Original paper

ECOSYSTEM SERVICE – SOIL WATER ACCUMULATION OF CROPLAND UNDER DIFFERENT CLIMATIC AND PEDO-ECOLOGICAL CONDITIONS OF SLOVAKIA

Miloš Širáň, Jarmila Makovníková, Boris Pálka

National Agricultural and Food Centre – Soil Science and Conservation Research Institute Bratislava, Slovak Republic

Corresponding author: *Ing. Miloš Širáň, PhD., National Agricultural and Food Centre, Soil Science and Conservation Research Institute, Mládežnícka 36, 974 04 Banská Bystrica, Slovakia, e-mail: milos.siran@nppc.sk; ORCID ID: 0009-0005-0471-4786*

Citation: Širáň, M., Makovníková, J., Pálka, B. (2024). Ecosystem service – soil water accumulation of cropland under different climatic and pedo-ecological conditions of Slovakia. *Pedosphere Research,* vol. **4,** 2024, no. 1, pp. 24–35. NPPC – VÚPOP Bratislava. ISSN 2729-8728.

Abstract

This study aims to evaluate soil water accumulation of cropland agroecosystem in seven regions with various climatic and soil-ecological conditions. The potential of water accumulation in the soil (one of the regulating ecosystem services) was assessed through the hydro-limit of the field water capacity expressed in volume percentages. For the needs of spatial analysis and assessment of the potential of ecosystem services, mapping units were created based on biophysical data in combination with land use data. Result from our study showed that soil water accumulation in cropland ecosystems is higher in lowland positions and decreases with increasing altitude. Negative correlation between water accumulation and climatic regions (R=-0.63) is statistically significant. Cropland ecosystems with very high potential of water accumulation service are significantly represented in the region of Michalovce (93% of the area), Rožňava (58%) and Krupina (40%). In the Poprad region, there are mainly areas with a low potential (90%). The value of soil water storage potential can help in the development of functional strategies for optimal land use in the country.

Keywords: ecosystem services, soil water accumulation, climatic region, cropland, Slovakia

INTRODUCTION

The analysis and assessment of ecosystem services is a widely discussed topic across the spectrum of natural science. According to Birghofer (Birghofer *et al*. 2015), ecosystem services are determined by mutual interaction between ecological and social systems, ecosystem services are those ecosystem processes and functions that contribute to the fulfilment of human needs. Ecosystem services of agriculturally used lands, linked to natural capital, are divided by Dominati *et al.* (2010) into three basic groups, namely provisioning, regulating and cultural services.

Climate change brings with it a greater risk of extreme weather, including flash floods, which increases the importance of water regulation in the country. Ecosystem service, water regime regulation includes water distribution, water retention, water cycling for all ecosystems, and flood control. The presence or absence of water in the landscape significantly affects also provisioning services, regulating ecosystem services as well as supporting processes and biodiversity.

The ability of soil to accumulate water depends on soil parameters (soil texture, soil mineralogical composition, quality and arrangement of soil horizons, soil compaction or bulk density, soil structure, content, and quality of organic matter) and environmental locality characteristics (relief, slope, climate, precipitation, groundwater level) (Bujnovský *et al*. 2009). The clay fraction and humus have the greatest ability to attract water, and this ability depends not only on their quantity but also on their quality. The quality of the clay fraction is mainly determined by the presence of individual clay minerals – phyllosilicates, differing in structure and ability to swell. Soils with a predominance of clay minerals of the smectite group have the greatest sorption capacity (Čurlík & Jurkovič 2012). A very important parameter is the soil depth, which determines the total amount of water that the soil can accumulate. Soil water holding capacity is adversely affected by soil skeleton. The negative effect of skeleton is manifested when its content exceeds 20 to 30% and causes a decrease in water reserves compared to skeleton-free soil (Damaška 1987). Water stability of macroaggregates and the representation of silt particles and pseudo-aggregates are also important factors (Fulajtár 2006). Humans can positively influence soil water accumulation through management aimed at increasing soil organic matter and negatively by physical degradation such as soil compaction and erosion. Soil compaction reduces soil porosity and soil water storage capacity. The water permeability, infiltration and drainage capacity of the soil is reduced, which in turn can lead to surface runoff and soil erosion. Soil compaction is also influenced by the quantity and quality of organic matter in the soil. Mineral soils with less than 1% humus content (Luvisols, Regosols) have less ability to resist compaction compared to soils containing 3-6% humus (Chernozems, Mollic Fluvisols) (Šarapatka *et al.* 2002).

Arable soils often have a regulating capacity affected by land melioration and modified watercourses, causing accelerated runoff, drying out as well as insufficient groundwater production. Intensive melioration in the past has caused several negative changes. The drop in groundwater levels due to drainage consequently changes the nature and composition of the ecosystems in the broad vicinity of the drained fields. Landscapes so altered are unable to retain water during intense rainfall events, river networks converted into covered or open channels accelerate water runoff from the landscape and altered stream channels allow the rapid movement of huge masses of water, which in turn increases the risk of flooding.

Analysis and assessment of ecosystem services based on scientific standards, despite intensive research in this area, is not easy (Carpenter *et al.* 2009, Hou *et al.* 2013). It depends on the spatial association (Tixier *et al.* 2013), the type of ecosystem (Feld *et al.* 2009) as well as the availability of suitable indicators.

