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ESTIMATING ELEMENT TRANSPORT RATES ON SLOPING AGRICULTURAL LAND AT CATCHMENT SCALE (VELENCE MTS., NW HUNGARY)

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Abstract: The erosion-induced spatial redistribution of macro- and microelements in the surface soils is rarely investigated. The 14-km^2 study area is located in the drainage basin of Lake Velence in NW Hungary. At the micro-scale on two study plots of a vineyard and arable land, we measured element redistribution rate due to rainfall with sediment collectors. At the meso-scale, the amount of soil motion was determined with the soil erosion model Erosion 3D. The soil erosion model was validated by comparing measured (collector) and estimated (model) values of eroded soil in the two study plots. Subsequently, the erosional losses of each element were calculated with the help of the element maps and enrichment ratios. The enrichment ratio (ER), as a quotient of the concentration measured in the topsoil and that in the sediment, was calculated. There were slight differences between enrichment ratios calculated from the two study plots with distinct land uses. Organic matter (OM) (ER=2.1-2.2), P_2O_5 (ER=1.8-2.1) and Ni (ER=2.2) accumulated the most in the sediment moved by erosion. The Cu, Pb, Zn and Co accumulated moderately (ER= ~1.2), whereas Cr has not accumulated at all. The AL-P_2O_5 wash-off was significant, primarily in arable lands with higher phosphorus contents than the surrounding areas. The average AL-P_2O_5 wash-off during the studied rainfall events was 5.5 – 15.1 mg m^{-2}, the estimated Zn transport was 14.3-39.1 mg m^{-2}, Cu 5.02-13.75 mg m^{-2}, Pb 4.1-11.3 mg m^{-2}. Our final element loss maps are excellently used in environment-friendly nutrient management in order to delimit the areas of the nutrient accumulation.

Keywords. land use; soil erosion, Erosion 3D; enrichment ratios; element transport; environmental sustainability

1 INTRODUCTION

Knowledge and modelling of macro- and microelement transport and temporal and spatial changes in horizontal element redistribution at the level of small watersheds is crucial (Fletcher et al., 2004). The thesis that life in lakes depends on the watershed is highly applicable to the drainage basin of Lake Velence. Estimations suggest (Karászi, 1984) that 713.000 t of soil eroded from the entire watershed of the lake each year, and about 83.000 t of sediment are carried into the lake (2 mm-per-year increase silt accumulation) and indirectly caused the eutrophication process (Mucsi, 1995).

Precise calculation of the horizontal component of macro- and microelement transport in the soil is crucial from another point of view, as well. Erosional surface wash-off is the second most important aspect in element balance (Joó, 1980; Déri, 1986; Horváth, 1996; Marton, 2000; Szabó & Szabó, 2004). Estimations of the volume of particles moving due to erosion and the movements of attached elements differ greatly, from 0-34 kg N ha^{-1} year^{-1}, 1.5-18.7 kg P ha^{-1} year^{-1} and 3-8 kg K ha^{-1} year^{-1} (Debreczeni, 1987; Pansak et al., 2008), to 5-20 kg P ha^{-1} year^{-1} (Duttmann, 1999). The effects of soil erosion on the physical and chemical properties of the soil have been widely studied (Isringhausen, 1997; Kerényi & Szabó, 1997; Heathwaite et al., 2003; Bogena et al., 2003; Ulén & Kalisky, 2005; Jakab & Szalai, 2005; Veum et al., 2009; Wang et al., 2009; Arghius & Arghius, 2011; Stefanescu et al., 2011). Lal et al., (2000) examined changes in the physical and chemical properties of soil as a function of landscape position and erosional phase. Boy and Ramos

(2002) studied the relationship between the macro- and microelement concentrations moving with sediment and rainfall events. Zhang et al., (2004) characterised nutrient loss of the topsoil and its connection with physical soil parameters by measuring the enrichment ratio. The movement by erosion of P of macro- and micro elements is frequently studied owing to its environmental significance. Sharpley (1995) ranked the vulnerability for P loss from 30 unfertilized and P-fertilized, grassed, and cropped watersheds in the Southern Plains, USA. He claimed that a watershed vulnerability to P loss in runoff was closely related to actual losses measured 0.1-5 kg P ha^{-1} yr^{-1}.

In order to carry out soil element transport calculations and introduce environmentally friendly, sustainable nutrient economy practices (Csathó et al., 2009; Fletcher et al., 2004), it is essential to know the volume of element loss due to surface macro- and microelement movement and wash off for both individual rainfall events and for a complete vegetation period in a given area. By creating appropriate digital map files, this information could be applied to precision agricultural practices (Czinege, 1999). As post-fertilisation rainfall events greatly rearrange the soil element maps of fields having greater relief, differentiated element depositions must be based not only on the so-called static element map, but also on dynamic ones that summarise element rearrangement patterns.

Our aim was to track the spatial variability patterns of horizontal macro- microelement transport in the 14-km^2 watershed of the Cibulka stream (Fig. 1), a sub-catchment of the Vereb-Pázmánd headwaters, which plays a crucial part in the variability of the water quality of Lake Velence.

2 THE STUDY AREA

The studied area is situated in the catchment area of Lake Velence in North-Western Hungary (Fig. 1). The climate of the area is moderately cool and dry. The annual average temperature is 9.5-9.8^{o}C and the volume of rainfall is 550-600 mm/year, with 50-55% coming in the form of severe summer rainstorms (Marosi & Somogyi, 1990).

The catchment area exhibits great variety, both petrologically and pedologically, as well as from the aspect of land use (Fig. 2). The soil-forming rock is granite and andesite at higher plots, while slopes are covered with loess.

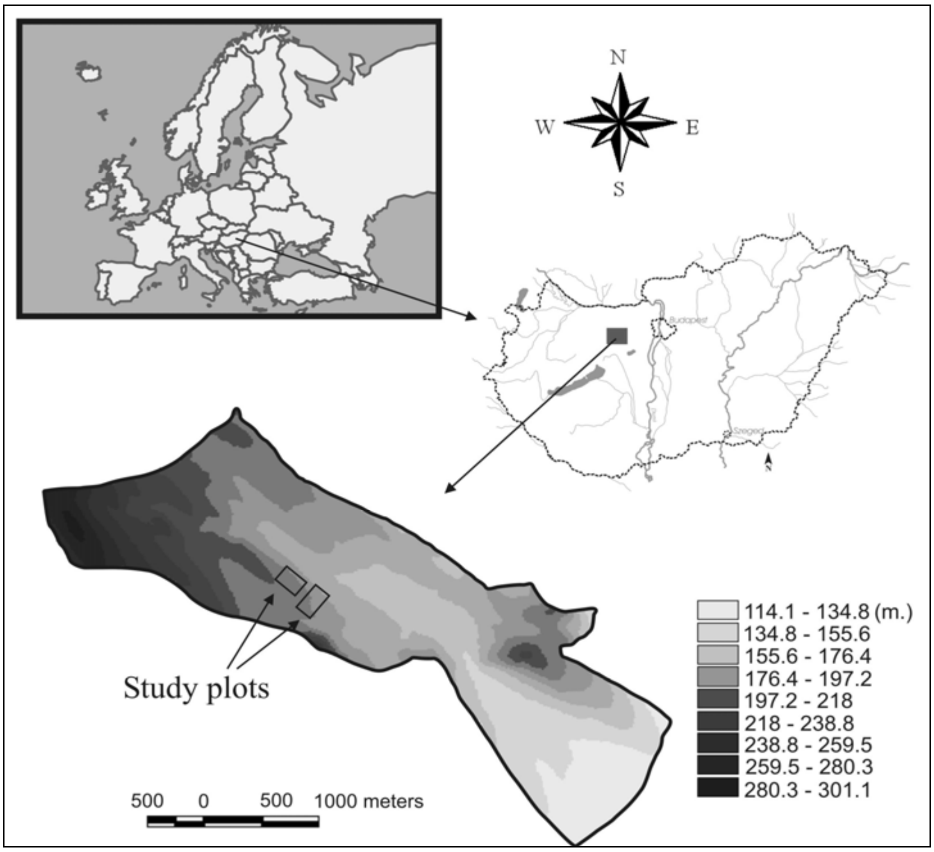

Figure 1. The situation and the relief of the study area

Areas covered with loess contain primarily moderately eroded Chernozems and Phaeozems (Zech & Hintermaier-Erhard, 2002). In lower areas and in smaller patches, Gleyic Chernozems and Fluvisols appear. In granite and andesite areas, Cambisols are characteristic (FAO et al., 2007).

