Original paper

POSSIBILITIES FOR ASSESSING ECOSYSTEM SERVICES IN AN AGRARIAN LANDSCAPE

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Abstract

The quantification and assessment of ecosystem services (ES) is also one of the driving forces of the sustainable development of human activities in the context of natural capital. The aim of the article is to apply and compare three different approaches to the assessment of regulatory ecosystem services on the example of the agrarian landscape (model region Krupina) in Slovakia: 1) using a matrix system, 2) assessment based on soil functions and 3) assessment of ecosystem services through the multiplicative soil health index. The matrix system only allows for the overall assessment of individual ecosystems, the quantification of ES using soil functions, as well as the assessment of ES through the Soil Health Index, with good data availability, pro-vide more accurate results at the regional and local level. Our results showed that the use of the composite index in the assessment of regulatory services is comparable to the assessment of water regime regulation and cleaning potential. Individual models for two regulatory services, climate regulation potential and erosion regulation potential, with dominance of only one category, are incomparable to the composite soil health index in evaluating regulating services. The results of the assessment of ES using the healthy soil index belong to robust models de-scribing the relationship between the potential of regulating ES and explanatory variables.

Keywords: ecosystem services, matrix approach, soil indicators, soil health, Krupina region

INTRODUCTION

The concept of ecosystem services (ES) has become an important tool for modelling interactions between ecosystems and their external environment in terms of global bio-climatic changes. The ecosystem approach is now an essential strategy for integrated land management, water resources and biota management, as it is an approach that promotes the conservation and sustainable use of ecosystems (Costanza *et al.* 1997, 2008, Millennium Ecosystem Assessment 2005). ES are inherently determined by the mutual interaction between ecological and social systems, because only those ecosystem processes and functions that contribute to the fulfilment of human needs are defined as ES (Birkhofer *et al.* 2015). The potential of ES was defined by Burkhard *et al.* (2014) as the hypothetical maximum yield of selected ES that natural capital (ecosystem) can provide. Benefits obtained from nature to people in the form of agroecosystem services can be divided into three categories: provisioning, regulating, and cultural services (Dominati *et al.* 2010). The main idea of the concept of ES is to realize the value of natural capital, its contribution to society, as well as to understand the connection between natural capital and human well-being (Mengist *et al.* 2020). The quantification and assessment of ES is also one of the driving forces of the sustainable development of human activities in the context of natural capital.

There are currently several suitable methods for assessment the ES, which can be divided into two basic groups according to the basic principle of evaluation (Černecký *et al.* 2020, Makovníková *et al.* 2022). Biophysical methods that use spatial data also include the matrix method for assessing the potential of ES (Burkhard *et al.* 2009, 2014, Černecký *et al.* 2020). The matrix method for the assessment of ES was used in case studies (e.g., Kandziora *et al.* 2013, Kaiser *et al.* 2013, Kroll *et al.* 2012, Nedkov & Burkhard 2012). Matrix method has the advantage of an open matrix system regarding the level of detail and level of assessment of ES (Burkhard *et al.* 2014). The matrix approach is proving to be one of the appropriate approaches in landscape planning and nature protection at the regional and national level (Müller *et al.* 2020), and the matrix system of ES assessment can be a suitable basis for their subsequent valuation (Koløšta *et al.* 2023).

Soil as natural capital represents the basis for assessing the potential and consequently for the flow of ES (Vačkár *et al.* 2013). Haines-Young & Potschin (2009) and Maltby (2009) depict ecosystem services as mediating between the structures, processes, and functions of ecosystems on the one hand, and the benefits they contribute to human well-being on the other. The ES provided by the soil, agroecosystem service (soil ecosystem services) is a subset of ES related to the soil, directly and quantifiably controlled, or provided by the soil and its chemical, physical and biological properties, processes, and functions. ES can be assessed in more detail based on soil functions and indicators that directly or indirectly determine soil functions (Bujnovský *et al.* 2011; Burkhard *et al.* 2014, Makovníková *et al.* 2017).

Soil is sound when it is in good chemical, biological and physical condition and is therefore able to provide as many of the ES as possible on a continuous basis's (EU Soil Strategy 2030; EC 2021). Soil health has also been defined in the "Soil Deal for Europe" as the soil's sustainable capacity to support the ES (Bonfante *et al.* 2020). Soil health is the continued ability of the soil to function as a vital living ecosystem that supports plants, animals and people and links agriculture and soil to policy, stakeholder needs through sustainable supply chain management. The concept of soil health fulfils an important stakeholder need for sustainable development by increasing recognition of the role of soil in modern society and creating a workable platform for farmers, land managers, local governments, and policy makers. It is possible to assess ES in one numerical value through a multi-composite healthy soil index, which accumulates information on the state of soil health and thus its ability to provide soil functions and ES in the optimal range for a particular land use. A soil health index composed from soil indicators must respect knowledge about their critical limits (Arshad & Martin 2002, Abbot & Manning 2015). Defining soil health indicators and their range of values is critical for monitoring soil health. The reference values for each soil health indicator need to be context-specific (climate, soil type, land use (Costanza *et al.* 2017) and should be tracked within the monitoring of soils in each country.

The aim of the article is to apply and compare three different approaches to the assessment of regulating ecosystem services on agricultural used land on the example of a model region. 1) using a matrix system, 2) assessment based on soil functions, and 3) assessment of ecosystem services through the multiplicative soil health index.

MATERIAL AND METHODS

1. Theoretical and methodological baselines of matrix approach

A fundamental step in implementing a matrix-based assessment of ES is to define an initial matrix, which can be based either on an existing matrix from an already published study or on an empty matrix to be filled (Campagne & Roche 2018). To evaluate the potential of ES of natural capital, we modified and supplemented the matrices of authors Burkhard *et al.* (2014), Müller *et al.* (2020), and Černecký *et al.* (2020). In case of the absence of ecosystem values proposed by Müller *et al.* (2020) ranging from 0 to 100, we supplemented them by Burkhard *et al.* (2014) matrix; these values were transferred into a 0–100 scoring system by simple multiplications. Table 1 represents the resulting modified matrix for the evaluation of regulating ES, which can be generally used for the assessment of regulating ES for different regions or countries.

Table 1
Modified matrix for evaluating the potential of regulating ecosystem services

Ecosystem	Capacity scores								
	1	2	3	4	5	6	7	8	9
Arable land	40	20	20	20	30	30	30	30	30
Grassland	40	70	20	30	90	90	80	80	50
Vineyards	30	30	30	10	30	30	50	90	50
Fruit trees and berries	30	30	30	10	30	30	50	80	50
Agro-forestry areas: fast growing woody plants	40	70	20	60	90	90	70	90	40

Explanation: 1 – Local climate regulation, 2 – Global climate regulation, 3 – Air quality regulation, 4 – Water regulation, 5 – Erosion regulation, 6 – Nutrient regulation, 7 – Filtration/immobilization of risk elements, 8 – Pollination, 9 – Biodiversity protection.

The calculation of the total rating value (CBH_{ES}) based on the potential matrix of individual regulating ES (according to Vihervaara *et al*. 2012) for the model regions was:

$$\mathbf{CBH_{ES} = (\Sigma\ BHe.Pe)}$$

where BHe is the index score of the potential of the evaluated service of a particular ecosystem, and Pe is an area of a particular ecosystem in model region.

