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Using soil quality indicators to assess their production and ecological functions

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Abstract: The project dealt with an evaluation of the soil quality in the Central Bohemian Region in the Czech Republic. The relevant attributes and characteristics were found regarding the soils in this selected area. Based on the data from soil probes, climate characteristics, soil production function and data on the land use, the characteristics, known as soil quality indicators, were selected. Then the soils were sorted into groups which indicated their suitability for the best land use and planning. The characteristics of the soils that contributed the most to the ecosystem services provided by this part of the environment were chosen as the soil quality indicators. In order to find out how the soils are able to provide ecosystem services, two types of approaches were used – the average score and the total amount of points gained. Maps indicating the soil quality were created using the ArcGIS program. At the same time, research on the differences in the quality in two different layers of the soil was carried out. In most cases, there was a decrease in the soil quality with an increasing depth. The results of this project can be used as a basis for a new soil valuation in the Czech Republic.

Keywords: indicators; soil characteristics; soil ecosystem services; soil protection; soil quality

Soil valuations are increasing in importance with climactic changes and it is also more necessary to evaluate non-productive properties besides the production capacity. The concept of ecosystem services, which is gaining more and more attention from many authors, fits this concept.

Ecosystem services are the benefits that ecosystems are capable of delivering to society (Haines-Young

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& Potschin-Young 2010). Costanza et al. (1997) describes ecosystem services as the flow of materials, energy and information from natural resources that create human well-being.

Assessing and evaluating ecosystem services is a way to help simplify decisions about using the landscape. The TEEB study (2010) distinguishes several purposes of evaluating ecosystem services (visualising nature's value, evaluation of ecosystem services and their inclusion in decision making, reducing risk and uncertainty, value for the future, measurement for management).

In the European Union, the Mapping and Assessment of Ecosystem Services (MAES) process has introduced a conceptual framework linking biodiversity, ecosystem status and ecosystem services to human well-being (Veidemane 2019).

The goal of this contribution is to suggest possible new methods to assess both ecological and production functions.

MATERIAL AND METHODS

Assessment and evaluation of soil quality. There are a number of frameworks by which soil quality is assessed and evaluated, and they take different aggregation forms. Although these frameworks share the objective of providing a comprehensive description of soil quality, they can be divided into two groups with respect to their main focus.

The first group consists of indicator frameworks that describe the current state of the soil system by assessing the quality of agricultural soils. This is based on detailed field measurements (Arshad & Martin 2002), a statistical analysis of soil databases or elaboration of the status of specific soil threats. A statistical soil database analysis is used to determine which soil properties and functions are the most important for high quality soils (Shukla et al. 2006; Desaules et al. 2010).

The second group are indicator frameworks that focus on changes in the soil quality and applied soil management. These frameworks talk about the soil productivity in different farming systems (Oberholzer et al. 2012), compare farming systems (Fliessbach et al. 2007) or talk in detail about the benefits of the soil biota as an indicator of soil quality (Schloter et al. 2003).

Further examples of soil quality indicators falling into these two groups can be found in the work of Bastida et al. (2008). Many of the proposed soil quality indicators focus on soil management in the context of a single discipline, such as agriculture or soil pollution. There are also indicators that are designed from a purely scientific perspective and do not make sense to a layperson. Soil fertility is affected by the natural conditions in which the soil was formed, but especially by human intervention, which modified many physical and chemical properties of the soil in order to increase its fertility (Sáňka & Materna 2004).

The soil has many functions. It is possible to use a system of soil property indicators that can be measured and expressed numerically. Important indicators for determining the soil quality are the amount of water retained in the soil, the humus content or soil texture. (Sáňka & Materna 2004).

Soil quality frameworks designed for land use planning are rare. According to Drobnik et al. (2018), in Germany, they developed a concept for considering soil quality in spatial planning in the Stuttgart region. Another similar concept has been developed in Austria. Both of these concepts exclusively focus on limiting any settlement expansion and the related infrastructure. The German concept divides soil quality using scores (the higher the score, the better the soil) based on natural soil functions and anthropogenic soil degradation (landfills). The natural soil functions are their suitability for agriculture and plants, water retention and filtering ability for polluting materials. The author then assigns the availability of the soil quality points to municipalities for new urban areas.

Also, Haslmayr et al. (2016) consider different soil functions to determine the overall soil quality, which is then implemented as the so-called spatial resistance for developing a place. The functions assessed include the habitat for organisms, the habitat potential for natural plant communities, the natural soil fertility, and others. The spatial resistance of a soil depends on the highest performance of the soil function being assessed (the higher the performance, the higher the resistance). If a soil achieves the highest spatial resistance score, it is considered to be an area where any anthropogenic development requires compensatory measures.

Both of these soil indicators are highly aggregated and work well in top-down environmental planning, meaning that planning targets are defined and set at the highest hierarchical level without considering the feedback coming from the lower levels of this hierarchy. However, it turns out that aggregated indi-

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cators are less effective when there are compromises in the assessment and evaluation of any impacts. This is particularly true in the case of land. Many authors agree that several soil quality indicators are needed if the soil quality is to be implemented in decision-making processes in a meaningful way (Drobnik et al. 2018).

SQUID index. Soil quality indicator (SQUID) is a soil quality index that combines a set of ten different soil functions into different ecosystem services using the Delphi expert approach. This index uses the results of a Delphi survey to identify the contributions of soil functions to ecosystem services. Estimates of the soil function (OPF or SFA) contributing to each ecosystem service are multiplied by the weighted factors provided by the experts. The resulting ecosystem service values are then averaged into a SQUID index. The minimum overall score is equal to 0, indicating that the soil does not contribute to the ecosystem service at all. In contrast, the maximum overall result, which is equal to 5, means that the soil contributes very significantly to the ecosystem service. The SQUID index is calculated according to the following formula:

$$\mathrm{SQUID} = \frac{\sum_{i=1}^{n} \mathrm{ES}_i}{i} \tag{1}$$

Auxiliary calculations (Drobnik et al. 2018) are:

$$\mathrm{ES}_i = \sum_{j=1}^{n} sf_{ij} \times w_{ij}$$

$$\sum_{j=1}^{n} w_j = 1$$

where:

ES_i – soil-based ecosystem services with i taking values from 1 to 23;

sf_{ij} – the quality of the soil function where j contributes to a given ecosystem service denoted by i;

w_{ij} – the weight assigned by experts, i.e., the level of contribution of soil function j to ecosystem service i.

BOKS index. The BOKS index was developed in Germany for use in the Stuttgart region (Wolff 2006). This index is based on the sum of six attributes that are used to characterise the soil quality. Unlike many other soil quality indices, BOKS considers both natural and anthropogenic factors as constituting the final soil quality index. Four of these six attributes are classified as natural factors, which are the suitability for the natural vegetation and crop production, regulation of the water cycle, capacity for filtration and buffering of contaminants, and archiving of cultural and natural history. The remaining two attributes belong to anthropogenic factors, which are contaminated sites and the soil sealing level. Each of these attributes is normalised from 0 (non-existent) to 5 (very good). The original BOKS is a parcel of land, where each attribute value comes from a point within the respective parcel and is then multiplied by the area of the parcel it belongs to. The final BOKS result is calculated using the following equation (Wolff 2006; Drobnik et al. 2018):

$$\begin{aligned}\mathrm{BOKS} = {} & (svc \times a) + (wc \times a) + (fbc \times a) + \\ & + (cnh \times a) + (cont \times a) + (seal \times a)\end{aligned} \tag{2}$$

where:

a – size of the parcel;

svc – suitability for natural vegetation and crop production;

wc – regulation of the water cycle;

fbc – capacity for filtration and buffering of contaminants;

cnh – archiving of cultural and natural history;

$cont$ – contaminated sites;

$seal$ – soil sealing level.