The basic layer that enters most available ecosystem service models is the ecosystem category layer and the landscape cover layer (InVEST model (Kareiva *et al.*, 2011), ARIES model, SolVES model). Linking ecosystem service models to land cover is also one of the conditions for the use of these models in monitoring changes in land use management, in spatial planning as well as in the implementation of assessment of natural capital services potential in socio-economic planning within the region and the country (Haines-Young *et al.* 2012). Also, according to Lescourret *et al.* (2015), land use data are an important component in quantifying the potential of ecosystem services.

The aim of the contribution is the assessment and comparison of the regulation of water regime (regulating ecosystem service – water accumulation in the soil) of arable land ecosystems on model sites located in different climatic and pedo-ecological conditions.

MATERIAL AND METHODS

The potential of soil water accumulation was evaluated through the field water capacity hydro -limit which belongs to the basic hydro-physical characteristics of soil (Hrivňáková, Makovníková *et al.* 2011). The field water capacity was expressed in volume percentages, since we evaluate the volume of retained or of accumulated water in the soil and converted to soil water supply in mm according to its depth (Bujnovský *et al.* 2009, Brodová 2008, Houšková 2011, Matti *et al.* 2009).

We evaluated the water accumulation potential in 5 categories based on the weighted average of the soil water supply in mm in context with soil depth (Bujnovský *et al.* 2009) (Table 1).

Original paper

Table 1
Categories of soil water accumulation potential

Category	Potential	Water accumulation in mm	Point value
1	very low	<135	1
2	low	135–175	2
3	medium	176 –215	3
4	hight	216–275	4
5	very hight	>275	5

For spatial analysis and assessment of this agroecosystem service potential, mapping units based on biophysical data in combination with land use data were created. We generated the layer for spatial quantification and subsequent evaluation of ecosystem services by combining four input layers - relief slope, climatic units, soil texture and land type (Fig. 1) (Makovníková *et al.* 2017). The basic spatial unit for the representation of geographic data is a regular grid with a cell size of 100 × 100 m.

For a complex comparison of model areas, we chose a point system:

TPV = Σ(Pi * PVi),

TPV = total point value

Pi = representation of the given category in the model area in % (Table 6)

PVi = points value of the given category (Table 1)

Referring to the soil nomenclature and classification, it uses the national Morphogenetic Soil Classification System of Slovakia (Societas pedologica slovaca 2014) which individual soil types were correlated to the WRB (IUSS Working group WRB 2022).

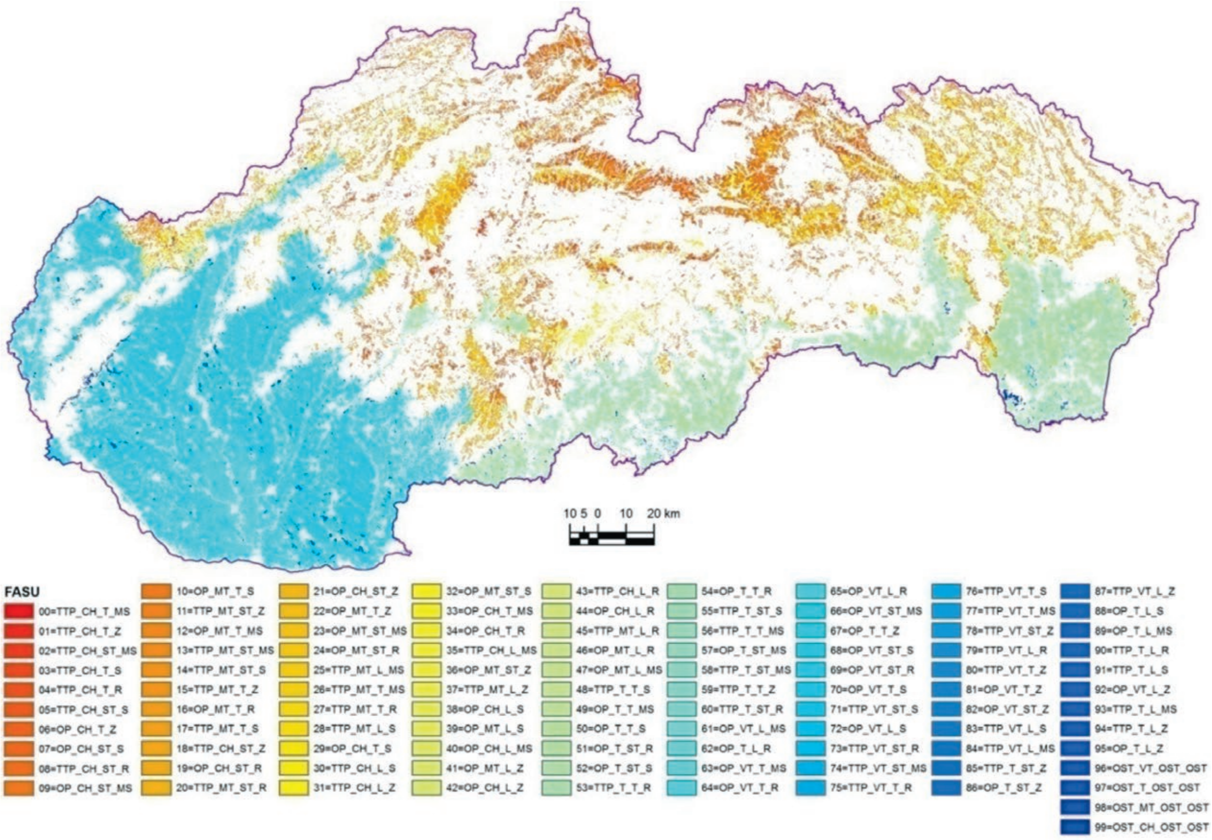

Figure 1 Spatial units for the assessment of ecosystem services

The created layer of functional aggregated spatial units is also compatible with the spatial units in the internationally used CLC (Corine Land Cover) database, as it carries land use information that is also part of the CLC units.

