemerobic level (Csorba, 2021). The increase in built-up areas also showed the expansion of the polyhemerobic level.

CONCLUSIONS

During our research, we examined the territory of the village of Verpelét in the Tarna Valley, located between the Mátra and Bükk mountains, in order to uncover the soil types of the settlement and the extent of sheet erosion. Based on the examination of 22 soil profiles in the settlement, we identified the following World Reference Base (WRB) reference groups: Fluvisols (36%), Cambisols, Arenosols (23-23%), Chernozems (14%), and Luvisols (4%). According to the Hungarian Soil Classification System, the following soil types are presented in Verpelét: Brown forest soils (36%), Meadow soils (27%), Stony soils (23%), Alluvial and slope soils (9%), and Chernozem soils (5%).

After determining and describing the reference groups and soil types, we examined the extent of sheet soil erosion using three methods. Our results confirmed that the soil erosion risk map constructed based on GIS did not show any soil erosion in the vicinity of the village, as well as between Verpelét and Feldebrő (63,6%). Additionally, the low, medium soil erosion (27.45%) and the medium, strong soil erosion (9%) categories were characteristic of the sample area. The results of the examinations of the environment of soil profiles and the specific soil profiles revealed predominantly medium and strongly eroded soil profiles. The FAO (2006) method distinguished categories of strongly (31.8%), medium (36.4%), weakly (4.5%), and accumulation (27.3%). In the case of the Kerényi and Martonné Erdős method, we were able to detect strongly (31.8%), medium (63.7%), and weakly (4.5%) soil erosion categories. Therefore, there is a significant difference between the results of the applied methods. The GIS method at a scale of 1:10,000 did not yield realistic results, as it only considered slope category values during map editing and did not take into account the influencing physical geographic processes, the vegetation coverage index or changes in land use. The results of the other two methods matched 59% in the area, as they examined multiple influencing factors, thus providing more realistic results.

The geomorphological processes in the sample area do not support the significant degree of sheet soil erosion (strongly and medium soil erosion: 95.5%), thus it raises the question of whether climate change or changes in land use system may have induced this significant discrepancy in our results. In our research, we also examined land use changes from the 1700s to the present day, approximately every 100 years at the investigated soil profiles. In deforested areas, we identified predominantly strongly or medium (VP001, VP002; 9%); in the arable land converted to forested areas, we found mainly medium levels of sheet soil erosion (VP004, VP012, VP017; 13.6%). Where continuous arable farming was practiced, we observed strongly and medium levels of soil erosion (VP005, VP006, VP010, VP011, VP018, VP020, VP021; 31.8%). When arable land was transformed into pastures, the soil profiles (VP007, VP008, VP015; 13.6%) showed medium and weakly levels of soil erosion, whereas when arable land was converted into vineyards (VP009, VP013; 9%), we detected strongly and medium levels of soil erosion. In soil profiles exhibiting alternating land use, areas categorized as arable – vineyard – arable – vineyard (VP003, 4.5%) and areas categorized as arable – grassland – arable – grassland – pasture (VP022; 4.5%) show strong and medium levels of soil erosion. In areas categorized as arable – grassland – arable (VP003, 4.5%) and areas categorized as forest – arable – grassland – arable – vineyard (VP016, 4.5%), medium levels of sheet soil erosion are present.

It was found that the landscape, which was once covered with forests, has significantly transformed, gradually evolving into active arable and vineyard areas around Verpelét since the 1700s, where grassland farming and forestry have steadily receded. Active agricultural cultivation has spread to increasingly lower morphological levels, therefore significant soil erosion can be attributed to the spread of inappropriate land use methods and significant anthropogenic impacts (arable lands, vineyards; β-euhemerobic level).

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