To determine the monetary value of the potential of individual ecosystem services we used the Value transfer method (Frelichová *et al*. 2014). Frélichová *et al.* (2014) stated the original value of 36.586 EUR per hectare; this value was adjusted for inflation of 3.2% in the Slovak Republic in 2022. The value of score 1 was assigned an amount of EUR 40.70 per hectare. Followed this procedure, the values of regulating ecosystem services of individual ecosystems were subsequently calculated using the matrix of indices (Table 1). The assessment of the complex monetary value for the model region was as follows:

$$\mathbf{CBH_M = CBH_{ES}.M}$$

where CBH_M = complex monetary value, and M – monetary value of score 1 in EUR

2. Theoretical and methodological baselines of ecosystem services assessment using soil functions indicators

In terrestrial ecosystems, the majority of ES come precisely from soil functions to a greater or lesser extent dependent on interactions between organisms, organic and mineral soil fractions (Kibblewhite *et al.* 2008). ES can be evaluated using soil functions and indicators that directly or indirectly determine these functions (Bujnovský *et al.* 2011, Burkhard *et al.* 2014, Makovníková *et al.* 2017). In agroecosystems, regulation of water regime (water storage), control of soil erosion (erosion control), climate regulation (carbon reserves in the soil) and filtration of pollutants (cleaning potential) are main regulation services (Dominati *et al*. 2013).

The regulating services

Potential of regulation of water regime – was based on the value of retention water capacity recalculated to soil water storage in context with the soil depth. Values were categorized into five groups: 1 – very low potential (<135 mm), 2 – low potential (135–175 mm), 3 – medium potential (175–215 mm), 4 – high potential (216–275 mm), 5 – very high potential (>275 mm).

Potential of regulation of soil erosion, regulation of water erosion – was derived from maps and databases based on empirical model of the Universal Soil Loss Equation – USLE (Wischmeier & Smith 1978, Styk & Pálka 2005). The relative ratio of the calculated values of soil loss and acceptable erosion expresses the degree of soil erosion endangerment (SEOP value). Values were categorized into five categories: 1 – very low potential (more than 2.60), 2 – low potential (2.21–2.60), 3 – medium potential (1.81–2.20), 4 – high potential (1.40–1.80), 5 – very high potential (less than 1.40).

Cleaning potential (immobilization of soil pollutants) of agricultural land ecosystem depends on the actual soil contamination and potential of sensitive soil sorbents to the sorption of risk elements. Due to considerable differences of soil sorbents on arable soils and grassland, as well as differences in the limit values of pollutants in the produced biomass, score evaluation was determined separately for different cultivation. The method is described in detail in our previous article Makovníková *et al.* (2007). Values were categorized into five categories as follows: 1 – very low potential (more than 6.50 points), 2 – low potential (5.51–6.50), 3 – medium potential (4.51–5.50 points), 4 – high potential (3.50–4.50 points), 5 – very high potential (lower than 3.50 points).

Climate regulation – within agroecosystems, soil organic matter represents the largest share of total organic carbon. Agroecosystems contribute to climate regulation by sequestration of organic carbon in the soil. Soil organic carbon stock (SOCS) was calculated as a function of soil bulk density (BD, g.cm^{-3}) and soil organic matter content (SOC, %) according to the equation (Makovníková *et al.* 2017):

SOCS (depth 0–0.30 m) in t. ha^{-1} = 10*(BD (0–0.10 m) * SOC (0–10 cm) + BD (0.10–0.20 m) * SOC (0.10–0.20 m) + BD (0.20–0.30 m) * SOC (0.20–0.30cm)

BD – soil bulk density in g.cm^{-3}, SOC – soil organic matter content in %.

The categories are as follows: 1 – very low potential (lower than 58.00 t C.ha^{-1}), 2 – low potential (58.00–62.00 t C.ha^{-1}), 3 – medium potential (62.01–67.00 t C.ha^{-1}), 4 – high potential (67.01–72.00 t SOC.ha^{-1}) 5 – very high potential (more than 72.00 t SOC.ha^{-1}).

For a comprehensive assessment and mapping the ES, a regular spatial network was done from a combination of agro-ecological indicators (climatic region, slope topography, land cover, soil texture) in accordance with the proposed assessment system as follows:

1. Climatic region (categories: moderately cold, moderately warm, warm, and very warm),
2. Slope topography (categories: 0–2°, 2.1°–5°,5.1°–12° and more than 12°),
3. Soil texture (categories: soil particles <0.01 mm less than 20%, 20–45%, more than 45%) and
4. Land use (arable land, grassland).

For this study, we used a classification of agro-climatic regions provided by the Information Service of the National Agricultural and Food Centre / Soil Science and Conservation Research Institute. For our purpose, the original vector layer with 11 categories were merged into 4 categories (climatic regions: moderately cold (regions 09,10), moderately warm (regions 06, 07, 08), warm (regions 03, 04, 05), and very warm (regions 00, 01, 02).

The method is described in detail in our previous article Makovníková *et al.* (2022).

3. Theoretical and methodological baselines of ecosystem services assessment using soil health index

In Slovakia, authors such as Juráni (2005), Bujnovský *et al.* (2011), Makovníková, Barančíková & Pálka (2007), Barančíková *et al.* (2011) defined a minimum set of soil indicators necessary for a sufficient assessment of individual soil functions, which are considered ES if they provide benefits to people (Kanianska *et al.* 2016). These indicators can be evaluated for each function and ES separately (as in the evaluation of ES based on soil functions), or they can be used as a basis for a complex multiparametric Soil Health Index (SHI). SHI was constructed using a minimum data set of physical and chemical soil indicators (direct indicators) in combination with environmental parameters, land use, slope, which have a direct or indirect impact on soil health (for example, Makovníková *et al.* 2007, Kiblewhite *et al.* 2008, Alam *et al.* 2016, Costanza *et al.* 2017, Vilček & Koco 2018). The selection of indicators will be based on our previous results (Bujnovský *et al.* 2011, Makovníková *et al.* 2019, Makovníková *et al.* 2022) using the scoring function “optimum is better” (Lenka *et al.* 2022).

Table 2
Indicators and indicators score of Soil Health Index (SHI)

Indicator	Value of indicator	Score of indicators (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	0.8
	> 8.00	0
Total organic carbon content	<1 %	0
	1–5 %	1
	> 5 %	2
Quality of organic carbon content (Q^4_6)	< 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 (MPRV SR 2004)	< hygienic limit value	0
	> hygienic limit value	-1

Above mentioned soil indicators are included within the soil monitoring system in Slovakia (Kobza *et al.* 2019) according to the recommendation of the European Commission for comprehensive soil monitoring system in Europe (van Camp *et al.* 2004). All indicators are significant and quantifiable. Each indicators value was converted into a scoring system (from – 1 to 2) with respect to the knowledge concerning their critical limits (Table 2) (Bujnovský *et al.* 2011, Makovníková *et al.* 2007, Barančíková *et al.* 2010). Indicator´s scores were included into a SHI which quantified the potential of soil health in context with agroecosystem services.

Soil Health Index: SHI = Σ SHI_i)

SHI values were categorized into 5 healthy soil classes: 1 – very low index (lower than 1.50 points), 2 – low index (1.5–3.50 points), 3 – medium index (3.51–5.00 points), 4 – high index (5.01–6.50 points), 5 – very high index (more than 6.50 points).

4. Study area Krupina

The region Krupina (Figure 1, Table 3), which has been chosen as a study area of our mapping, covers the Štiavnica Mts from the northwest, the Krupinská plain from the northeast and the Ipeľ upland from the south. 96% of the area is located at the altitude of 600 m above sea level. Most of the area is in very warm (58.9%) and moderately warm (36.6%) climatic regions.