Natural oak forests, locust-trees and low-quality grazing grounds are common on Cambisols. On designated in order to calibrate the Erosion 3D model. The characteristics of these plots are as follows: One of the two studied plots is used for large-scale production of grapes, while the other is arable land. The soil type is eroded Chernozems, and the soil texture is loam and sandy loam. The average slope angle is 4^{o}, ranging from 1^{o} to 6^{o}. The pH of soil is neutral to moderately alkaline Chernozems, arable land cultivation (winter wheat, maize, sunflower, rape), vineyards and orchards are typical (Bódis & Dormány, 2000.

3 METHODS AND MATERIALS

3.1 Plot and laboratory examinations

Sediment collectors were placed on the above mentioned plots and spaced at a distance of 25 m in March 2004. Fourteen and twelve collectors were applied in the vineyard and on the arable land, respectively. At the bottom of the slopes, two big tanks were placed in order to measure the total sediment loss from the plots (Figs. 3, 4). The primary aim of the examination was the validation of the soil erosion model E3D (Schmidt et al., 1999). Additionally, we compared the macro- and microelement content, organic matter (OM) content and particle size distribution of the washed-off sediment and that of the soil samples taken in the catchment area (average sample from the upper 0-10 cm). Finally, we calculated enrichment ratios (ERs) (Duttmann, 1999; Boy & Ramos, 2002; Zhang et al., 2004). The sediment build-up in the collectors and the topsoil around the collectors was gathered after every rainfall event. Enrichment ratios (ER) were calculated as follows:

$$ER_{element} = \text{Element concentr.}_{sedim.} / \text{Element concentr.}_{soil}$$

$$ER_{clay} = \text{Clay content}_{sedim.} / \text{Clay content}_{soil}$$

$$ER_{OM} = \text{O.M. content}_{sedim.} / \text{O.M.content}_{soil}$$

Average topsoil samples were taken at 32 locations of the Cibulka catchment (at a depth of 0–10 cm covering an area of 2–4 m^2).

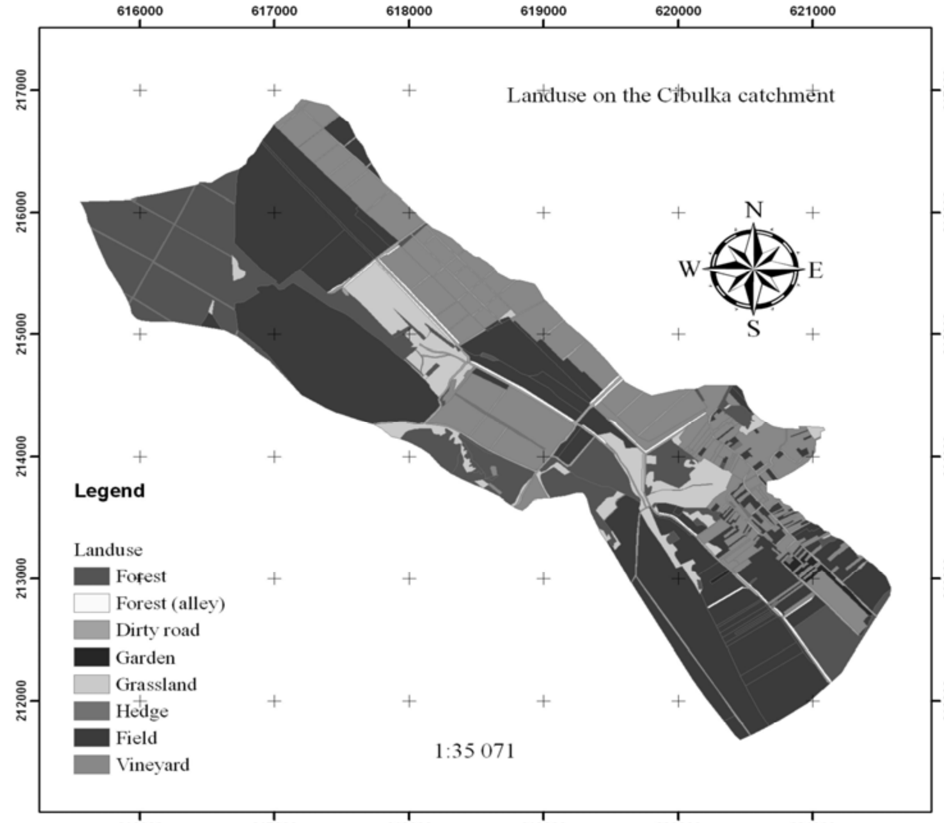

Figure 2. Land use on the Cibulka catchment

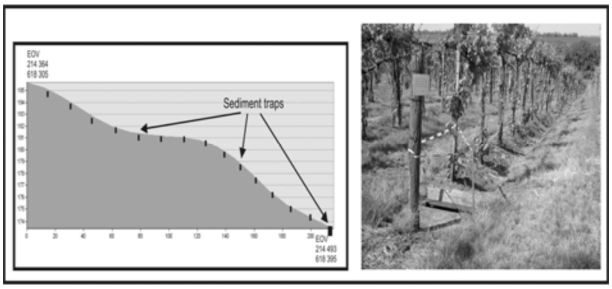

Figure 3. The slope profile under the vineyard and the collector tank

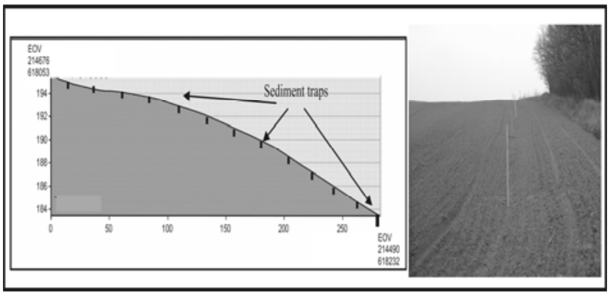

Figure 4. The slope profile on arable land and the covering winter wheat before sowing

Element maps were drafted from these data as the initial state of the investigation. The soil properties and macro- and microelements taken into consideration included pH (H_2O), particle size distribution (%), organic matter content (%), ammonium-lactate soluble P_2O_5 (AL-P_2O_5) content (Riehm, 1958; Egner et al., 1960) and microelement (Zn, Cu, Ni, Pb, Cd) contents. The tests were carried out in accordance with the current Hungarian standards (Buzás, 1988). In the case of microelements, measurements were made using aqua regia digestion with a Perkin Elmer AAS (Atomic Absorption Spectrometer) 3110 (Buzás, 1988). These measurements took place between 2005 and 2007.

