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ASSESSING THE VULNERABILITY TO LAND DEGRADATION OF (NOT ONLY) RURAL LANDSCAPES USING THE ESAI INDEX

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ABSTRACT

Determining the vulnerability of land to degradation is a crucial factor enabling policy makers to take targeted actions. The main aim of this work was to determine vulnerability to land degradation using the Environmentally Sensitive Area Index (ESAI) in the territory of 206 municipalities with extended power (MEPs), regions (NUTS 3) and in the Czech Republic (CR). The other two aims were found out i) whether land degradation is affected by land use characterized by landscape types according to Löw *et al*. (2006) and ii) whether land degradation occurred in larger territorial units (regions) or scattered across the CR (in individual isolated MEPs). The Environmentally Sensitive Area (ESA) method assesses the vulnerability of an area to land degradation using a composite index containing indicators divided into four thematic groups: human activity pressure and management intensity, vegetation cover and vegetation quality, climate, and soil in the assessed area. The ESAI index is expressed on a semi-quantitative scale ranging from the lowest levels of degradation (land not affected and land potentially affected by degradation) to the highest level of degradation (land at high risk). Most MEPs with a share of more than 70 % of their area were in the category "moderately critical areas" at risk of land degradation were located in the Central Bohemia region (15 MEPs) and in the South Moravia region (14 MEPs). For the whole territory of the Czech Republic, 51 % of the territory was found to be critically vulnerable to land degradation, and 38 % of the republic area was vulnerable to land degradation. Vulnerability to land degradation was strongly influenced by the landscape type. Almost all MEPs with a predominantly agricultural landscapes were critically vulnerable to land degradation, as were about half of the MEPs in the forest-agricultural and urban landscapes and only a few MEPs in the forest landscapes. Given the selected indicators, the MEP seems to be the appropriate smallest administrative unit to assess vulnerability to land degradation in the Czech Republic. The map of individual ESAI values can be viewed free of charge online at http://www.imalbes.cz/vysledek.php. We are currently preparing a proposal for appropriate measures to prevent and reduce land degradation throughout the territory of the Czech Republic, and our proposals are coordinated with representatives of the MEPs and regions.

Keywords: land degradation, vulnerability, Environmentally Sensitive Area Index, region, municipality with extended power, Czech Repulic

INTRODUCTION

Our lives depend on our environment, of which the soil is an essential part. Since the beginning of the 21st century, the quality of soil has become unsustainable in the long term due to increasing problems of land abuse. The European Environment Agency (EEA, 2012) estimates that 115 million hectares (i.e., 12 %) of the total European land area are exposed to degradation, and Eurostat (2016) stated that 75 % of EU agricultural land is exposed to erosion. According to the Czech Ministry of Agriculture (2016), water erosion occurs on roughly 60 % of Czech agricultural land, wind erosion occurs on 18 %, soil compaction occurs on 40 %, and acidification occurs on 62 %; loss of organic matter is a problem especially in drained areas and soils on sandy substrates (Bednář & Šarapatka, 2018; Janeček *et al*., 2012). The continuation of this trend may pose a major problem for the future satisfaction of basic life needs (ELD Initiative, 2015). Therefore, land degradation is now considered one of the most serious environmental problems at the global, regional, and local levels (Kosmas *et al*., 2014).

Soil condition occurs in conjunction with other environmental features, so the more general term "land degradation" is usually used, encompassing soil, local water resources, and vegetation, including agricultural crops (Baartman *et al*., 2007; Middleton & Thomas, 1997). Land degradation refers to the decline in the biological and economic productivity of soils (Basso *et al*., 2012) and the decrease in their ability to provide ecosystem services. It occurs in many forms, including water and wind erosion, organic matter decline, local and diffuse pollution, soil sealing, soil compaction, biodiversity decline, salinization, flooding, landslides, desertification (Montanarella, 2007; Pimentel *et al*., 1995; Salvati *et al*., 2011; Stolte *et al*., 2016,), acidification (Salvati *et al*., 2011), and nutrient loss (Arheimer & Lidén, 2000; Bechmann & Våje, 2002). Land degradation threatens fertile soils and freshwater resources and negatively affects food production and biodiversity (Andeltova *et al*., 2013; Bajocco *et al*., 2011; Smiraglia *et al*., 2016), while in arid, semi-arid, and dry sub-humid areas, land degradation can lead to a complete and irreversible loss of ecosystem functions—desertification (Baartman *et al*., 2007; Forino *et al*., 2015; UNCCD, 1994).

The cause of land degradation is usually a complex interaction between environmental processes and anthropogenic pressures (Wilson & Juntti, 2005). Human activities leading to land degradation are exacerbated by natural conditions and often amplified by the effects of climate change and biodiversity loss (UNCCD, 1994). On a global scale, global warming, economic development, landscape change, and increasing population pressure are the driving forces for soil and landscape deterioration leading to land degradation (Geist & Lambin, 2004), as are urbanization and the establishment of industrial areas (Oliveira *et al*., 2018).

Vulnerability to degradation varies under different environmental conditions despite similar land use (Darradi *et al*., 2012; Van der Werf & Petit, 2002). For example, natural conditions such as topography, soils, climate, and geology significantly shape the susceptibility of agricultural landscapes to land degradation (Nowak & Schneider, 2016). In general, we can describe the most endangered areas in Central Europe as regions with low precipitation and a high proportion of soils with degraded or naturally occurring low water-holding capacity, as well as regions with steeper than average slopes (Trnka *et al*., 2016a).

