

Permanent soil monitoring system as a basic tool for protection of soils and sustainable land use in Slovakia

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Abstract. The purpose of soil monitoring system in Slovakia is to better protect the soils with regard to sustainable land use. The main object is the observation of soil parameters indicative of change to the equilibrium of soil system as far as to the irreversible change with possible development of degradation processes in soil. The soil monitoring system in Slovakia has been running since 1993. Its importance consists of providing the information on changing spatial and temporal variations of soil parameters as well as the evolution of soil quality in topsoil and subsoil. The soil monitoring network in Slovakia is constructed using ecological principles, 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 other land uses. The results of soil monitoring of 318 sites on agricultural land in Slovakia have been presented. 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, soil compaction, decline in soil organic matter, soil salinization and sodification and soil contamination. The most significant change has been determined in physical properties of soils. The physical degradation was especially manifested in compacted and the eroded soils. On the basis of our results about 40 % of agricultural land is potentially affected by soil erosion in Slovakia. In addition, decline in soil organic matter and available nutrients indicate seriousness of soil degradation processes observed during the last monitoring period in Slovakia. Measured data and required outputs are reported to Joint Research Centre (JRC) in Ispra (Italy) and European Environmental Agency (EEA) in Copenhagen (Denmark). Finally, the soil monitoring system thus becomes a basic tool for protection of soils and sustainable land use as well as for the creation of legislation not only in Slovakia, but in EU, too.

1. Introduction

Conception of the European soil policy and soil protection strategy as well as its sustainable use of land was established in the 6th Environmental Action Programme, which was accepted by European Council as well as European Parliament on the 22nd of July, 2002. The basic strategy involved developing a system to monitor soil and changes in soil over time. The main aim of the soil monitoring system is to obtain the data of the most current soil condition and to monitor changes in soil properties over time according to concrete threats to soil (soil contamination, salinization and sodification of soils, decline in soil organic matter, soil compaction and erosion) in Slovakia, what is in harmony with the European strategy of soil monitoring there are permanently monitored important



parameters in connection to recommendations of EC for evaluation of actual state and development of soils [1].

Government soil policy in Slovakia declares that the soil is and will be the basic building block of environmental, ecological, economic and social potential of Slovakia and therefore it must be carefully protected against damage. The new regulation concerning agricultural soils are Act n. 220/2004 Z.z. on protection of agricultural soils and agricultural land use [2] and Act n. 59 of Ministry of Agriculture and Rural Development of Slovakia from the 11.-th of March, 2013 [3]. The aim of the Acts is to provide protection of agricultural soils against degradation. The soil monitoring system developed in Slovakia is therefore an essential tool to identify the current state of soils and monitor future changes to assist with the effective implementation of these regulations.

The soil monitoring system in Slovakia has been running consistently since 1993. Its importance consists of providing actual and objective information on temporal trends in important soil properties on agricultural soils of Slovakia. Data measured and collected are reported to JRC (Joint Research Centre) in Ispra (Italy) and to EEA (European Environmental Agency) in Copenhagen (Denmark).

2. Material and Methods

The soil monitoring network in Slovakia is constructed on ecological principles and includes 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 and alpine land in Slovakia. All soil monitoring sites are located in WGS 84 coordinates. The monitoring site is represented by a circular shape, of radius 10 m and an area of 314 m². 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 these depths are adjusted to correlate with the main soil horizons. The soil monitoring in Slovakia is carried out on 5 year cycles. 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 unified soil monitoring system in Europe [1].

Methodical and analytical procedures have been realized according to work [4].