Prior to modelling of the soil loss, the input plot and soil parameters affecting erosion were determined by measuring of initial soil moisture, soil texture, soil organic matter content, changes in canopy cover and rainfall parameters and mapping of land use. Canopy cover was measured in the field with a 15-m long wire divided into 100 equal parts. The two ends of the measuring line were fixed so that it angled 45^o with respect to the plant rows. Parts above plant remains were summarised by percentage. Depending on the size of the plot, the number of measurements was repeated (Keveiné & Farsang, 2002). Data regarding precipitation in the sample area might be obtained from rain gauge set up in the catchment (Type BCU LITE2, Boeras Ltd., Hungary).

To determine soil erosion (10x10-m pixel accumulation and soil loss, i.e., net erosion), the Erosion 3D (E3D) model developed in Germany was applied (Schmidt, 1996; Schmidt et al., 1999; Michael, 2000). Digital elevation models and maps of soil properties (soil structure, soil type, OM content, etc.) and land use were generated with ArcView (3.3) and ArcGIS (8.0) software. For statistical analysis, we used the statistical program package SPSS (11.0) for Windows.

3.2 Analysis of measurement data

Erosion 3D (Schmidt 1991, 1996) is a physically based mathematical model that is suitable for simulating runoff and sediment transport in a catchment area (Werner, 1995) (Fig. 5). E3D is based on a regular grid of variable size that must be consistent within the matrix. For this model, a modified 'nearest neighbour' algorithm (O'Callaghan & Mark, 1984) was used to identify the surface runoff. The digital elevation model (DEM) necessary for Erosion 3D was based on analogue topographical maps (scale: 1:10.000) (Bódis & Dormány, 2000) (Fig. 5).

Only the accurate definition of the catchment areas of the two plots, the position and size of loess subsoil paths and other artificial and natural formations (e.g., unmetalled roads, grape terraces, coppices) were adjusted by GPS measurements and adapted in the DEM. The surface properties of the catchment area that affect erosion were determined by the resolution of the DEM (10 m).

Soil parameters were determined in the laboratory before the studied rainfall events (Table 1). Canopy cover was measured for the different land use plots every month. In addition, nine grids were created, one for each soil property and others for additional parameters necessary for modelling. By exporting data from ArcView as ASCII grids, we were able to transfer them to E3D. We calculated 10-minute intensity values from the measured rainfall data, which served as a base for the PR rainfall file of the E3D. The main program processed the three data files generated by the pre-processor, calculated the erosion for one rainfall event in the given area and provided data by cells. Such data for a 10x10-m cell were, for example, soil loss (kg m^{-2}), deposition (kg m^{-2}), and net erosion (t ha^{-1}). The results can be saved in an ASCII file and can be displayed in Arc/View, where further analysis is possible.

The erosion model was previously calibrated in the study area (Farsang & Barta, 2005). The measured data from the two above-mentioned plots were used for testing the model in order to determine the so-called "sensitive" parameters. The input parameters were changed with +10 and -10 % during sensitivity test. The parameters are defined as sensitive ones that cause higher deviation in output ones than 10%.

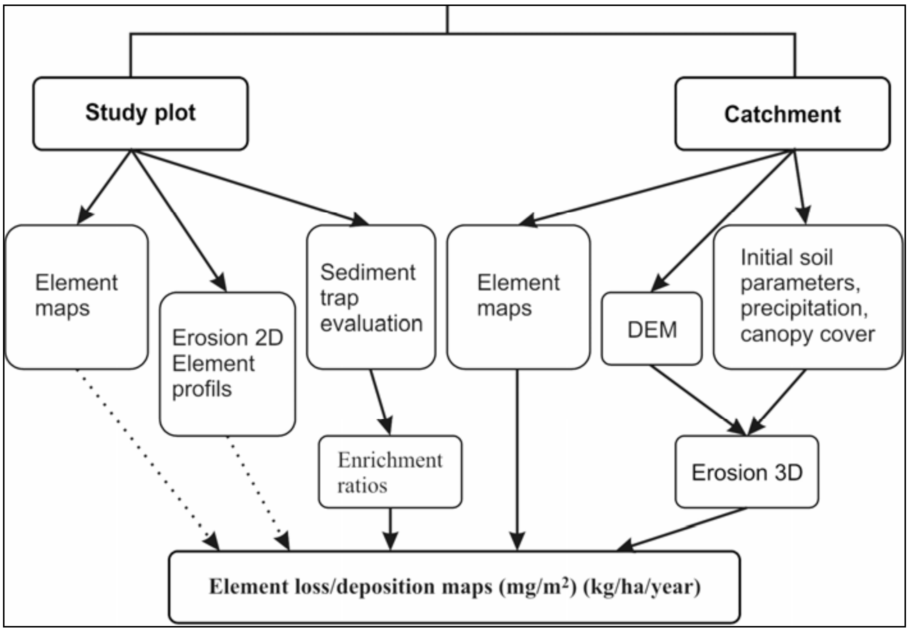

Figure 5 The research process flowchart

Table 1. Applied parameters for model Erosion 3D (before rainfall event on 11th July 2005)

	Arable land (winter wheat)	Vineyard
Measured parameters		
initial soil moisture (v/v %)	23	23
canopy cover (%)	93	53
particle size distribution[a]	sandy loam (9 classes)	sandy loam (9
Org. matter cont. (m/m%)	2.0	2.75
From parameter catalogue		
Manning's n ($s\ m^{-1/3}$)	0.1	0.16
bulk density ($kg\ m^{-3}$)	1550	1500
critical impulse flow ($N\ m^{-2}$)	0.1	0.009
correction factor	1.5	1.0
Other		
saturated hydraulic conductivity ($mm\ h^{-1}$)	inner data, calculated from the bulk density , particle size distribution by the software	

[a] German grain size analysis standard and terms are used

Changes in the four input parameters demonstrated large variability in the output runoff and soil loss values such as bulk density, initial soil moisture and soil cohesion and correction factor.

Several rainfall events in 2004 and 2005 helped us to calibrate the three chosen input parameters for the two different land use types (Farsang & Barta, 2005). The calibrated model was validated on the vineyard and the arable land. The differences between the simulated and measured values were less than 30%.

With the help of the final erosion map, the initial element content (EC) map and the enrichment ratios (ERs), a map of macro- and microelement due to erosion in the catchment area was created via the following two steps:

1. Calculation of element concentration motion with sediment in mg kg^{-1}:

$$EC_{sediment} = ER_{element} * EC_{original\ topsoil} \qquad (1)$$

2. Calculation of element movement for each pixel in mg m^{-2}:

$$\text{Element loss/deposition} = \text{Soil erosion / deposition } (kg\ m^{-2}) * EC_{sediment}\ (mg\ kg^{-1}) \qquad (2)$$

4 RESULTS AND DISCUSSION

4.1 Soil characteristics

The soil texture in the catchment area is loam and sandy loam. The ratio of the silt+clay fraction shows great variation in different parts of the area, ranging between 25.4 and 78.5%. The organic matter content of the topsoil ranged from 0.2 to 4.8%. The extremely low values were measured in the eroded areas. The macro- and microelement contents of the soil were low (Farsang & Tóth, 2003). The vineyards had not received a nutrient supply since nutrient replacement in 1990. In the arable lands, maintenance of the nutrient content is a primary goal; thus, mainly nitrogen and phosphorus fertilisers were applied.