Drobnik et al. (2018) used high-resolution maps and, thus, calculated BOKS on an individual raster level, while multiplication by the parcel area was not applied.

Comparing soil quality indices. Effective and informed decision-making in terms of land development requires constant land use assessments and their impact on the environment. This is even more necessary today, when conflicts over land resources are increasing (O'Neill & Walsh 2000; von der Dunk et al. 2011; Hersperger et al. 2015). In order to avoid hidden compromises in terms of soil quality, and to incorporate soil quality more effectively into land-use planning, information is needed not only on the absolute value of soil quality, but also on its spatial distribution.

In Switzerland, the outputs of two soil indicators, BOKS and SQUID, presented in a case study were investigated. The outputs of the assessment methods were compared with respect to each other in terms of their absolute values (pixel-based), in terms of clusters of similar soil qualities, and whether these clusters coincide within the two indicators, as well as how the results change with distance (Drobnik et al. 2018).

Multi-criteria decision making is an analytical hierarchical process (Ramík 1999). An important step

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in the evaluation of multi-criteria problems is the determination of weights (importance of criteria). A wider range of methods can be used to determine them. One of the possible alternatives is the scoring method (Fiala 2008). Another option is to use the Saaty method (Saaty 2008).

For this study, the Central Bohemian Region was selected. This region is the largest one and its landscape and soil cover is highly variable.

Data collection. Following the purposes of the work, it was imperative to collect the necessary data regarding the soil characteristics. A total of 19 different soil characteristics were collected in the Central Bohemian Region. The following data were obtained through the geographic information system ČR PUGIS (Kozák et al. 1996): pH_{H_2O}, pH_{KCl}, humus content (%), depth of humus horizon (m), $CaCO_3$ (%), P_2O_5 (mg/kg), K_2O (mg/kg), total sorption capacity (mmol/kg) and texture (%). The Research Institute for Soil and Water Conservation provided data on the soil protection classes (Anonymous 2011). The ecosystem quality was obtained using information on the landscape cover using CORINE Land Cover 2012 (Geoportal.gov.cz 2014). The percentage of built-up area (soil sealing) was obtained from CORINE Land Cover 2018 (Land.copernicus.eu 2018). Furthermore, we were provided with data on newly emerging climatic regions, and the average precipitation for these regions was obtained from the characteristics of climatic regions in the book "Soil and its assessment in the Czech Republic, Volume II" (Vopravil et al. 2011). In addition, the Research Institute for Soil and Water Conservation provided data on the water retention capacity and hydrological soil groups. These data are the result of the Ministry of Agriculture research project NAZV QJ1520026.

Subsequently, it was necessary to obtain the data needed for the creation of the maps. The soil map of the Central Bohemian Region was taken from the 1 : 250 000 map of the Czech Republic (Kozák et al. 2009). The basis for the production of the maps of hydrological soil groups and water retention capacity was provided by the Research Institute for Soil and Water Conservation, but these are the results of the Ministry of Agriculture project NAZV QJ1520026. The maps concerning the characteristics based on the Agricultural Land Resources Evaluation were created using data from the Database of Evaluated Soils (Anonymous 2019). The Czech Hydrometeorological Institute provided data for the creation of the new climate region maps.

Data analysis and map creation. The data collected on soil characteristics were analysed using Microsoft Office Excel. From all the available data, it was necessary to select the most important characteristics that have an influence on the soil quality. For two different soil depths (0.00–0.30 and 0.30–0.60 m), pH_{KCl}, humus content, texture (clay content) and total sorption capacity. In addition, the humus horizon depth, soil protection class, water retention capacity, hydrological soil groups, annual average precipitation, ecosystem quality and soil sealing were selected. The specific values of the selected characteristics were then divided into three categories that characterise the range of values. These categories were good, medium and poor. The ranges of values and the respective categories are shown in Table 1. The table was based on a similar assessment used in

Table 1. Distribution of the selected soil-related characteristic values

Characteristic	Good (3)	Medium (2)	Poor (1)
pH exchange	6.5–7.0	6.4–4.0	< 4.0; > 7.0
Humus content (%)	> 3.5	3.5–1.0	< 1.0
Depth of the 1st soil horizon (m)	> 0.30	0.30–0.10	< 0.10
Agricultural land resources evaluation/ soil protection classes	I, II	III, IV	V
Texture (%)	< 25% clay and sand	other	sand; clay
Water retention capacity	4	3, 2	1
Hydrological soil groups	A	B	C, D
Annual average precipitation (mm)	550–650	500–550; 650–900	< 500; > 900
Total sorption capacity (mmol/kg)	> 25	25–13	< 13
Ecosystem quality	deciduous forests, meadows, grasslands	mixed forests, agricultural land	industrial areas, coniferous forests
Soil sealing (%)	< 5	5–25	> 25

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the EU URBAN Soil Management Strategy project (Kozák & Galušková 2010).

The maps in this work, which characterise the natural conditions in the Central Bohemian Region, were created in ArcGIS version 10.7.1. The maps showing the classification of the selected soil characteristics into the above-mentioned categories were created in cooperation with HYDROSOFT Veleslavín s.r.o.

RESULTS

A total of 33 maps were created.

Maps characterising natural conditions. A total of eleven maps were created using ArcMap (Ver. 10.7.1.) that summarise the characteristics of the Central Bohemian Region and are related to the soil properties. These include a soil map, a water retention capacity map, hydrological soil groups and maps based on the Agricultural Land Resources Evaluation, which include a summary map of the soil depth and type of skeleton and a map of the slope and exposure to cardinal directions. The Agricultural Land Resources Evaluation also provides a map of the main soil units, soil type groups and climatic regions.

Maps of selected soil characteristics. After selecting the necessary soil characteristics of the Central Bohemian Region that affect the ecosystem services, these characteristics were classified into three groups indicating a good, medium and poor soil quality. For all these characteristics, a range of values was first established in order to classify the soil characteristics. Each category was scored. The category "good" received 3 points, "medium" 2 points and "poor" 1 point. Based on the categorisation, 22 maps were created. A total of 702 soil probes were surveyed in the Central Bohemia Region, of which 16 probes were related to forest soils. The soil probes are shown in Figure 1.

The following maps are the result of the categorisation of soil properties and quality results are expressed as points. In all these maps, the urban development is shown in red and the forests are in deep green. The best quality values are shown in light pink to white. In contrast, the lowest quality soils are coloured dark green on the maps. Other colours highlight medium or average quality soils.