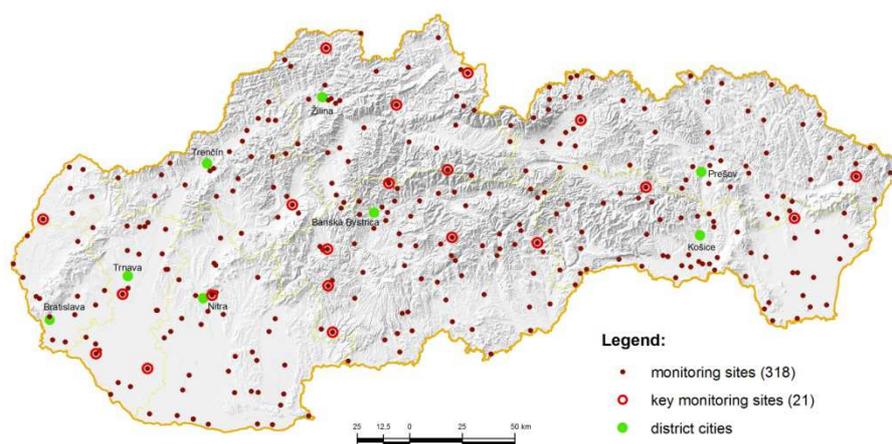


Figure 1. Soil monitoring network in Slovakia.

2.1. Monitored indicators of soil monitoring system according to threats to soil in Slovakia

The most important soil indicators concerning threats to soil, according to Recommendation of European Commission (EC) for unified soil monitoring system in Europe [1], are included in soil monitoring system for Slovakia. These threats and their associated indicators include:

Soil contamination:

- Cd, Cr, Pb, Ni, Zn, Cu, Se, Co (extracted with *aqua regia*), Hg (total content);
- As, Cu, Ni, Zn, Cd, Pb (extracted with 1 mol/l NH_4NO_3) – bioavailable forms;
- Fwater. (watersoluble fluorine measured by ionselective electrode);
- Polycyclic aromatic hydrocarbons (PAH_s);
- Polychlorinated biphenyls (PCB);
- Non-polar extractive substances

Soil acidification:

- pH/H₂O;
- pH/KCl;
- pH/CaCl₂;
- cation exchange capacity (CEC);
- exchangeable cations (Ca^{2+} , Mg^{2+} , K^+ , Na^+);
- active Al (if pH/KCl < 6.0).

Salinization and sodification:

- electrical conductivity (ECe);
- exchangeable sodium percentage (ESP);
- sodium adsorption ratio (SAR);
- pH/H₂O;
- exchangeable cations and anions (Ca^{2+} , Mg^{2+} , K^+ , Na^+ , Cl^- , SO_4^{2-} , CO_3^{2-} , HCO_3^-).

Quantitative and qualitative composition of soil organic matter:

- organic carbon (C_{ox});
- total nitrogen (N_t);
- humic acids (HA) and fulvo acids (FA);
- colour quotient (Q₆⁴);
- fractional composition of humic acids (elementary analysis of C, H, N, O).

Macro- and micronutrients:

- available macronutrients P, K, Mg (Mehlich III);
- micronutrients Cu, Zn, Mn (DTPA).

Soil compaction:

- bulk density (ϕ_d);
- porosity (P);
- maximum capillary water capacity (w_{KMK});
- texture (according to FAO).

Soil erosion (on selected soil transects):

- ¹³⁷Cs;
- pH/KCl;
- C_{ox};
- P, K;
- texture (according to FAO).

3. Results and discussion

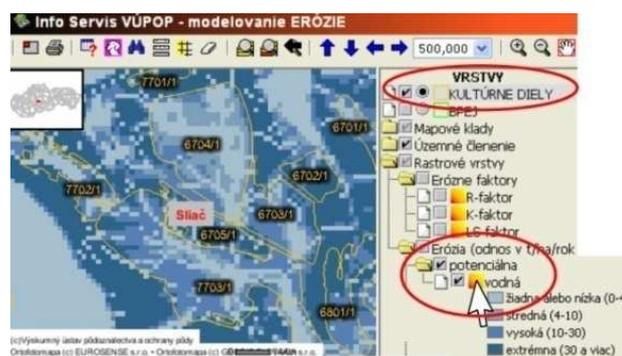
3.1. Soil erosion

Soil erosion is a significant environmental problem and the most widespread degradation process in Slovakia. Erosion is measured on soil transects using ^{137}Cs profile distribution. In addition, the area of soil erosion distribution is determined by using the erosion prediction model that incorporates the USLE [5]. Results showed that there are actually about 40 % of agricultural soils affected by soil erosion in Slovakia (Table 1).

Table 1. Soil erosion distribution in agricultural land of Slovakia.