The GIS software ArcGIS for Desktop Advanced version 10.3 from ESRI was used for graphical processing of databases, creation of data layers and spatial quantification of models. Statistical processing of databases and measured data as well as evaluation of the results was carried out in STATGRAPHICS CENTURION.

Model areas

For modelling and evaluation of water regime regulation we selected 7 model areas (districts) located in different pedo-climatic conditions of the Slovak Republic (Fig. 2, Table 2).

Figure 2 Location of model areas

Table 2
Characteristics of model areas

Region	Area* (km²)	Climate	Elevation	Geographical location
Trnava (TT)	479/741	99.7% very warm climate.	84% of area up to 300 m above sea level and 75% on the plain.	Located in the northern part of the Danube Lowland, in the Trnavská tabula Upland subdivision. It is bordered by the Malé Karpaty Mountains in the northwest and the Považský Inovec Mountains in the east.
Senica (SE)	301/684	90.5% very warm climate.	84% up to 300 m a.s.l. and 53% on the plain.	Situated in the Záhorská nížina Lowland, bordered by the Biele and Malé Karpaty Mountains and the Myjavská pahorkatina Upland from the east.
Michalovce (MI)	504/1019	99.4% warm climate.	96% up to 300 m a.s.l. a 92% on the plain.	Located in the East Slovak Lowland, bordered to the north by the volcanic Vihorlat Mountains.

Original paper

Region	Area* (km^2)	Climate	Elevation	Geographical location
Krupina (KA)	161/585	58.9 % very warm and 36.6 % moderately warm climate.	60% from 300 to 600 m a.s.l., 26% on the plain and 50% with a slight slope.	The Štiavnické vrchy Mountains intervene from the north-west, the Krupinská planina Plateau from the north-east and the Ipeľská pahorkatina Upland from the south.
Rožňava (RV)	97/1173	67 % warm climate.	48% from 300 to 600 m a.s.l., and 39% on the plain.	It belongs to the area of the Slovak Ore Mountains with the Slovak Karst in the south and the Volovské vrchy Mountains in the centre and the sub-unit of the Slovak Paradise in the north.
Banská Bystrica (BB)	43/809	69.1% moderately warm climate.	57% of area >600 m a.s.l., 28% on the plain a nd 40% with a medium slope.	The territory is bordered by the Kremnické vrchy mountains from the west, Veľká Fatra, Starohorské vrchy and Low Tatra Mountains from the north, Poľana Mountains from the southeast and Zvolenská kotlina Basin from the south.
Poprad (PP)	110/1105	99.7 % cold climate.	98.3% of area >600 m a.s.l., 34% on the plain and 45% with a slight slope.	The High Tatra Mountains in the north and the Low Tatra Mountains in the south, which are separated by the Podtatranská kotlina Basin, are situated on the territory.
* Cropland area / region area				

Table 3 shows the main soil textures and their percentage representation in the model regions on arable land.

Table 3
Representation of soil textures on cropland in model areas

Region	Soil texture in % of model area				
	S – LS	SL	L	CL	C
Trnava	0.0	0.8	90.2	8.8	0.2
Senica	31.4	7.9	49.4	10.8	0.5
Michalovce	3.1	7.1	49.3	22.5	18.0
Krupina	0.0	4.4	77.3	18.2	0.1
Rožňava	0.4	11.7	67.3	20.6	–
Banská Bystrica	2.9	22.9	70.6	3.6	–
Poprad	2.6	20.2	53.6	23.7	–
Soil texture: S – sand (0–10% of clay fraction <0,01mm), LS – loamy sand (10–20%), SL – sandy loam (20–30%), L – loam (30–45%), CL – clayey loam (45–60%), C – clay (60–75%)					

Table 4 shows the representation of soil types on cropland in individual model areas.

Table 4
Representation of soil types on cropland in model areas

Region	Soil type in % of model area										
	CH	FL mo	FL	GL	LV	CM	LV ab	PL	RG	LP rz	HS
Trnava	44.7	8.2	4.1	0.1	24.1	4.8	1.1	1.3	10.7	0.9	0.1
Senica	2.6	17.8	16.7	0.7	23.7	12.2	0.7	1.5	22.4	1.5	0.2
Michalovce	9.0	0.2	55.3	11.2	5.4	1.8	1.3	14.9	0.9	0.0	–
Krupina	–	0.1	5.5	0.0	19.6	48.8	21.9	3.9	–	0.1	–
Rožňava	–	1.2	24.8	0.1	4.3	29.7	4.2	26.2	0.2	9.3	–
Banská Bystrica	–	2.3	21.0	0.3	–	62.8	1.0	6.2	–	6.4	–
Poprad	–	8.6	4.4	1.5	–	77.0	–	2.5	–	5.8	0.2

Soil types: CH – Chernozems, FLmo – Mollic Fluvisols, FL – Fluvisols, GL – Gleysols, LV – Luvisols, CM – Cambisols, LVab – Albic Luvisols, PL – Planosols, RG – Regosols, LPrz – Rendzic Leptosols, HS – Histosols

Soil types with a generally high potential to accumulate water include soils with a higher humus content such as Chernozems, Mollic Fluvisol and Histosols, or with a higher clay content at least in part of the soil profile such as Luvisols, Albic Luvisols, Planosols (IUSS Working Group WRB 2022). The ability of Fluvisols, Gleysols and Cambisols to accumulate water is determined by their soil texture, skeleton content and profile depth. Regosols and Rendzic Leptosols belong to the group of soils with a lower accumulation capacity due to the smaller profile thicknesses (Demo *et al.* 1998).