Table 2. Descriptive Statistics – summary about the measured data along the two slopes (arable land and vineyard) during the early summer of 2004 (three rainfall events)

Vineyard	Unit	N	Min.	Max.	Mean	Std. Dev.
Cu Sed[a]	mg kg^{-1}	41	12.6	61.3	28.3	7.3
Cu Soil[b]	mg kg^{-1}	41	16.9	36.1	23.9	5.3
Ni Sed	mg kg^{-1}	41	30.1	103.3	58.5	17.2
Ni Soil	mg kg^{-1}	41	9.6	59.9	30.1	11.9
Pb Sed	mg kg^{-1}	41	12.8	56.2	31.4	13.1
Pb Soil	mg kg^{-1}	41	15.0	36.2	25.9	7.2
Zn Sed	mg kg^{-1}	41	38.4	134.9	57.1	15.7
Zn Soil	mg kg^{-1}	41	20.1	59.8	46.2	7.8
Cr Sed	mg kg^{-1}	41	91.9	196.5	135.7	23.1
Cr Soil	mg kg^{-1}	41	56.0	173.9	136.2	23.1
Co Sed	mg kg^{-1}	41	0.6	38.6	16.9	13.1
Co Soil	mg kg^{-1}	41	4.8	42.1	21.3	11.3
Clay+Silt Sed	m/m %	41	32.0	81.1	58.7	11.9
Clay+Silt Soil	m/m %	41	25.4	73.2	52.3	15.6
OM[c] Sed	m/m %	28	0.4	3.9	2.1	1.0
OM Soil	m/m%	28	0.5	4.8	1.1	0.8
P_2O_5 Sed	mg kg^{-1}	28	11.5	64.0	35.1	16.8
P_2O_5 Soil	mg kg^{-1}	28	5.9	51.6	22.7	13.7
Arable land						
Cu Sed[a]	mg kg^{-1}	35	20.4	58.7	31.9	9.2
Cu Soil[b]	mg kg^{-1}	35	14.5	57.8	31.9	9.9
Ni Sed	mg kg^{-1}	35	18.2	112	57.8	27.1
Ni Soil	mg kg^{-1}	35	19.1	55.8	33.6	10.9
Pb Sed	mg kg^{-1}	35	10.6	56.3	31.2	13.5
Pb Soil	mg kg^{-1}	35	12.5	53.3	31.7	10.8
Zn Sed	mg kg^{-1}	35	30.1	76.0	52.6	10.7
Zn Soil	mg kg^{-1}	35	16.2	65.2	46.1	10.4
Cr Sed	mg kg^{-1}	35	93.8	167.7	137.8	23.6
Cr Soil	mg kg^{-1}	35	101.7	166.8	129.6	20.1
Co Sed	mg kg^{-1}	35	1.3	41.1	22.1	12.5
Co Soil	mg kg^{-1}	35	2.9	45.2	27.1	11.9
Clay+Silt Sed	m/m %	35	38.2	83.2	60.5	11.6
Clay+Silt Soil	m/m %	35	27.0	78.5	52.4	17.7
OM[c] Sed	m/m %	24	0.5	3.1	1.4	0.6
OM Soil	m/m%	24	0.2	2.7	0.9	0.5
P_2O_5 Sed	mg kg^{-1}	24	8.4	61.6	19.0	11.8
P_2O_5 Soil	mg kg^{-1}	24	3.0	18.6	10.3	3.8

[a]Concentration in sediment. [b]Concentration in soil.[c]Organic matter

Table 3. The results modeled by E3D based on rainfall events between 2002 and 2006 (successful measurement with sediment collectors are highlighted)

Date	**Quantity of**	**Netto erosion**	**Rainfall**	**Summation**	**Rainfall intensity**
13. 07. 2002.	1.00	0.05	20	5	28.2
18. 07. 2002.	1519.10	6.27	140	32.9	51
06. 08. 2002.	7.00	0.77	140	13.1	18.6
07. 08. 2002.	300.94	1.24	90	17.6	45.6
20. 08. 2002.	311.17	1.28	50	15.5	55.8
20. 09. 2002.	54.28	0.22	100	11.6	27.6
24. 06. 2003.	1.00	0.06	20	9.4	37.8
07. 05. 2004.	**n.d.**	**n.d.**	**20**	**2.85**	**10.8**
06. 06. 2004.	**1.50**	**0.03**	**60**	**8.95**	**16.8**
24. 06. 2004.	**2.00**	**0.04**	**90**	**18**	**31.2**
30. 07. 2004.	5.00	0.05	70	7.5	21
14. 05. 2005.	1.14	0.08	90	8.5	21
18. 05. 2005.	1124.6	4.64	100	17.3	55.2
15. 06. 2005.	6.00	0.66	20	6.9	39
29. 06. 2005.	1.59	0.11	70	12.6	39
11. 07. 2005.	**741**	**0.06**	**120**	**25.3**	**45**
06. 03. 2006.	**n.d.**	**n.d.**	**n.d.**	**7.2**	**Snow melting**
09. 07. 2006.	1534	6.34	n.d.		n.d.
19. 09. 2006.	1134	4.68	40	19.1	12.7