Degree of erosion (soil loss)	Area, ha	% of farmland
Normal profile and slightly eroded ($0-4 \text{ t ha}^{-1} \text{ year}^{-1}$)	1,454.925	60.35
Moderately eroded ($4-10 \text{ t ha}^{-1} \text{ year}^{-1}$)	245.421	10.18
Severely eroded ($10-30 \text{ t ha}^{-1} \text{ year}^{-1}$)	356.318	14.78
Extremely severely eroded ($>30 \text{ t ha}^{-1} \text{ year}^{-1}$)	354.148	14.69
Total	2,410.812	100.00

In addition, an interactive and predictive soil erosion model was created for use by the farmers. The model can be found at <http://www.podnemapy.sk> [6]. This application can be useful for providing information concerning soil - erosion intensity on agricultural field using the following procedure: Users of agricultural fields (farmers) move step by step through the model from region level through district, cadaster as far as parcel (field) level where the important data on soil erosion are required (Figures 2a, b). The farmers can obtain the available data on following factors of soil erosion (R – rain factor, K – factor of erodibility, LS – factor of relief influence, C – factor of vegetation cover, P-factor of measures against erosion) and the amount of potential and actual soil loss in interaction with agricultural crop on agricultural field can be calculated.



Figures 2 a, b. Soil portal with the image of potential water erosion.

3.2. Soil compaction

Soil compaction is monitored in the soil monitoring network only on arable land (topsoil and subsoil are included) on the basis of measured physical indicators such as bulk density, porosity and texture.

1. Primary compaction – controlled by natural characteristics of the soil (soil texture, soil organic matter content)
2. Secondary compaction - influenced by human activity (kind of machinery used, compliance with optimal soil conditions for machinery use, mainly soil moisture at the time of the agronomical operations).

The main indicator for soil compaction is bulk density. Its values in Slovakian soils are running between 1.0 - 1.8 kg m⁻³. According to measured bulk density values (Figure 3) the soils sensitive to soil compaction occur mostly in south-western and south-eastern parts of Slovakia (these are the lowlands used mostly for agricultural – arable soils, loamy to clayey textures with usage of heavy machines).

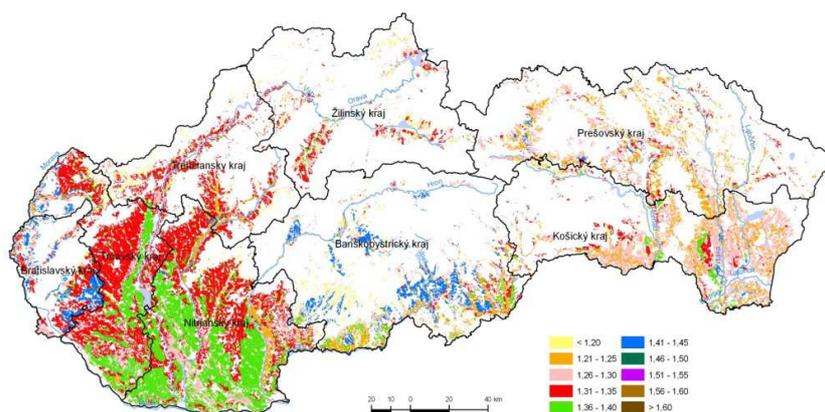


Figure 3. Map of topsoil bulk density in Slovakia (kg .m⁻³).

Table 2. Percentage of monitoring sites showing compaction according to soil types (average values from 4 previous monitoring cycles).

Soil profile (depth)	Soil texture	ČA	ČM	FM	HM	KM	PG
Topsoil (0-0.10 m)	sandy	17	-	-	-	-	-
	loamy	25	35	27	27	28	37
	clayey	45	63	38	31	36	35
Subsoil (0.30-0.35 m)	sandy	67	-	-	-	-	-
	loamy	56	46	59	60	72	82
	clayey	72	67	70	90	81	87

Explanations: ČA – Mollic Fluvisol, ČM – Chernozem, FM – Fluvisol, HM – Luvisol, KM – Cambisol, PG – Planosol

Percentage of monitoring sites showing compaction according to soil types and soil texture are given in table 2. The soil monitoring network in Slovakia consists of 318 monitoring sites (100 %). On the basis of obtained results it may be said that the most severe compaction occur in subsoil especially on clayey soils. Differences in soil compaction between soil types are not very significant. Finally, it may be said that the physical conditions of observed soils are deteriorating in the direction from texturally loamy to clayey soils which are the most sensitive to soil compaction. There are about 200 000 hectares of compacted agricultural soils and about 500 000 hectares potentially compacted agricultural soils in Slovakia.