RESULTS AND DISCUSSION

The spatial distribution of individual categories of the water accumulation potential of arable soils in the model territories is shown in Figures 3 to 6.

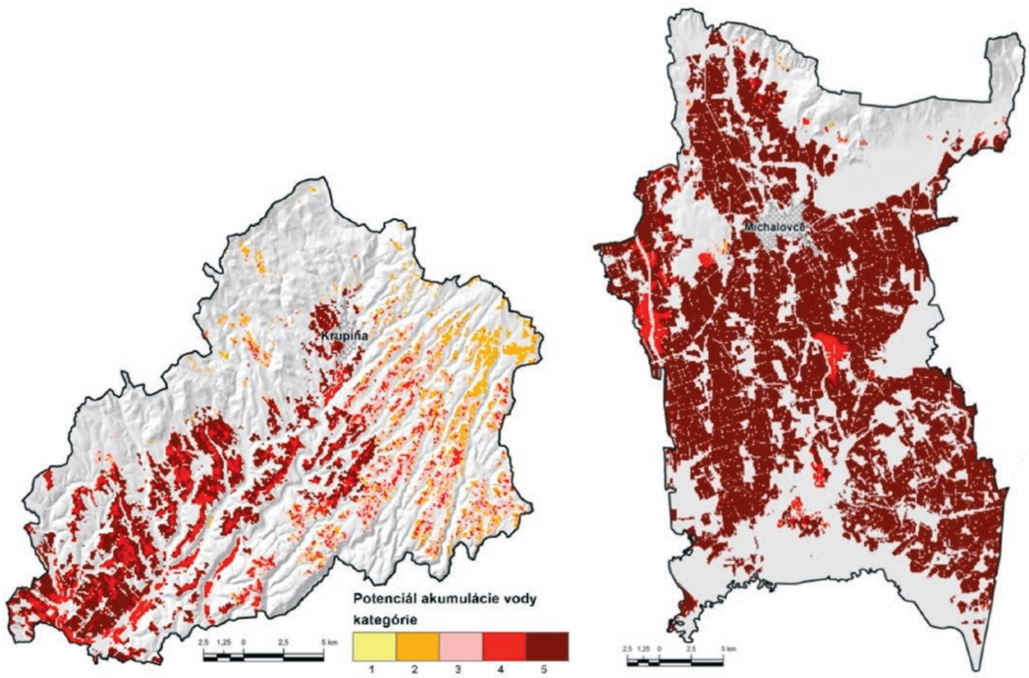

Figure 3 Water accumulation potential of arable soils in Krupina region and Michalovce region

Original paper

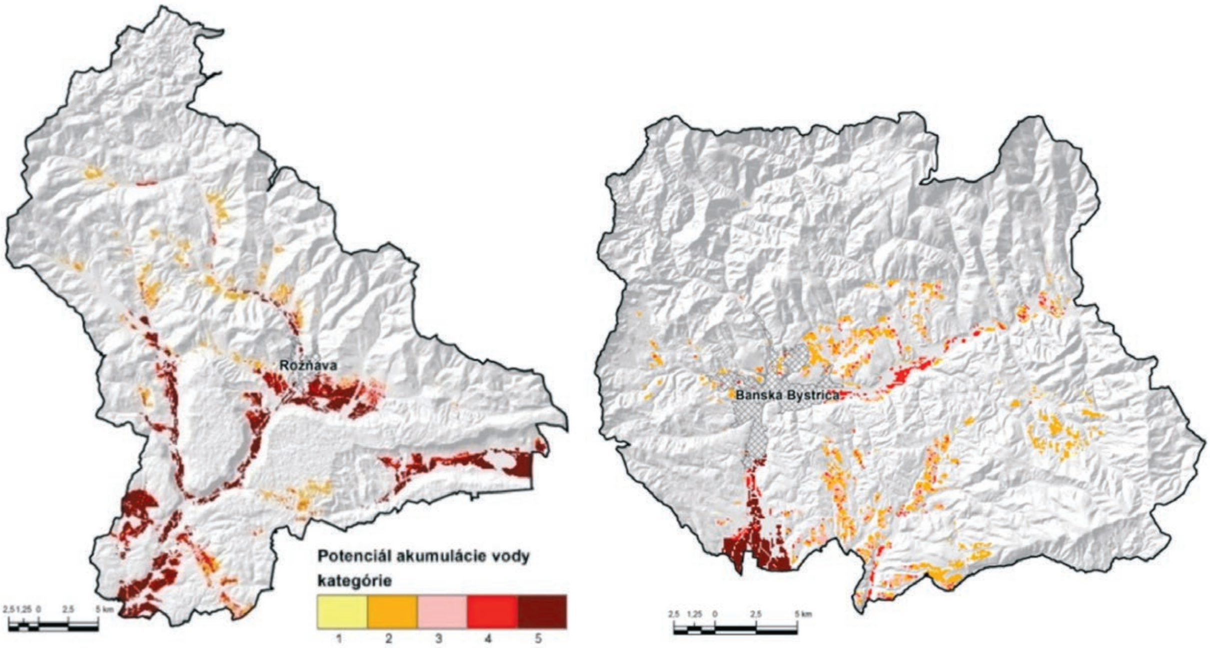

Figure 4 Potential of arable soil water accumulation in Rožňava region and Banská Bystrica region