Original paper

Table 3
Area representation of ecosystems in Krupina model region

Ecosystem	ha	% of the area of ecosystems
Arable land	15 266.6	38.5
Grassland	9 362.1	23,6
Vineyards	73.2	0.2
Fruit trees and berries	30.5	0.1
Fast growing woody plants	163.7	0.4

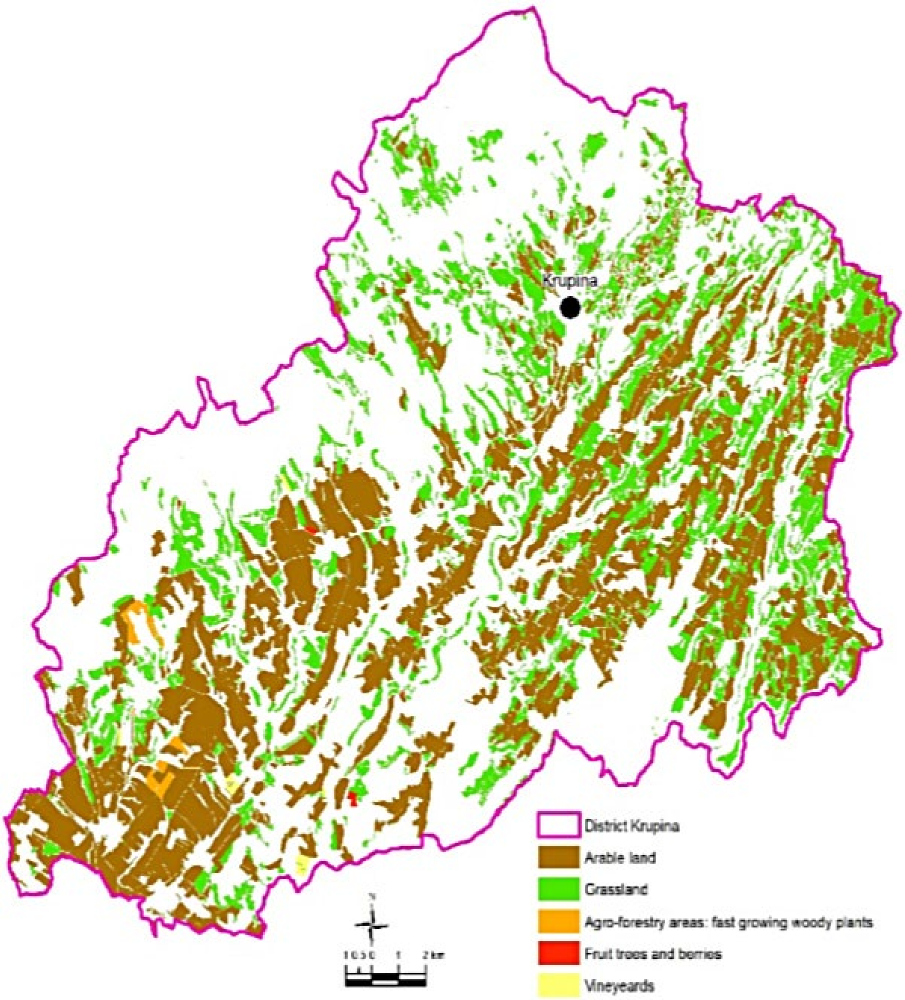
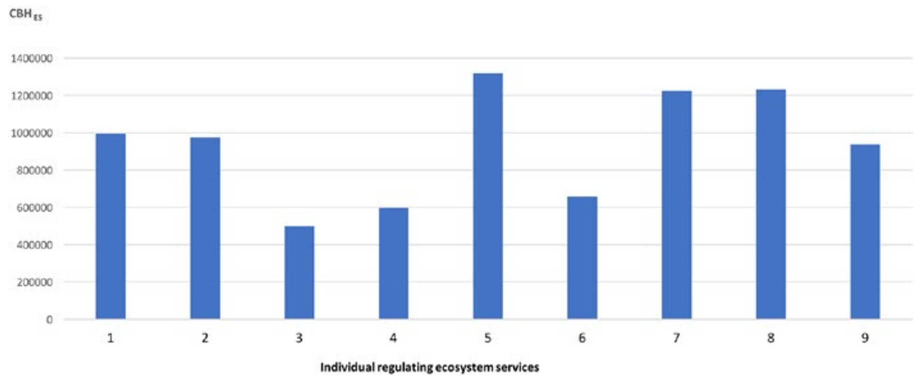


Figure 1 Ecosystems in Krupina model region

RESULTS AND DISCUSSION

1. Assessment of ecosystem services using a matrix system

Graph 1 and Figure 2 show the non-monetary point value of the index for individual categories of regulating ES (local and global climate regulation, air quality regulation, water regulation/flood protection, water erosion regulation, nutrient regulation, risk substance regulation, pollination, and biodiversity protection) in study area.



Graph 1 Non-monetary values of individual regulating ES in Krupina region
Explanation: 1 – Local climate regulation, 2 – Global climate regulation, 3 – Air quality regulation, 4 – Water regulation, 5 – Erosion regulation, 6 – Nutrient regulation, 7 – Filtration/immobilization of risk elements, 8 – Pollination, 9 – Biodiversity protection

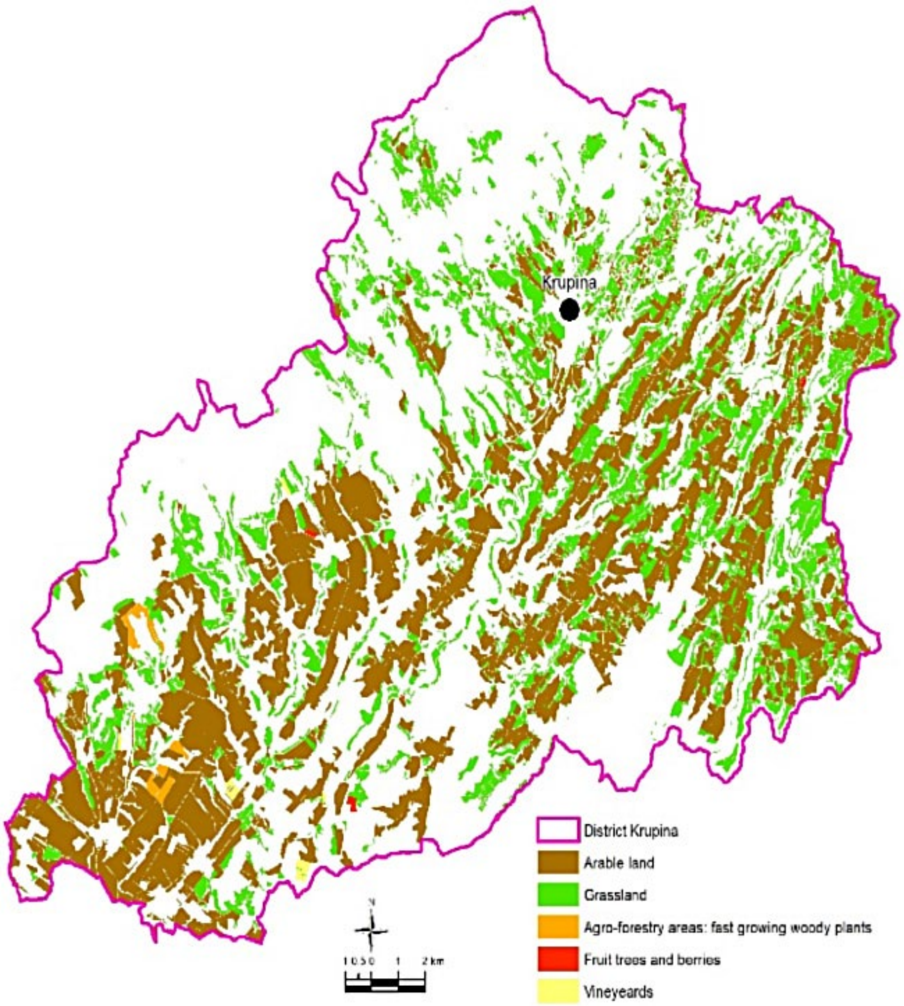


Figure 2 Individual regulating ES in Krupina region

Müller *et al*. (2020) report lower average values of individual regulatory ecosystem services for all assessed ecosystems (for the northern region of Germany) than Černecký (2020) for Slovakia. The total point value of the potential of regulating ES of individual ecosystems makes it possible to link the matrix assessment with geospatial units and display the area distribution of point non-monetary values of regulating ES in the Krupina model region (Fig. 3).