Recently, climate change has been a much-discussed issue and has become a hot topic in debates on land degradation. Degradation of soil properties due to unsustainable management combined with climate change can lead to a decline in productivity beyond the point of no return, with devastating impacts on ecosystem services in large areas (Trnka *et al.*, 2016b).

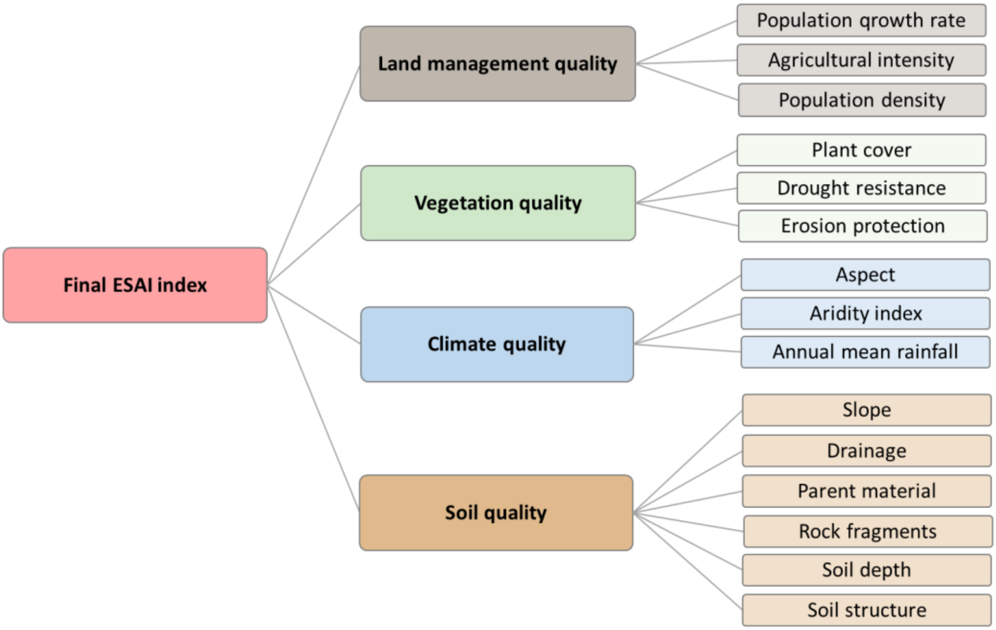
Environmental sensitivity can be defined as the response of the environment or its parts to one or more external factors and degradation occurs when that response is considered detrimental to the "health" of the environment (Basso *et al*., 2000). To assess the sensitivity of land to degradation, we need to focus on a particular combination of factors, both human pressures and environmental conditions, which result in a particular mixture that is susceptible to degradation. There are several approaches to assessing sensitivity to land degradation, but the most widely used, not only in Europe, is the method using the Environmentally Sensitive Area Index (ESAI), developed as a result of the MEDALUS (Mediterranean Desertification And Land Use) project. This project, which ran from 1991 to 1999, was funded by the European Commission and focused on understanding, identifying, and mitigating the problems of desertification in the Mediterranean region. The methodological approach is based on the combination of factors grouped into four thematic categories—climate, soil, human pressure, and vegetation quality—expressed by the ESAI, to identify areas at risk of land degradation or desertification. The method was first applied in Italy, Greece, and Portugal (Kosmas *et al*., 1999), and later in other parts of the Mediterranean region, mainly in Italy (Basso *et al*., 2000; Canora *et al*., 2014; Imbrenda *et al*., 2014; Salvati *et al*., 2016), Spain (Contador *et al*., 2009; Martínez-Sánchez *et al*., 2015), and Greece (Symeonakis *et al.*, 2014), but also in other countries such as Romania (Prăvălie, 2017), Serbia (Momirović *et al*., 2019), Brazil (Vieira *et al*., 2015), Mongolia (Lee, 2019), and Vietnam (Hien, 2019).

The main aim of this work was to determine the vulnerability to land degradation, using the Environmentally Sensitive Area Index (ESAI), of the territory of municipalities with extended power (MEPs), regions (NUTS 3) and in the Czech Republic (CR). The other two aims were to find out i) whether land degradation is affected by land use characterized by landscape types according to Löw *et al*. (2006) and ii) whether land degradation occurred in larger territorial units (regions) or scattered across the CR (in individual isolated MEPs).

METHODS

The area of interest is the Czech Republic (CR). Of the total area of 78,866 km^2, 67 % lies at an altitude of up to 500 m above sea level, 32 % lies at an altitude of 500 to 1000 m above sea level, and 1 % lies at an altitude of over 1000 m above sea level (Culek *et al*., 2005), see a map of the relief of the Czech Republic, Fig. A.1. The extent of settlements is mainly characterized by a larger number of mostly small municipalities and a relatively uniform population density. The largest city, and the capital, is Prague, with more than one million inhabitants; the limit of 100,000 inhabitants is exceeded by 5 other cities (Statistical Yearbook, 2020). According to the Quitt classification of climatic zones, 66 % of the area of the CR is located in areas with moderately warm climate, 20 % is in areas with warm climate, and 14 % is in areas with cold climate. Of the total area, 36 % is arable land, 36 % is forests and pastures, 20 % is other agricultural land, 7 % is urban areas, and 1 % is water and wetlands (Statistical Yearbook, 2020). The degree of vulnerability to land degradation can be determined and quantified using the Environmental Sensitive Area Index (ESAI), and this index can be used to assess the sustainability of land use. The ESAI index is determined using four thematic groups of indicators: the Soil Quality Index (SQI), Climate Quality Index (CQI), Vegetation Quality Index (VQI), and Land Management Quality Index (MQI). Each thematic group is expressed by an index representing the geometric mean of the scores assigned to each input variable (Fig. 1).