3.3. Decline in soil organic matter

Soil organic matter represents more than 95 % of total carbon contained in soils under grassland and near 100 % of total carbon accumulated in soils under arable land [7]. Quantitative and qualitative indicators of soil organic matter (SOM) are permanently monitored in soil monitoring network in

Slovakia. After slight decline in soil organic carbon (SOC) at the beginning of soil monitoring system in Slovakia (1993 year), all arable soils showed an increase in SOC its increase has been indicated on all arable soils during the last monitoring period (Figure 4). The increase could be caused by subsidies from the Slovak Government for increasing of soil organic matter in soils.

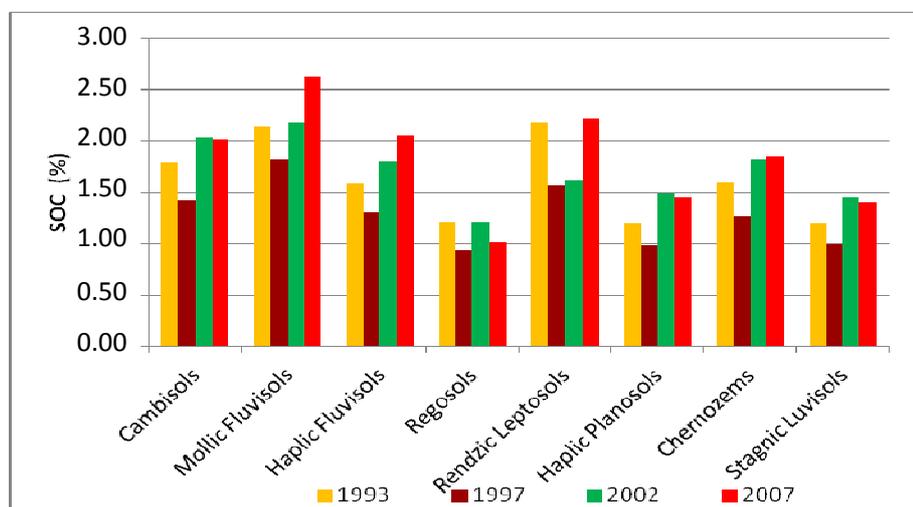


Figure 4. Comparison of soil organic carbon (SOC %) values in topsoil of arable soils of Slovakia.

Qualitative indicators of soil humus (HA/FA ratio, colour quotient Q_6^4 , fractional composition of humic acids - HA) are without significant trends. However, the measured values are characteristic for the concrete soil type as well as for the chemical structure of humic acids (HA). These indicators seem to be a result of soil genesis.

The content of organic carbon (SOC) in soils is largely conditional upon the processes of soil formation. The content of SOC in cultivated soils, mainly in arable soils, is limited by intensity and depth of cultivation that affect degree of mineralization. For this reason the average values of SOC in arable Slovak soils ranged from 1 to 2.5 %. This corresponds to the moderately and good content of soil humus when the values of SOC is converted into humus (conversion coefficient is 1.724). The lowest values of soil organic carbon are typical for Regosols and the highest values of SOC – for Mollic Fluvisols.

Recent data indicate that changes in SOC levels in arable soils differ depending on soil type. The gradual increase of SOC concentration is clear mainly in Mollic Fluvisols and Haplic Fluvisols. The average value of SOC in Rendzic Leptosols after an early decline then displayed a substantial back to the original levels SOC values in Chernozems and Cambisols have stabilised at the same level as in the previous cycle. Slight reduction of SOC content in Haplic Planosols and Stagnic Luvisols were observed, but they were not statistically significant. Proportionately, the greatest reduction of SOC level was observed in Regosols.