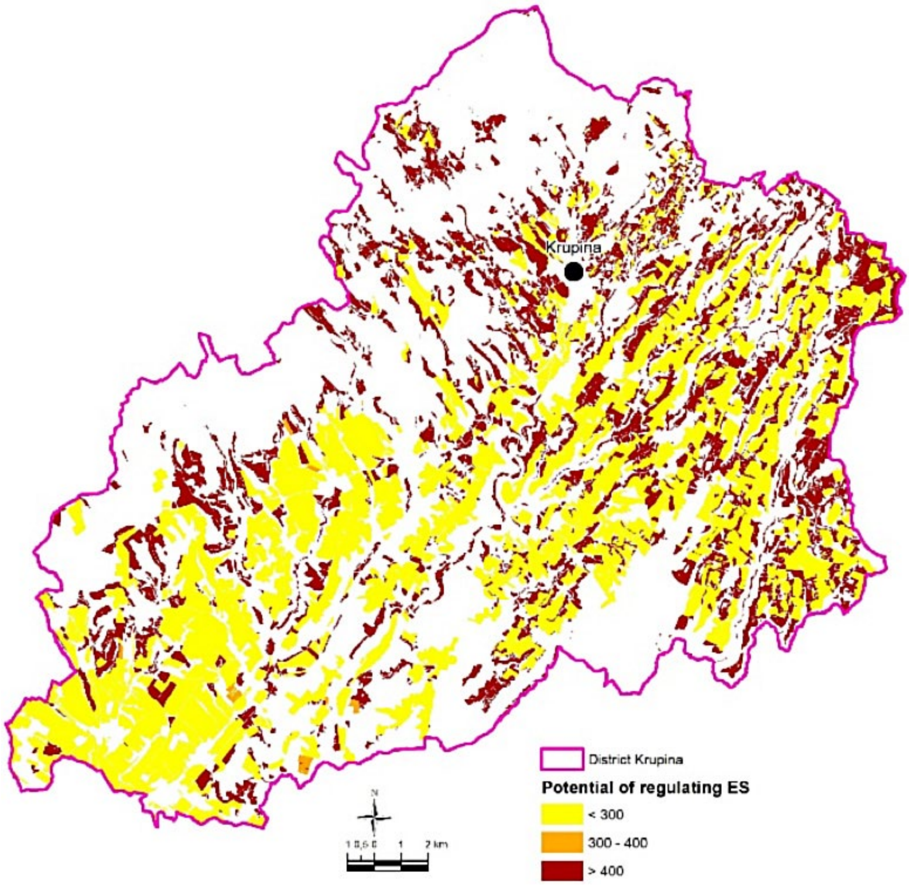
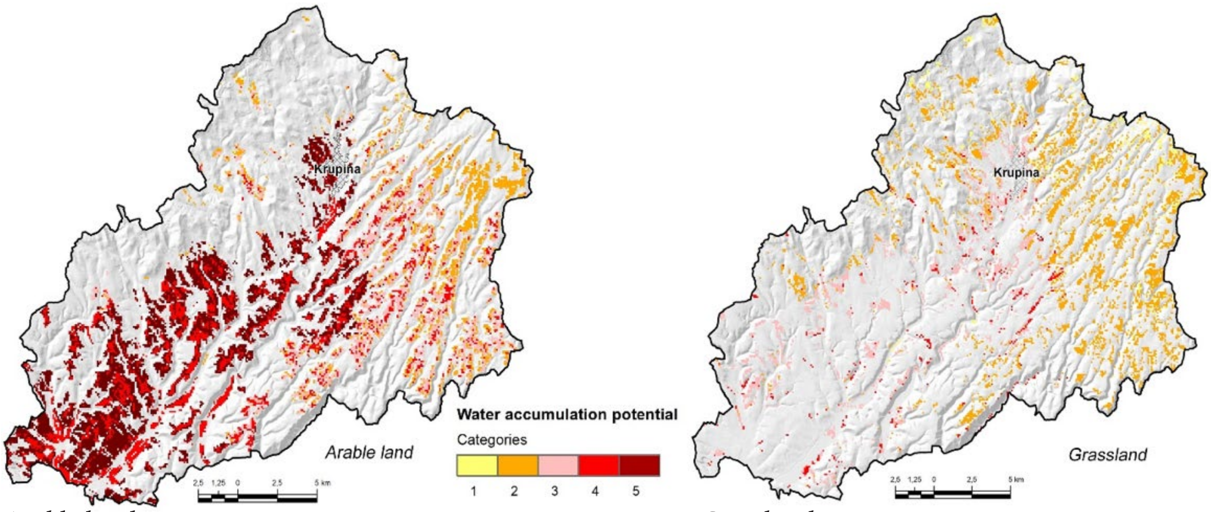


Figure 3 Mapping using the point value of the potential of regulating ES in Krupina region

When using the matrix system, we evaluated the potential of ES (maximum possible capacity). The total value of the potential of regulating ES of agricultural land in the Krupina region was 8,436,056 points in non-monetary units. In monetary units the value of natural capital was EUR 343,347,479 (the value of 1 point was EUR 40.7 for the year 2022). Krupina belongs to the regions with a medium value of regulatory ES, which is influenced on the one hand by the climatic area and on the other hand by the high representation of arable land in this region (Makovníková *et al.* 2023). Regulating ES to the highest extent reflect the multifunctionality of the territory. Multifunctional territories have a positive effect on the protection of biodiversity and the overall maintenance of ES, on soil quality, as well as on biomass production (Raudsepp-Hearne *et al.* 2010), thereby increasing the ecological resilience of the territory (O'Farrell & Anderson 2010).

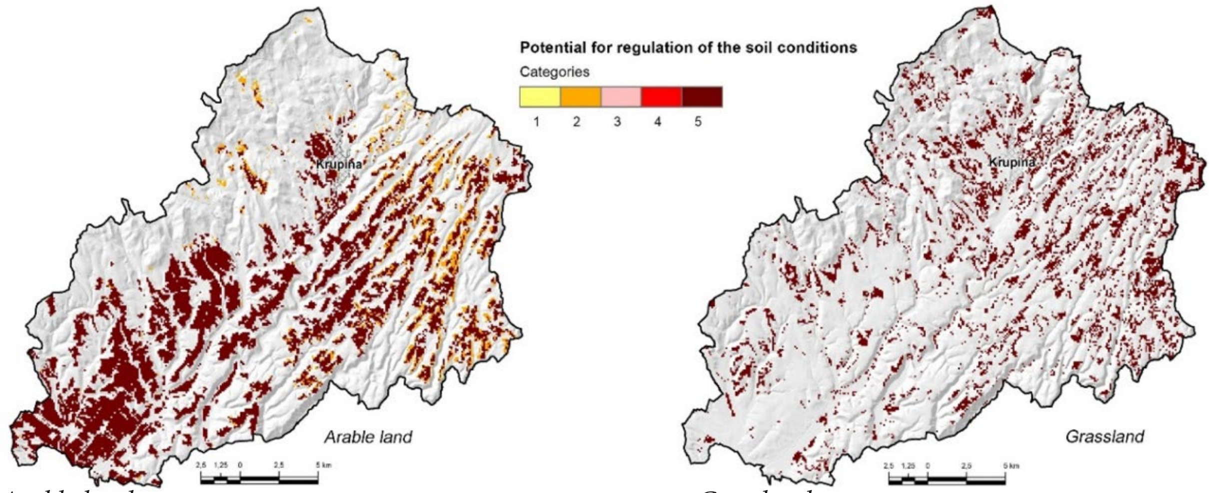
2. Assessment of ecosystem services using indicators of soil functions

The evaluation of ES using soil functions enables the evaluation of agriculturally used lands even with the distinction of their use (especially arable land and grassland). The area-wide assessment of the regulating ES of arable land ecosystems and grassland ecosystems is shown in Figures 4 to 7. Other cultures are not widely distributed, so we evaluate them together with permanent grasslands.