In Figure 2, the measured values of the soil exchange reaction in the first 0.30 m from the soil surface have been categorised according to the quality. Values between 6.5 and 7, corresponding to a neutral soil reaction, were considered to be a suitable pH. It was found that a greater number of sites with a suitable pH of the soil were mainly located in the northern half of the Central Bohemian Region and then in its eastern part. The largest sites with neutral pH were found on the north-western outskirts of the city of Prague and between Kolín and Kutná Hora. A larger number of sites with good soil quality were also found in the north of the region between Mladá Boleslav and Mělník and near Poděbrady and Čáslav. On the other hand, poor, i.e., very acidic or alkaline soils were found on the northern edge of the Central Bohemian Region above the towns of Mělník and Slaný. Poor quality soils are marked in dark green on the

(A) (B)

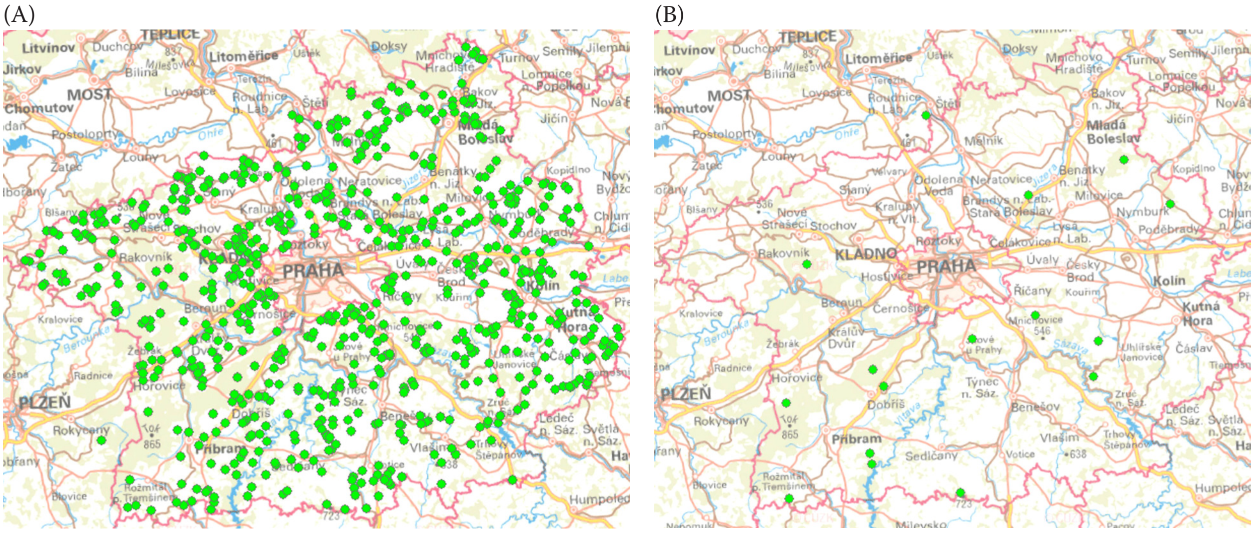

Figure 1. Map of the soil probes on the agricultural land in the Central Bohemian Region (A) and map of the soil probes on the forest land in the Central Bohemian Region (B)

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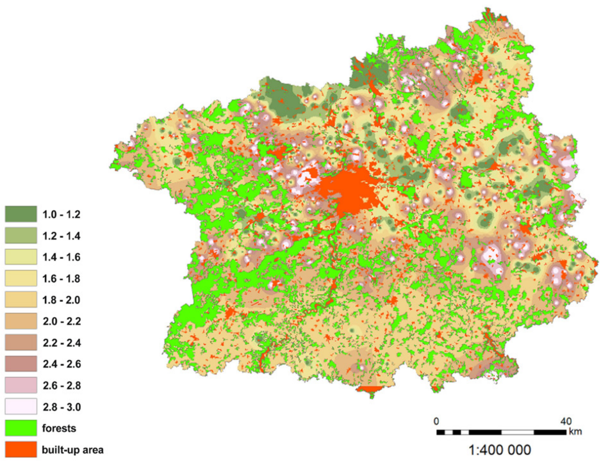

Figure 2. Soil exchange reaction score map at a soil depth of 0.00–0.30 m from the surface

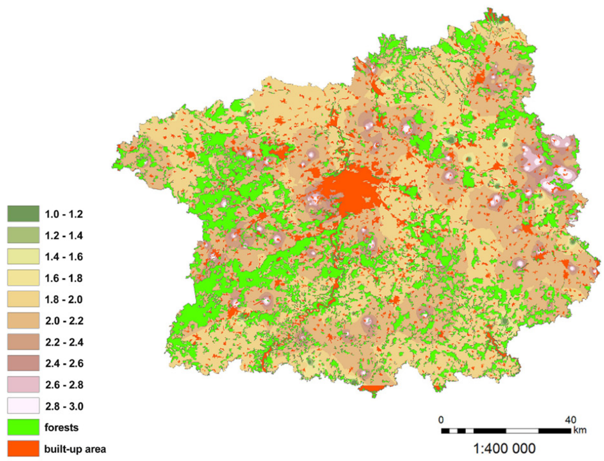

Figure 3. Map for the point assessment of the humus content at a soil depth of 0.00–0.30 m from the surface

map. Other places with an unsuitable pH were also found in the Prague-East and Kolín districts along the Labe River. The southern half of the region is covered with medium quality soils.

At soil depths of 0.30 to 0.60 m, areas with an unsuitable pH are more extensive. The soil reaction is one of the basic properties assessing the condition of the soil. pH values also significantly affect other soils characteristics – the soil processes, bioavailability and mobility of the nutrients and risky elements. The pH value is one of the criteria for processing differentiated limit values of the risky elements in the soil (Sáňka & Materna 2004).

In forest soils, the pH value is one of the basic indicators of the soil condition.

Figure 3 shows the humus content of the soils in the Central Bohemian Region at a depth of up to 0.30 m from the soil surface. Most humus was found in the Nymburk district, which had the most extensive areas with a humus content above 3.5%. Other areas with good soil quality are, for example, on the western edge of Prague and in the Polabí region. Other places where the humus is at good levels are small in extent. Overall, the humus content in the region is rather average, meaning that soils contain between 1 and 3.5% of humus. Poor humus values were only found in small areas on the border of the Mladá Boleslav and Poděbrady districts. They are highlighted in dark green.

The humus content decreases with an increasing soil depth. The evaluation of the humus content should be used to assess the organic matter supply needs with organic fertilisers and also to evaluate the implementation of anti-erosion measures and the possible evaluation of their effectiveness. The organic matter content is one of the possible criteria for processing differentiated limit values of the risky elements in the soil. (Sáňka & Materna 2004).