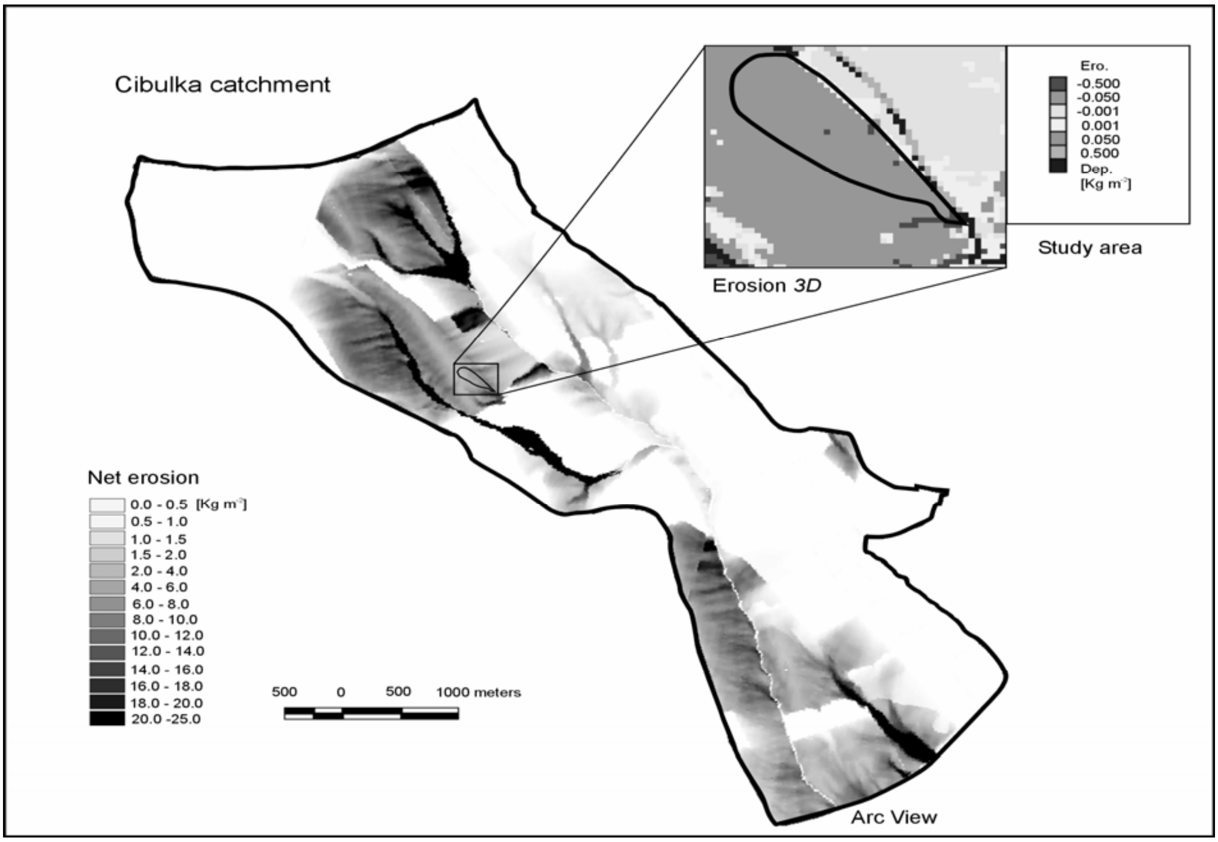

Figure 6. Spatial pattern of erosion/accumulation in the Cibulka catchment

Table 4. Descriptive Statistics – summary of the calculated enrichment ratios along the two slopes (arable land and vineyard) during the early summer of 2004 (three rainfall events) ([a]Enrichment ratio - ER [b]Organic matter - OM)

Vineyard	N	Min.	Max.	Mean	Std.
Cu_ER[a]	41	0.7	3.0	1.2	0.4
Ni_ ER[a]	41	1.0	6.8	2.2	1.1
Pb_ ER[a]	41	0.7	2.1	1.2	0.5
Zn_ ER[a]	41	0.8	3.1	1.3	0.4
Cr_ ER[a]	41	0,7	2.8	1.0	0.3
Co_ ER[a]	41	0.1	6.9	1.2	1.5
Clay+Silt_ER[a]	41	0.6	2.4	1.2	0.5
OM[b]_ ER[a]	28	0.4	5.5	2.1	1.2
P_2O_5_ ER[a]	28	0.6	3.4	1.8	0.7
Arable land					
Cu_ER[a]	35	0.4	1.9	1.0	0.3
Ni_ ER[a]	35	0.4	5.8	2.2	1.6
Pb_ ER[a]	35	0.6	1.6	0.9	0.2
Zn_ ER[a]	35	0.6	2.5	1.2	0.3
Cr_ ER[a]	35	0.8	1.5	1.1	0.2
Co_ ER[a]	35	0.1	4.9	0.9	0.8
Clay+Silt_ER[a]	35	0.7	2.2	1.3	0.4
OM[b]_ ER[a]	24	0.5	6.3	2.2	1.7
P_2O_5_ ER[a]	24	0.7	4.9	2.1	1.2

The macro- and microelement contents of the topsoil were lowest in the north-western arable lands (maize, winter wheat) with greater relief, which is the area most exposed to erosion, as well as in the study areas characterised by vineyards.

The lower south-western arable lands, with lower relief, had higher element contents. The values characteristic of the soils and of the sediments that accumulated in the collectors of the two study plots are summarised in table 2.

4.2 Modelling soil erosion with Erosion 3D

19 erosion rainfall events were registered in the sample area between 2002 and 2006. The rain gauge in this area recorded 18 rainfall events in 2004, but intensity and quantity of just 4 ones exceeded the 10 mm/h (Table 3). Consequently, these can be considered to erosive events. These events caused significant erosion in the sampling site on the 6th and 24th of June. At the same time, measurements with sediment collectors succeed in carrying out.

The E3D model was run to study these rainfalls. The rainfall on June 6th was not as intense as the other rainstorm, and the intensity exceeded 15 mm h^{-1} in the first 10 minutes. After a 20-minute light rainfall in the following 30 minutes, the intensity was about 8-10 mm h^{-1}. The rainstorm on June 24th was much more severe, with intensity in the first half -hour of almost 30 mm h^{-1}, followed by only a slight drizzle.

Table 5. The correlation matrix of the studied parameters measured in the sediment moving with erosion. Pearson Correlations.

	Cu	Ni	Pb	Zn	Cr	Co	Clay+silt	OM^b	P_2O_5
Cu	1								
Ni	-0.128	1							
Pb	-0.223	-0.056	1						
Zn	0.464^a	-0.320^a	0.214	1					
Cr	0.252	0.466^a	-0.556^a	-0.038	1				
Co	-0.246	0.004	0.897^a	0.09	-0.564^a	1			
Clay+silt	-0.149	**0.424^a**	0.221	0.011	**0.304^a**	0.114	1		
OM^b	**0.406^a**	-0.175	-0.256	**0.412^a**	0.181	-0.468^a	-0.127	1	
P_2O_5	0.379^a	-0.379^a	-0.189	0.505^a	0.062	-0.395^a	-0.258	**0.801^a**	1

^{a}Correlation is significant at the 0.01 level (2-tailed). ^{b}Organic matter.

