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CURRENT STATE AND DEVELOPMENT OF LAND DEGRADATION PROCESSES BASED ON SOIL MONITORING IN SLOVAKIA

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Current state and development of land degradation processes based on soil monitoring system in Slovakia is evaluated in this contribution. Soil monitoring system in Slovakia is consistently running since 1993 year in 5-years repetitions. Soil monitoring network in Slovakia is constructed using ecological principle, taking into account all main soil types and subtypes, soil organic matter, climatic regions, emission regions, polluted and non-polluted regions as well as various land use. The result of soil monitoring network is 318 sites on agricultural land in Slovakia. Soil properties are evaluated according to the main threats to soil relating to European Commission recommendation for European soil monitoring performance as follows: soil erosion and compaction, soil acidification, decline in soil organic matter and soil contamination. The most significant change has been determined in physical degradation of soils. The physical degradation was especially manifested in compacted and the eroded soils. It was determined that about 39% of agricultural land is potentially affected by soil erosion in Slovakia. In addition, slight decline in soil organic matter indicates the serious facts on evaluation and extension of soil degradation processes during the last period in Slovakia. Soil contamination is without significant change for the time being. It means the soils contaminated before soil monitoring process this unfavourable state lasts also at present.

Key words: soil monitoring, threats to soil, soil degradation processes, soils in Slovakia

The main aim of this contribution is to obtain the knowledge of the most current state and development of soil properties according to concrete threats to soil (soil erosion, soil compaction, soil acidification, decline in soil organic matter, soil contamination) on the basis of soil representative monitoring system in Slovakia, which consists of 318 monitoring sites where all soil types, geology, climatic regions, various land use – arable land, grassland and protected areas are included and what is in harmony with European strategy of soil monitoring. There are permanently monitored important parameters in connection to recommendation of EC for evaluation of current state and development of soils (van Camp *et al*. 2004) with regard to quantitative and qualitative parameters of soils (Kobza *et al.* 2014) concerning land degradation processes. Land degradation is a decrease in the optimum functioning of soils in ecosystems (de Kimpe & Warkentin 1998). The objective of this contribution is to offer objective information on current state and development of important soil parameters according to main threats to soil as significant component of environment (Linkeš *et al.* 1997). The obtained results from agricultural

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land are evaluated in this paper. In addition, forest land is a part of other monitoring system – Monitoring of forest ecosystems, which is developed by National Forestry Centre – Research Institute in Forestry in Zvolen.

Finally, obtained important current soil outputs are regularly imported to JRC (Joint Research Centre) in Ispra (Italy) and to EEA (European Environment Agency) in Copenhagen (Denmark), as well.

MATERIAL AND METHODS

Monitoring network

Soil monitoring system in Slovakia has been running consistently since 1993 year. Soil monitoring network in Slovakia is constructed on ecological principles and includes the research data of all main soil types and subtypes, soil substrates, climatic regions, emission regions, polluted and non-polluted regions as well as various land use (Figure 1). There are 318 monitoring sites on agricultural land in Slovakia. All soil monitoring sites are located in WGS 84 coordinates. These ones are permanently monitored and evaluated since 1993 in 5-years repetitions. We have completely finished 4 monitored cycles (1st – 1992–1996, 2nd – 1997–2001, 3rd – 2002–2006 and 4th – 2007–2012) for the time being. Nowadays, the 5th monitored cycle is still running and will be completely finished and evaluated in 2018 year soonest. Therefore the latest complete results on current state and land degradation processes development are evaluated in this contribution.

The monitoring site represents the circular shape, with a radius of 10 m and an area of 314 m^2. The standard depths of 0–0.10 m, 0.20–0.30 m and 0.35–0.45 m on soils under grassland and 0–0.10 m and 0.35–0.45 m on arable land are sampled, but the depth is adjusted to characterize the main soil horizons. The most important soil indicators concerning threats to soil are included in the soil monitoring system in Slovakia according to the recommendation of the European Commission (EC) for united soil monitoring system in Europe (van Camp *et al*. 2004).

Monitored indicators and analytical procedures

The most important soil indicators concerning threats to soil are included in soil monitoring system in Slovakia according to Recommendation of European Commission (EC) for unified soil monitoring system in Europe (van Camp *et al*. 2004). *Soil erosion (on selected soil transects)*: ^{137}Cs (gamaspec-