Fig. 1: Calculation of the composite Environmental Sensitive Area Index (ESAI) which includes the assessment of indicators divided into four thematic groups.



The ESAI score ranges from 1 (lowest sensitivity to degradation) to 2 (highest sensitivity to degradation). The total ESAI index was determined in each *i*th spatial unit and *j*th year as the geometric mean of the four quality indicators, Formula 1 (Basso *et al*., 2000; Kosmas *et al.*, 1999; Pechanec *et al*., 2021).

$$ESAI_{i,j} = (SQI_{i,j} * CQI_{i,j} * VQI_{i,j} * MQI_{i,j})^{1/4} \quad (1)$$

Maps and databases at a detailed scale of 1:10,000 for the years 2016–2019 were used to calculate the four thematic groups of indicators and the total composite ESAI index for the entire Czech Republic (Tab. 1), for detailed information see Pechanec *et al*. (2021). In addition, the average ESAI values were calculated for the territories of 206 local municipalities with extended powers (MEPs), for 14 regions (NUTS-3), and for the entire Czech Republic (CR). In order to interpret the results, the individual MEPs were divided according to the predominant landscape type. For the division of the landscape into several types, the basic characteristics according to Löw *et al*. (2006) of urban, agricultural, forest-agricultural, forest landscapes, pond landscapes, landscapes of mountain open areas and landscapes without differentiated use were used, see Fig. A.2. Individual MEPs were assigned to the most common prevalent types of landscapes (urban, agricultural, forest-agricultural and forest) based on the predominant landscape type using cluster analysis in the program R. The pond landscapes, landscapes of mountain open areas and landscapes without differentiated use were attributed to another landscape type, because it did not prevail in any MEPs. The land degradation risk scale within the ESAI index, which ranges from 1 to 2, was divided into 8 categories in the original approach by Kosmas *et al*. (1999). Pechanec *et al*. (2021) also used these 8 categories for the entire CR.

Table 1: List of variables used for the state of the Environmental Sensitive Area Index (ESAI) assessment in Czech Republic (Pechanec *et al*. 2021).

Indicator	Layer description	Data source	Last update	Scale
Soil texture	Map of soil associations, on an agricultural soils refined by BPEJ soil maps (maps of rated soil-ecological units)	Research Institute for Soil and Water Conservation + Forest Management Institute	2018	1:10 000
Soil depth	Map of soil associations, on an agricultural soils refined by BPEJ soil maps (maps of rated soil-ecological units)	Research Institute for Soil and Water Conservation + Forest Management Institute	2018	1:10 000
Rock fragments	Map of soil associations, on an agricultural soils refined by BPEJ soil maps (maps of rated soil-ecological units)	Research Institute for Soil and Water Conservation + Forest Management Institute	2018	1:10 000
Parent material	Geological map	Czech Geological Survey	2019	1:100 000
Drainage	Combination of soil infiltration ability, groups of forest types and maps of soil associations	Research Institute for Soil and Water Conservation + Forest Management Institute	2018	1:10 000
Slope	DMR 5G	The Czech Office for Surveying, Mapping and Cadastre	2016	5m/px
Annual mean rainfall	Climate data	CzechGlobe	2019	100m/px
Aridity index	Climate data	CzechGlobe	2019	100m/px
Aspect	DMR 5G	The Czech Office for Surveying, Mapping and Cadastre	2016	5m/px
Erosion protection	Combined layer of habitats	CzechGlobe	2019	1:10 000
Drought resistance	Combined layer of habitats	CzechGlobe	2019	1:10 000
Plant cover	Combined layer of habitats + Copernicus data	CzechGlobe+ESA+Palacký University	2019	1:10 000
Population density	ArcCR 500 ver. 3.2 / Basic settlement units	Arcdata Praha + Czech statistical office	2016	1:10 000
Population growth rate	ArcCR 500 ver. 3.2 / Basic settlement units	Arcdata Praha + Czech statistical office	2016	1:10 000
Agricultural intensity	Result from CZ GLOBIO model, based on Combined layer of habitats	CzechGlobe + Palacký University	2018	1:10 000