Figure 4 characterises the depth of the humic horizon. The deepest soils occur in the Polabska Lowland in the north-east and north of the region. These areas are marked in white on the map and include the area between Mladá Boleslav and Lysá nad Labem and the confluence of the Vltava and Labe Rivers. There are also a number of smaller sites in the region which also fall into the category of a suitable depth of the first soil horizon. These are, for example, areas near Rakovník or in the north-west of Prague in the Prague plateau. In almost all the cases, these are sites close

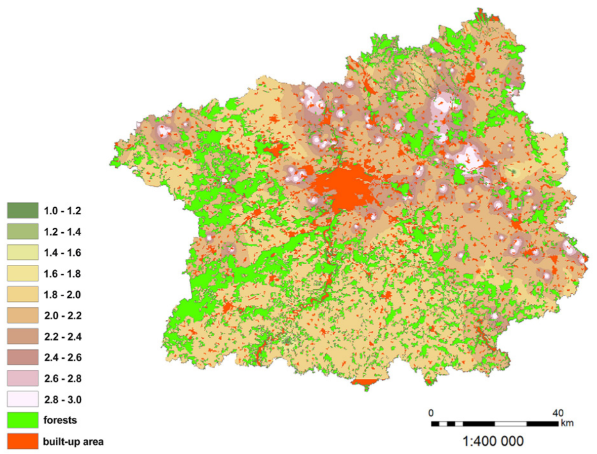

Figure 4. Map of the point assessment of the depth of the humus (first soil) horizon

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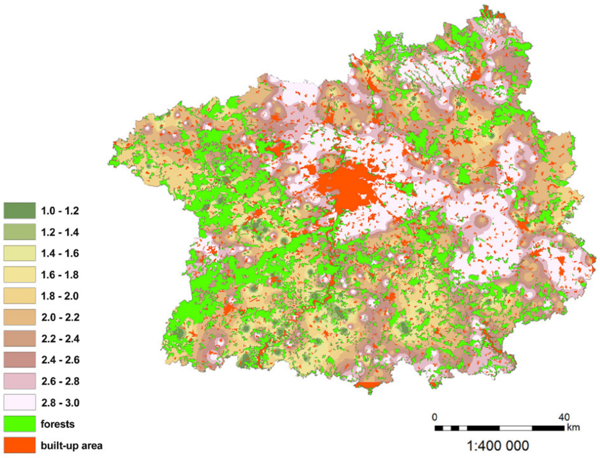

Figure 5. Soil protection class scoring map

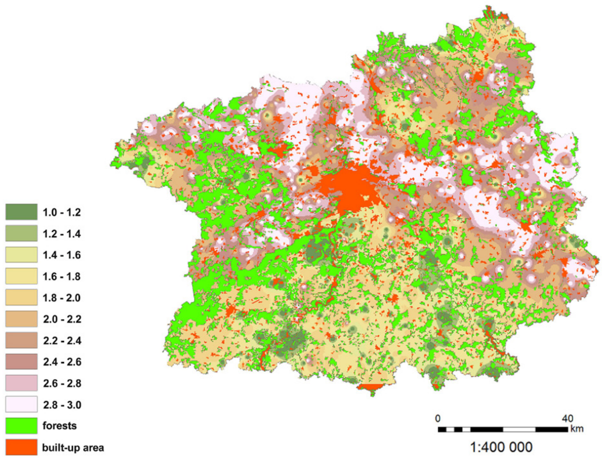

Figure 6. Map of the texture at a soil depth of 0.00–0.30 m

to rivers. Horizon depths of less than 0.10 m were found in only two locations, one in the east of the region near Poděbrady and the other in the south near Kamýk nad Vltavou. However, most of the Central Bohemian Region is covered by a medium-deep humic horizon.

Figure 5 indicates the soil protection classes found in the Central Bohemian Region. The most valuable soils in terms of the protection classes are those belonging to Class I and II. These are mainly plains that are above average in terms of their production. These soils are shown in white on the map and can be found around Prague and in the Polabska lowlands, especially in the districts of Kladno, Mladá Boleslav, Nymburk, Kolín and Kutná Hora. The soils in these areas should not be excluded from the agricultural land fund at all or only in very exceptional cases. Soils of medium value are found mainly in the south of the region. On the other hand, the worst soils belonging to protection Class V are small in extent and were found, for example, in the Příbram and Beroun regions. They are marked in dark green.

Figure 6 shows the soil grain size in the Central Bohemian Region in the first 0.30 m from the soil surface. The grain size was classified according to the Novák scale and the best soil was determined to be that containing less than 25% clay or sand. Conversely, the lowest quality soil was identified as being a sandy or clayey soil. Within this stratum, the best soil was found mainly in the north and east of the region and then in the central part of the region. Here, good quality soils are found mainly in the Polabska lowland area, on the north-eastern edge of Prague and to a lesser extent also in the Beroun region. A comparison of the northern and southern half of the region shows that there are virtually no good quality soils in terms of grain size in the south. In the south, the most sites with sands and clays were also found. These areas are marked in dark green and found along the Vltava River near the Slapy and Orlík reservoirs and in the Benešov region.

At soil depths between 0.30 and 0.60 m from the surface, the grain size is more suitable compared to the first 0.30 m of the soil. With an increasing soil depth, the soil grain size improves.

Figure 7 shows the water retention capacity map. Soils in the areas around Prague and in the Polabí region are best at retaining water. The locations in the districts of Mladá Boleslav and Nymburk and partly in Beroun have also good water retention. Other suitable locations are very small areas, e.g., in the Příbram region. The southern half of the region

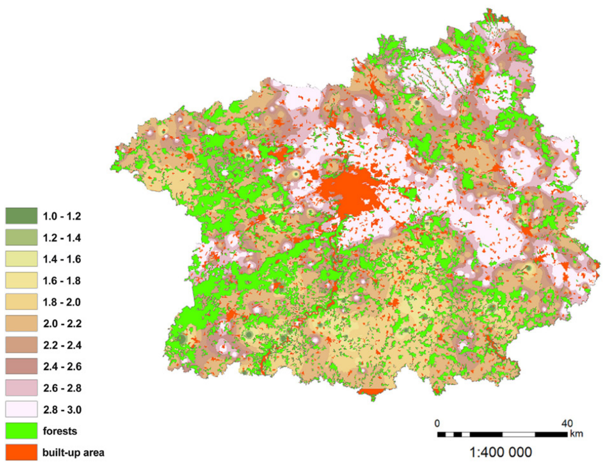

Figure 7. Map of the water retention capacity

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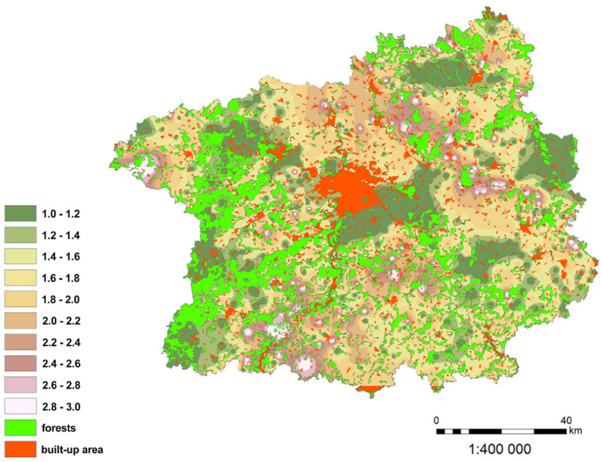

Figure 8. Map of the hydrological soil group scores

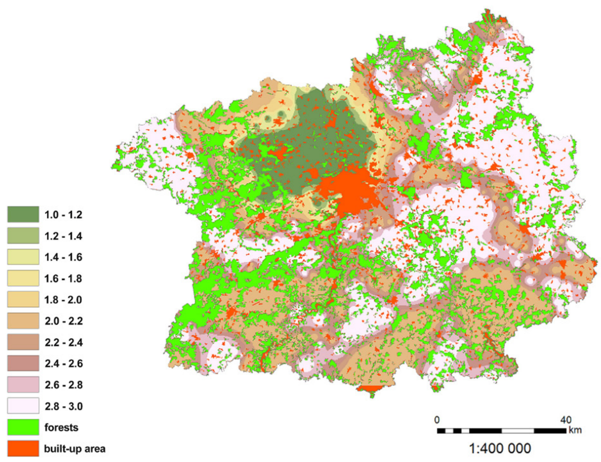

Figure 9. Map of the annual precipitation

is inferior in the water retention capacity (WRC) compared to the northern half, with almost the entire area having a moderately good WRC. A low WRC was found only in a few small localities, especially in the Příbram and Kutná Hora districts.