In summary, after a slight decline in soil humus, especially in arable land, since the beginning of soil monitoring the tendency for stabilization of soil humus content and in some cases an increase in soil humus has been observed during more recent monitoring periods in Slovakia. Changes in total nitrogen are not significant except in some soils such as Cambisols, Chernozems, Mollic and Haplic Fluvisols and Luvisols, where only slight increase has been registered. In qualitative parameters of humus (HA/FA, Q_6^4) no significant changes were indicated during last 20 years (period of soil monitoring in Slovakia).

3.4. Soil salinization and sodification

On the basis of obtained results it was indicated that *salinization and sodification* processes are running more or less in parallel, but the sodification process seems to be dominant under the soil - and climate conditions of Slovakia, and are to be found mostly in south-western and south-eastern parts of

Slovakia [8]. There estimated to be three thousand hectares of saline soils in Slovakia that represents 0.1 % of agricultural land.

Salinization is a process of the accumulation of neutral sodium salts in soil, primarily NaCl and Na₂SO₄ is the indicators of salinization process are the total content of water-soluble salts in soil and electrical conductivity of saturated soil extract (EC_e).

Sodification is a process of the fixation of exchangeable sodium in sorption complex of soil. This process is influenced by the presence of alkaline salts in soil, primarily Na₂CO₃, NaHCO₃ and Na₂SiO₃. The content of exchangeable sodium in soil sorption complex (ESP) and pH value are indicators of the sodification process.

These processes are running more or less simultaneously, but the sodification process seems to be dominant under conditions of Slovakia.

In principle, it is primary (Figure 5) or secondary, anthropogenic, processes (e.g. strongly alkaline waste deposits from aluminium production - Figure 6).



Figure 5. Example of the primary saline soil located under semiarid conditions.



Figure 6. Example of the secondary saline and polluted soil influenced by strongly alkaline waste deposits.

3.5. Soil contamination

The significant change in concentration of inorganic (Cd, Pb, Cu, Zn, Cr, Ni, Co, Se, As, Hg and F) and organic (PAHs and PCB) contaminants was not observed during the of 20 years monitored period. It appears that the soils which were contaminated at the beginning of soil monitoring, are still contaminated at present. There are about 20 thousand hectares of contaminated soils in Slovakia. This constitutes 1 % of the total area of soils in Slovakia, but the predominant part of them is contaminated by geogenic influence.

The various impacts influencing soil contamination can be described as follows:

- human influence (industry, agriculture, municipal waste materials, etc.);
- influence of geochemical anomalies;
- combination of the above.

The human influence on contamination of soils in Slovakia (former Czechoslovakia) was most significant after the Second World War and especially during the industrial period in the second half of the 20-th century. Later, after 1990, soil pollution was slight, without significant changes. It means that soils, which were polluted in the past have remained practically unchanged and continue to be in an unhealthy condition.

The observation of geochemical anomalies occurs particularly in volcanic and crystalline rocks, found mainly in mountainous regions and more rarely within agricultural land. The most extensive areas of geochemical anomalies occur in the Štiavnické vrchy (mountains), Low Tatras and Slovenské Rudohorie (mountains). These regions are characterized by high and very high concentrations of risk trace elements, especially heavy metals (Cd, Pb, Cu, Zn, As and Hg) in all soil profiles.

Finally, the highest concentrations of risk trace elements have been registered in soils in the areas with a combination of anthropogenic and geogenic contamination, in Central Spiš region – Krompachy and Rudňany industrial-metallurgical zone, where the high concentration of risk trace elements, primarily Cd, Pb, Cu, Zn, As and Hg were determined.

The type of soil contamination determines the type of remediation with subsequent land use and soil protection. The basic criterion is to limit transport of contaminants' into the food chain and crops.

It is possible to use several remediation techniques regarding to pollutants and soils exposed to anthropogenic pollution [9, 10].

3.6. Soil monitoring database of Slovakia and data reporting

The database of the soil monitoring system allows to creation and maintenance of data for each of the monitoring sites of agricultural land as well as the preparation of data for further processing through specialized programs (statistical programs, spreadsheets and other databases). Position information provides a link to the geographical information systems, and thus opens the possibilities for the further spatial analysis and representation of results.