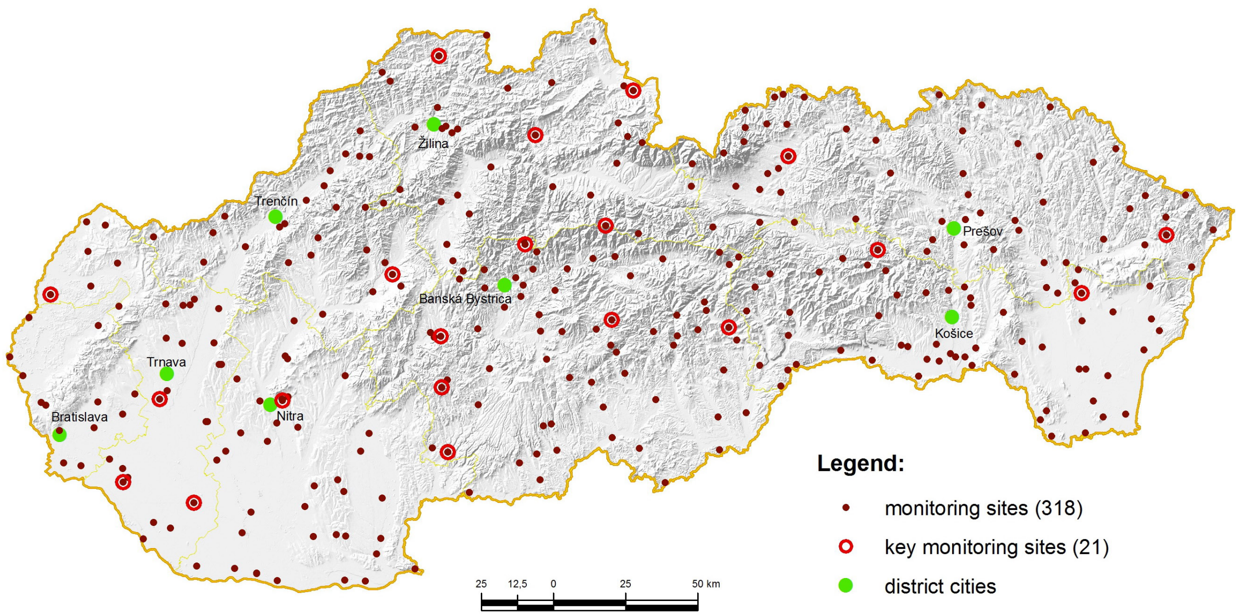


Figure 1. Soil monitoring network in Slovakia

trometrically with high resolution); pH/KCl; SOC (soil organic carbon; dry way using CN analyser); P (according to Egner´s method), K (according to Schachtschabel´s method); texture (according to FAO); s*oil compaction*: bulk density (çd); porosity (P); maximum capillary water capacity (wKMK) in 100 cm^3 cylinders; texture (according to FAO); s*oil acidification*: pH/H_2O, active Al (according to Sokolov); *quantitative and qualitative composition of soil organic m*atter: SOC, Nt (total nitrogen; dry way using CN analyser), C_{HA}/C_{FA}, Q^4_6 (C_{HA}/C_{FA} carbon ratio of humic and fulvic acids, optical parameter Q^4_6 ratio of optical density of C_{HA} solution measured at 465 and 665 nm; according to Kononova and Beľčikova (ex. Kobza *et al.* 2011); s*oil contamination*: Cd, Cr, Pb, Ni, Zn, Cu, As Se, Co (extracted with aqua regia), Hg (total content, analyser AMA 254).

All described methodical and analytical procedures in more details were realized according to the work Uniform analytical procedures for soil (Kobza *et al*. 2011).

Evaluation of measured data

Statistical analysis and data evaluation was carried out using the program Statgraphic XV. Centurion.

RESULTS AND DISCUSSION

Soil erosion

Soil erosion belongs to the most environmental problems and the most extended degradation process in Slovakia. The process of soil erosion is significantly accelerated by unreasonable human activities in the current period of intensification of agriculture. Erosion is measured on erosive transects (series of pedological sites located down the slope) using ^{137}Cs profile distribution. This method was also used by other authors in conditions in Slovakia (Linkeš *et al*. 1992; Fulajtár & Janský 2001; Stankoviansky 2003; Styk 2005; 2007). In addition, the area of soil erosion distribution and its intensity is determined by using of the erosive predictive model where the USLE (Universal soil loss equation) is included (Wischmeier & Smith 1978). This interactive and predictive erosive model has been created for farmers on the purpose to obtain very helpful information on soil erosion intensity and its area distribution as well as to select and finally to implement appropriate methods of land management (Styk *et al.* 2009). They can find this model on http://www.podnemapy.sk.

The obtained results on potential water erosion on agricultural soils in Slovakia are given in Figure 2 and Table 1. On the basis of obtained results (Table 1) about 39% of agricultural soils registered in LPIS (Land Parcel Identification System) are potentially affected by water erosion in Slovakia. It means approximately 10% in medium, 15% in high and 14% in extremely high level (% of agricultural land). Regarding individual soil types, categories of extremely high to medium erosion predominates on soil types located at the mountainous and submountainous regions (Cambisols, Rendzic Leptosols) where about 75% of total area each of these soil types can be affected by potential water erosion.