The differences in the soil texture are responsible for the different hydrophysical properties and suitability for growing plants and also in the decomposition of forest soils, what is important for the value of the ecological function of soil (Sáňka & Materna 2004).

Figure 8 shows the hydrological soil groups (HSP). The best HSP, i.e. A, is found in only a small number of sites in the Central Bohemian Region. Most of them are located in the Příbram region, in the Polabska lowland and partly in the Rakovník district. On the other hand, there is a relatively large number of sites in groups C and D, which indicate a poor HSP. The areas with these HSPs are marked in dark green on the map and occur mainly on the northern and north-eastern outskirts of Prague, near Mladá Boleslav, Poděbrady, Kolín, Kutná Hora and Český Brod. A larger number of smaller localities were also recorded in the Příbram, Beroun and Kladno regions. The Central Bohemian Region is very diverse in terms of the hydrological soil groups.

Figure 9 shows the average rainfall in the Central Bohemian Region. It is considered a good condition when the average annual rainfall is 550–650 mm. The ideal area is almost the entire east of the region except for the southeast, where the rainfall is less. Other suitable areas are around Sázava and Český Brod, partly the districts of Rakovník, Beroun, Příbram and Benešov. The unsuitable areas are the northern outskirts of Prague and almost the entire Kladno district, where the annual precipitation is either less than 500 mm or more than 900 mm.

Figure 10 shows the total sorption capacity at a soil depth of 0.00–0.30 m. The total sorption capacity indicates the maximum amount of cations that 1 kg of soil can hold, the amount of which is given in chemical equivalents. The total sorption capacity is highest in the east of the region, specifically in the Nymburk district. The largest area of the whole Central Bohemia Region was found there. In other parts of the region, sites with good sorption capacity are also represented, but these are very small areas. The larger number of such areas is, for example, are found in the Beroun, Kladno and Kolín districts. A poor situation was recorded especially in Brdy and its vicinity and in the vicinity of the Sázava River.

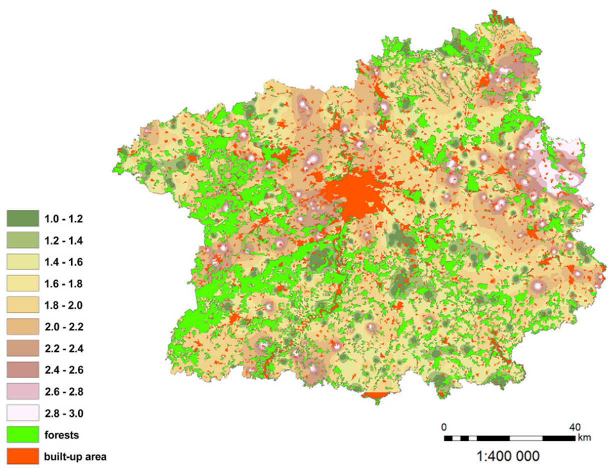

Figure 10. Map of the point assessment of the total sorption capacity at a soil depth of 0.00–0.30 m

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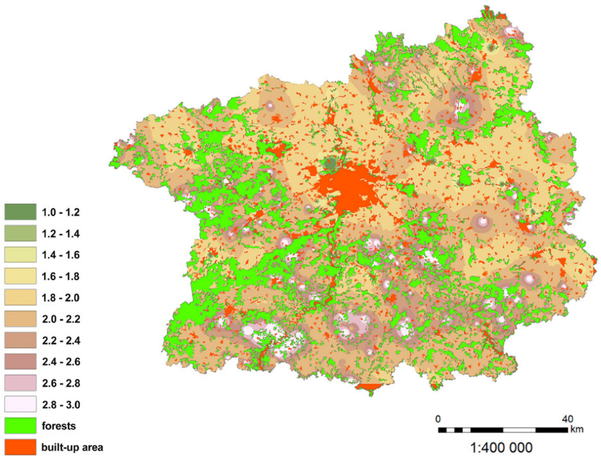

Figure 11. Map of the point assessment of the ecosystem quality

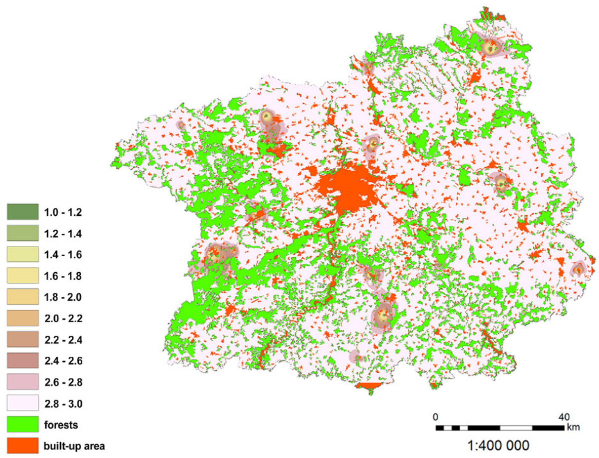

Figure 12. Assessment map of the permanent soil sealing at a diameter of 100 m around the probe

In the Central Bohemia Region, the overall sorption capacity is moderately good in most areas.

In most cases, a slight deterioration with the increasing depth was recorded.

Figure 11 shows the map of the quality of the ecosystem. For each probe, it was determined if it was located in a built-up area, meadow, farmland, or a specific type of forest. Probes that were in grassland or deciduous forest were marked as good categories. The map shows that the south of the county has higher quality ecosystems than what was found in the north. The highest quality ecosystems were found around the Vltava, Jizera and Sázava rivers. These places are marked in white on the map, which are mainly meadows and permanent grasslands. The poor quality of the ecosystem is mainly above the northern edge of Prague, and to a lesser extent near the towns of Poděbrady and Kolín and also in the north-east in the Mladá Boleslav district. The situation presents that there are many industrial enterprises with a high density of suburbs as well (urban sprawl).

Figure 12 shows the permanent soil sealing. For each soil probe, the percentage of built-up area was determined using a 100 m diameter area around the probe. It can be seen from the map that the Central Bohemian Region does not yet face a problem of built-up areas exceeding 25% in most of its territory. A worse situation was especially recorded in the towns of Hořovice in Beroun, Slaný in Kladno, Mnichovo Hradiště in the Mladá Boleslav Region, Poděbrady, Čáslav, Benešov, Týnec nad Sázavou and in the north of the Prague-East district.

Final evaluation of results. All the mapping documents that have been produced are used for the final assessment of each site in terms of its ability to provide ecosystem services. For this purpose, two approaches were chosen. The first was to calculate the average score of each site and the second was to determine the total sum of the points attributable to the site.