User interface database also allows insertion and viewing of data, their selection and printing tables of data stored on the soil profiles.

Structural harmonization of the database, rebuilding the original structure of the geodatabase and the transition to an ORACLE platform are progressing simultaneously. In addition, a new network interface database system also has been built to facilitate new data capture. The main functional services for publishing the spatial information of soil monitoring are on-line with OGC - WMS & WFS specifications to define the standard reporting data structures.

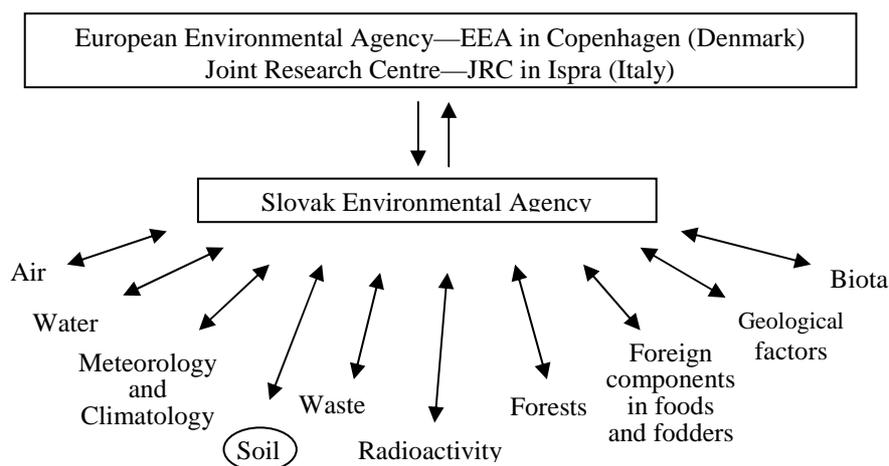
In addition, the database is stored to the regular monitoring data which are archived from a network of monitoring sites where the soil samples have been sampled and analysed in monitoring period. Metadata about performance of monitoring period are attached in the database – together with updated data, descriptions of soil monitoring site characteristics and soil classification.



Figure 7. Integration of soil monitoring database with other soil databases in Slovakia.

The integrated soil database in Slovakia enables value adding of information from the soil monitoring system to be achieved. In figure 7 the application of various digital layers (land use database, orthophotomaps of landscape, LUCAS and soil monitoring database) can better explain actual soil changes caused by different and changed land uses around known monitoring site (400044 in red above).

Ten partial monitoring systems of environment in Slovakia are described in Figure 8. The data summaries are regularly reported to the European Environmental Agency in Copenhagen (Denmark) and Joint Research Centre in Ispra (Italy).



Partial monitoring systems of environment in Slovakia

Figure 8. Implementation of soil monitoring system with monitoring of environment in Slovakia and EU.

4. Conclusions

The soil monitoring system is the source of the comparable and objective data on the current state and evolution of soils in Slovakia. The obtained results are useful in decision-making (e.g. for soil protection) and in various branches of national economy as well as in research institutes and universities with environmental focus. In addition, reporting of stored data to EEA in Copenhagen (Denmark) and to JRC in Ispra (Italy) contributes to important outputs concerning the actual state and evolution of soil cover in EU.

The most significant change has been recorded in physical properties of soils. The physical degradation was especially manifested in compacted and the eroded soils. About 40 % of the agricultural land is potentially affected by soil erosion in Slovakia. In addition, the decline in soil organic matter and available nutrients (mostly P and K) are evidence of continued existing soil degradation processes observed during the last monitoring period in Slovakia.

Finally, the soil monitoring system has become a basic tool for protection of soils and sustainable land use as well as for creation of legislation not only in Slovakia, but in EU, also. The role of soil monitoring system in the protection of soil and land use could be identified as follows:

- identification of risk areas and their assessment;
- prognosis of the subsequent evolution of soil parameters according to threats to soil;
- a basic tool for protection of soils and sustainable land use;
- creation of ecological legislation;
- evaluation of soils and environment (including recommendations and measures).

Acknowledgements

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