Soil compaction

Soil compaction is monitored in the soil monitoring network only on arable land on the basis of measured physical indicators such as bulk density, porosity and texture. The values of bulk density on agricultural soils of Slovakia are mostly running between 1.2–1.6 g/cm^3 and are evaluated in the context of their critical values. Risk of soil compaction expressed as percentage of compacted monitoring sites from all evaluated soil types and soil texture is presented in the Figure 3 and 4.

Rate of soil compaction depends mainly on soil texture (significant differences between texturally medium heavy and heavy soils), the type of crop and its cultivation management (combination of crops concerning soil types and textures in sampling cycles) and weather conditions during preparation of soil and crops sowing as well as spring months (partially differences between sampling cycles). Other authors also report the influence of soil texture fractions (Heuscher *et al*. 2005; Benites *et al*. 2007; Shiri *et al*. 2017), the humus content (Soane 1990; Kummar *et al*. 2012), the different tillage and residual practice (Dam *et al*. 2005; Veiga *et al.* 2008) or soil moisture (Timm *et al*. 2006; Logsdon 2012) on soil compaction. Differences in topsoil compaction between soil types are not very significant. Suuster *et al*. (2011) state similar results in humus horizon of soils concerning Estonian soil monitoring. Higher rate of compaction was observed in intensively cultivated Chernozems, heavy Fluvisols and heavy Cambisols probably as a result of reduced tillage at some crops of crop rotation or in texturally differentiated soils (Albic Luvisols and Planosols). Rate of soil compaction is increasing in direction from texturally loamy to clayey soils which are the most sensitive to soil compaction. For the soil compaction development, the best soil physical conditions were recorded in the last monitoring cycle (except medium heavy Luvisols) particularly in relation to content of humus development (Figure 7). The worst state of soil physical properties at the most soil types were observed in the 2. cycle and improved to the last cycle. It likely relates also to the increase of soil organic carbon (Figure 3 and 4). According to soil types distribution the sensitive soils to soil compaction are situated mostly on southwestern and southeastern parts of Slovakia in the lowlands used mostly as agricultural – arable soils (loamy to clayey) cultivated by heavy machinery.

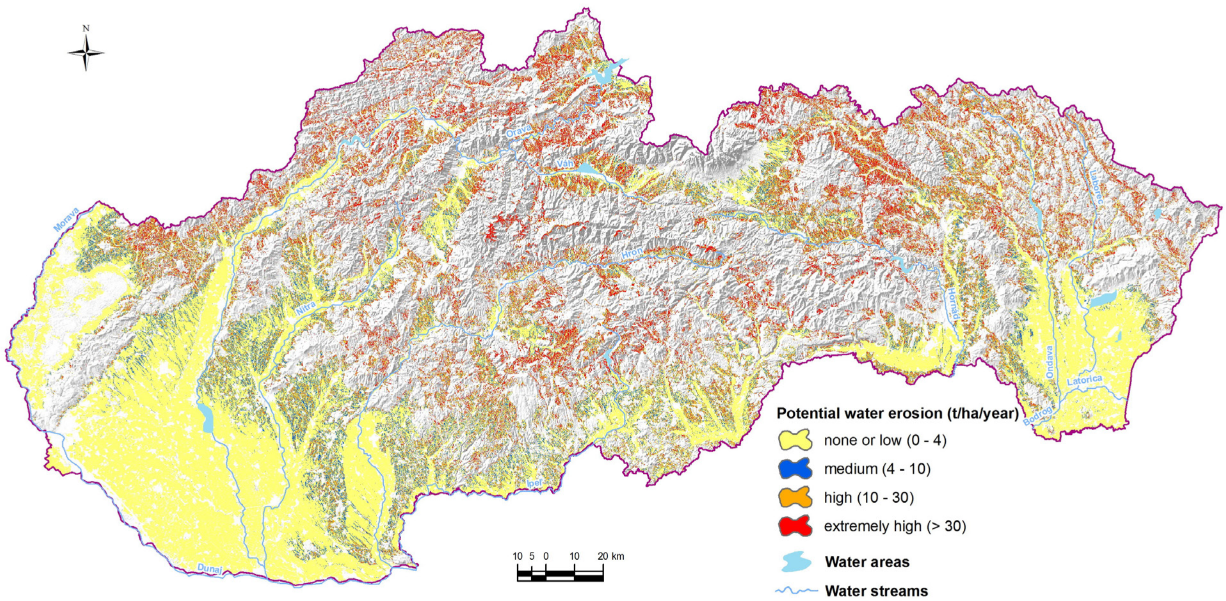


Figure 2. Potential water erosion on agricultural soils in Slovakia

T a b l e 1

Dominant agricultural soils [registered in LPIS] affected by potential water erosion in Slovakia