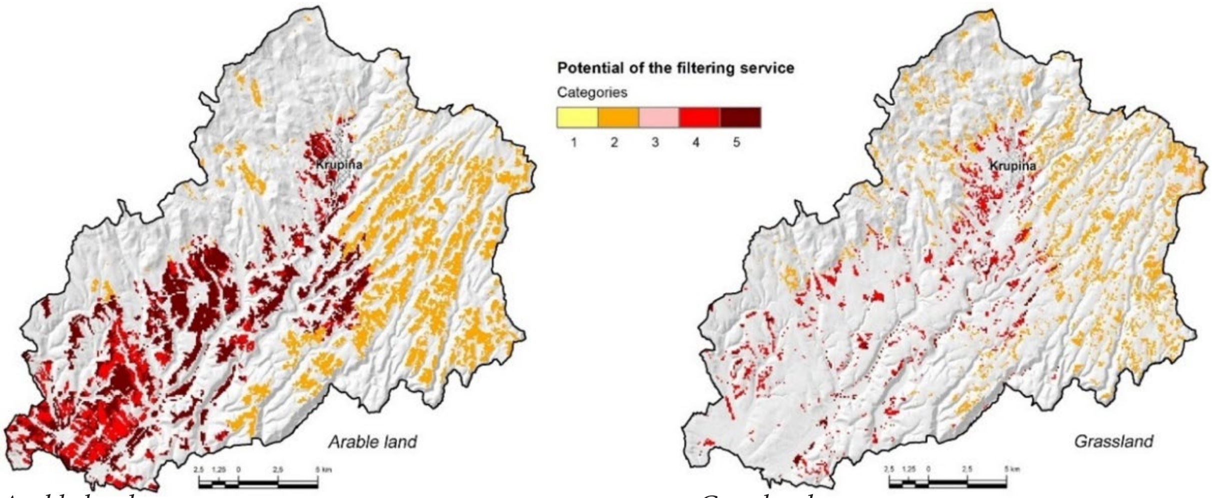
Arable land *Grassland*

Figure 4 Water accumulation potential in the Krupina region



Arable land *Grassland*

Figure 5 Potential for regulation of soil conditions (soil erosion) in the Krupina district



Arable land *Grassland*

Figure 6 The potential of the filtering service in the Krupina region

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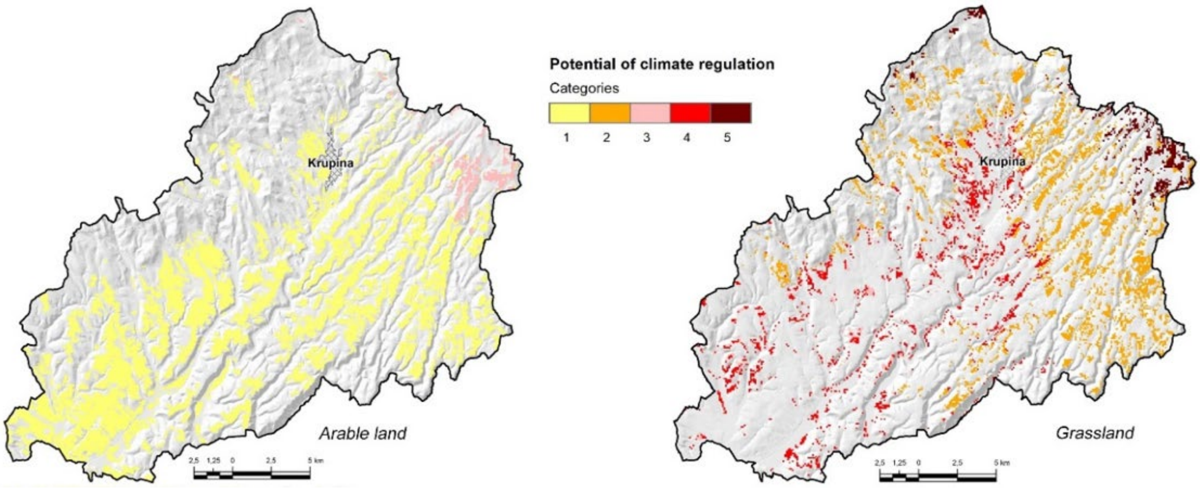


Arable land *Grassland*

Figure 7 The potential of climate regulation in the Krupina region

The potential of the regulating ES of agricultural land is determined by its location in the landscape with climatic conditions (temperature and precipitation), and it is a combination of abiotic, biotic, morphological, and socio-economic factors (management of arable land and grassland). Tables 4 and 5 show the overall representation of individual categories of the potential of regulating agro-ecosystem services in the Krupina model region.

Table 4

Categories of the potential of water regime regulation and potential of erosion regulation in % of total area of agricultural land

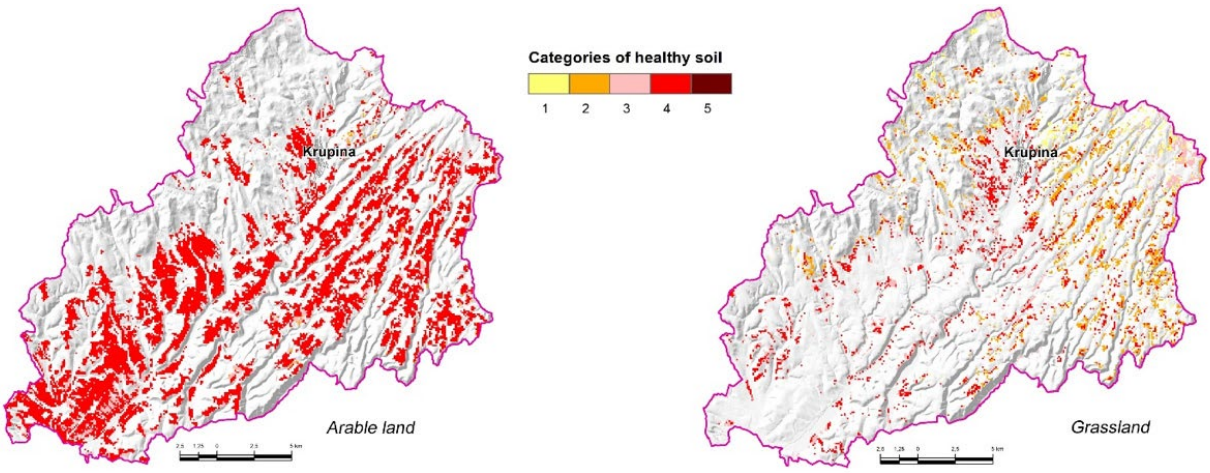
Categories	% of total area					
	Potential of water regime regulation			Potential of erosion regulation		
	Agricultural land	Arable land	Grassland	Agricultural land	Arable land	Grassland
1	13.50	0.41	41.91	0.23	5.44	0.00
2	16.26	15.31	25.40	0.85	10.94	0.00
3	17.49	17.07	13.64	7.68	6.87	0.00
4	11.16	27.14	18.78	4.64	4.91	0.00
5	41.59	40.07	0.27	86.61	71.84	100.00
sum	100	100	100	100	100	100

Table 5
Categories of cleaning potential (immobilization of pollutants) and potential of climate regulation of ecosystem in % of the total agricultural land area

Categories	% of total area					
	Cleaning potential of ecosystem			**Climate regulation potential of ecosystem**		
	Agricultural land	Arable land	Grassland	Agricultural land	Arable land	Grassland
1	0.00	0.00	0.00	83.02	95.70	55.23
2	15.90	40.58	0.20	2.12	0.01	1.68
3	77.79	0.17	49.28	8.46	4.29	24.47
4	6.30	19.87	50.52	6.40	0.00	18.41
5	0.00	39.38	0.00	0.00	0.00	0.21
sum	100	100	100	100	100	100

3. Assessments of ecosystem services using soil health index

Area distribution of soil health index categories in the Krupina model region is in Figures 8 and 9 and Table 6.



