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Relationships between physical–geographical factors and soil degradation on agricultural land

Marek Bednář[a,b,*], Bořivoj Šarapatka[a]

[a] Department of Ecology and Environmental Sciences, Palacký University, Šlechtitelů 27, 771 46 Olomouc, Czech Republic
[b] Department of Land Use and Improvement, Czech University of Life Sciences Prague, Kamýcká 129, 165 21 Praha 6 – Suchdol, Czech Republic

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ABSTRACT

It is a well-known fact that soil degradation is dramatically increasing and currently threatens agricultural soils all around the world. The objective of this study was to reveal the possible connection between soil degradation and seven physical-geographical factors - slope steepness, altitude, elevation differences, rainfall, temperature, soil texture and solar radiation – in the form of threshold values (if these exist), where soil degradation begins and ends. The analysis involved the whole area of the Czech Republic which consists of 13,027 cadasters (78,866 km^2). The greatest total degradation threat occurs in areas with slope steepness > 7 degrees, average annual temperature < 5.9 °C, elevation differences > 10.54, altitude > 766 m a.s.l. Similarly, the results for water erosion, wind erosion, soil compaction, loss of organic matter, acidification and heavy metal contamination were processed. The results enable us to identify the relationships of different levels of threats which could consequently be used in various ways – for classification of threatened areas, for more effective implementation of anti-degradation measures, or purely for a better understanding of the role of physical geographical factors in soil degradation in the Czech Republic, and thus could increase the chances of reducing vulnerability to land degradation not only in the Czech Republic.

1. Introduction

Soil degradation is a 21st-century global problem. Accelerated soil degradation has reportedly affected as much as 33% of the Earth's surface (Bini, 2009) and implies a decline in soil quality with an attendant reduction in ecosystem function and services (Lal, 2015, 2009). Soil erosion is one of the most serious types, and is, among other degradation factors (DFs), emphasized in the Soil Thematic Strategy (CEC, 2006).

The European Environment Agency (EEA) estimates that 115 million hectares (i.e. 12% of total European land area) are exposed to water erosion and 42 million ha to wind erosion, of which 2% to a significant level. Panagos et al. (2015) state that average annual soil loss due to water erosion amounts to 2.46 t/ha and total annual loss in EU countries is estimated to be as much as 970 Mt. One of the latest GIS based models quantifying wind erosion (RWEQ) (Borrelli et al., 2015), shows an average soil loss of up to 62 million Mg yr^{-1} due to wind erosion in European countries with an average area-specific soil loss of 0.53 Mg ha^{-1} yr^{-1}(Borrelli et al., 2017).

Another problem of arable land is in the relatively low content of organic matter (OM), as current agricultural activity often provides insufficient input of carbon to the soil, which is broken down quickly by agro-technical interventions, and not of least significance is OM loss due to erosion processes (Montgomery, 2007). This results in approximately 45% of land in Europe containing a low, or significantly low proportion of organic matter (i.e. 0–2% of organic carbon), and 45% containing an average amount (i.e. 2–6% of organic carbon). Another significant degradation factor (DF) is that of soil compaction. According to Schjønning et al. (2015), a quarter of all European soils were compacted. Due to about 200 years of industrialization, Europe has also been struggling with soil contamination. There are an estimated 2.5 million potentially contaminated locations, while 342,000 may need urgent remediation (Panagos et al., 2013).

The situation is similar in the Czech Republic (CZ) where, according to the latest data (Czech Ministry of Agriculture, 2015), water erosion threatens more than 50% of agricultural land, wind erosion 17.99%, compaction pertains to 49% of agricultural land, acidification to 43%, and as regards loss of organic matter, problems arise on drained areas

Abbreviations: WAE, water erosion; WIE, wind erosion; ACI, soil acidification; COM, soil compaction; LOM, loss of organic matter; HMI, heavy metal intoxication; TD, total soil degradation; TEMP, annual average temperature; SLOPE, slope steepness; ALT, altitude; ELEDIF, elevation differences; PRE, precipitation; SGR, soil texture; SolRad, solar radiation; DF, degradation factor; PGF, physical-geographical factor

* Corresponding author at: Department of Ecology and Environmental Sciences, Palacky University, Šlechtitelů 27, 771 46 Olomouc, Czech Republic
E-mail address: marek.bednar@upol.cz (M. Bednář).

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and in soils formed on sandy substrate. Soil contamination is often a local issue relating to mining activity or industrial production; as for soil type, Fluvisols are usually more burdened due to flooding.

A number of official reports have warned of some level of soil degradation threat (European Environment Agency, 2015), but there is a lack of relevant mapping and reports describing the degradation of soils on a national and global scale are still rare (Prince et al., 2009). Research mostly deals with individual DFs such as erosion, desertification, etc., even in relation to tillage (e.g. Cerdà et al., 2010; Conoscenti et al., 2013; De Alba et al., 2004; Martín-Fernández and Martínez-Núñez, 2011; Salvati et al., 2016) using both traditional and GIS techniques or remote sensing (e.g. El Baroudy, 2011).

Examples of models for the evaluation of multiple degradation factors can be found in the model for the Czech Republic (Šarapatka and Bednář, 2015), methodology of desertification assessment in the Greek island of Lesvos introduced by Silleos et al. (2008) or in the modified MEDALUS (Mediterranean Desertification and LandUse) method which was used for analysing land degradation sensitivity in south-western Romania (Prăvălie et al., 2017). Although there are approaches to assess individual types of degradation which take into consideration qualified physical-geographic parameters, as yet there has been no contemporary study that would analyze this relationship quantitatively in a reverse manner.