Soil type	Total area of soil type [ha]	Erosivity categories – soil loss [% of total area of soil type]			
		None or low (0–4 [t/ha/year]	Medium (4–10 [t/ha/year]	High (10–30) [t/ha/year]	Extremely high (more than 30 [t/ha/year])
Chernozem	286,861	95.4	3.2	1.2	0.2
Luvisol	251,209	58.9	19.5	17.5	4.1
Cambisol	864,749	24.1	9.3	23.6	43.0
Planosol, Luvisol	235,955	51.3	19.4	21.3	8.0
Rendzic Leptosol	103,631	24.4	7.9	22.3	45.4
Total area of agricultural soils	1,985,535	61.2	10.4	14.8	13.6

Soil acidification

Soil acidification, normally indicated by the pH decline of a certain soil, has recently received increasing attention due to its important impact on soil environmental quality, food security and human health (Godfray *et al.* 2010). The optimal value of the pH value is the key aspect in soil quality evaluation that belongs to the dynamic soil parameters. It means, that the slight changes of this parameter influence the potential of soil sorbents and inorganic contaminants mobility and their transport (Borůvka & Drábek 2004; Makovníková *et al*. 2007; Jones *et al*. 2012). In the 4th monitoring cycle (sampling in 2007) the decrease of average of active pH value (compared with 1993) in 9 groups of soils was recorded in the depth of 0–10 cm (Figure 5).

The most significant pH reduction in arable land was recorded in the group of Dystric Fluvisols, in grassland in Haplic Podzols group, Skeletic Leptosols and Lithic Leptosols group and the Planosols group. The acidification process in dystric Fluvisols, located on alluvial deposits (along Váh, Hron and Bodrog rivers), decreases their ability to the immobilisation of the potential risk element just due

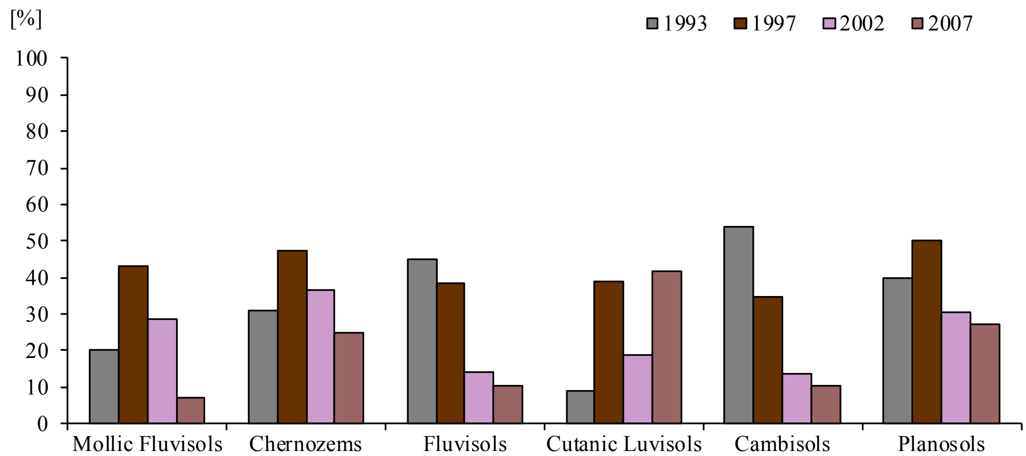


Figure 3. Risk of soil compaction [% of compacted monitoring sites] for main soil types – texturally medium heavy soils in Slovakia

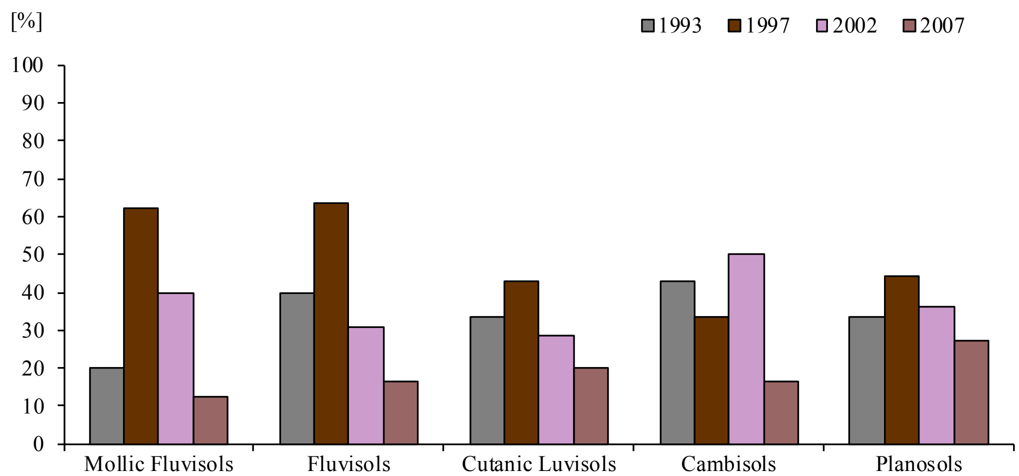


Figure 4. Risk of soil compaction [% of compacted monitoring sites] for main soil types – texturally heavy soils in Slovakia

low pH value of soils as well as low content of soil organic matter. Soils with very low immobilisation potential are reported predominantly in Košice region and Banská Bystrica region, where soils are contaminated by geochemical anomalies and anthropogenic sources, as well (Čurlík & Šefčík 1999; Makovníková *et al.* 2007; Fazekašová *et al.* 2016).