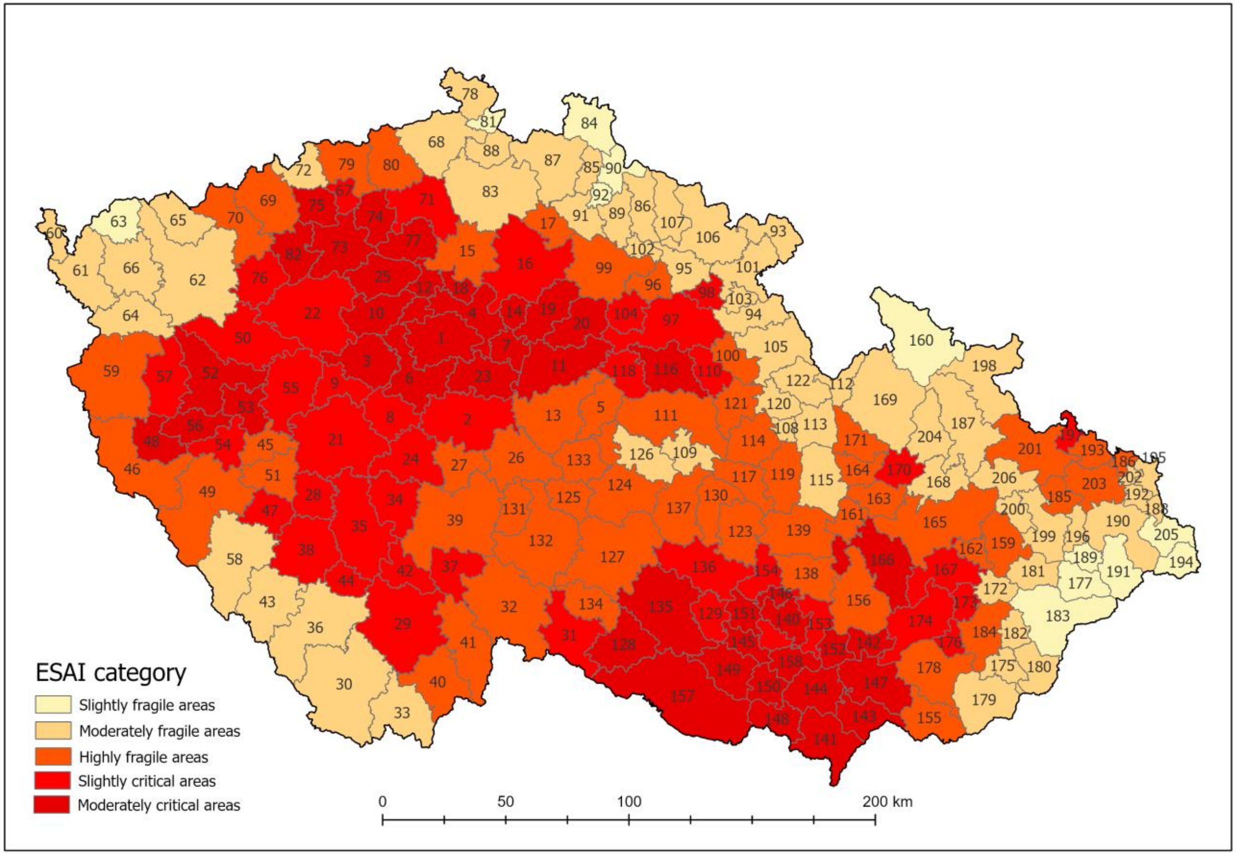
To compare ESAI values in 206 MEPs we used 5 predominant categories from 8 categories: slightly fragile areas (F1), moderately fragile areas (F2), highly fragile areas (F3), slightly critical areas (C1) and moderately critical areas (C2). However, for clarity and interpretation the ESAI index for 14 regions, we used only 3 groups of categories: unaffected areas and potentially affected areas (UP; 1.17 < ESAI < 1.22), slightly fragile to severely fragile areas (F1-F3; 1.23 < ESAI < 1.37), and slightly critical to severely critical areas (C1-C3; 1.38 < ESAI < 1.53). For data processing and all calculations in the ESRI ArcGIS Pro 2.7 program, the following tools were mainly used: Identity, Merge, Dissolve, Zonal Statistics, Clip, and other sub-procedures leading to the final calculation of the ESAI index. The program R was used to create a box-plot diagram.

RESULTS

Vulnerability to land degradation was assessed at different levels in the CR. It was found that 98 municipalities with extended power (MEPs) out of the total number of 206 municipalities belonged to the critically vulnerable land degradation groups of categories (C1–C3) with ESAI values in the range 1.36–1.5. Most of these MEPs were located in forest-agricultural and agricultural landscapes. The most vulnerable MEP was Prague with an average ESAI value of 1.5, followed by Brandýs nad Labem-Stará Boleslav (1.49) and Brno (1.48), i.e., mostly lowland and agricultural residential areas that have historically been settled for a long time. The least vulnerable MEPs were Frýdlant and Frýdlant nad Ostravicí, with an average ESAI value of 1.23; these are foothill to mountain areas where the forest landscape type predominates. Each MEP was also assigned to one of the five ESAI categories according to the degree of vulnerability to land degradation. It was found that 81 MEPs were predominantly represented in ESAI groups of moderately and slightly critical areas (C1, C2), 55 MEPs were predominantly represented in highly fragile areas (F3), and 70 MEPs belonged to the groups of moderately and slightly fragile areas (F1, F2) groups in terms of land degradation vulnerability (Fig. 2).

From the results for individual regions, it can be deduced that the largest proportion of critically vulnerable areas to land degradation (in the groups of critical areas (C1–C3) according to the degree of vulnerability to land degradation) was in Prague (89 %), South Moravia (71 %), and Central Bohemia (68 %). The largest share of unaffected or only potentially affected areas (N, P) to land degradation was located in the regions of Liberec (26 %), Zlín (20 %), and Moravian-Silesia (20 %) (Table 2). For the whole territory of the Czech Republic, it was found that 51 % of the national territory fell into the groups of categories of critical areas (C1–C3), 38 % fell into the groups of categories of very vulnerable areas (F1–F3), and only 11 % fell into the groups of categories of unaffected or only potentially affected areas (UP) in terms of vulnerability to land degradation. For a more detailed description of the ESAI results for the whole Czech Republic, see Pechanec *et al*. (2021).