Arable land *Grassland*
Figure 8 Categories of healthy soil (arable land, grassland)

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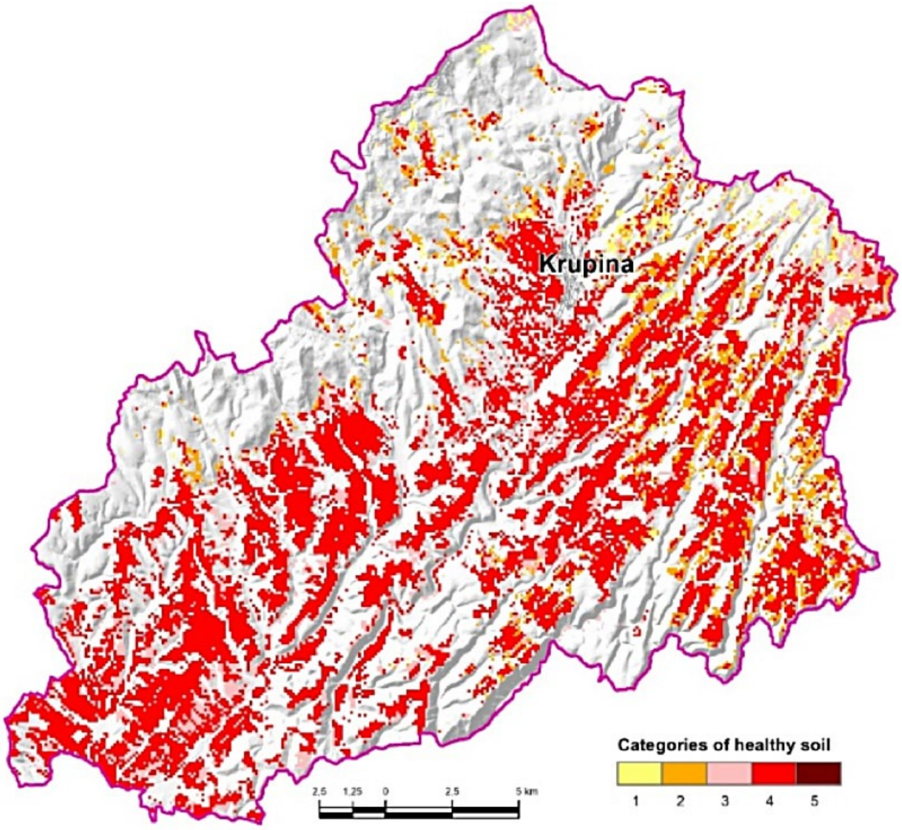

Figure 9 Categories of healthy soil (agricultural land)

In model region 75.30 % of the area of agricultural ecosystems has high potential of SHI (SHI category 4). They are mostly ecosystems of arable land located in very warm to moderately warm parts of Danube hilly and Krupinska planina (plain) with loam to clay loam deep soils without skeleton. The lowest value of SHI (categories 1 and 2) is in the northern part of study area and in higher altitudes. Diehl *et al.* (2013) and Frélichová & Fanta (2015) state the climate as one of the important factors affecting the distribution of ES.

Table 6
Categories of the SHI in % of total area of agricultural land

SHI categories	% of total area		
	Agricultural land	Arable land	Grassland
1 – very low index	2.5	0.00	6.83
2 – low index	12.6	0.76	4.03
3 – medium index	31.5	7.21	51.47
4 – high index	53.4	92.03	37.67
5 – very high index	0.00	0.00	0.00

Our results showed that the use of the composite index in the assessment of regulating ES is comparable to the assessment of water regime regulation and cleaning potential. Individual models for two regulating ES, climate regulation potential and erosion regulation potential, with dominance of only one category, are incomparable to the composite soil health index in evaluating regulating ES.

Suitability of used methods

Criticism of the use of matrix systems based on expert estimates consists in the introduction of varying degrees of subjectivity or ambiguity regarding the procedure for creating the final matrix score. Despite the limitations, the matrix system has its positives for practical ecosystem management, such as the credibility of the results (results of the matrix values are highly correlated with independent quantitative data; Rosche & Campagne 2019), adaptability to local conditions, ease of understanding the results for different stakeholders, including policy makers and managers ecosystems, efficient use of time and resources, pragmatism and overcoming limitations due to lack of resources. For future research using a matrix approach, it will be important to have proper communication and transparency of the methods used to quantify individual services, including the assessment of uncertainty (Campagne *et al.* 2020); preventing the transfer of values from existing matrices to non-comparable case studies or adapting values to a local participatory approach and local data; improving the quantification of ES values in the matrix.

Modelling and evaluation of individual ES (through the evaluation of soil functions) allows for a more detailed assessment of ES (the matrix system evaluates e.g., arable land with the same value without considering its location and properties), evaluates their interconnection and defines sources of variability as well as spatial differences. The indicators included in the assessment are part of the CMS soil monitoring system and are monitored in regular 5-year cycles. However, in this approach to ES assessment based on separate categorization of individual soil functions, the same indicators are repeatedly entered into the models but with different weights for individual functions, thus overestimating their resulting impact in the overall assessment.

The Soil Health Index assesses soil health in terms of the provision of ES. This index linked to map units representing the use of agricultural land (arable land, grasslands) and the climatic region enables a comprehensive assessment of the potential of agroecosystem services. The evaluation of ES using the linear aggregation of indicators in the composite index does not increase the influence of those indicators that enter several ES models in the individual evaluation of individual ES. The results of the assessment of ES using the healthy soil index belong to robust models describing the relationship between the potential of regulating ES and explanatory variables. Modelling and evaluation of individual regulating ES, however, allows for a more detailed assessment of individual agroecosystem services and to define sources of variability as well as spatial differences.

The mentioned methods of evaluating and quantifying the potential of ES have their pros and cons, varying degrees of subjectivity, the availability of the necessary documents, the credibility of the results, as well as the possibility of using the results in practice (Table 7).

Table 7

Comparison of the appropriateness of the methods used to evaluate ecosystem services

	Assessment method		
	Matrix approach	**Assessment using indicators of soil function**	**Assessment using soil health index**
ES potential	x	x	x
Actual value ES (1 to 3)	-	3	2
Data availability (1 to 3)	3	1	2
Area rating/point rating	x	x/x	x/x
Robustness of the method (1 to 3)	3	1	2
Degree of subjectivity	3	1	1
Availability of data layers for assessment (1 to 3)	3	1	1
Availability of indicators for assessment (1 to 3)	3	1	2
Sensitivity of indicators to changes in land use and land management (1 to 3)	2	3	1
x – valuation, 1 – low, 2 – medium, 3 – high			

By comparing the results of the ES evaluation using indicator of soil function and the evaluation using soil health index (we did not evaluate the matrix system in 5 categories, therefore we did not include it in this comparison), we found a significant correlation between SHI and the cleaning potential of the ecosystem (r = 0.97) (immobilization of pollutants), negative correlation between the SHI index and the potential of erosion regulation for grassland (r= -0.48) (Table 8, 9), but similar results were not confirmed in the case of grassland.

Table 8

Categories of the potential of individual ES and SHI in % of total area of arable land

Categories	**% of total area**				
	Potential of water regime regulation	**Potential of erosion regulation**	**Cleaning potential of ecosystem**	**Climate regulation potential of ecosystem**	**SHI index**
1	0.41	5.44	0.00	95.70	0.00
2	15.31	10.94	40.58	0.01	0.76
3	17.07	6.87	0.17	4.29	7.21
4	27.14	4.91	19.87	0.00	92.03
5	40.07	71.84	39.38	0.00	0.00

Table 9
Categories of the potential of individual ES and SHI in % of total area of grassland

Categories	% of total area				
	Potential of water regime regulation	Potential of erosion regulation	Cleaning potential of ecosystem	Climate regulation potential of ecosystem	SHI index
1	41.91	0.00	0.00	55.23	6.83
2	25.40	0.00	0.20	1.68	4.03
3	13.64	0.00	49.28	24.47	51.47
4	18.78	0.00	50.52	18.41	37.67
5	0.27	100.00	0.00	0.21	0.00

The assessing of regulating ES using the linear aggregation of indicators in soil health index does not increase the impact of those indicators, which enter in multiple models in the individual evaluation of each service. However, the SHI results belong to the robust models describing the relationship between regulating services potential and explanatory variables.