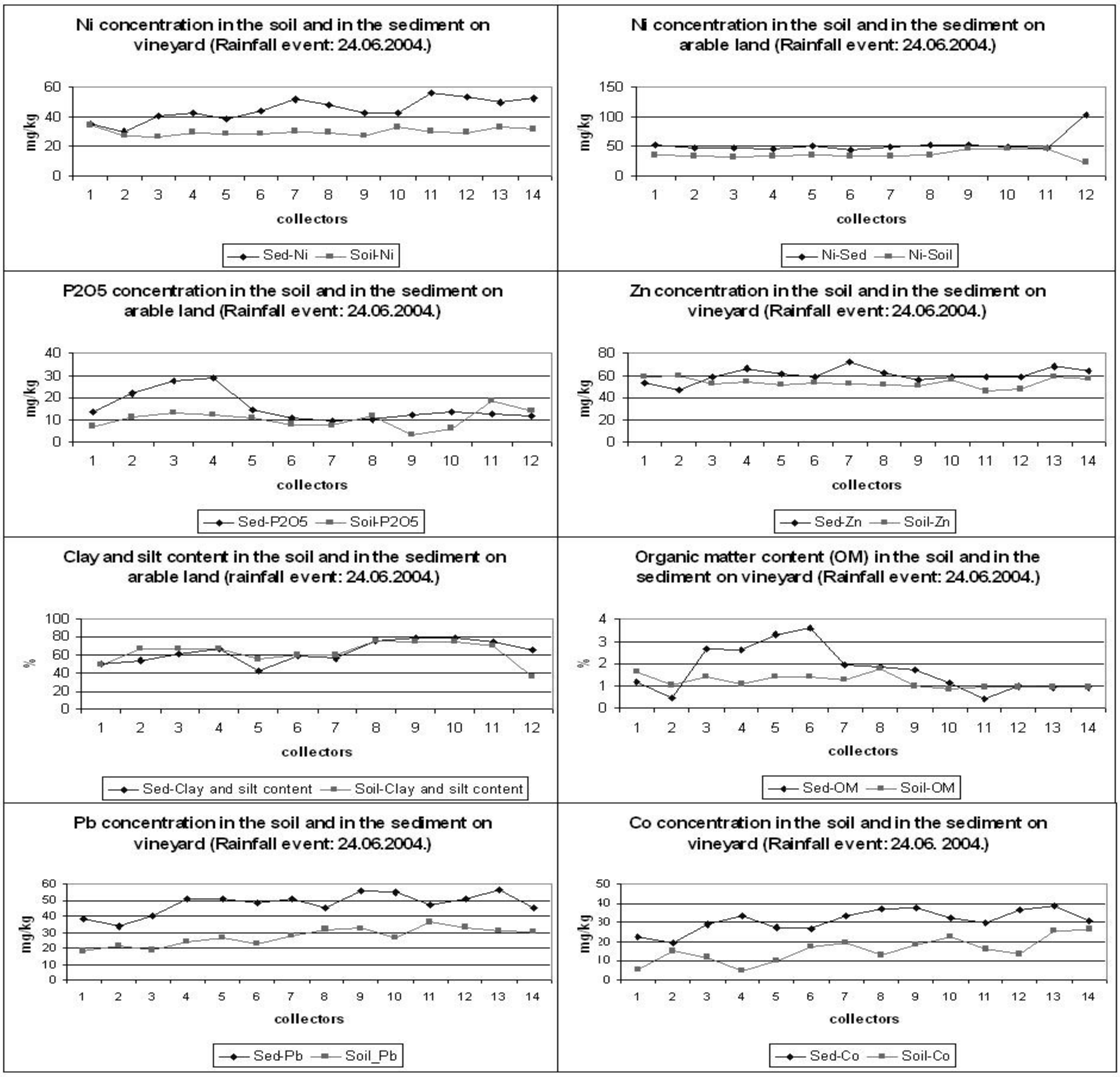

Figure 7. Examples of concentration differences in soils and sediments along the two slopes for various elements

Using E3D (Fig. 6), analysis of macro- and microelement transport at the catchment scale has become possible. Arable lands seem to be more critically affected by erosion than vineyards. The roles of water and sediment transporting of soil roads are also clear. Both events resulted in similar patterns in the catchment; however, while erosion caused by the first rain was below 1-2 kg m^{-2}, the storm on the 24th resulted in erosion rates of 2-6 kg m^{-2} in areas with underdeveloped linear drainage networks.

4.3 Macroelement and microelement concentration in sediment and enrichment ratios

On the basis of experiments conducted with 14 (vineyard plot) and 12 collectors (arable plot) on two slopes of the sample plots (Fig. 2, 4), we observed that the organic matter and silt+clay fraction ratio did not show any increase down the slope. The element content statistic was created in accordance with soil and sediment samples collected after erosive precipitation events in 2004. There were no significant differences in the above-mentioned parameters.

Comparing macro- and microelement contents in soil with those in sediment, it can be seen that Cu concentrations in the vineyard plot were high, whereas the average values in both soil and sediment were similar. There was considerable element excess in the sediment of both plots in the cases of Ni, Zn and P_2O_5 (Fig. 7, Table 4).

As far as macro- and microelements are concerned, in the cases of all the studied rainfall events and slopes, Ni, Pb and Co showed increases in concentration in both soil and sediment in the collectors. Elemental Cu, Cr, Zn and AL-P_2O_5 concentrations changed irregularly down the slope (Fig. 7). However, in connection with all of the studied parameters, the concentration measured in the washed-off sediment was higher than that in the soil.

The biggest measured difference was between the element (Ni, Pb and AL-P_2O_5) concentrations in the sediment caught in the collectors and those of the original soil surrounding them, in connection with the erosion due to the rainfall event on 24th June 2004.

On the basis of our measurement results, we can state that, given the soil type and slope conditions in the erosional sediments compared to the original soil, organic matter enrichment (ER_{arable}=2.1, ER_{vine}=2.2) and clay +silt enrichment (ER_{arable}=1.3, ER_{vine}=1.2) were characteristic. Among the microelements, primarily Ni (ER_{arable} and ER_{vine}=2.2), Zn (ER_{arable}=1.2, ER_{vine}=1.3) and Cu (ER_{arable}=1.0, ER_{vine}=1.2) were enriched. P_2O_5 was also enriched to a great extent (ER_{arable}=2.1, ER_{vine}=1.8) (see Table 4). The enrichments of Pb and Co were different on two slopes with an enrichment ratio of 1.2 in the case of metals originating from the vineyard plot. These two elements did not accumulate in sediment from arable land (ER=0.9). In addition, there was no enrichment in the case of Cr for both slope types (ER=1.0-1.1).

A great proportion of the macro- and microelements of the topsoil that were moved were adsorbed to the humus and clay colloids of the sediment. This was indicated by the fact that the concentrations of some elements showed significant correlations with the organic matter and silt+clay contents of the sediment (Table 5).

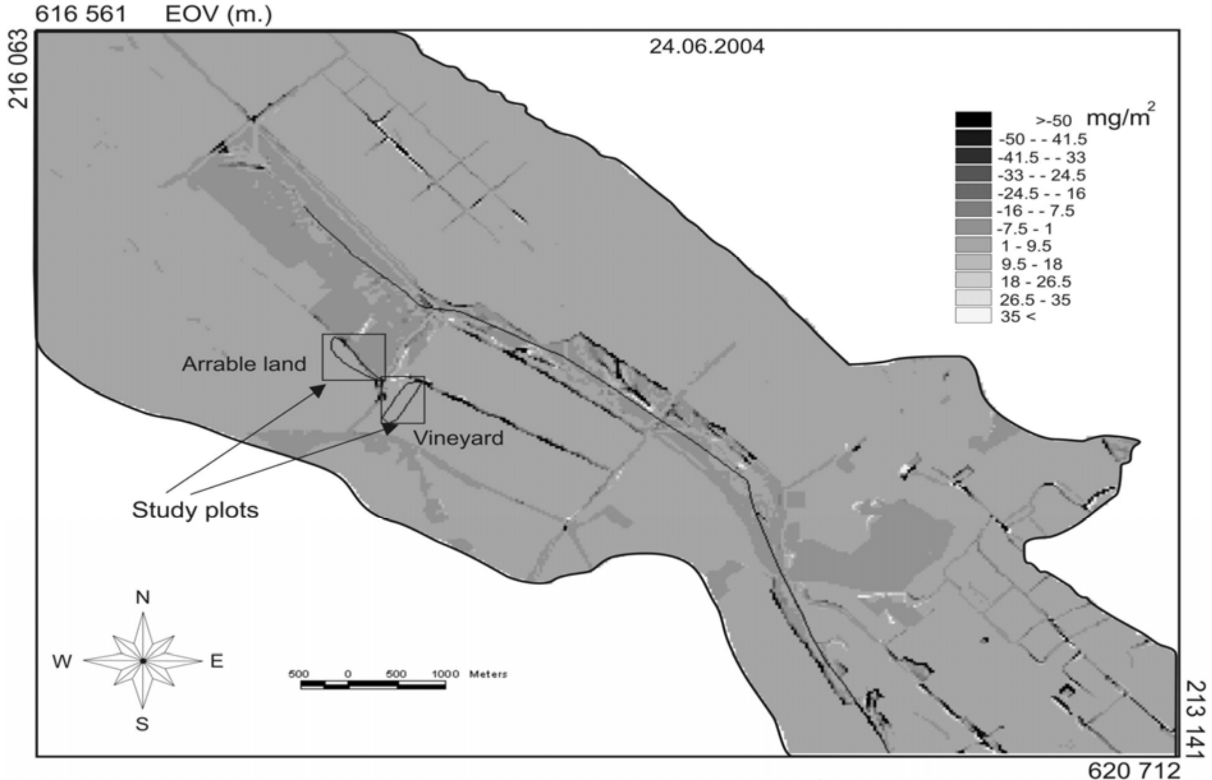

Figure 8. AL-P_2O_5 movement due to the rainfall event of 24th June 2004 (mg m^{-2})

Table 6. Values of element movement connected with the particles of the topsoil in the catchment on June 2004 (mg m^{-2})

		06.06.2004.			24.06.2004.	
	Max.	Mean	SD	Max.	Mean	SD
AL-P_2O_5	408.09	5.48	20.55	1017	15.05	55.32
Zn	784.39	14.26	49.35	1928	39.09	133.44
Cu	255.45	5.021	16.38	626.03	13.75	44.29
Pb	251.08	4.11	13.93	620.9	11.26	37.29

The concentrations of Cu, Zn and AL-P_2O_5 showed significant positive correlations with the organic matter content, while the concentration of Ni did so with clay+silt content.

