

Current State and Development of the Soil Health Index in Localities with Various Soil-Climatic Conditions in the Slovak Republic

Jarmila Makovniková¹, Boris Pálka¹, Stanislav Kološta²

¹National Agricultural and Food Centre/Soil Science and Conservation Research Institute Bratislava, Regional Station Banská Bystrica, Slovakia

²Faculty of Economics, Matej Bel University, Banská Bystrica, Slovakia
Email: jarmila.makovnikova@nppc.sk, jarmila.makovnikova@nppc.sk

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Abstract

The aim of the study was to assess the current state and development of the Soil Health Index (SHI) at 13 localities with various soil-ecological conditions in the Slovak Republic. The SHI was developed using a minimum soil data set, physical and chemical soil parameters in combination with environmental parameters (land use, gradients). The SHI is one numerical value accumulates information about the state of soil health and its ability to provide soil functions and thus ecosystems in the optimal range. The highest SHI values were determined at model localities used as arable land (Haplic Chernozem, Fluvisol) located in a warm climate at altitudes up to 200 meters above sea level. Ecosystems with very low and low value are mostly grasslands with mildly cold climate (Cambisol) and considerable slope, agroecosystem on low organic matter (Arenosol). Arable ecosystem SHI is also reduced in areas of geochemical anomalies and areas with anthropogenic load, where there is a higher content of risk elements. The SHI changes are mainly the result of changes in dynamic indicators such as soil response and soil bulk density.

Keywords

Soil Health, Agroecosystem Services, Soil Parameters, Minimum Soil Data Set

1. Introduction

Soil plays a vital role in the functioning of terrestrial ecosystems and provides invaluable ecosystem services for human societies and well-being. Soil health has been defined in the “A Soil Deal for Europe” as the sustainable ability of soil to

support ecosystem services (Bonfante et al., 2020; Veerman et al., 2020). Kibblewhite et al. (2008) defined the healthy agricultural soil as soil that is able to support production of food together with continued delivery of the other ecosystem services essential for maintenance mankind life quality and conservation of biodiversity. The quality and health of soil determine agricultural sustainability as well as environmental quality which determine plant, animal and human health (Doran, 2002; Kobza, 2017). The new EU Soil Strategy 2030 calls for all land to be in good health by 2030 and for soil protection, sustainable use and restoration to become the new standard (EU, 2020; Wittkowski, 2020).

Defining soil health indicators is crucial for monitoring soil health (Arshad & Martin, 2002). Although a unique framework of indicators is needed, the reference values of soil health indicators must be context-specific (climate, soil type, land use). The soil health index compiled from soil indicators must respect knowledge of their critical limits (Laishram et al., 2012; Abbott & Manning, 2015). Karlen and Stott (1994) developed a soil quality index based on four soil functions (the ability of the soil to accommodate water entry, facilitate water movement, absorption, resist surface degradation and supply nutrients for plant growth). Several methods of soil health evaluation have been developed, including soil card design and test kits, geostatistical method or soil quality index methods (Bünemann et al., 2018; Jian et al., 2020). Soil health assessment is carried out by selecting a minimum data set of soil properties that are considered to be indicators of soil health (Vasu et al., 2016). Recently, soil health assessment has become increasingly integrated into sustainable soil management, environmental risk assessment as well as environmental monitoring and soil restoration (Gelaw et al., 2015; Bünemann et al., 2018).

The aim of the study was: 1) to develop SHI based on soil functions, 2) to apply this method to assess the current state and development of the SHI in localities with various soil-ecological conditions in the Slovak Republic, 3) to evaluate the impact of soil types, climatic conditions and changes of land use on SHI.

2. Material and Method

2.1. SHI Evaluation

The calculation of the SHI included three steps: 1) selection of the appropriate indicators for a minimum data set (MDS), 2) score assignation for the selected indicators, and 3) the integration of the indicator scores into an overall SHI (Rahmanipour et al., 2014). In Slovakia, Bujnovský et al. (2011), Makovníková, Barančíková and Pálka (2007), Barančíková and Makovníková (2003), Vilček and Koco (2018) define the MDS of soil indicators needed for sufficient assessment of soil functions. These indicators were used as a basis for composite SHI. The SHI was created using the MDS of physical and chemical soil indicators (direct indicators) combined with environmental parameters, land use and climatic region (Kibblewhite et al., 2008; Alam et al., 2016; Costanza et al., 2017). These soil in-

dicators are included in the soil monitoring system in Slovakia (Kobza et al., 2014) according to the recommendation of the European Commission (EC) for comprehensive soil monitoring system in Europe (van Camp et al., 2004). All indicators are significant, representative and quantifiable. Each observed value was converted into a score (from -1 to 2) with respect to the knowledge concerning their critical limits (Table 1). Based on correlation analysis (Makovníková et al., 2019), the SHI is also a suitable comprehensive indicator for the evaluation of regulatory ecosystem services of agricultural land.