Fig. 2: Environmental Sensitive Area Index (ESAI) values for individual municipalities with extended power (MEPs) within the Czech Republic.



Legend: 1, Praha; 2, Benešov; 3, Beroun; 4, Brandýs n.L.-S.Boleslav; 5, Čáslav; 6, Černošice; 7, Český Brod; 8, Dobříš; 9, Hořovice; 10, Kladno; 11, Kolín; 12, Kralupy nad Vltavou; 13, Kutná Hora; 14, Lysá nad Labem; 15, Mělník; 16, Mladá Boleslav; 17, Mnichovo Hradiště; 18, Neratovice; 19, Nymburk; 20, Poděbrady; 21, Příbram; 22, Rakovník; 23, Říčany; 24, Sedlčany; 25, Slaný; 26, Vlašim; 27, Votice; 28, Blatná; 29, České Budějovice; 30, Český Krumlov; 31, Dačice; 32, Jindřichův Hradec; 33, Kaplice; 34, Milevsko; 35, Písek; 36, Prachatice; 37, Soběslav; 38, Strakonice; 39, Tábor; 40, Trhové Sviny; 41, Třeboň; 42, Týn nad Vltavou; 43, Vimperk; 44, Vodňany; 45, Blovice; 46, Domažlice; 47, Horažďovice; 48, Horšovský Týn; 49, Klatovy; 50, Kralovice; 51, Nepomuk; 52, Nýřany; 53, Plzeň; 54, Přeštice; 55, Rokycany; 56, Stod; 57, Stříbro; 58, Sušice; 59, Tachov; 60, Aš; 61, Cheb; 62, Karlovy Vary; 63, Kraslice; 64, Mariánské Lázně; 65, Ostrov; 66, Sokolov; 67, Bílina; 68, Děčín; 69, Chomutov; 70, Kadaň; 71, Litoměřice; 72, Litvínov; 73, Louny; 74, Lovosice; 75, Most; 76, Podbořany; 77, Roudnice nad Labem; 78, Rumburk; 79, Teplice; 80, Ústí nad Labem; 81, Varnsdorf; 82, Žatec; 83, Česká Lípa; 84, Frýdlant; 85, Jablonec nad Nisou; 86, Jilemnice; 87, Liberec; 88, Nový Bor; 89, Semily; 90, Tanvald; 91, Turnov; 92, Železný Brod; 93, Broumov; 94, Dobruška; 95, Dvůr Králové nad Labem; 96, Hořice; 97, Hradec Králové; 98, Jaroměř; 99, Jičín; 100, Kostelec nad Orlicí; 101, Náchod; 102, Nová Paka; 103, Nové Město nad Metují; 104, Nový Bydžov; 105, Rychnov nad Kněžnou; 106, Trutnov; 107, Vrchlabí; 108, Česká Třebová; 109, Hlinsko; 110, Holice; 111, Chrudim; 112, Králíky; 113, Lanškroun; 114, Litomyšl; 115, Moravská Třebová; 116, Pardubice; 117, Polička; 118, Přelouč; 119, Svitavy; 120, Ústí nad Orlicí; 121, Vysoké Mýto; 122, Žamberk; 123, Bystřice n.Pernštejnem; 124, Havlíčkův Brod; 125, Humpolec; 126, Chotěboř; 127, Jihlava; 128, Moravské Budějovice; 129, Náměšť nad Oslavou; 130, Nové Město na Moravě; 131, Pacov; 132, Pelhřimov; 133, Světlá nad Sázavou; 134, Telč; 135, Třebíč; 136, Velké Meziříčí; 137, Žďár nad Sázavou; 138, Blansko; 139, Boskovice; 140, Brno; 141, Břeclav; 142, Bučovice; 143, Hodonín; 144, Hustopeče; 145, Ivančice; 146, Kuřim; 147, Kyjov; 148, Mikulov; 149, Moravský Krumlov; 150, Pohořelice; 151, Rosice; 152, Slavkov u Brna; 153, Šlapanice; 154, Tišnov; 155, Veselí nad Moravou; 156, Vyškov; 157, Znojmo; 158, Židlochovice; 159, Hranice; 160, Jeseník; 161, Konice; 162, Lipník nad Bečvou; 163, Litovel; 164, Mohelnice; 165, Olomouc; 166, Prostějov; 167, Přerov; 168, Šternberk; 169, Šumperk; 170, Uničov; 171, Zábřeh; 172, Bystřice pod Hostýnem; 173, Holešov; 174, Kroměříž; 175, Luhačovice; 176, Otrokovice; 177, Rožnov pod Radhoštěm; 178, Uherské Hradiště; 179, Uherský Brod; 180, Valašské Klobouky; 181, Valašské Meziříčí; 182, Vizovice; 183, Vsetín; 184, Zlín; 185, Bílovec; 186, Bohumín; 187, Bruntál; 188, Český Těšín; 189, Frenštát pod Radhoštěm; 190, Frýdek-Místek; 191, Frýdlant nad Ostravicí; 192, Havířov; 193, Hlučín; 194, Jablunkov; 195, Karviná; 196, Kopřivnice; 197, Kravaře; 198, Krnov; 199, Nový Jičín; 200, Odry; 201, Opava; 202, Orlová; 203, Ostrava; 204, Rýmařov; 205, Třinec; 206, Vítkov.