With the help of the erosion map (kg m^{-2}) (Fig. 5) calculated per rainfall event in the catchment area, the initial element distribution maps (mg kg^{-1}) and the enrichment factors calculated on the study plot, we generated macro- and microelement variability maps for each rainfall event (mg m^{-2}) (Fig. 5, Fig. 8). The enrichment ratios for each land use type (vineyard, arable land) were used to create maps of element movements. As a result, two areas were outlined that are endangered by erosion and sensitive to element wash-out. One area included the high-relief arable lands in the northwest of the catchment area (maize, winter wheat), while the other consists of the area under grape production.

The map (Fig. 8) clearly shows that the ridges exposed to erosion, along with gills, ditches and roads, carried most of the moving sediment. These are the most important tracks for element transport. In these areas, net erosion may reach 14-18 kg m^{-2}. As a result of the 8.9 mm of precipitation that fell between 15:40 and 16:40 on 6th June 2004 (maximum intensity of 16.8 mm h^{-1}), 200-400 mg m^{-2} of Zn transport was observed in the areas eroding most intensely. The average Zn transport in the sample area was 14.26 mg m^{-2}. As a result of the more intense rainfall event on 24th June 2004 (18 mm of precipitation) at the portion of the slopes exposed to the most intense erosion, Zn transport exceeded 1500 mg m^{-2} depending on the initial element content (Table 6). AL-P_2O_5 wash-off was significant in arable lands having greater phosphorus contents than the surrounding areas (Fig. 7). The arable lands in the northern and south-western parts of the catchment area were the most endangered from the point of view of nutrient loss. We compared the measured phosphorus wash-off values ($P= P_2O_5 * 0.4364$) to the values for the catchment area of Lake Balaton (the largest Hungarian lake), which were 15.0-18.7 kg P ha^{-1} $year^{-1}$ (Debreczeni, 1987). Based on our rainfall data, we can say that in 2004 there were 14 erosive rainfalls in the area, and 8 of those occurred in May and June. In our catchment area, the phosphorus wash-off ranged between 0.02–4.44 kg ha^{-1}. The resulting lower value may be caused by the fact that the fertilisation practice in Hungary has changed since the 1990s. The volume of deposited fertilisers has largely decreased with halts of subsidies; therefore, the volume of nutrient wash-off from arable lands has also decreased. As far as microelements are concerned, there were no comparable data for the catchment area of Lake Balaton.

5 SUMMARY AND CONCLUSIONS

During our research, we carried out examinations in a typical rural area of Hungary in the catchment area of a shallow, environmentally sensitive lake (Lake Velence, NW Hungary). We examined enrichment ratios (ER) in erosive sediment created by rainfall events by setting up sediment collectors. Taking the whole catchment area into consideration (14 km^2), we modelled soil erosion with Erosion 3D software. After soil sampling and analysis, we constructed initial element maps (AL-P_2O_5, Zn, Ni, Pb, Cr, Co, Cu), and with the help of the enrichment ratios, we modelled macroelement and microelement transport caused by rainfall events in the catchment area.

As a result of our examinations, the two modelled rainfall events resulted in similar patterns in the catchment; however, while total erosion due to the first rain (6th June 2004) remained under 10 t ha^{-1}, erosion due to the rainstorm on the 24th reached 20-60 t ha^{-1} in the areas with undeveloped linear drainage networks. Our analyses of the sediment collectors set up along the slopes showed that the element concentration measured in the washed-off sediment exceeded the concentration in the soil for every studied parameter. Studying the element loss maps, it can be stated that spatial changes were not determined by the differences in the initial element map, but by erosional conditions. They clearly show that ridges exposed to intensive erosion, as well as gullies, ditches and roads, carry the most moving sediment. These are the most important tracks for element transport. There were slight differences between enrichment ratios calculated from the two plots with distinct land uses. OM (ER=2.1-2.2), P_2O_5 (ER=1.8-2.1) and Ni (ER=2.2) accumulated the most in the sediment moved by erosion. The particle sizes less than 0.02 mm, Cu, Pb, Zn and Co accumulated moderately (ER= ~1.2), whereas Cr has not accumulated at all.

The AL-P_2O_5 wash-off was significant, primarily in arable lands with higher phosphorus contents than the surrounding areas. The average AL-P_2O_5 wash-off during the studied rainfall events was 5.5 – 15.1 mg m^{-2}, the estimated Zn transport was 14.3-39.1 mg m^{-2}, Cu 5,02-13.75 mg m^{-2}, Pb 4.1-11.3 mg m^{-2}.

The erosion model for the entire catchment area based on the above method, and the detection of macro- and microelement transport patterns, is useful. These models help with land use planning, determination of land use and the determination of cultivation methods optimal for reducing erosion in rural areas. Our final maps are excellently used in environment-friendly nutrient management in order to delimit the areas of the nutrient accumulation.

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REFERENCES

Arghius, C. & Arghius V. 2011. *The quantitive estimation of the soil erosion using usle type romsen model. Case study the Codrului Ringe and Piedmont (Romania).* Carpathian Journal of Earth and Environmental Science, 6, 2

Bódis, K. & Dormány, G. 2000. *Three decades of land use changes in the Velence Mountains, Hungary.* Acta Geographica Szegediensis (in Hungarian) 37, 11-19.

Bogena, H., Diekkrüger, B., Klingel, K., Jantos, K. & Thein, J. 2003. *Analysing and modelling solute and sediment transport in the catchment of the Wahnbach River.* Physics and Chemistry of the Earth, 28, 6-7, 227-237.

Boy, S. & Ramos, M.C. 2002. *Metal enrichment factors in runoff and their relation to rainfall characteristics in a Mediterranean vineyard soil.* In. SUMASS 2002. Murcia, Proceedings Volume II., 423-424.

Buzás, I. (ed) 1988. *Methodology of soil and agrochemical examinations 2* (in Hungarian). Mezőgazdasági Kiadó, Budapest, 243.

Czinege, E. 1999. *New prospects of agrotechnics considering the characteristics of soil cover. Agrochemistry and Pedology* (in Hungarian). 48, 1-2, 224-232.

Csathó, P., Osztoics, E., Sárdi, K., Sisák, I., Osztoics, A., Magyar, M. & Szűcs, P. 2003. *Phosphorus load of surface waters from agricultural areas I. Evaluating phosphorus transport examinations.* Agrochemistry and Pedology (in Hungarian). 52, 3-4, 473-486.

Csathó, P., Árendás, T., Fodor, N., & Németh, T. 2009. *Evaluation of Different Fertilizer Recommendation Systems on Various Soils and Crops in Hungary.* Communications in Soil Science and Plant Analysis, 40, 11-12, 1689-1711.

Déri, J. 1986. *The effects of floral changes on nutrient wash-out in a catchment area* (in Hungarian). Journal of Hydrology 66, 6, 323-328.

Debreczeni, B. 1987. *The NPK balance of Hungarian agriculture* (in Hungarian). International Agricultural Review, 2-3, 150-153.

