Analysis of Soil Degradation in the Czech Republic: GIS Approach

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Abstract: In our work, we have evaluated the available data on the individual types of soil damage, which has been processed in the Czech Republic in recent decades. The individual types of degradation (water erosion, wind erosion, soil compaction, extreme soils (clay soils), loss of organic matter, acidification, dryness impact, and intoxication) were classified in one of three groups: physical degradation, desertification and chemical degradation. Each type of degradation was assigned a specific weight reflecting the importance of this kind of soil degradation. The maps of individual areas of degradation were processed by overlay and assigning weighting techniques in ArcView Spatial Analyst GIS environment to create the final maps for each class of the degradation threat. The same technique was used to create the final map showing the most troubled areas in the Czech Republic, threatened by soil damage.

Keywords: degradation; GIS; modelling; soil

At present, there is a great concern all over the world for the sustainability of the land use. A lot of evidence has been found to show that soil quality is, or may be, worsening (Doran & Parkin 1994, 1996; Šarapatka *et al.* 2002). Lal *et al.* (1989) and Lal (1997) described the land resources of the world as finite, fragile, and non-renewable and reported that only about 22% of the total area of the globe is suitable for cultivation and only 3% has a high agricultural production capacity. A series of subsequent official reports (e.g. from UNO) warn of some degree of soil degradation threat (European Environment Agency 2000), but the maps of the extent and severity of the degradation on country and global scales do not exist (Prince *et al.* 2009).

According to Oldeman (1994), water erosion is the predominant form of soil degradation (55.7%), followed by wind erosion (27.8%), chemical (12.3%) and physical damage. In the Czech conditions according to the database of Research Institute for Soil and Water Conservation (2008), individual types of degradation differ with the area, the most notable being water erosion which threatens more than 45% of agricultural areas. This is followed by wind erosion (11%), extreme soils – clay soils (4.5%), and soils affected by dryness (1.5%).

Lots of attempts were made worldwide at developing methods of identification of the most threatened areas (Yansui *et al.* 2003; de Paz *et al.* 2006). The goal of our work was to find a suitable tool, to identify the phenomena needing to be covered in the process in the Czech Republic, to find suitable datasets often provided in non-unique form by different independent organisations.

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MATERIALS AND METHODS

Because the nature of our task was spatial, the need for GIS systems for presenting and modelling data was a must. We used GIS systems provided by ESRI – GIS ArcView 3.2 system in connection with ArcGIS 9.2, for specific purposes ArcGIS Spatial Analysis and ArcGIS Geostatistical Analyst extensions applied used using common methods of GIS analyses described in Johnston *et al.* (2003), Maguire *et al.* (2005) and McCoy *et al.* (2002).

The first step was to specify all relevant phenomena which could lead to agricultural degradation threat. A set of phenomena was chosen: water erosion, wind erosion, loss of organic matter, heavy metal intoxication, acidification, soil compaction, dryness impact, and extreme – clay soils. Sandy bottom soils were not processed within the extreme soils, but in dryness impact areas which have a great effect on total desertification. All these phenomena were investigated independently in individual institutes at nationwide level. The scale which was used mostly corresponded to one cadastre unit. In this way the overall area of the Czech Republic could be processed.

The next step was to obtain the data from all sources available – mostly from the institutes of Soil and Water Conservation in Prague and from the Central Institute for Supervising and Testing in Agriculture in Brno. Because of the non unique format of the data provided these had to be unified into a form acceptable for the subsequent GIS evaluation.

All these raster sources constituted the so called representation models – models which show some distribution of the types of degradation threat within the Czech Republic. The minimum area unit processed is cadastre which applies also for newly created models. The models methodology corresponds to the common use of the modelling technique described in Skidmore and Prins (2002).

These models were divided into two groups according to the model type (see Figure 1). Chemical models (loss of organic matter, acidification, and heavy-metal intoxication) and physical models (wind erosion, water erosion, extreme soils, soil compaction, and dryness impact). In addition the items which lead to the degradation threat were selected to achieve a secondary task – the creation of a degradation model.

Then we created the process models – models that would describe some interactions between the superimposed representation models. The aim was