CONCLUSIONS

The matrix system for evaluating ES has the highest degree of subjectivity, primarily in the value of indexes. The value of the indexes of individual ES depends on the creation of the matrix. However, it makes it possible to evaluate a wide range of ES. The level of uncertainty in the regional or local assessment scale can be reduced by confronting the values in the used matrix with the values obtained based on a questionnaire survey of preferences and evaluation of individual ES in local conditions. The matrix system is suitable when the availability of data sources is limited. Its advantage is also the connection of non-monetary and monetary evaluation through the "transfer value" method. Monetary expression is an important tool for raising awareness of the importance of ecosystems and biodiversity in the formulation of public policies. Despite the limitations, the application of the matrix approach as a tool for sustainable landscape management is beneficial and can be further developed, especially to facilitate the practical application of the concept of ES. Modelling and assessment of individual ES (through the evaluation of soil functions) allows for a more detailed assessment of ES, to evaluate their interconnection and to define sources of variability as well as spatial differences. Evaluation of ES using the Soil Healthy Index belongs to the aggregated methods describing the relationship between the potential of ES and explanatory variables. This method is also suitable for the assessment of ES at the regional and local level when input variables are available, it is sensitive to changes in land use and land management.

It is not only the choice of method that is important, but also the appropriately chosen spatial resolution for the interpretation of the results. The matrix system only allows for the overall assessment of individual ecosystems, the quantification of ES using soil functions, as well as the assessment of ES through the Soil Health Index, with good data availability, provide more accurate results at the regional and local level.

An important aspect of the assessment and quantification of ES is also the assessment of the degree of synergy and compromises between individual groups of services as well as individual ES. ES are non-linearly interconnected, and changes in one service can positively or negatively affect the other. In synergy, the cooperation of individual components occurs, and the resulting effect is a higher potential of individual ES. One of the big challenges for policymakers and for effective land use management is the coordination of relationships between trade-offs of ES to achieve win-win results for society and ecosystems.

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REFERENCES

Abbot, L.K., Manning, D.A.C. (2015). Soil health and related ecosystem services in organic agriculture. *Sustainable Agriculture Research*, vol. 4(3): 116–125. ISSN 1927-0518. DOI: http://dx.doi.org/10.5539/sar.v4n3p116.

Alam, M., Dupra, J., Messier, Ch. (2016). A framework towards a composite indicator for urban ecosystem services. *Ecological indicators*, 2016, vol. 60: 38–44.

Arshad, M.A., Martin, S. (2002). Identifying critical limits for soil quality indicators in agro-ecosystems. *Agriculture, Ecosystems & Environment*, vol. 88: 153–160.

Barančíková G., Gutteková, M., Halas, J., Koco, Š., Makovníková, J., Nováková, M., Skalský, R., Tarasovičová, Z., Vilček, J. (2011). *Pôdny organický uhlík v poľnohospodárskej krajine – modelovanie zmien v priestore a čase.* Výskumný ústav pôdoznalectva a ochrany pôdy, Bratislava, 85 str., ISBN 978-80-89128-86-0 (in SK).

Birkhofer, K., Wolters, V. (2012). The global relationship between climate, net primary production and the diet of spiders. *Glob. Ecol. Biogeography*. vol. 21: 100–108. DOI: 10.1111/j.1466-8238.2011.00654.x.

Bonfante, A., Basile A., Bouma J. (2020). Targeting the soil quality and soil health concepts when aiming for the United Nations Sustainable Development Goals and the EU Green Deal. *SOIL* (open discussion) https://doi.org/10.5194/soil-2020-28. *Soil*, vol. 6(2): 453–466. ISSN 2199-3971. https://doi.org/10.5194/soil-6-453-2020.

Bujnovský, R., Vilček, J., Blaas, G., Skalský, R., Barančíková, G., Makovníková, J., Balkovič, J., Pálka, B. (2011). *Hodnotenie kapacít pôdy a efektov z jej využívania*. VÚPOP Bratislava, 70 str., ISBN 978-80-89128-83-9 (in SK).

Burkhard, B., Kroll, F., Müller, F., Windhorst, W. (2009). Landscapes 'Capacities to Provide Ecosystem Services – a Concept for Land-Cover Based Assessments'. *Landscape Online*, vol. 15: 1–22.

Burkhard, B, Kandziora, M.S., Müller, F. (2014). Ecosystem Service Potentials, Flows and Demands – Concepts for Spatial Localisation, Indication and Quantification. *Official Journal of the International Association for Landscape Ecology – Regional Chapter Germany* (IALE-D). Available at http://www.landscapeonline.de/103097lo201434.

Burkhard, B., Maes, J. (eds.) (2017). *Mapping Ecosystem Services*. Sofia: Pensoft Publishers. 374 pp.

Campagne, C.S., Roche, P.K. (2018). May the matrix be with you! Guidelines for the application of expert-based matrix approach for ecosystem services assessment and mapping. e24134. *One Ecosystem* 3: e24134, DOI:10.3897/oneeco.3.e24134.

Costanza, R., d´Arge, R., de Groot, R.S., Farber, S., Grasso, M. *et al.* (1997). The value of the world´s ecosystem services and natural capital. *Nature*, vol. 387: 253–260.

Costanza, R. (2008). Ecosystem services: multiple classification systems are needed. *Biological Conservation*, vol. 141: 350–352.

Černecký, J., Gajdoš, P., Ďuricová, V., Špulerová, J., Černecká, Ľ., Švajda, J., Andráš, P., Ulrych, L., Rybanič, R., Považan, R. (2020). *Hodnota ekosystémov a ich služieb na Slovensku*. Banská Bystrica: ŠOP SR (in SK).

Dominati, E., Patterson, M., Mackay, A. (2010). A framework for classifying and quantifying the natural capital and ecosystem services of soils. *Ecological Economics*, vol. 69: 1858–1868.

European Commission (2021). EU Soil Strategy 2030. COM (2021) 699 final https://ec.europa.eu/environment/publications/eu-soil-strategy-2030_en(2021).

Frélichová, J., Vackár, D., Pártl, A., Loucková, B., Harmácková, Z., Lorencová, E. (2014). Integrated Assessment of Ecosystem Services in the Czech Republic. *Ecosystem Services*, 8, 110–117. https://doi.org/10.1016/j.ecoser.2014.03.001

Frélichová J., Fanta J. (2015). Ecosystem service availability in view of long-term land use changes: a regional case study in the Czech Republic. *Ecosystem Health and Sustainabilty*, vol. 1: 1–15.

Haines-Young, R.H., Potschin, M.B. (2009). *Methodologies for defining and assessing ecosystem services.* Final Report, JNCC, 69 pp.

Juráni, B. (2005). Ochrana, využívanie pôdy a vplyv človeka. In: *Štvrté pôdoznalecké dni v SR. Zborník referátov z ved. konf. pôdoznalcov SR,* Čingov, 14.–16.6.2005, Jaroslava Sobocká (ed.), SPS a VÚPOP Bratislava 2005, s. 178–180, ISBN 80-89128-18-1 (in SK)

Kaiser, G., Burkhard, B., Römer, H., Sangkaew, S., Graterol, R., Haitook, T., Sterr, H., Sakuna-Schwartz, D. (2013). Mapping tsunami impacts on land cover and related ecosystem service supply in Phang Nga, Thailand, *Nat. Hazards Earth Syst. Sci.*, vol. 13: 3095–3111, https://doi.org/10.5194/nhess-13-3095-2013.

Kandziora, M., Burkhard, B., Müller, F. (2013). Interactions of ecosystem properties, ecosystem integrity and ecosystem service indicators–A theoretical matrix exercise. *Ecological Indicators,* vol. 28: 54–78.