Duttmann, R. 1999. *Partikulare Stoffverlagerungen in Landschaften Geosyntesis* 10, Abteilung Physische Geographie und Landschaftsökologie, Universitat Hannover, p. 233.

Egner, H., Riehm, H. & Domingo, W. R. 1960. *Untersuchungen über die chemische Bodenanalyse als Grundlage für die Beurteilung des Nahrstoffzustanden der Böden. II.* Chemische Extraktionsmethoden zur Phosphor und Kaliumbestimmung. Kungl Lantbr-Högsk Ann. 26., 401-410.

FAO (Food and Agriculture Organization of the United Nations), IUSS (International Union of Soil Sciences), ISRIC (International Soil Reference and Information Centre) 2006. (the first update 2007) *World reference base for soil resources.* A framework for international classification, correlation and communication, Rome, Italy, pp.128. ISBN: 92-5-105511-4. (http://www.fao.org/ag/agl/agll/wrb/doc/wrb2006final.pdf).

Farsang, A. & M.Tóth, T. 2003. *Spatial distribution of soil nutrient in a cultivated catchment area: estimation using basic soil parameters.* In: 4th European Congress on Regional Geoscientific Cartography and Information Systems, Bologna, Italy, 2003 jun. Proceedings Book, 154-156.

Farsang A. & Barta K. 2005. *The effect of soil erosion on the macro- and microelement content of topsoil. Soil protection.* Special Issue (in Hungarian). Pedology Conference, Kecskemét 24-26 August 2004, 268-277.

Fletcher C. F., Arshad M.A., Izaurralde R. C. & McGill W. B. 2004. *Spatial Variability of Nutrient Requirements in Fields of the South Peace River Region, Alberta.* Communications in Soil Science and Plant Analysis, 35, 7-8, 903 -919.

Heathwaite, L., Sharpley, A. & Bechmann, M. 2003. *The conceptual basis for a decision support framework to assess the risk of phosphorus loss at the field scale across Europe.* Journal Plant Nutrition and Soil Science, 447-458.

Horváth, J. (ed) 1996. *Review of the regional environmentalist melioration plans of the catchment area of Lake Balaton.* AGROBER, Budapest.

Isringhausen, S. 1997. GIS-gestützte Prognose und Bilanzirung von Feinboden und

Nahrstoffaustragen in einem Teileinzugsgebiet der oberen Lamme in Südniedersachsen Diplomarbeit, Universitat Hannover, pp. 34-42.

Jakab, G. & Szalai, Z. 2005. *Erosional sensitivity investigation with rainfall on brown soil of the catchment of Tetves-patak* (in Hungarian). Tájökológiai Lapok, 177-189.

Joó, O. 1980. *Data of eutrophisation of Lake Balaton and considerations related to control activities.* MTA VEAB Veszprém (in Hungarian)

Karászi, K. 1984. *The recreation of Lake Velence. Circular of conservancy, engineering and economics* (in Hungarian). Budapest, 145.

Kerényi, A. & Szabó, Gy. 1997. *The role of morphology in environmental pollution.* Zeitschrift für Geomorphologie, 110, 197-206.

Keveiné, B. I. & Farsang, A. 2002. *Field and Laboratory Methods in Physical Geography.* (in Hungarian) Szeged, 67-68.

Lal, R., Ahmadi, M. & Bajracharya, R.M. 2000. *Erosional impacts on soil properties and corn yield on alfisols in central Ohio.* Land degradation & development, 11, 575-585.

Marosi, S. & Somogyi, S. (eds) 1990. *The cadastre of the Hungarian small regions II.* MTA FKI (in Hungarian), Budapest, 684-699.

Marton, I. 2000. *Examining biogenic material transport in the agricultural areas of the catchment area of Lake Balaton.* Agrochemistry and Pedology (in Hungarian) 49, 1-2, 84-104.

Michael, A. 2000. *Anwendung des physikalisch begründeten Erosionsprognosemodells Erosion 2D/3D - empirische Ansätze zur Ableitung der Modellparameter.* Ph.D thesis, Universität Freiberg.

Mucsi, L. 1995. *Investigation of reed development on Lake Velence.* Proceeding of ERDAS Users Group Meeting. Atlanta, 41-46.

O'Callaghan, J.F. & Mark, D.M. 1984. *The extraction of drainage networks from digital elevation data.* Computer Vision, Graphics, and Image Processing 28, 323-344.

Pansak W., Hilger T.H., Dercon G., Kongkaew T. & Cadisch G. 2008. *Changes in the relationship between soil erosion and N loss pathways after establishing soil conservation systems in uplands of Northeast Thailand Agriculture.* Ecosystems and Environment, 128, 167-176.

Riehm, H., 1958. *Die Ammoniumlaktat-essigsäure. Methode zur bestimmung der leichtlöslichen phosphorsäure in karbonathaltigen böden.* Agrochimica, 3, 49-65.

Schmidt, J., 1991. *A mathematical model to simulate rainfall erosion.* In: Bork, H.-R., de Ploey, J. and Schick, A.P. (eds): Erosion, Transport and Deposition Processes - Theories and Models. Catena Supplement, 19, 101-109.

Schmidt, J. 1996. *Entwicklung und Anwendung eines physikalisch begründeten Simulationsmodells für die Erosion geneigter landwirrtschaftlicher Nutzflächen.* Berliner Geogr. Abhandlung

Schmidt, J., Werner M.V. & Michael, A. 1999. *Application of the EROSION 3D model to the CATSOP watershed, The Netherlands.* Catena, 37, 449-456.

Sharpley A. 1995. *Identifying sites vulnerable to phosphorus loss in agricultural runoff.* Journal of Environmental Quality, 24, 947-951.

Stefanescu L., Constantin V., Surd V., Ozunu A., & Vlad S. N. 2011. *Assessment of soil erosion potential by the USLE method inRos¸ia Montana mining area and associated NATECH events.* Carpathian Journal of. Earth and Environmental Science., 6,1, 35-42.

Szabó Sz. & Szabó Gy. 2004. *Environmental evaluation of effect of acid loads on instance of manganese and copper mobilization of the soil.* (in Hungarian). II. Magyar Földrajzi Konferencia közleményei, Konferencia CD ROM, 8.

Ulén, B.M. & Kalisky, T. 2005. *Water erosion and phosphorus problems in an agricultural catchment – Need for natural research for implementation of the EU Water Framework Directive.* Environmental Science and Policy, 8, 5, 477-484.

Veum K.S., Goyne K. W., Motavalli P.P. & Udawatta R.P. 2009. *Runoff and dissolved organic carbon loss from a paired-watershed study of three adjacent agricultural Watersheds Agriculture.* Ecosystems and Environment 130, 115-122.

Wang Z., Zhang B., Song K., Liu D., Ren C., Zhang S., Hu L., Yang H. & Liu Z. 2009. *Landscape and Land-Use Effects on the Spatial Variation of Soil Chemical Properties.* Communications in Soil Science and Plant Analysis, 40, 15 -16, 2389-2412.

Werner, M.V. 1995. *GIS-orienterte Methoden der digitalen Reliefanalyse zur Modellierung von Bodenerosion in kleinen Einzugsgebieten.* Dissertation, Freie Universitat Berlin.

Zech, W. & Hintermaier-Erhard, G. 2002. *Böden der Welt.* Spektrum Akademischer Verlag, Heidelberg-Berlin, 120.

Zhang B., Yang Y. & Zepp H. 2004. *Effect of vegetation restoration on soil and water erosion and nutrient losses of a severely eroded clayey Plinthudult in southeastern China.* Catena, 57, 77-91.

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