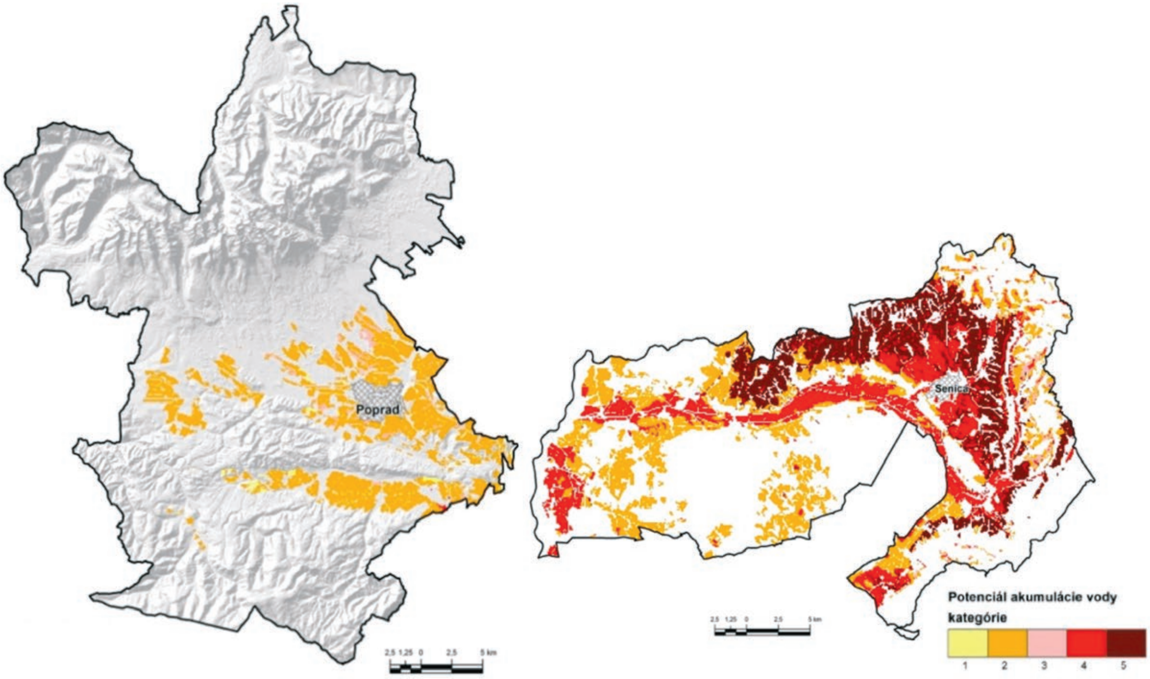

Figure 5 Water accumulation potential of arable soils in Poprad region and Senica region

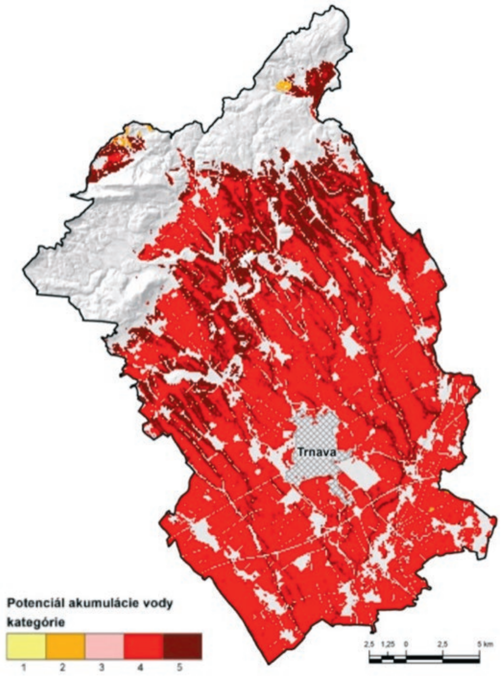

Figure 6 Water accumulation potential of arable soils in Trnava region

The representation of individual categories of water regime regulation potential (arable soil water accumulation potential) is shown in Table 5.

Table 5
Water regime regulation potential (water accumulation potential in arable soils) in model areas

Region	**The potential of water accumulation in the soil in % of the area of agriculturally used arable land (P)**				
	very low	**low**	**medium**	**hight**	**very hight**
Trnava	0.00	0.26	0.06	75.42	24.26
Senica	0.33	36.50	1.98	30.85	30.34
Michalovce	2.84	0.11	0.45	3.61	92.99
Krupina	0.41	15.31	17.07	27.14	40.07
Rožňava	1.43	18.58	7.95	14.21	57.73
Banská Bystrica	2.41	47.11	21.17	13.81	15.50
Poprad	2.46	90.48	6.83	0.23	0.00

The water accumulation potential in arable soil ecosystems is negatively correlated with climatic categories (r = -0.63). This potential also depends on other soil properties (content and quality of humus, textural differentiation within the soil profile, sequence of horizons, skeleton content, soil depth) to a certain extent included in the characteristics of soil types and related to their geographical distribution. With decreasing altitude, the average temperature, the content of the clay fraction, the depth of the soil as well as the potential for water accumulation increases and the content of soil skeleton decreases.

Ecosystems with a very low potential to accumulate water are poorly represented in the model regions (from 0.00% of the area of agriculturally used arable land in the Trnava region to 2.84% in the Michalovce region). Arable lands are mostly flat areas with good accessibility and a low risk of erosion. In the category with low potential, the largest area is represented by the region of Poprad (90.5% of the area) and Banská Bystrica region (47.11% of the area) with a relatively strong representation of sandy to sandy-loam soils or shallower skeletal Cambisols and Rendzic Leptosols, and the Senica region (36.5% of the area) with a significant proportion of Regosols on wind-sands.