This has been the focus of our research and we addressed the question of how soil degradation factors relate to physical-geographical factors (PGFs). The aim of this research was to evaluate the possible relationship between 7 DFs: water erosion (WAE), wind erosion (WIE), soil acidification (ACI), soil compaction (COM), heavy metal intoxication (HMI), loss of organic matter (LOM), total soil degradation (TD), and 7 PGFs: annual average temperature (TEMP), slope steepness (SLOPE), precipitation (PRE), solar radiation (SolRad), elevation differences (ELEDIF), soil texture (SGR) and, altitude (ALT) in the form of possible threshold values (if these exist), where soil degradation begins and ends. This can be used in many practical ways, mainly for better classification of endangered areas, or just for better understanding of the mutual bonds between factors, which could increase the chances of reducing soil degradation, not only in CZ.

2. Material and methods

2.1. Background of methodology used

The research presented in this paper is based on data and the published soil degradation model of the Czech Republic (Šarapatka and Bednář, 2015). This model was based on the approach of Salvati et al. (2011), who assessed the significance of input geographic and socio-economic factors via multi-criteria PCA analysis, and subsequently created an index which gave an overall evaluation of the extent of the degradation threat to landscape within Italy. The Czech model and method published in this article are based on available real data on the physical and chemical properties of agricultural soils, which are regularly monitored within the Czech Republic. Based on methodology by Novák et al. (2003), input parameters of soil susceptibility to degradation threats were derived, which also served as input parameters for model multi-criteria analysis. Within the Czech Republic the most serious degradation factors were processed, i.e. soil susceptibility to water and wind erosion, acidification, loss of organic matter, and soil compaction and contamination. These degradation factors have a varying impact on the overall pattern of degradation distribution in the Czech Republic, which has been determined by assessing the weight of significance of individual factors via multi-criteria PCA analysis. The resulting TD aggregation index was then given by a linear combination of weighted normalized input factors. The TD index ranges from 0 to 1. The map of the resulting vulnerability to soil degradation in CZ is shown in Fig. 1.

The values of degradation threat relate to the administrative unit of

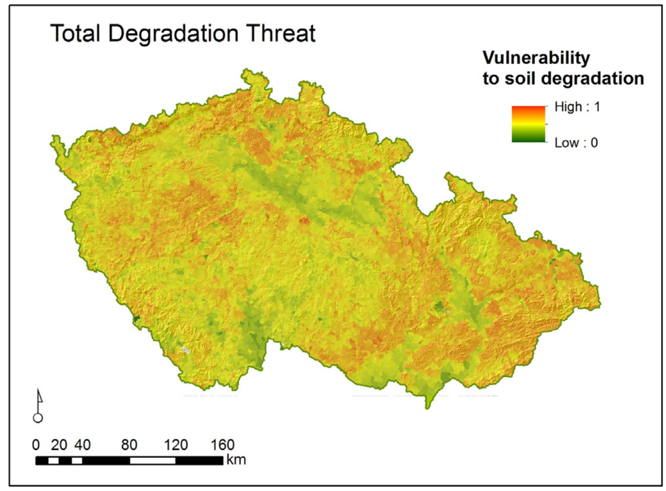

Fig. 1. Total soil degradation threat in CZ (Šarapatka and Bednář, 2015).

the cadastre (municipal unit), of which there are 13,027 within the Czech Republic. Soil monitoring only considers agricultural land, but for more transparent mapping, a map covering whole cadastres was used. The input parameters of susceptibility to degradation threat, supplemented by the output of the degradation model in the form of the TD index, were the basis for further research presented in this article. Its aim is to gain a more complete picture of the nature of the relationship between the selected physical-geographic factors and the factors of degradation threat, and to determine if there is any specific threshold of a physical-geographical factor that would point to a clear degradation threat.

In the search for interrelationships between multiple variables, after initial testing of correlation of input variables, linear analysis (LA) and multilinear analysis (MLA) were both options. MLA does not reveal the thresholds, but the analysis was performed to at least elucidate the possible dependence of parameters and to suggest their relationship. Given that the concept of threshold values implies a clear categorization of threat values, we have divided the range of threat values into five classes expressing the level of susceptibility of the soil to degradation threats. Several methods of division were on offer. In the first stage, quintile division was tested, but this approach is dependent on specific input values and would be difficult to use for other, e.g. comparative, studies. Therefore, a split method independent of input data was chosen, the equal interval method. Although, by dividing into categories, we forfeit a degree of precision in the form of finding a perfect equation explaining the degradation based on a combination of several factors, but we can now use the method of linear (nonlinear) analysis of the pairs of degradation values x PGF with a smaller derived sample of data and thus a greater chance of deriving the relationship. The simplest method that allows the determination of absolute threshold values, assigning a PGF region to a given threat category, is the boxplot diagram. However, this determination depends on the configuration of the input data. In addition, it points to thresholds that assign certain PGF segments to the appropriate threat class only in the case of 100% probability which, for practical reasons, is not always required.

In our research, therefore, for further use, we propose a method of stepwise data analysis, which allows the determination of thresholds based on the gradual calculation of the relative frequency of representation of individual threat classes for the minimum section of the monitored PGF. Similar methods of categorization and thresholding are applied, for example, in methods of physical optics, where processing of a very large sample of measured values would not otherwise be possible (Stanke et al., 2015). The detailed procedure of the proposed methods, together with the parameters entering into the calculation, is described below.