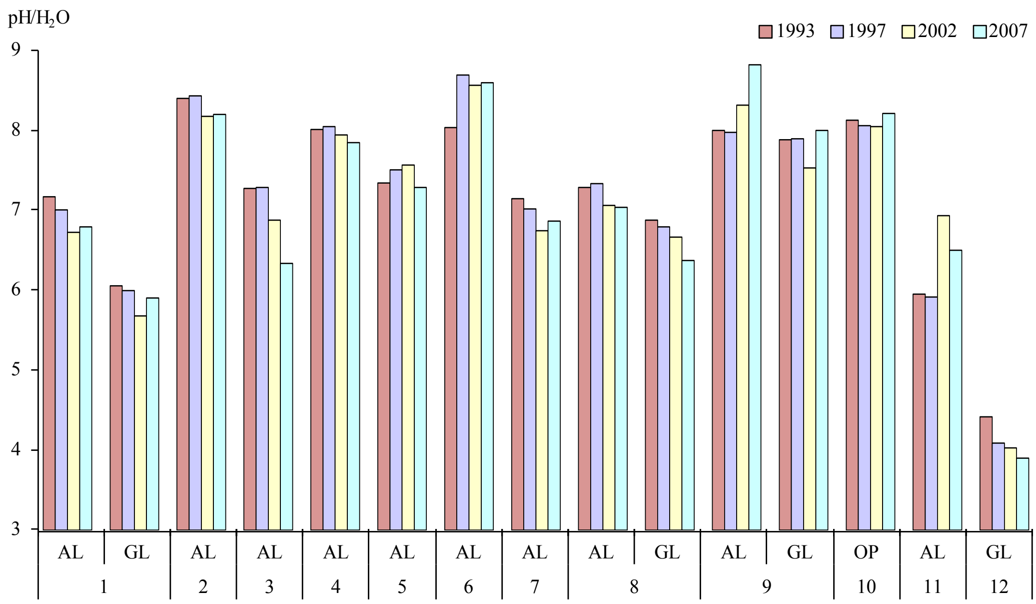
The active Al content in context with pH value is monitored. Al toxicity to plants manifests from slightly acidic to acidic soils. High Al concentrations as Al^{3+} represent an important growth and yield limiting factor for crops in acid soils (pH in $H_2O \leq 6.0$) (Makovníková & Kanianska 1996; Mačuha 1999; Meriño-Gergichevich 2010).

Determined negative correlation between pH value and active Al content ($r = -0.77$) (Figure 6) in soil is consistent with the work of various authors (Hiradate 2004; Meriño-Gergichevich 2010) and highlights the potential danger of acidification. The increase of the active aluminium content (between the first and the last monitoring cycles) was determined in the group of Podzols, Lithic Leptosols and Skeli-Dystric Leptosols used as permanent grassland as well as in the group of Cambisols on the crystalline rocks and in the group of Dystric Fluvisols used as arable land. These results are consistent with pH value trends during the observed period. Increased attention must be given high maximum values of active aluminium on arable land, which can significantly inhibit the growth of cultivated crops and subsequently to contaminate the nutrient chain.

Decline in soil organic matter

Soil organic matter represents more than 95% of total carbon accumulated on soils under grassland and near 100% of total carbon accumulated on arable land (Stolbovoy & Montanarella 2008). Quantitative and qualitative indicators of soil organic matter (SOM) are permanently monitored in soil monitoring network in Slovakia. Originally, after slight decline in soil organic carbon (SOC) on the beginning of soil monitoring system in Slovakia (1993 year), its increase has been indicated on all arable soils during last period (Figure 7).