The largest share of areas with medium water accumulation potential is in the Banská Bystrica region (21.17%). This category includes ecosystems of arable soils on predominantly medium-deep and medium-heavy soils determined by the presence of skeleton.

Most of the territory of Trnava region belongs to the high category of water accumulation potential. This category is represented by ecosystems on deep loamy to clay-loamy soils with a lower proportion of cementing clay fraction and a higher proportion of silt. In terms of soil types, these include mainly silty Chernozems with a higher humus content, medium-grained Luvisols, albic Luvisols, Planosols or, in river floodplains, Fluvisols and humus Mollic Fluvisols. High humus content with high quality is reflected in high water retention with maintaining good aeration (Fulajtár 2006).

Arable ecosystems with a very high potential for water accumulation are mostly represented in the region of Michalovce (92.99% of the area), Rožňava (57.73%) and Krupina (40.07%), but a relatively high share is also in other regions except for Poprad region. These ecosystems are located on deep and skeleton-free soils with a high content of physical clay or organic matter. The predominant soil types

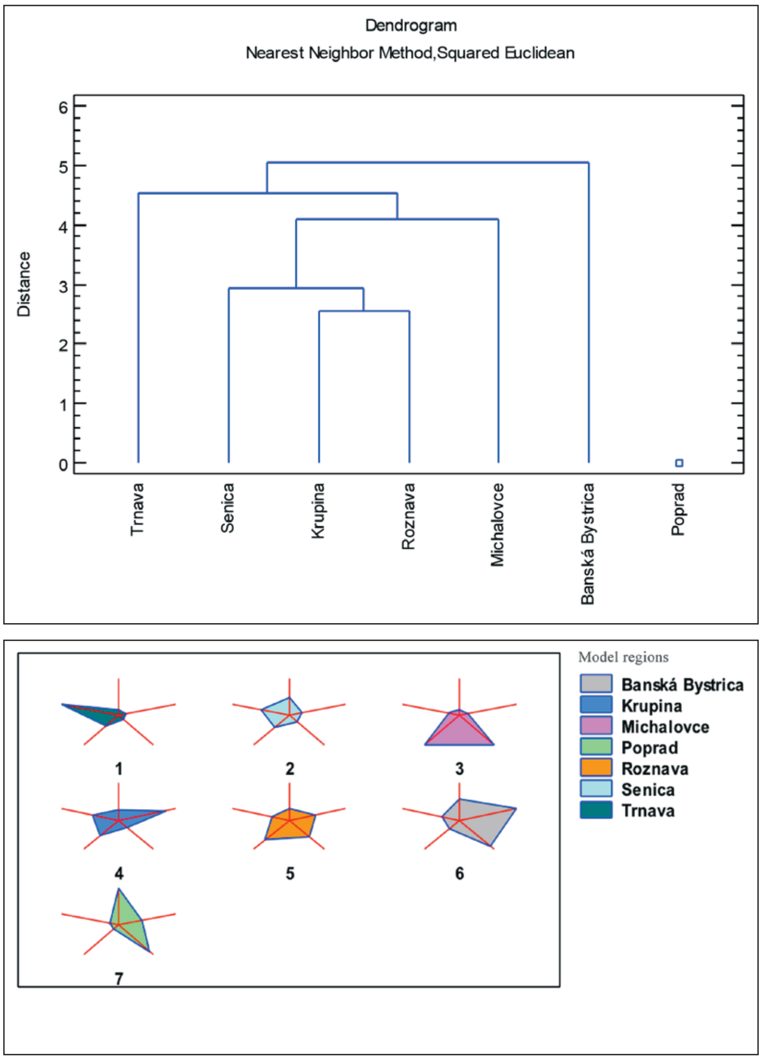

Figure 7 Comparison of model areas using cluster (dendrogram) and sun-ray analysis

here are valley soils around watercourses, such as heavy Fluvisols and Mollic Fluvisols, Planosols and Albic Luvisols on river terraces, and lowland soils represented by heavy Chernozems and Luvisols. In the Michalovce region, there is a high proportion of heavy clay loam (22.5%) or clayey soils up to clays (18.0%). In the fraction of clay particles (< 0.002 mm), montmorillonite, belonging to the smectite group of clay minerals, is predominant, forming the absolute predominant part of the inorganic soil colloids. Clay minerals called phyllosilicates (watery alumo-silicates) with a layered (rarely also chained) structure are carriers of important colloidal properties of soils, such as mainly sorption capacity, but also water and nutrient retention and release (Čurlík 2011). High values of water retention capacity for the clay soils of the East Slovak Lowland, are also reported by Mati & Kotorová (2009). The water retention capacity of this soils is up to 286.03–420.71 mm, i.e. 2860–4207 m^3 per hectare (Mati & Kotorová 2009).

The overall order of the evaluated model areas according to CBH is as follows: MI (484) > TT (424) > RV (408) > KA (391) > SE (354) > BB (293) > PP (205). The order determines the representation of the category with a very high-water accumulation potential. The exception is the Trnava region, which moved up to second place in the ranking due to the large area of the category with high water accumulation, and the Senica region, on the other hand, moved down to fifth position due to the relatively high representation of soils with low water retention developed on wind-sands.

Comparison of the model areas (Fig. 7) showed the most pronounced regional differences between the model regions depending on their climatic conditions in combination with the representation of soil types (Tables 2, 3).