Figures 13 and 14 show maps of the average scores for all the included soil characteristics. Figure 13 shows the average values at soil depth 0.00–0.30 m from the surface. It is the result of a process whereby all the points assigned to a given probe were summed and then averaged. The best averages were achieved by several sites in the eastern part of the region in the Polabí Region. These locations are marked in the lightest colour on the map. Good results were recorded especially in the Nymburk district, where the greatest number of these sites is found. Other suitable areas include the districts of Mladá Boleslav and Kolín.

Figure 14 shows the average values at soil depths between 0.30 and 0.60 m. Suitable sites decrease with the increasing soil depth. However, the differences in the average values at the different soil depths are very small. Again, these are small areas, particularly in the Nymburk district. In particular, fewer suitable sites were recorded in the Mladá Boleslav region. Of the three sites originally found at a depth of 0.00–0.30 m, only one was found at a greater soil depth. However, smaller averages were found in most of the region, as indicated by the yellow-purple colouring of the maps.

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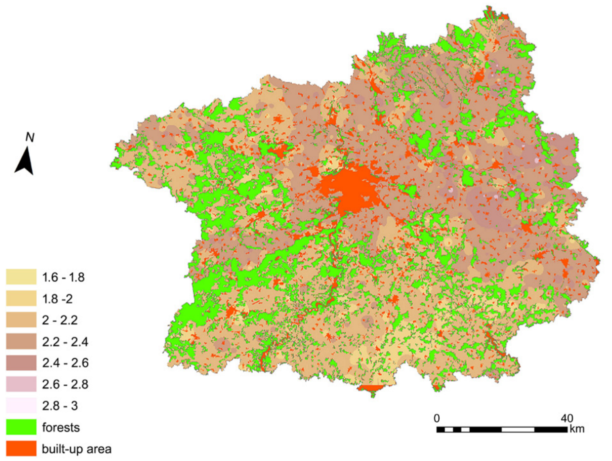

Figure 13. Map of the average evaluation scores at a soil depth of 0.00–0.30 m

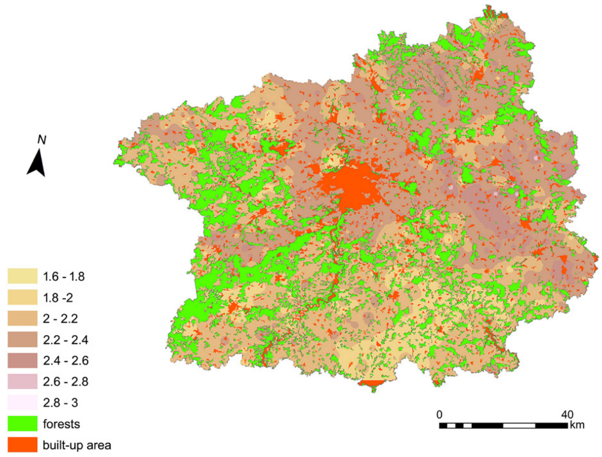

Figure 14. Map of the average evaluation scores at a soil depth of 0.30–0.60 m

In our opinion, it is appropriate to use the total scores determined at the individual sites, as this method of scoring could provide a theoretical basis for evaluating the soil habitats. For both the 0.00–0.30 and 0.30–0.60 m soil depths, the soil habitats are categorised into nine groups.

The maps in Figures 15 and 16 are the result of the sum of all the scores that have been assigned to the soil characteristics. It is, therefore, an aggregate number that indicates the overall soil quality in a given area. Figure 15 shows the most suitable soils at a depth of 0.00–0.30 m from the surface. The highest value is found in the east of the Central Bohemian Region, especially in the Nymburk district. Here, the best quality soils were found in terms of all the examined properties, which are marked in light pink in the map. Most of the best quality sites are located in the Polabska lowland. Another area with high quality soils was recorded to the east of the town of Mladá Boleslav. On the other hand, poor quality soils were found on the northern outskirts of Prague, near the town of Příbram and in the central area of the Benešov district.

Figure 16 shows the overall value of the soil at a depth of 0.30–0.60 m. Again, the largest number of sites with good quality soils was found in the Nymburk district. While, in the north of the district, the soil quality decreases with the depth, in the south of the district, it improves. The largest number of sites with good quality soils is located on the border

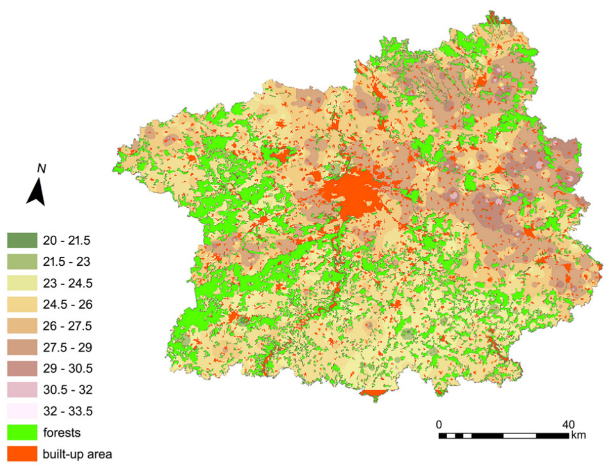

Figure 15. Map of the overall sum of points at a soil depth of 0.00–0.30 m

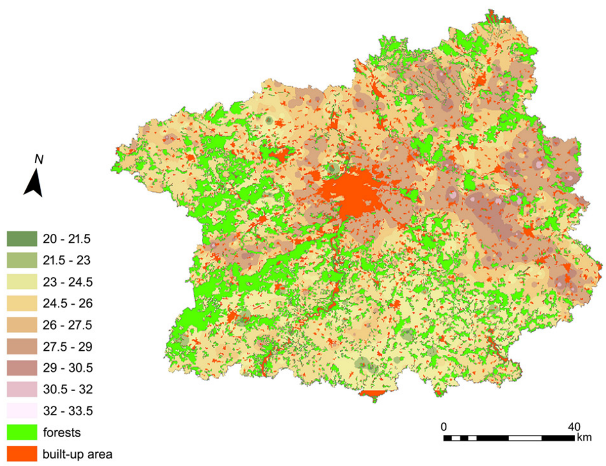

Figure 16. Map of the overall sum of points at a soil depth of 0.30–0.60 m

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of the Nymburk and Kolín districts. In the Mladá Boleslav region, there were less suitable sites, while they were not found at all in the east. The only site with the best quality soil was found in the west. In comparison with the map in Figure 15, suitable soils were also found in the Kutná Hora region near the town of Čáslav. Unsuitable soils at this soil depth are again found to the north of Prague, where the area with unsuitable soils has expanded. In contrast, near Příbram, the soil condition has improved, but the soils in this area are still of a poor quality. In the Benešov region, the soil quality has hardly changed compared to the map in Figure 15. A new area of poor quality has also been registered near the town of Slany in the north of the region. Overall, however, it can be summarised that the soils around Prague and in the east of the Central Bohemian Region are of better quality. This can be seen from the fact that most of the areas marked in purple, indicating soils close to the best quality, were recorded here.

DISCUSSION

This work was based on the soil quality indices used in Drobnik (2019). This soil quality assessment was referenced for consideration, but made use of assessment systems that are available and applicable to soils in the Czech Republic, which include the URBAN Soil Management Strategy (SMS). For the purposes of the work, a soil assessment system was developed that works on a similar principle to that developed by Kozák and Galušková (2010) and used in the URBAN SMS project.