According to the results of SHI value, we classified model localities into 5 classes (Table 2).

Table 1. Indicators and indicator scores for SHI evaluation.

Indicator	Value of indicator	Score of indicator (SHI _i)
Slope	<5°	1
	≥5°	0
Soil bulk density	<1.5 g·cm ⁻³	1
	>1.5 g·cm ⁻³	0
Soil texture (soil particles <0.01 mm)	<20%	0
	20% - 45%	1
	>45%	0
Depth of humus horizon	<30 cm	0
	>30 cm	1
pH value	<4.5	-1
	4.51 - 6.00	0
	6.01 - 7.50	1
	7.51 - 8.00	0.5
	8.00	0
Total organic carbon content	<1%	0
	1% - 5%	1
	>5%	2
Quality of organic carbon content (Q46)	<4.5	2
	4.5 - 6.0	1
	>6.0	0
Soil contamination (Cd, Pb, Cu, Zn, Cr, Ni, Co, Se, As, Hg) evaluated by hygienic limit for Slovakia (MP SR, 2004, MPRV SR)	<hygienic limit value	0
	>hygienic limit value	-1

Soil Health Index: SHI = ΣSHI_i.

Table 2. Soil health classes.

Soil health class	SHI value
1—very low index	<1.50
2—low index	1.50 - 3.50
3—middle index	3.51 - 5.00
4—high index	5.01 - 6.50
5—very high index (healthy soil)	>6.50

2.2. Model Localities

The model localities represent the main soil types of agriculturally used soils in various soil-ecological regions of the Slovak Republic (**Figure 1, Table 3**).

We performed spring soil sampling at model localities during years 1995-2021 (we used four points sampling in the shape of the letter Z; **Kobza et al., 2011**). We analysed potential static soil parameters (depth of humus horizon, soil texture, content and quality of organic matter in the soil, total content of inorganic pollutants), and potential dynamic soil parameters (bulk density, soil reaction value) that enter into the construction of the SHI.

Within model localities the values of soil reaction (pH in KCl) ranged from 3.95 to 7.30, the content of organic matter in the soil ranged from 0.79% to 3.37%, the values of bulk density ranged from 1.21 g·cm⁻³ to 1.78 g·cm⁻³. Contamination level, exceeding the limit value of 4 elements was set at two localities (Dvorníky and Krompachy). In one locality (Nacina Ves) the values of 3 elements were exceeded and at 2 localities the limit for one (Ziar n/Hronom) or two elements (Raková) was exceeded.

2.3. Data Sources

Data from the Digital Soil Map of Slovakia and data of Soil Monitoring of Slovakia were used to evaluate the SHI. The basis for a classification of agro-climatic regions were provided by the Information Service of the National Agricultural and Food Centre/Soil Science and Conservation Research Institute (NAFC-SSCRI, 2015), Land Parcel Identification System (LPIS) and Digital Soil Map of Slovakia.

3. Results and Discussion

Figure 2(a) shows the current state (year 2021) and the development of a multiparametric SHI values at model localities in the context of soil types and subtypes, while **Figure 2(b)** in the context of climate regions. We have determined the highest SHI values in localities used as arable land (Haplic Chernozem, Fluvisol) located in a warm climate area at an altitude of up to 200 meters above sea level. Ecosystems with very low and low SHI values are predominantly grasslands, located in areas with a mildly cold climate (predominantly Cambisol) and a considerable slope as well as a low organic matter content (Arenosol). The SHI