On the one hand, there are the model regions – Krupina and Rožňava with a high proportion of the area in a very warm and warm climate region and with a high representation of clay soils. The regions of Trnava and Michalovce with the highest proportion of land in a very warm climate region also show a significant similarity. On the other hand, there are the regions of Banská Bystrica and Poprad, in which most of the arable land is in a moderately warm and cold area.

CONCLUSION

Soil water accumulation in cropland ecosystems is higher in lowland locations and decreases with increasing altitude. Its negative correlation with climate categories is statistically significant (r = -0.63). This ecosystem service largely depends on the soil texture, soil type and soil-forming substrate, which are region-specific. In lower positions, there is a greater representation of deep, stoneless soils with a higher proportion of clay fraction and higher quality humus.

Arable land ecosystems with very low potential to accumulate water in the soil are not widespread in the evaluated regions (the highest quality and easier to cultivate soils are used as cropland, other agricultural soils are used as grassland). Cropland ecosystems with a very high potential for water accumulation service are significantly represented in the regions of Michalovce (93% of the area), Rožňava (58%) and Krupina (40%), and with a low potential in the Poprad region (90%). Explicit quantification and mapping of ecosystem services is one of the main requirements for the implementation of the ecosystem services concept in institutional decision-making.

The potential for water accumulation in the soil can be regulated by changes in management aimed at increasing C sequestration (sufficient organic manuring) and protecting the soil from compaction in terms of preventive soil conservation measures. A more pronounced effect of an increase in soil organic matter on increasing soil water retention can be expected especially on light sandy soils (Rawls 2003). The proper management of agroecosystems can affect the regulation of the water regime by appropriate loosening of the soil surface, while the depth of the loosened layer is also important, which affects the speed and amount of infiltrated water (Rehák & Janský, 2000). Proper management of agroecosystems can influence the regulation of the water regime by appropriate loosening of the soil surface, while the depth of the loosened layer is also important, as it influences the rate and amount of infiltrated water (Rehák & Janský 2000). Tillage, which is aimed at changing the bulk density, also influences the amount and intensity of

Original paper

water infiltration. Soil transport in the erosive parts of slopes has a negative effect on soil water holding capacity and water storage in the soil profile, especially in the case of shallower and skeletal soils.

The assessment of the ecosystem service, soil water accumulation, linked to spatial visualization, allows to optimize the management of agroecosystems and thus to promote synergy between ecosystem functioning and the social dynamics of the area.

ACKNOWLEDGEMENT

This publication was supported by the Slovak Research and Development Agency via contract APVV- 18-0035 "Valuing ecosystem services of natural capital as a tool for assessing the socio-economic potential of the area", and this work was done as a part of the project "Towards climate-smart sustainable management of agricultural soils" (EJP-SOIL, grant agreement ID: 862695) funded by the European Union´s Horizon 2020 research.

REFERENCES

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

Bujnovský, R., Balkovič, J., Barančíková, G., Makovníková, J., Vilček, J. (2009). *Hodnotenie a oceňovanie ekologických funkcií poľnohospodárskych pôd Slovenska (Assessment and pricing of ecological functions of Slovak agricultural soils)*. Bratislava: VÚPOP, 72 p. ISBN 978-80-89128-56-3.

Brodová, M. (2008). Ohodnocovanie environmentálnych funkcií poľnohospodárskej pôdy (Valuation of environmental functions of agricultural land). In: *Ekonomika poľnohospodárstva (Economics of agriculture)*, vol. 8(4): 53–58.

Carpenter, S.R., Mooney, H.A., Agard, J., Capistrano, D., de Fries, R.S. (2009). Science for managing ecosystem services: beyond the millennium ecosystem assessment. *Proceedings of the National Academy of Sciences of the USA*, vol. 106: 1305–1312. doi: https://doi.org/10.1073/pnas.0808772106.

Crossman, N. D., Burkhard, B., Nedkov, S., Willemen, L., Petz, K., Palomo, I., Drakou, E.G., Martín-Lopez, B., McPhearson, T., Boyanova, K., Alkemade, R., Egoh, B., Dunbar, M., Maes, J. (2013). A blueprint for mapping and modelling ecosystem services. *Ecosystem Services,* vol. 4: 4–14.

Čurlík, J. (2011). *Potenciálne toxické stopové prvky a* ich *distribúcia* v *pôdach Slovenska (Potentially toxic trace elements and their distribution in Slovak soils)*. Bratislava: PriFUK, 462 p. ISBN 978-80-967696-3-6.

Čurlík, J., Jurkovič. Ľ. (2012). *Pedogeochémia (Pedogeochemistry).* UK Bratislava, 228 p. ISBN 978-80-223-32101.

Damaška, J. (1987). Skeletovitost, jako limitující faktor úrodnosti zemědělských půd (Skeleton as a limiting factor in the fertility of agricultural soils). *Rostliná v*ýroba*,* vol. 33: 785–791.

De Groot, R. S. (1992). *Functions of nature: evaluation of nature in environmental planning, management and decision making*. Groningen: Wolters-Nordhoff.

Demo, M., Bielek, P., Džatko, M., Lacko-Bartošová, M., Juráni, B., Vilček, J., Gaisbacher, J. (1998). *Usporiadanie a využívanie pôdy v poľnohospodárskej krajine (Arrangement and use of soil in the agricultural landscape)*. Nitra: SPU, 302 p. ISBN80-7137-525-X.