In Swiss research (Drobnik 2019), the Delphi exploration technique was used to identify the soil functions that are the most important for the provision of ecosystem services. It was a two-round questionnaire that collected the opinions of experts. In our work, we did not use a questionnaire survey because a selection of these functions was obtained from the URBAN SMS project. Based on a workshop attended by a number of experts in this project, the opinions were successfully discussed, considered and then successfully used in the Soil in the City project.

Our hypothesis that a combination of data on soil characteristics, climate, land use and soil productive capacity can be used as indicators of the soil production and ecosystem services has been confirmed.

Unlike other studies conducted, a database was used. The soils were divided by depth and then we tried to trace any possible differences between these depths. Some properties, which include, for example, the nutrient content of the soil, can only be demonstrated in the top layers and, therefore, the nutrient content was not included in the work.

Janků et al. (2016) defined land take as one of the main reasons for land loss in the Czech Republic. The worst situation was recorded around the main and other larger cities. In this work, a map was created based on the soil sealing scores, which marks the soil quality around soil probes with a diameter of 100 m. The percentage of permanent impervious soil cover was found in CORINE Land Cover 2018. It was confirmed that the most developed areas are found around cities. Interestingly, however, the situation around Prague is good and the soil sealing does not exceed 25%. A worse situation was found in the northern part of the Prague-East district only. Higher percentages of built-up areas were recorded mainly around the towns of Hořovice, Slaný, Mnichovo Hradiště and Benešov. However, these are not the largest cities in the Czech Republic, so the claim made in Janků et al. (2016) has not been proven.

It was found that the Central Bohemian Region is very heterogeneous in terms of the soil quality. A large difference is noticeable when comparing the northern and southern half of the region. The north and the north-east of the region have better quality soils, with the best quality being recorded particularly in the Polabska lowland area. In contrast, the southern half of the county has soils of lower quality, which is noticeable in almost all the maps of the selected soil characteristics. This is mainly due to the particular soil types that are most commonly represented here. In the north and east of the county, there is a large proportion of chernozem, which is not found elsewhere in the county. The quality of the soils is also reflected in the presence of *Phaeozems* and Fluvisols, which are found here. In contrast, the south and west of the county are mainly covered with Cambisols, with other soil types being represented to a much lesser extent. At the same time, they are not found in the same quantity as in the north and east.

One way of assessing soils is through soil scoring. Josef Kopecký was the first to determine a credit rating of arable soils in Czechoslovakia in 1931. He included, in the rating table, the texture, skeleton, humus content, calcium, iron and sodium content, soil waterlogging, slope of the area, exposure of the land and altitude (Kopecký 1931).

Džatko et al. (1979) proposed another attempt at a uniform assessment of the relative productive

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capacity of soils based on an evaluation of the then existing knowledge of soil properties, soil-ecological units and the interrelationships between the environmental properties and the crop production intensity. The soil-ecological unit groups were scored between 0 and 100 points. The authors included phaeozem, their transitions to chernozems in the best climatic regions, in the 1st soil-ecological unit group with the relatively highest production capacity. They are scored between 100 and 95. The last three rating groups are scored between 20 and 1. These include all soils on slopes above 12° and hydromorphic soils.

Mašát et al. (1985) introduced a scoring system for the production potential of an "evaluated land ecological unit" – or BPEJ. This system is based on the properties and characteristics of the soil and the habitat. The calculation is given by the sum of the points for the main soil unit (HPJ), texture, slope and exposure of the land, type of skeleton and depth of the soil profile, all multiplied by a climate region coefficient in the range 0.6–1. The HPJ score represents the point value for the soil (genetic type, subtype, variety, water regime) together with the soil substrate. The values are determined according to the relationships between yields per hectare, complemented by knowledge of the soil fertility and behaviour. The production potential scores were ranked into ten classes, with the highest scores (100–96) for highly productive soils with stable yields, and the lowest scores (< 10) for soils with an insignificant production amount in group 10.

Mašát et al. (1986) proposed criteria for selecting the final variant of the score calculation. The aim was to evaluate the ruggedness of the conditions (agroecological complexity) of the cadastral territory as objectively as possible, so that the influence of each factor is reflected in the overall score to the extent that it actually contributes to the ruggedness (agroecological complexity) of the territory. A total of seven criteria were used, the main ones being the slope, suitability of the BPEJ (evaluated soil ecological unit) sites to be integrated into continuous units, site size, and the others being permanent the obstacles, how boulder the site is, the accessibility for farming, and the moisture conditions. This resulted in seven categories according to altitude.

Novák et al. (1995) proposed a modified methodology for determining the point value of land in the BPEJ system. The formula already presented in the paper (Mašát et al. 1985) was used for the calculation of the production potential score. The methodology proposes adjustments to the basic point value of the BPEJ for protected areas, for hydrosphere protection zones, for erosion-prone soils, contaminated soils, agricultural soils in areas designated for development or in built-up areas, for degraded soils, soils threatened by emissions and for soil podzolisation, for drained soils, for irrigated soils, for terraced soils, for anthropogenic and reclaimed soils. The authors believe that this system can better express the relational and absolute values of each BPEJ than the current BPEJ prices in CZK per 1 m^2. It is also possible to express the price of 1 point, thus, obtaining the price of a BPEJ, and it is possible to identify differences between the 'natural' point value of a BPEJ and its point value affected by any of the above interventions.

For the purpose of this work, the main physical, chemical and hydropedological factors, as well as environmental factors related to the soil probe sites, were evaluated.

The most important result of this paper was the scoring of each site, always in the vicinity of the soil probes found in the database. This method of evaluation can be the basis for a new way of evaluating the soil as a landscape element. The results of this work may also serve in the future to refine the criteria on the basis of which soils are divided into soil protection classes.

CONCLUSION

The work dealt with a soil quality assessment in the Central Bohemian Region and the soils' ability to provide ecosystem services. The method of the average score and total score was chosen to assess the quality at the soil probe sites. The soil properties at the individual sites were examined at depths of 0–0.3 and 0.3–0.6 m from the surface. The most valuable soils were located in the north-east of the region, mainly in the Nymburk district, as well as in parts of the Kolín and Mladá Boleslav districts. There were differences between the two soil layers studied, but nevertheless, the most valuable soils occurred in identical locations.

At the beginning of this work, a hypothesis was defined which stated that diverse information about soils and a given area can be used as indicators of the productive and ecological services of soils. The results of this work confirmed this hypothesis. The aim of this work was to evaluate soil quality data, and these data were used to evaluate the ecosystem services.

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This work provided evidence that can be used in the future to adjust the criteria by which soils are classified into soil protection classes. The results of this work could help to develop a new soil rating that takes changes in climate and natural conditions into account. Currently, the Czech Republic is facing a lack of moisture, which is exacerbated by inappropriate soil management. As a result of the work, the most valuable soils were identified as sites that should be subject to the most stringent protection protocols and, therefore, should not be removed from the agricultural land fund.

The experience of this work will be used for the development of a new method that will be suitable for an evaluation for the whole territory of the Czech Republic.

REFERENCES

Anonymous (2011): Decree 48/2011 on the Establishment of Protection Classes. The Ministry of the Environment of the Czech Republic in line Act No. 334/1992 Coll., On the Protection of the Agricultural Land Fund. Available at https://www.sagit.cz/info/sb11048 (accessed Nov 26, 2021).