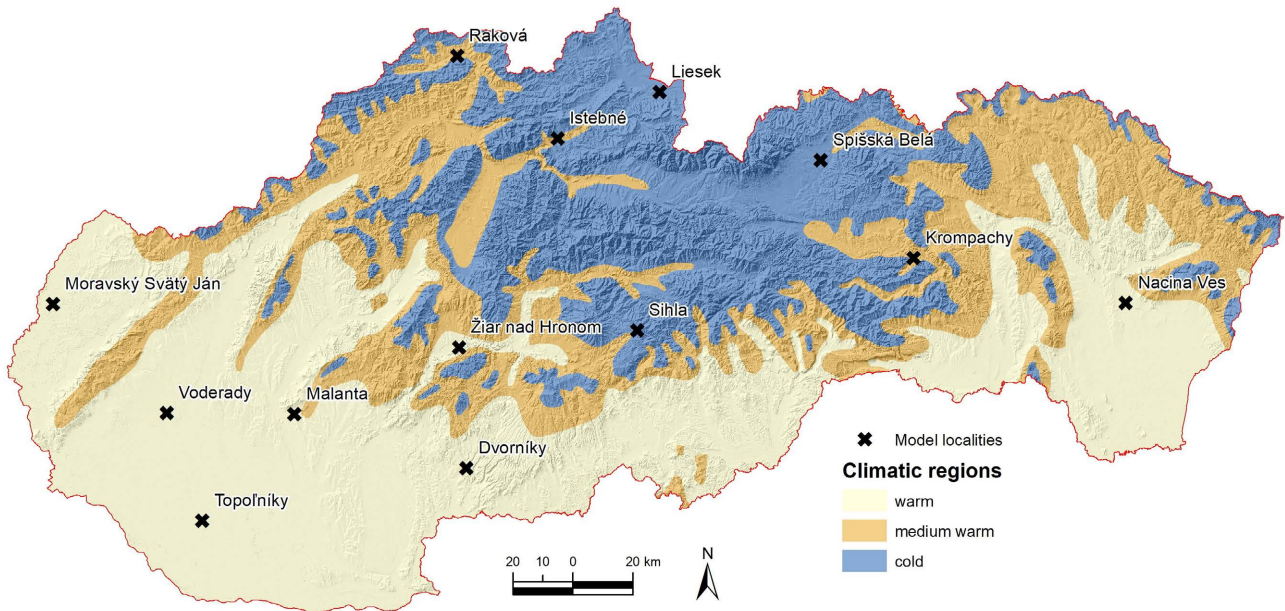
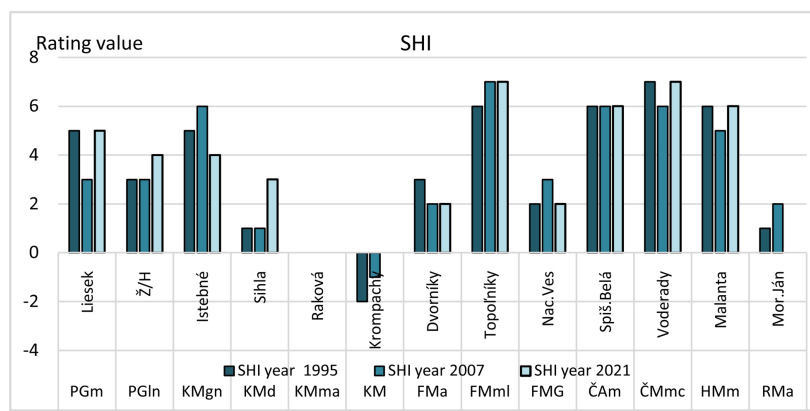
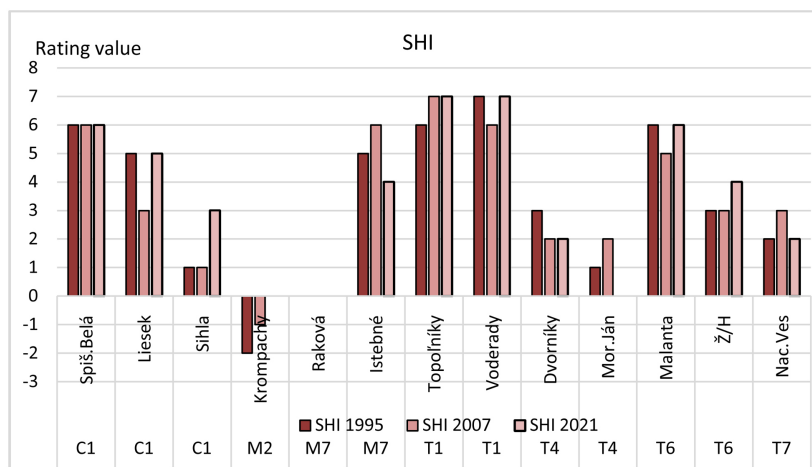


Figure 1. Geographical location of model localities.



(a)



(b)

Figure 2. (a) SHI values at model localities in the context of soil types and subtypes. (b) SHI values at model localities in the context of climate regions.

Table 3. Model localities—characteristics.