Džatko, M., Sobocká, J. *et al.* (2009). *Príručka pre používanie máp pôdnoekologických jednotiek (Manual for the use of maps of pedoecological units)*. Bratislava: VÚPOP, 102 p. ISBN 978-80-89128-55-6.

Feld, C.K., da Silva, P.M., Sousa, J.P., de Bello, F., Bugter, R., Grandin, U., Hering, D., Lavorel, S., Mountford, O., Pardo, I., Pärtel, M., Römbke, J., Sandin, L., Jones, K.B., Harrisonová, P. (2009). Indicators of biodiversity and ecosystem services: a synthesis across ecosystems and spatial scales. *Oikos*, vol. 118: 1862–1871. doi: https://doi.org/10.1111/j.1600-0706.2009.17860.x.

Fulajtár, E. (2006). *Fyzikálne vlastnosti pôdy (Physical properties of soil)*. Bratislava: VÚPOP, 142 p. ISBN 80-89128-20-3.

Haines-Young, R., Potschin, M. & Kienast, F. (2012). Indicators of ecosystem service potential at European scales: mapping marginal changes and trade-offs. *Ecological Indicators*, vol. 21: 39–53.

Hou, Y., Burkhard, B., Müller, F. (2013). Uncertainties in landscape analysis and ecosystem service assessment. *Journal of Environmental Management,* vol. 127: 117–S131.

Houšková, B. (2011). Retenčná kapacita poľnohospodárskych pôd Slovenska (Water holding capacity of agricultural soils in Slovakia). *Vedecké práce Výskumného* ústavu *pôdoznalectva a ochrany pôdy*, vol. 33: 72–77.

Hrivňáková, K., Makovníková, J., Barančíková, G., Bezák, P., Dodok, R., Grečo, V., Chlpík, J., Kobza, J., Lištjak, M., Mališ, J., Píš, V., Schlosserová, J., Slávik, O., Styk, J., Širáň, M. (2011). *Jednotné pracovné postupy rozborov pôd (Uniform Operation Procedures of Soil Analyses)*. Bratislava: VUPOP, 136 p. ISBN 978-80-89128-89-1.

IUSS Working Group WRB (2022). World Reference Base for Soil Resources. International soil classification system for naming soils and creating legends for soil maps. 4th edition. International Union of Soil Sciences (IUSS), Vienna, Austria.

Kareiva, P., Tallis, H., Ricketts, T.H., Daily, G.C., Polasky, S. (eds) (2011). *Natural capital: Theory and practice of mapping ecosystem Services.* Oxford, UK: Oxford University Press

Lescourret, F., Magda, D., Richard, G., Blondon, A.F.A., Bardy, M., Baudry, J., Doussan, I., Dumont, B., Lefèvre, F., Litrico, I., Clouaire, R.M., Montuelle, B., Pellerin, S., Plantegenest, M., Tancoigne, E., Thomas, A., Guyomard, H., Soussana, L.F. (2015). A social–ecological approach to managing multiple agro-ecosystem services. *Environmental Sustainability*, vol. 14: 68–75. http://dx.doi.org/10.1016/j.cosust.2015.04.001.

Mati, R., Kotorová, D., Naščáková, J. (2009). Evaluation and pricing of soil water-retention capacities in the East-Slovak Lowland. *Agriculture (Poľnohospodárstvo)*, vol. 55(4): 189–196.

Power, A.G. (2010). Ecosystem services and agriculture: trade-offs and synergies. *Philosophical Transactions of the Royal Society B*, vol. 365: 2959–2971. doi: https://doi.org/10.1098/rstb.2010.0143.

Rawls, W.J., Pachepsky, Y.A., Ritchie, J.C., Sobecki, T.M., Bloodworth, H. (2003). Effect of organic carbon on soil water retention. *Geoderma*, vol. 116: 61–76.

Rehák, Š., Janský, L. (2000) *Fyzika pôdy 1*, *Základné fyzikálne vlastnosti pôdy.* (Soil physics, basic physical soil properties), 108p. Univerzita Komenského Bratislava, ISBN 80-223-1544-3.

Seják, J., Cudlín, P., Pokorný, J., Zapletal, M., Petříček, V., Guth, J., Chuman, T., Romportl, D., Skořepová, I., Vacek, V., Vyskot, I., Černý, K., Hesslerová, P., Burešová, R., Prokopová, M., Plch, R., Engstová, B., Stara, L. (2010). *Hodnocení funkcií a služeb ekosystému* České *republiky (Valuing Ecosystem Functions and Services* in *the Czech Republic*). Ústí nad Labem: FŽP UJEP, ISBN 978-80-7414-235-2.

Societas pedologica slovaca (2014). *Morfogenetický klasifikačný systém pôd Slovenska. Bazálna referenčná taxonómia.* Druhé upravené vydanie. Bratislava: NPPC – VÚPOP Bratislava 2014, 96p. ISBN: 978-80-8163-005-7.

Šarapatka, B., Dlapa, P., Bedrna, Z. (2002). *Kvalita a degradace půdy (Soil quality and degradation)*. Olomouc: Univerzita Palackého, 2002, 246 p. ISBN 80-244-0584-9.

Tixier, P., Peyrard, N., Aubertot, J. N., Gaba, S., Radoszycki, J., Caron-Lormier, G., Vinatier, F., Mollot, G., Sabbadin, R. (2013). Modelling interaction networks for enhanced ecosystem services in agroecosystems. *Advances in Ecological Research,* vol. 49: 437–480. doi: https://doi.org/10.1016/B978-0-12-420002-9.00007-X.

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 p. (in Czech).