Table 2: Environmental Sensitive Area Index (ESAI) values were combined to form the three groups of categories for each region. The three categories of land degradation are: unaffected areas and potentially affected areas (UP), slightly to highly vulnerable areas (F1–F3), and slightly to highly critical areas (C1–C3).

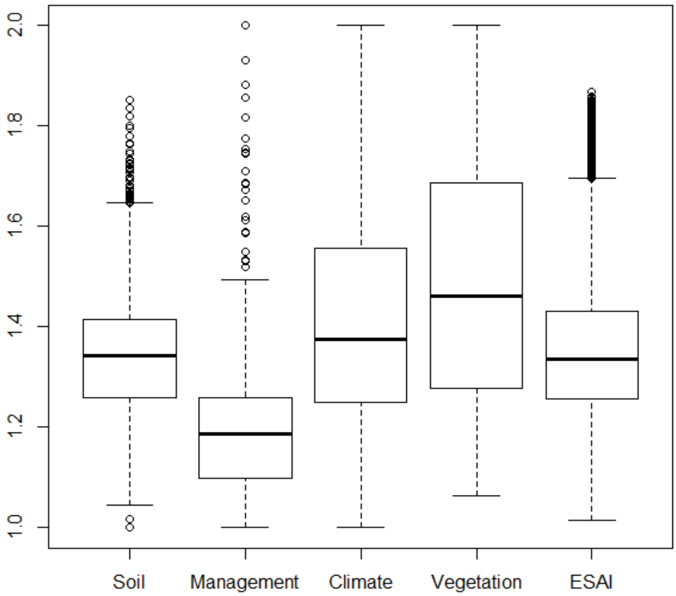
Name of region/categories	NA+P %	F1–F3 %	C1–C3 %
Hlavní město Praha	1	10	89
Středočeský kraj	4	28	68
Jihočeský kraj	10	44	46
Plzeňský kraj	9	43	47
Karlovarský kraj	19	54	25
Ústecký kraj	10	36	53
Liberecký kraj	26	53	20
Královéhradecký kraj	14	38	46
Pardubický kraj	12	37	50
Kraj Vysočina	8	34	57
Jihomoravský kraj	3	26	71
Olomoucký kraj	16	34	48
Zlínský kraj	20	39	40
Moravskoslezský kraj	20	44	34

Analysis revealed the strong influence of landscape types on land degradation. Almost above 70 % of the MEPs areas belonging to the agricultural landscapes were classified in the groups of critical degradation risk categories (C1-C3); into the same categories (C1-C3) about half of the MEPs area belonging to the forest-agricultural and urban landscapes and 25 % of MEPs area belonging to the forest landscapes were classified. At the same time, it was found that increased vulnerability to land degradation occurred in larger territorial units (mostly regions), and individual MEPs with the same degree of ESAI or with a value in one category lower or higher formed larger territorial units. Only the MEPs Chotěboř and Hlinsko had ESAI values in the lowest category of land vulnerability (slightly fragile area—F1), although they were surrounded by MEPs with a higher risk category to land degradation (highly fragile area—F3) (Fig. 2).

Comparing the values of all four ESAI indices and the total ESAI value (Fig. 3), we found that except for the Vegetation Quality index, most of the values were in the lower half of the range of sensitivity values for land degradation up to the value of 1.5. The Land Management Quality index had the lowest dispersion, in contrast to the Vegetation Quality index, which had the highest dispersion. For the total ESAI value, values ranged from 1.0 to 1.65 (Fig. 3).

The ESAI values for the entire Czech Republic were processed into a map application using ArcGIS Web AppBuilder. The map contains four thematic groups of ESAI indices and the total value of the composite ESAI index for the whole CR. These map layers are available in the ESAI application, which is available in the section "Výstupy" at http://www.imalbes.cz/.

Fig. 3: Distribution of Environmental Sensitive Area Index (ESAI) values for the whole territory of the Czech Republic in each of the four thematic indicators and the overall ESAI value.



Legend: Soil—Soil Quality Index, Management—Land Management Quality Index, Climate—Climate Quality Index, Vegetation—Vegetation Quality Index, ESAI—total value from the four thematic indicators.

DISCUSSION

The Environmentally Sensitive Area (ESA) method for assessing an area's sensitivity to degradation was developed in the Mediterranean region and validated in a relatively large number of studies under different climatic conditions, e.g., in Italy, Greece, Portugal (Kosmas *et al*., 1999), Romania (Prăvălie, 2017), and in Serbia (Momirović *et al*., 2019). The ESA methodological approach does not focus only on the process of soil degradation (e.g., erosion, desiccation, soil compaction); it quantifies the interaction of different factors over time (e.g., climatic conditions, land use change, land cover change) that can lead to soil degradation and desertification (Basso *et al.*, 2000; Salvati & Bajocco, 2011). Sensitive environmental areas may be characterized by environmental and socioeconomic factors that are unsustainable for the area (Basso *et al*., 2000).