Model locality	Soil type/subtype (MKSP 2014)	Land type r.1995/2007/2021	Inclination in °	Altitude in m above sea level	Climate region
Liesek	Haplic Stagnosol—PGm	AL/GL/GL	3	631	C1
Ž/H	Luvic Stagnosol—PGI ⁿ	GL	7	361	T6
Istebné	Stagnic Cambisol—KMg ⁿ	AL/GL/GL	5	545	M7
Sihla	Haplic Cambisol—KMd	GL/GL/AL	15	975	C1
Raková	Haplic Cambisol—KMm ^a	GL	5	500	M7
Krompachy	Stagnic Cambisol—KM	GL	12	415	M2
Dvorníky	Gleyic Fluvisol—FMa	AL	0	151	T4
Topoľníky	Haplic Fluvisol—FMm ^l	AL	0	112	T1
Nacina Ves	Haplic Fluvisol—FM _G	AL	0	114	T7
Spiš.Belá	Mollic Fluvisol—ČAm	AL	0	653	C1
Voderady	Haplic Chernozem—ČMm ^c	AL	2	136	T1
Malanta	Cutanic Luvisol—HMm	AL	3	175	T6
Moravský Ján	Haplic Arenosol—RMa	AL/GL/GL	5	170	T4

Explanations: AL—arable land; GL—grassland; climatic region: C1—moderately cold, M2—moderately warm, moderately humid, with cold winter, valley/basin, M7—moderately warm, very humid, highlands, T1—warm, very dry with mild winter, T4—warm, mildly dry with mild winter, T6—warm, mildly humid with mild winter, T7—warm, mildly humid with cold winter.

value is also reduced in areas of geochemical anomalies (Fluvisol—Dvorníky) and in areas with anthropogenic load (Ziar n/Hronom, Krompachy), where there is a higher content of risk elements. Soil contamination is a widespread threat to proper soil functioning and its quality and most soils from the area of high anthropo-pressure had very low SHI values, and should be incorporated into the SHI assessment (Klimkowicz-Pawlas et al., 2019; Rahmanipour et al., 2014; Vasu et al., 2016).

The average SHI values (average of soil type) within different soil types (**Figure 2(a)**) decreased as follows: Chernozem—ČM > Mollic Fluvisol, CA > Cutanic Luvisol, HM > Stagnosol, PG > Fluvisol, FM > Cambisol, KM > Arenosol, RM. Lower average of Fluvisol was mainly influenced by the Dvorníky locality with anthropogenic and geogenic load (inorganic pollutants), and the locality with a high proportion of clay fraction (Nacina Ves located in the East Slovakian lowlands). Soil texture has also significant influence on the SHI values (Triantafyllidis, 2019). Within model localities the lowest SHI values were observed in clayey and loamy soils with fine texture.

Comparison of model localities using cluster analysis (**Figure 3**) showed the most significant differences among different soil types. However, there is also similarity between soil types with similar pedogenesis (Chernozem—Cutanic Luvisol).

The SHI changes are mainly the result of changes in dynamic indicators such

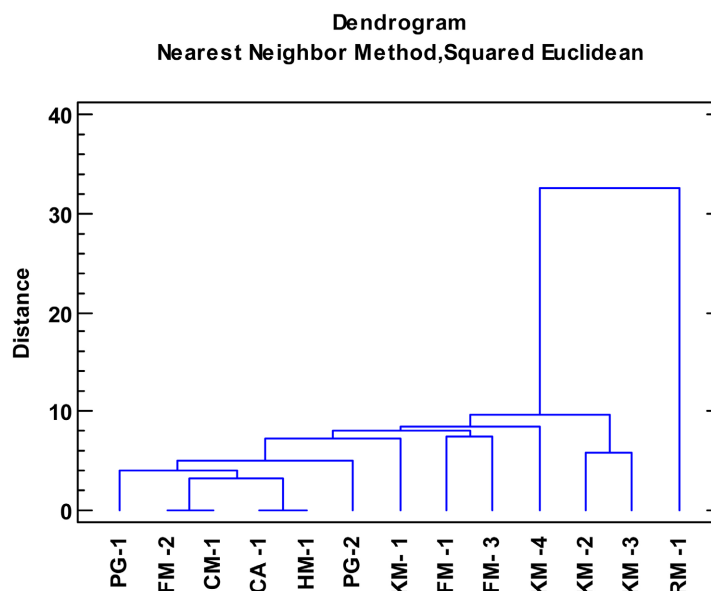


Figure 3. Comparison of model localities (cluster analysis). Explanations: PG-1—Liesek, PG-2—Žiar n/Hronom, KM-1—Istebné, KM-2—Sihla, KM-3—Raková, KM-4—Kompachy, FM-1—Dvorníky, FM-2—Topoľníky, FM-3—Nacina Ves, CA-1—Spišská Belá, CM-1—Voderady, HM-1—Malanta, RM-1—Moravský Ján.