There are many reasons of SOM decline as intensive conventional soil cultivation (Aranda *et al.* 2011), deep plowing (Caurasano *et al.* 2006), incorrect crop rotation (Machado *et al.* 2006), or insufficient supply of quality organic matter (Stetson *et al.* 2012). In Slovak agriculture reason of SOM decline



FAO – WRB 2015: 1– Cambisols, 2 – Calcaric Fluvisols, 3 – Fluvisols, 4 – Chernozems, 5 – Luvisols, 6 – Phaeozems, 7 – Calcaric Phaeozems, 8 – Albic Luvisols and Planosols, 9 – Rendzic Leptosols, 10 – Calcaric Regosols, 11 – Regosols, 12 – Podzols, AL – Arable land, GL – Grassland

Figure 5. Comparison of pH values in topsoil of arable soils of Slovakia

on his beginning of soil monitoring system could be sharply drop of organic fertiliser consumption (Bielek 2014). Also increase of SOM concentration or maintance on sufficient level of SOM can be caused by several methods of good agricultural practice, as application of quality organic fertilisers, adherence to optimal crop rotation and minimal soil cultivation (Janzen 2006; Abdalla *et al*. 2013). In our case increase of SOM in next monitoring period it could be probably caused by subsidies of Slovak Government for increasing of soil organic matter in soils.

Qualitative indicators (C_{HA}/C_{FA} and Q^4_6 ratio) of soil humus are without significant trends. However, the measured values are characteristic for the con-

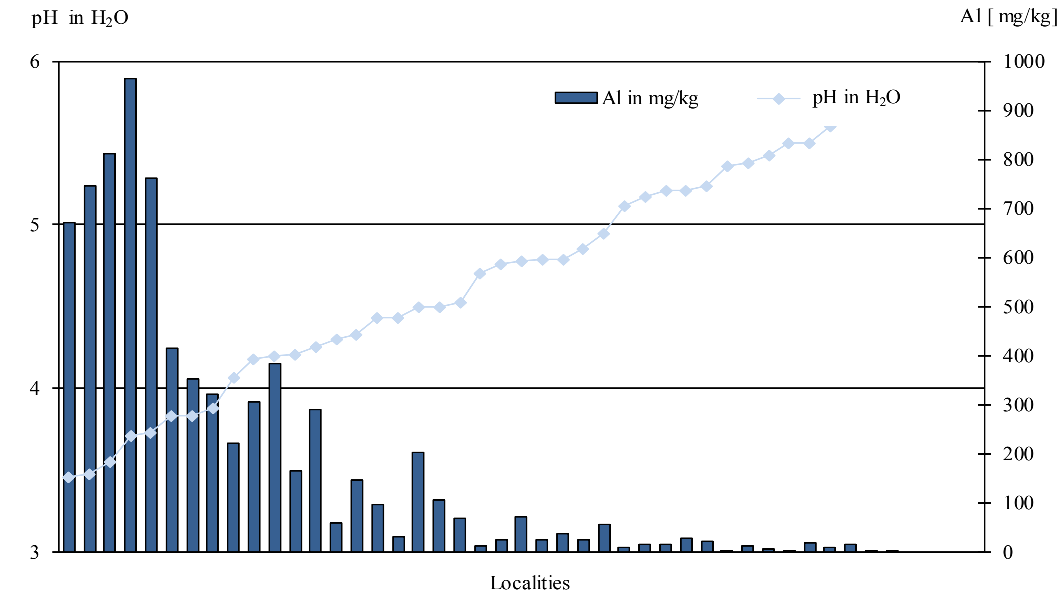


Figure 6. Active aluminium content in correlation with pH value

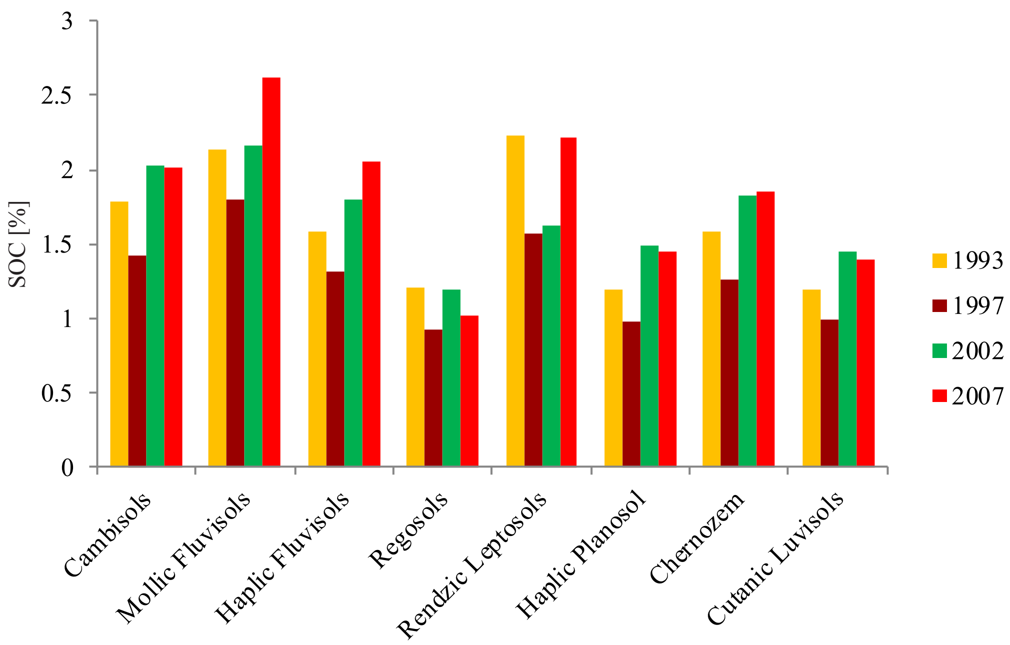


Figure 7. Comparison of soil organic carbon (SOC) [%] values in topsoil of arable soils of Slovakia