In our study, the highest vulnerability of land in the category of "moderately critical areas" was found for municipalities (MEPs) located mainly in the agricultural landscapes in the Elbe lowlands in the Central Bohemia region and in the Dyjskosvratecký and Dolnomoravský valleys in the South Moravia region (Fig. 2). Both areas are fertile and warm landscapes of the lowlands and plains, suitable for agriculture and the building of settlements. The agricultural landscapes were significantly affected after 1948 by land consolidation and the use of heavy machinery. However, after the revolution in the year 1989, the water and soil conditions in these areas did not improve significantly, and the intensification of agricultural production, accompanied by soil degradation, continues

(Kupková *et al*., 2016; Vopravil *et al*., 2009). The restoration of stabilizing elements in the landscape, such as biocorridors, wetland ecosystems, and extensive orchards, is still used only by some landowners on relatively small areas, even though they are supported by subsidies (Marada *et al*., 2012). Surprisingly, the urban landscapes presented a lower percentage of moderately critical areas than the agricultural landscapes. The main reason for this is probably the presence of large green spaces in the form of urban parks and forests. These areas are used for recreation and, at the same time, improve the condition of the urban environment by providing many other ecosystem services, such as water regulation, cooling by transpiration, reducing wind gusts, reducing noise, increasing biodiversity, etc. (Xing & Brimblecombe, 2020). The forest landscapes were the least affected by land degradation. The main reason for this is the ability of the forest ecosystem to maintain and improve soil quality (Barnes *et al*., 1997), which can be assessed by various indices, such as the soil productivity index (Burger & Kelting, 1999). Forest landscapes are most prevalent in mountain and foothill regions where several favourable factors such as a colder and wetter climate together with forest cover currently contribute to a low risk of land degradation. Vulnerability to land degradation was mostly found in large territorial units containing individual municipalities (MEPs) with the same degree of land degradation. The exceptions were the MEPs Chotěboř and Hlinsko, which each had an ESAI value two degree higher than that of the surrounding area. The main reason for this is the relatively large proportion of forests and the low occurrence of fields and built-up areas in these MEPs compared to the surrounding MEPs, where agricultural (MEP Chrudim) or urban (MEP Ústí nad Orlicí) areas were strongly represented. The data were calculated on a detailed scale of 1: 10,000, so it is no problem to apply the ESAI index to lower or higher administrative units as MEPs. However, we assume that decision-making processes, affecting the change of use of a part of the landscape should be planned in a larger area than only one cadastre or part of the cadastre. When only a small part of the area is changed, the surrounding area is not effectively protected against various types of degradation.

The resulting ESA method has been successfully used worldwide as a tool for assessing the sensitivity and mapping of areas prone to land degradation and desertification, mainly due to its simplicity and flexibility (Momirović *et al*., 2019). According to the average ESAI values, selected southern and south-eastern European countries were ranked from the lowest to the highest ESAI value: Croatia, Portugal, Bulgaria, France, Romania, Italy (Prăvălie *et al*., 2017). Although the process of desertification is not yet occurring at significant scale in the Czech Republic (CR), an increase in temperature and evapotranspiration has already been observed in the CR in recent years (Štěpánek *et al*., 2016). Drought had the greatest impact on Southern Moravia and Central Bohemia (Trnka *et al*., 2016b). Therefore we chose a different scaling of the input values of each indicator in contrast to the ESA method used for valuation of desertification in Mediterranean countries. The main reason for this was to establish a wider range in the classification of the input data of the individual indicators in order to determine the degree of land degradation in the CR.

For the territory of the entire CR, it was found that 51 % fell into the groups of categories of critical areas (C1–C3), 38 % was located in slightly to very fragile areas (F1–F3), and only 11 % fell into the unaffected or potentially affected (UP) categories in terms of sensitivity to land degradation. Pechanec *et al*. (2021) confirmed that the main factors contributing to land sensitivity to land degradation are climate, vegetation quality, and human pressure in the CR, as in Southern Europe. The most vulnerable areas to soil degradation were lowland districts subject to agricultural intensification and peri-urban areas subjected to urban sprawl in the CR. Šarapatka & Bednář (2015) also found that about 51 % of agricultural land in the CR is moderately threatened by physical degradation factors, with the most severe threats being water erosion, soil compaction, and loss of organic matter. In areas threatened by soil degradation, appropriate measures must be taken to mitigate the effects of degradation and establish a soil restoration process. However, at the same time, it is necessary to focus on areas that are not yet affected by degradation and which fall into the groups of categories of unaffected or potentially affected areas (UP), and to propose preventive measures for both these area types to reduce land degradation. Vopravil *et al*. (2012) suggested to use following measures to reduce the degradation of agricultural land: adding organic matter to the soil, intercropping, and minimization of chemical soil conservation techniques. Throughout the landscape, which is already disturbed by soil degradation and located in an area with low precipitation, it is necessary to restore the natural water cycle through organizational and technical measures, such as revegetation of erosion-prone areas, concentrated runways, infiltration zones, and other important elements.

The accuracy of the resulting ESAI index is directly proportional to that of the source data, and it was difficult to obtain all data with the same accuracy, e.g., precipitation or temperature data. Another problem was that the same data were not available for the whole area of the CR, and data from different sources had to be combined, e.g., forestry and agricultural data for soil quality. Inaccuracy of indicator values occurred when a different method of reclassification or conversion of real values into sensitivity values was used, in most cases requiring expert settings of the resulting scale of individual ESAI values (Pechanec *et al*., 2021). Discussions are currently taking place with representatives of local municipalities (MEPs) and regional governments on how to properly integrate the ESA method into landscape management decision-making processes, such as land use plans, complex land improvements, and appropriate management of agricultural and forest lands. Based on the ESAI values, expressing the degree of landscape degradation, we are preparing a proposal for appropriate measures to prevent and reduce landscape degradation throughout the CR.