as soil response and soil bulk density, similarly as in [Bünemann et al. \(2018\)](#). Soil properties, which can change rapidly in response to natural or anthropogenic effects, are considered as good indicators of soil health ([Rahmanipour et al., 2014](#)). Land use change can be significant factor influencing SHI ([Mukherjee & Lal, 2014](#)). In localities, where there was a change in land use—alternating arable land to permanent grassland—the total content of organic matter in the soil increased when the locality was grassed (model localities Istebné in year 2007, and Moravský Ján in year 2007). We recorded also a positive change in the value of the soil reaction at the Sihla model locality during the transition from permanent grassland to arable land. The SHI can be used as a support tool for efficient soil management, indirect measurement of soil functions, and for soil health assessment ([Lehmann et al., 2020](#)).

Figure 4 shows development of the healthy soil classes at model localities. We recorded positive changes in the representation of the middle class in the period 1995-2021 (an increase from 0.15% to 0.30% of the number of localities), a lower representation of the high index (a decrease from 0.23% to 0.07% of the number of localities), and a slight increase in the very high index (from 0.07% to 0.15% of the number of localities) (**Figure 4**). In 2021, most model localities (54%) were classified in the medium to very high healthy soil class.

The values of the SHI are correlated with the value of the soil reaction, the quality of organic matter, the bulk density of the soil and the level of contamination of the model locality (**Table 4**). The effect of soil texture on SHI and altitude values were not statistically significant.

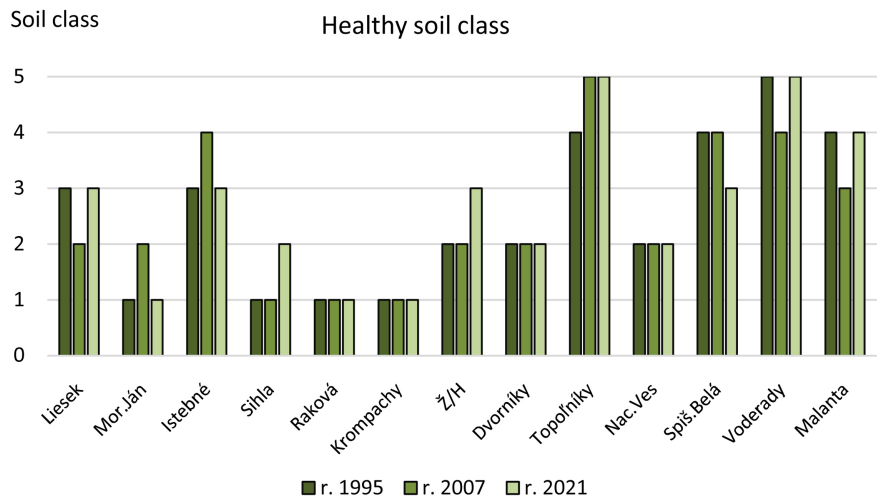


Figure 4. Healthy soil classes at model localities.

Table 4. Pearson correlation coefficient between SHI and soil parameters.

SHI	Parameter						
	pH value	Soil organic caron	Q ₆ ⁴	Contamination	Soil texture	Altitude	Soil bulk density
Correlation coefficient 1995 y.	0.64*	-0.27	-0.65*	0.66*	-0.34	-0.27	0.43
Correlation coefficient 2007 y.	0.65*	-0.29	-0.74*	0.61*	-0.34	-0.27	0.58*
Correlation coefficient 2021 y.	0.67*	-0.19	-0.64*	0.63*	-0.34	-0.27	0.38

Statistically significant at the level of significance $\alpha = 0.05$.

4. Conclusion

Soil health is the continuous ability of soil to function as a vital living ecosystem that supports plants, animals and humans, and connects agriculture and soil with policies, the needs of stakeholders through sustainable supply chain management. The concept of soil health meets the important need of stakeholders in the field of sustainable development by increasing the recognition of the role of soil in modern society and creating a functional platform for farmers, land owners, local authorities and policy makers. The multi-composite SHI accumulates in one numerical value information on the state of soil health, and thus its ability to provide soil functions and regulatory ecosystem services to the optimal extent in a specific way of its use.

Our results showed that monitoring of changes of SHI values represent the possibility of a comprehensive assessment of negative pressures on the soil eco-

system, degradation processes, as well as an assessment of the impact of land use change. The SHI provides a common soil health framework for sharing and integrating field measurements and related information, and thereby offers valuable information for farmers, agency personnel, and scientists as they plan and evaluate cropland management. The maintenance of soil health is critical for ensuring the sustainability of the environment, because only a healthy soil can potentially enable proper function of the entire ecosystem.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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