Anonymous (2019): Evaluated Soil-Ecological Units. Prague, State Land Office. Available at https://www.spucr.cz/bpej (accessed Oct 27, 2021).

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

Bastida F., Zsolnay A., Hernández T., García C. (2008): Past, present and future of soil quality indices: A biological perspective. Geoderma, 147: 159–171.

Costanza R., d'Arge R., de Groot R., Farber S., Grasso M., Hannon B., Limburg K., Naeem S., O'Neill R.V., Paruelo J., Gaskin R.G., Sutton P., van den Belt M. (1997): The value of the world's ecosystem services and natural capital. Nature, 387: 253–260.

Desaules A., Ammann S., Schwab P. (2010): Advances in long-term soil-pollution monitoring of Switzerland. Journal of Plant Nutrition and Soil Science, 173: 525–535.

Drobnik T. (2019): Ecosystem Services and Soil Quality. [Doctoral Thesis.] Zurich, ETH Zürich Research Collection. Available at https://doi.org/10.3929/ethz-b-000376809 (accessed Nov 8, 2021).

Drobnik T., Greiner L., Keller A., Grêt-Regamey A. (2018): Soil quality indicators – From soil functions to ecosystem services. Ecological Indicators, 94: 151–169.

Džatko M., Hraško J., Linkeš V., Mašát K., Němeček J. (1979): Assessment of relative production capacity soils in the Czechoslovak Socialist Republic. Plant Production, 25: 693–699. (in Czech)

Fiala P. (2008): Models and Methods of Decision-making. 2nd Ed. Prague, Oeconomica. (in Czech)

Fliessbach A., Oberholzer H.R., Gunst L., Mäder P. (2007): Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. Agriculture, Ecosystems & Environment, 118: 273–284.

Geoportal.gov.cz (2014):Corine Land Cover 2012. Available at https://geoportal.gov.cz/web/guest/news?id=59550 (accessed Nov 8, 2021).

Haines-Young R., Potschin-Young M. (2010): The links between biodiversity, ecosystem services and human well-being. In: Raffaelli D.G., Frid Ch.L.J. (eds.): Ecosystem Ecology: A New Synthesis. Cambridge, Cambridge University Press: 110–139.

Haslmayr H.P., Geitner C., Sutor G., Knoll A., Baumgarten A. (2016): Soil function evaluation in Austria – Development, concepts and examples. Geoderma, 264: 379–387.

Hersperger A.M., Ioja C., Steiner F., Tudor C.A. (2015): Comprehensive consideration of conflicts in the land-use planning process: A conceptual contribution. Carpathian Journal of Earth and Environmental Sciences, 10: 5–13.

Janků J., Jakšík O., Kozák J., Marhoul A.M. (2016): Estimation of land loss in the Czech Republic in the near future. Soil and Water Research, 11: 155–162.

Kopecký J. (1931): Scoring the Value of Arable Land in Czechoslovakia. Special Reprint from the Agricultural Archive, 22 (1–2). Prague, Political Printing House. (in Czech)

Kozák J., Galušková I. (2010): Urban Template 4 (Prague). Prague, Department of Soil Science and Soil Protection, Czech University of Life Sciences Prague.

Kozák J., Němeček J., Jetmar M. (1996): The database of Soil Information System – PUGIS. Crop Production, 42: 529–534. (in Czech)

Kozák J., Němeček J., Borůvka L., Lérová Z., Němeček K., Kodešová R., Janků J., Jacko K., Hladík J., Zádorová T. (2009): Soil Atlas of the Czech Republic. 2nd Ed. Prague, Czech University of Life Sciences Prague.

Land. copernicus.eu (2018): Corine Land Cover 2018. Available at https://land.copernicus.eu/pan-european/corine-land-cover/clc2018 (accessed Nov 8, 2021).

Mašát K., Němeček J., Džatko M. (1985): System of Point Valuation of Productivity of BPEJ. [System. MS, Final Report.] Prague, Research Institute for Soil and Water Conservation. (in Czech)

Mašát K., Svobodová D., Kohoutová L. (1986): Categorization of the Territory According to Agroecological Complexity. Sub-task: Deepening and Agronomic Use

https://doi.org/10.17221/146/2021-SWR

of the Agroecological Block of the Evaluating Information System of Czechoslovakia. Review number: SPEV 901.129.318.04.02. Prague, Research Institute for Soil and Water Conservation. (in Czech)

Novák P., Kohel J., Tomiška Z., Zlatušková S. (1995): Methodology for Determining the Point Value of the Soil (Task Output). Prague, Research Institute for Soil and Water Conservation: 1–14. (in Czech)

Oberholzer H.R., Freiermuth Knuchel R., Weisskopf P., Gaillard G. (2012): A novel method for soil quality in life cycle assessment using several soil indicators. Agronomy for Sustainable Development, 32: 639–649.

O'Neill J., Walsh M. (2000): Landscape conflicts: preferences, identities and rights. Landscape Ecology, 15: 281–289.

Ramík J. (1999): Multi-Criterion Decision-Making – Analytical Hierarchical Process (AHP). Karviná, Silesian University. (in Czech)

Saaty T.L. (2008): Relative measurement and its generalization in decision making why pairwise comparisons are central in mathematics for the measurement of intangible factors the analytic hierarchy/network process. Revista de la Real Academia de Ciencias Extras, Serie A. Matematicas, 102: 251–318.

Sáňka M., Materna J. (2004): Quality Indicators of Agricultural and Forest Soils in the Czech Republic. Prague, Ministry of the Environment of the Czech Republic. Available at https://www.mzp.cz/web/edice.nsf/CEFFC9BDDD360E2EC1256FAF0040EEF6/$file/indikatory_el.pdf (in Czech)

Schloter M., Dilly O., Munch J.C. (2003): Indicators for evaluating soil quality. Agriculture, Ecosystems & Environment, 98: 255–262.

Shukla M.K., Lal R., Ebinger M. (2006): Determining soil quality indicators by factor analysis. Soil and Tillage Research, 87: 194–204.

TEEB (2010). The Economics of Ecosystems and Biodiversity. Ecological and economic . Kumar P. (ed.). London, Washington, Earthscan.

Veidemane K. (2019): Contribution of ecosystem services to achievement of the sustainable development goals. Proceedings, 30: 8.

von der Dunk A., Grêt-Regamey A., Dalang T., Hersperger A.M. (2011): Defining a typology of peri-urban land-use conflicts – A case study from Switzerland. Landscape and Urban Planning, 101: 149–156.

Vopravil J., Novotný I., Khel T., Hladík J., Jacko K., Papaj V., Vašků Z., Vrabcová T., Pírková I., Rožnovský J., Havelková L., Huml J., Sekanina A., Novák P., Voltr V., Středa T., Kohoutová L., Poruba M., Czelis R., Janků J., Penížek V. (2011): Soil and its Evaluation in the Czech Republic, Part II. Prague, Research Institute for Soil and Water Conservation. (in Czech)

Wolff G. (2006): The Stuttgart Soil Protection Concept (BOKS). Stuttgart, Office for Environmental Protection. Available at http://www.nfp68.ch/SiteCollectionDocuments/Wolff_Bodenschutzkonzept_Stuttgart_2006.pdf

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