CONCLUSION

Vulnerability to land degradation was assessed using the Environmental Sensitive Area Index (ESAI) on the territory of municipalities with extended power (MEPs), regions (NUTS 3) and in the Czech Republic (CR). The most vulnerable MEPs with highest values of ESAI were found in Prague, Central Bohemia, Ústí nad Labem, Plzeň, South Moravia, and Vysočina. For the whole territory of the CR, it was found that 51 % of the territory fell into the groups of categories of critical areas (C1–C3), 38 % fell into the groups of categories of very fragile areas (F1–F3), and only 11 % fell into groups of categories of unaffected or only potentially affected areas (UP) in terms of vulnerability to land degradation. Analysis revealed the strong influence of landscape types on land degradation. Almost above 70 % of the MEPs areas belonging to the agricultural landscapes were classified in the groups of critical degradation risk categories (C1-C3); into the same categories (C1-C3) about half of the MEPs area belonging to the forest-agricultural and urban landscapes and 25 % of MEPs area belonging to the forest landscapes were classified. At the same time, it was found that land degradation occurred in larger territorial units (mostly regions), and individual MEPs with the same degree of land degradation or with a value of land degradation in one category lower or higher formed larger territorial units. In areas threatened by land degradation, appropriate measures must be taken to mitigate the effects of degradation and initiate a process of restoration. However, it is also necessary to focus on areas that are not yet affected by degradation and fall into the category of unaffected or potentially affected areas (UP) and to propose preventive measures to reduce soil degradation in these areas. We are preparing a proposal for appropriate measures to prevent and reduce landscape degradation throughout the CR.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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APPENDIX

Fig. A.1: Map of the relief of the Czech Republic with elevation.

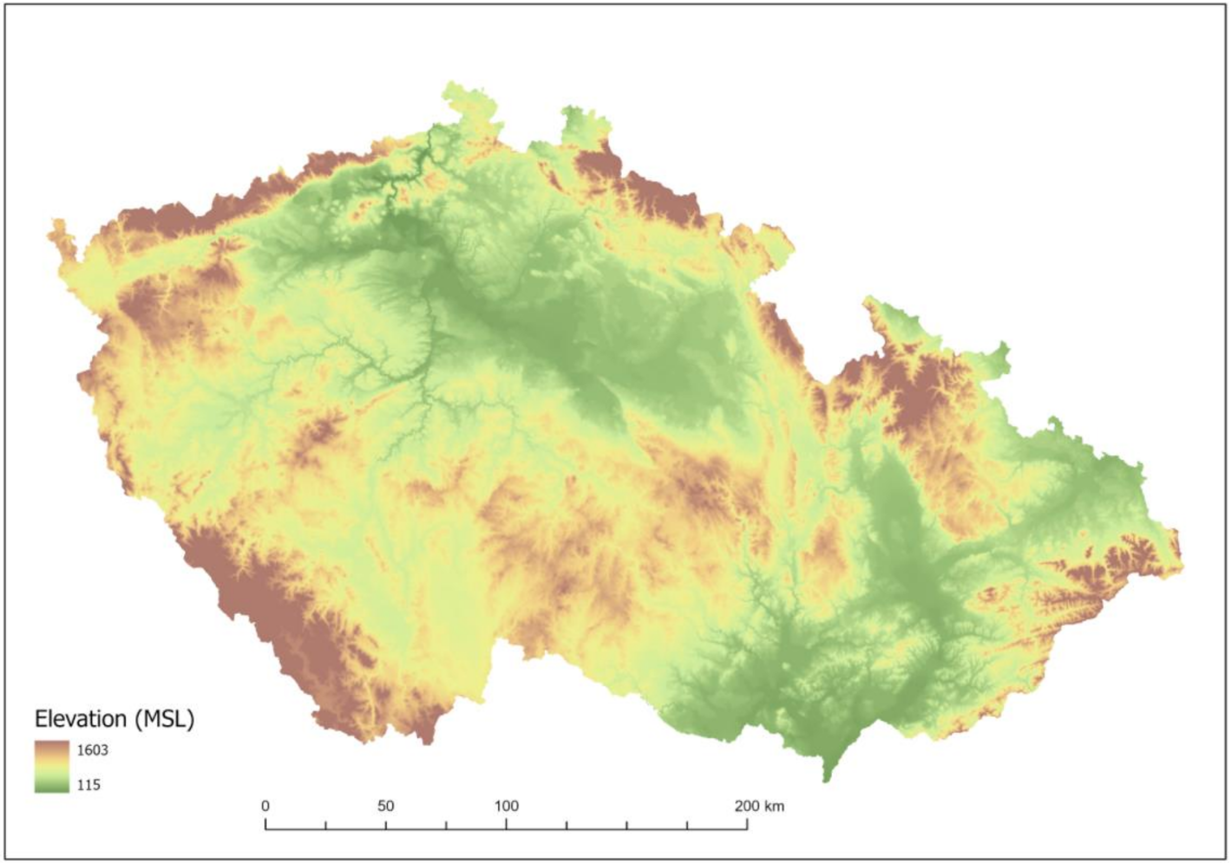

Fig. A.2: Map of landscape typology according to Löw et al. (2006). Legend: H - landscapes of mountain open areas, L - forest landscapes, M - forest-agricultural landscapes, R - pond landscapes, U - urbanised landscapes, X - landscapes without differentiated use, Z - agricultural landscapes.