crete soil type as well as for the chemical structure of humic acids. These indicators seem to be a result of soil genesis and plant cultivation system, as well.

The content of organic carbon (SOC) in soils is largely conditional for the soil genesis and depends on soil use and soil management. The content of SOC in cultivated soils, mainly in arable soils, is limited by intensity and depth of cultivation what affect on increasing of mineralization. For this reason the average values of SOC in arable Slovak soils ranged from 1 to 2.5%. This corresponds low to high content of SOC (Hanes *et al.* 1995). The lowest values of soil organic carbon are typical for Regosols and the highest values of SOC for Phaeozems (FAO – WRB 2015).

Recently, development of the SOC content in arable soils is quite different depending on soil types. The gradual increase of SOC content is clear mainly in Phaeozems and Haplic Fluvisols. The average content of SOC in Rendzic Leptosols after previous decline substantially had increased to the level of initial state. SOC content in Chernozems and Cambisols are maintained at the same level as in the previous cycle. Slightly reduction of SOC content in Haplic Planosols and Luvisols was observed, but it was not statistically significant. The relatively highest reduction of SOC level was determined in Regosols. This soil type contains the lowest SOC level during whole monitoring period. Despite the fact that critical value of SOC is a function of soil texture, as well as climate, soil material and topographic position (Stockmann *et al*. 2013) we assume that SOC level of Regosols is below critical value of SOC.

Finally, the tendency to stabilization of soil humus content and its some increase has been observed during the last period after slight decline, especially in arable land since the beginning of soil monitoring in Slovakia. Changes in total nitrogen are consistent with SOC as confirmed by significant linear correlation between SOC an Nt content. In qualitative parameters of humus (C_{HA}/C_{FA}, Q^4_6) no significant changes were indicated during last 20 years (period of soil monitoring realization in Slovakia).

Soil contamination

The contaminants reduce soil fertility, change the species composition of the flora and fauna, and endanger human health due to the enrichment of heavy metals in the food chain (Maxwell 1991; Lepp *et al*. 1996; Dudka & Adriano 1997). During soil monitoring process was changed the hygienic legislative in Slovakia. Instead of extraction with 2M HNO_3 was introduced extraction with aqua regia with new hygienic limits (MPRV SR 2013). Therefore the latest distribution of risk elements (extracted with aqua regia) in Slovak agricultural soils is presented in the following Table 2.

Measured average values of risk elements in soils are lower than valid hygienic limit for Slovakia (MP SR 2004; MPRV SR 2013). The distribution of risk elements depends on parent material, land use, soil type and potential source of elements origin (geogenic, anthropogenic, resp. mixed influence) (Wilcke *et al*. 2005). Concerning the measured values of risk elements presented in the Table 2 the slightly increased values of some risk elements (Cd, Cu, Pb, Zn) from among the evaluated soil types occur on the Fluvisols which could be transported from the catchments and accumulated on the alluvial deposits especially along down the rivers (Kobza *et al*. 2014).

Increased values of some elements are also characteristic for some Cambisols which are particularly influenced by geochemical anomalies occurrence especially on crystalline rocks and volcanic deposits, as well. The most extended areas of geochemical anomalies appear in Štiavnické vrchy, Low Tatras and Slovenské rudohorie mountains. These regions are characterized by high and very high concentrations of risk trace elements, especially heavy metals in all soil profile (Cd, Pb, Cu, Zn, As and Hg) (Kobza & Gašová 2014). Therefore also mean value of some risk elements on Cambisols are also increased (As, Cu, Zn, Pb, Cr, Co) – Table 2. On the contrary, the soils with low to very low content of humus and clay fraction (Regosols) are characteristic with the lowest content practically of all risk elements, what it was already mentioned in some previous works (Linkeš *et al*. 1997; Wilcke *et al*. 2005).

Finally, significant change in concentration of risk elements (Cd, Pb, Cu, Zn, Cr, Ni, Co, Se, As) was not indicated during monitored period of 20 years in Slovakia (Kobza *et al.* 2014). It means that the soils which were contaminated at the beginning of soil monitoring process, are still contaminated at present. In addition, antropogenically deposited heavy metals are less strongly bound in soils, because chemical equilibration of heavy metals in soils is a long-term process (Chlopecka *et al*. 1996; Wilcke & Kaupenjohann 1997).