Kanianska, R., Jaďuďová, J., Makovníková, J., Kizeková, M., Tomaškin, J. (2016). *Ekosystémové služby.* Belianum. Vydavateľstvo Univerzity Mateja Bela v Banskej Bystrici, 2016, 244 s., ISBN 978-80-557-1129-4 (in SK).

Kibblewhite, M.G., Titz, K., Swift, M.J. (2008). Soil health in agricultural systems. *Philosophical Transactions of the Royal Society*, London B, vol. 363: 685–701.

Kobza, J., Barančíková, G., Dodok, R., Makovníková, J., Pálka, B., Styk, J., Široň, M. (2019). *Soil monitoring of the Slovak Republic. Current state and development of monitoring soil properties as a basis to their protection and next land use*. National Agricultural and Food Centre. Soil Science and Conservation Research Institute Bratislava, 252 p. ISBN 978-808163-033-0 (in SK).

Kološta, S., Makovníková, J., Flaška, F., Pálka, B. (2023). *Peňažné a nepeňažné hodnotenie ekosystémových služieb vo vybraných regiónoch Slovenska*. Vysoká škola evropských a regionálních studií České Budějovice, EF UMB, NPPC – VÚPOP, 109 p. (in SK).

Kroll, F., Müller, F., Haase, D., Fohrer, N. (2012). Rural-urban gradient analysis of ecosystem services supply and demand dynamics. *Land Use Policy,* vol. 29: 521–535. DOI: 10.1016/j.landusepol.2011.07.008.

Lenka, N.K, Meena, B.P., Lal, R,, Khandagle, A., Lenka, S., Shirale, A.O. (2022). Comparing Four Indexing Approaches to Define Soil Quality in an Intensively Cropped Region of Northern India.Front. *Environ. Sci.* 10:865473.doi: 10.3389/fenvs.2022.865473.

Makovníková, J., Barančíková, G., Pálka, B. (2007). Approach to the assessment of transport risk of inorganic pollutants based on the immobilisation capability of soil. *Plant, Soil and Environment*, vol. 53: 365–373.

Makovníková, J., Pálka, B., Široň, M., Kanianska, R., Kizeková, M. (2017). *Potenciál agro-ekosystémových služieb orných pôd*. Banská Bystrica: NPPC – VÚPOP, 110 s. ISBN 978-80-8163-021-7 (in SK).

Makovníková, J., Pálka, B., Široň, M., Houšková, B. Kanianska, R., Kizeková, M. (2019). An approach to the assessment of regulating agroecosystem services. *Pol. J. Soil Sci.* 2019, vol. 52(1): 95. https://doi.org/10.17951/pjss.2019.52.1.95.

Makovníková, J., Pálka, B., Kološta, S. (2022). Current State and Development of the Soil Health Index in Localities with Various Soil-Climatic Conditions in the Slovak Republic. *Journal of Geoscience and Environment Protection*, vol. 10: 1–11. Available on https://doi.org/10.4236/gep.2022.10600.

Makovníková, J., Kološta, S., Flaška, F. Pálka, B., Široň, M. (2022). *Potenciál ekosystémových služieb prírodného kapitálu ako nástroj hodnotenia sociálno-ekonomického potenciálu územia*. Banská Bystrica: NPPC – VÚPOP, Ekonomická fakulta UMB. 131 s. ISBN 978-80-8163-042-2 (in Slovak).

Kološta, S., Makovníková, J., Flaška, F. Pálka, B. (2023). *Peňažné a nepeňažné hodnotenie ekosystémových služieb vo vybraných regiónoch Slovenska.* Vysoká škola evropských a regionálních studií České Budějovice, EF UMB, NPPC-VUPOP, 109 s., ISBN 978-80-7556-133-6. (in SK).

Maltby, E. (2009). *Functional assessment of wetlands: towards evaluation of ecosystem services*. Woodhead Publishing: Cambridge.

Mengist, W., Soromessa, T., Feyisa, G.L. (2020). A global view of regulatory ecosystem services: Existed knowledge, trends, and research gaps – ecological processes. *Ecological Processes*, vol. 9(1). DOI:10.1186/s13717-020-00241-w.

Millennium Ecosystem Assessment (2005). Ecosystems and Human Well-Being: Our Human Planet: Summary for Decision Makers. *The Millennium Ecosystem Assessment Series,* vol. 5, Island Press, Washington DC.

MPRV SR (2004). Zákon č. 220/2004 Z.z. o ochrane a využívaní poľnohospodárskej pôdy a o zmene zákona č. 245/2003 Z.z. o integrovanej prevencii a kontrole znečisťovania životného prostredia a o zmene a doplnení niektorých zákonov (in SK).

Müller, F., Bicking, S., Ahrendt, K., Kinh Bac, D., Blindow, I., Fürst, C., Haase, P., Kruse, M., Kruse, T., Ma, L., Perennes, M., Ruljevic, I., Schernewski, G., Schimming, C., Schnei-ders, A., Schubert, H., Schumacher, J., Tappeiner, U., Wangai, P., Windhorst, W., Zeleny, J. (2020). Assessing Ecosystem Service Potentials to Evaluate Terrestrial, Coastal and Marine Ecosystem Types in Northern Germany – an Expert-Based Matrix Approach. *Ecological Indicators*, 112, 106116. DOI: 10.1016/j.ecolind.2020.106116.

Nedkov, S., Burkhard, B. (2012). Flood regulating ecosystem services mapping supply and demand, in the Etropole municipality, Bulgaria. *Ecological Indicators,* vol. 21: 67–79.

O'Farrell, P.J., Anderson, P.M. (2010). Sustainable multifunctional landscapes: a review to implementation. *Current Opinion in Environmental Sustainability*, vol. 2: 59–65. DOI 10.1016/j.cosust.2010.02.005.

Raudsepp-Hearne, C., Peterson, G.D., Bennett, E.M. (2010). Ecosystem service bundles for analysing trade-offs in diverse landscapes. In Proc. Natl. Acad. Sci. U.S.A. vol. 107: 5242–5247.

Roche, P., Campagne, C.S. (2019). Are expert-based ecosystem services scores related to biophysical quantitative estimates? *Ecological Indicators*, vol. 106, https://doi.org/10.1016/j.ecolind.2019.05.052.

Styk, J., Pálka, B. (2005). Potenciálna ohrozenosť poľnohospodárskych pôd SR vodnou eróziou vyhodnotená využitím empirického modelu USLE. In: *Zborník prednášok. VII. zjazd Slovenskej spoločnosti pre poľnohospodárske, lesnícke, potravinárske a veterinárske vedy pri SAV. Pedologická sekcia*, Bratislava: Výskumný ústav pôdoznalectva a ochrany pôdy, 2005, s. 73–77 (in SK).

Vačkár, D., Frélichová, J., Lorencová, E., Pártl, A., Harmáčková, Z., Loučková B. (2013). *Methodological framework for integrated assessment of ecosystem services in Czech Republic*. Academie věd ČR, 2013, 26 pp. (in Czech).

Van Camp, B., Bujarrabal, A.R., Gentile, R.J.A., Jones, L, Montanarella, L., Olazabal, O., Sel-varadjpu, S.K. (2004). Reports of the Technical Working Groups Established under the Thematic Strategy for Soil Protection. EUR 21319 EN/5 (2004) p. 872. Office for Official Publications of the European Communities, Luxembourg.

Vihervaara, P., Kumpula, T., Ruokolainen, A., Tanskanen, A., Burkhard B. (2012). Using detailed biotope data for Ecosystem service assessment in Natural protection areas. Int. Journal of Biodiversity Science, *Ecosystem Services & Management,* vol. 8(1–2): 169–185. DOI: 10.1080/21513732.2012.686120.

Vilček, J., Koco, Š. (2018). Integrated index of agricultural soil quality in Slovakia. *Journal of Maps*, vol. 14(2): 68–76, DOI: 10.1080/17445647.2018.1428233

Wischmeier, W.H., Smith, D.D. (1978). Predicting rainfall erosion losses: Guide to conservation planning. *Agricultural Handbook,* No 537, USDA, 1978, 58 s.