The obtained results concerning current soil degradation processes in Slovakia are briefly presented in the Table 3.

Negative changes were indicated at soil erosion (on Cambisols and Rendzic Leptosols), soil compaction (heavy Luvisols), soil acidification (acid Fluvisols, Albic Luvisols and Planosols, Cambisols and Podzols), decline in soil organic matter (Luvisols, Albic Luvisols, Planosols and Regosols – there are the soils with low content of soil organic matter), contamination (the highest values were determined on Fluvisols as a result of transport and accumulation of risk elements on fluvial deposits along the rivers and Cambisols often with occurrence of geochemical anomalies, resp. with their influence).

T a b l e 2

Average content of risk elements [mg/kg] extracted with aqua regia in arable layer (0–10 cm) of agricultural soils of Slovakia

Soils	As	Cd	Co	Cr	Cu	Ni	Pb	Zn	Se
FM	10.8	0.7	8.8	39.1	34.0	37.0	54.3	122.8	–
ČA	10.0	0.4	7.8	42.9	22.7	29.6	21.1	75.6	0.2
ČM	10.0	0.4	7.8	42.9	22.7	29.6	21.1	75.6	0.3
HM	9.2	0.2	10.0	41.5	22.9	32.6	19.7	68.8	0.1
LM+PG	9.9	0.3	9.7	42.8	17.0	23.3	24.2	66.7	0.2
KM	14.8	0.3	12.6	52.2	28.9	29.2	27.0	93.5	–
RM	3.4	0.1	2.0	19.5	17.0	12.0	7.7	41.0	0.3
RA	13.1	0.5	11.8	55.2	30.6	42.0	36.3	103.1	–

Explanations (soils according to FAO – WRB 2015): FM – Fluvisols, ČA – Phaeozems, ČM – Chernozems, HM – Luvisols, LM+PG – Albic Luvisols and Planosols, KM – Cambisols, RM – Regosols, RA – Rendzic Leptosols

T a b l e 3

Current state and development of soil degradation processes in Slovakia

Soils	Soil degradation processes				
	Erosion	Compaction	Acidification	Decline in soil organic matter	Contamination
FM	–	↑	↓	↑	↓
ČA	–	↑	–	↑	–
ČM	–	↑	–	↑	–
HM	–	↓*	–	↓	–
LM+PG	–	↑	↓	↓	–
KM	↓	↑	↓	–	↓
RM	–	–	–	↓	–
RA	↓	–	–	↑	–
PZ	–	–	↓	↑	–

Explanations (soils according to FAO – WRB 2015): FM – Fluvisols, ČA – Phaeozems, ČM – Chernozems, HM – Luvisols (*except heavy Luvisol), LM+PG – Albic Luvisols and Planosols, KM – Cambisols, RM – Regosols, RA – Rendzic Leptosols, ↑ – positive changes, ↓ – negative changes, – without significant change

In the contrast, the positive changes were indicated at soil compaction on some soil types (Fluvisols, Phaeozems, Chernozems, Albic Luvisols, Planosols and Cambisols), it may be said that the parameters of soil compaction are relatively dynamic and depend on way of agrotechnics. Especially during last period the stabilization of soil organic matter is observed (on Fluvisols, Phaeozems, Chernozems, Rendzic Leptosols and Podzols, which are originally rich in soil organic matter content).

CONCLUSIONS

On the basis of obtained results the most significant negative changes of agricultural land degradation processes have been recorded in soil erosion and particularly in soil acidification especially on acid rocks and contamination especially as a result of soil-sedimentary material transport and its accumulation on down the rivers deposits and geochemical anomalies influence, as well. The physical degradation was especially manifested in compacted and the eroded soils. It was calculated that about 39% of the agricultural land (mostly on Cambisols and Rendzic Leptosols) is potentially affected by soil erosion in Slovakia. The slight sensitivity to compaction was detected mostly on cultivated arable soils – texturally heavy Fluvisols, Chernozems, Luvisols, Albic Luvisols and Planosols and heavy Cambisols. It is necessary in the future pay attention to the arable land with pH values in slight acid and the acidic range as well as with a low quantity and quality of soil organic matter. To overcome the limitations of Al phytotoxicity, Ca amendments are an agronomic practice commonly used to reduce acidity effect on plant growth and development. The tendency to stabilization of soil humus content and its some increase has been observed during the last period after slight decline, especially in arable land since the beginning of soil monitoring in Slovakia. Significant change in concentration of risk elements was not determined during monitored period of 20 years. Slight increase of contaminants was determined especially on Fluvisols situated down the rivers and on some Cambisols mostly influenced by geochemical anomalies.

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