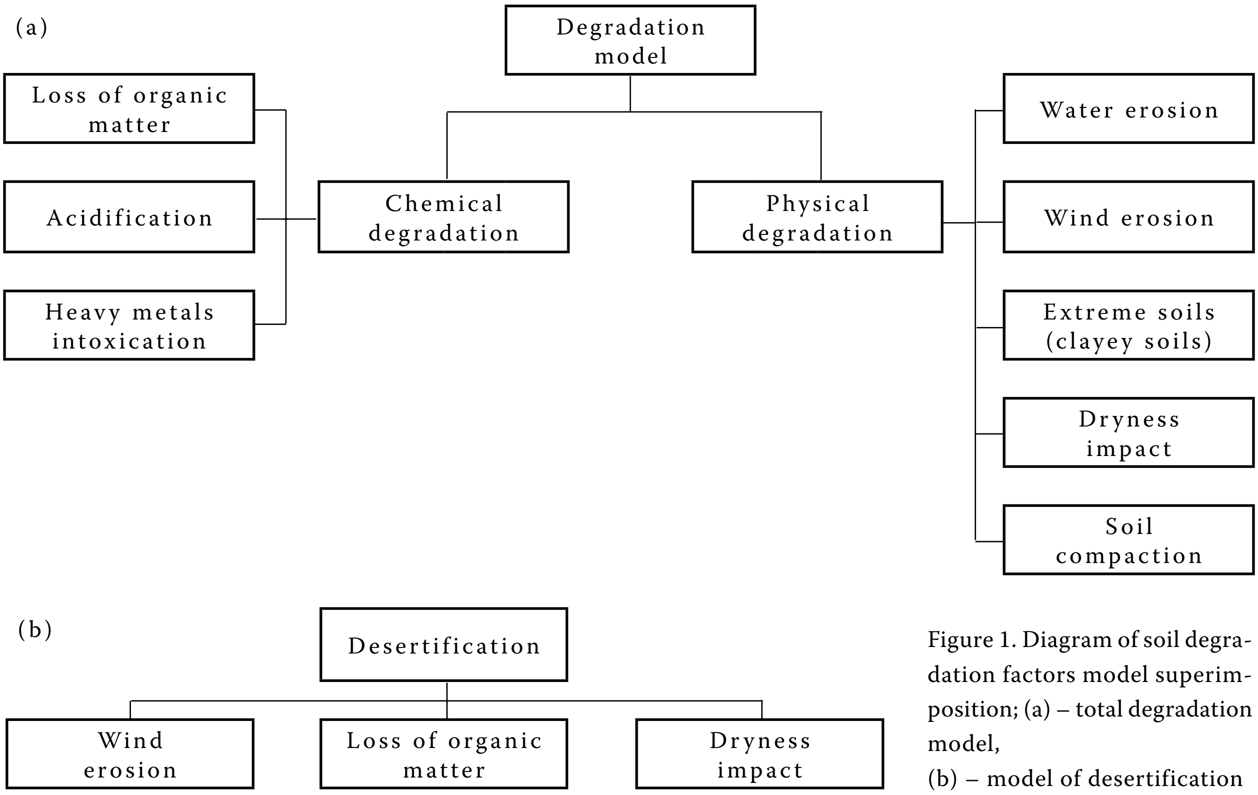

Figure 1. Diagram of soil degradation factors model superimposition; (a) – total degradation model,
(b) – model of desertification

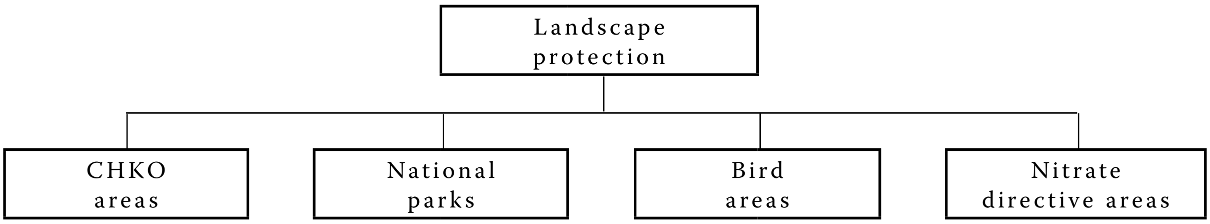

Figure 2. Diagram of landscape protection model superimposition

firstly to create a model of chemical degradation threat, secondly, models of physical degradation threat and a model of desertification. The last step was to create a model of the resulting degradation threat combining the process models of chemical and physical degradation.

A similar approach but with the combination of physical, chemical, and biological degradation was described by de Paz *et al.* (2006).

The process model functions were specified as:

$$CHM = a_1 \times LOM + a_2 \times A + a_3 \times HMI$$

$$PHD = b_1 \times WIE + b_2 \times WAE + b_3 \times ES + b_4 \times SC + b_5 \times DI$$

$$RDM = c_1 \times CHD + c_2 \times PHD$$

$$DSM = d_1 \times WIE + d_2 \times LOM + d_3 \times DI$$

where:
CHM – chemical degradation
LOM – loss of organic matter
A – acidification
HMI – heavy metal intoxication
WAE – water erosion
WIE – wind erosion
ES – extreme soils (clay soils)
SC – soil compaction
DI – dryness impact
CHD – chemical degradation
PHD – physical degradation
RDM – Resulting Degradation Model
DSM – Desertification Model

Individual weightings a_1–a_3, b_1–b_5, c_1, c_2, d_1–d_3 were specified by the judgment of an independent agricultural specialist.

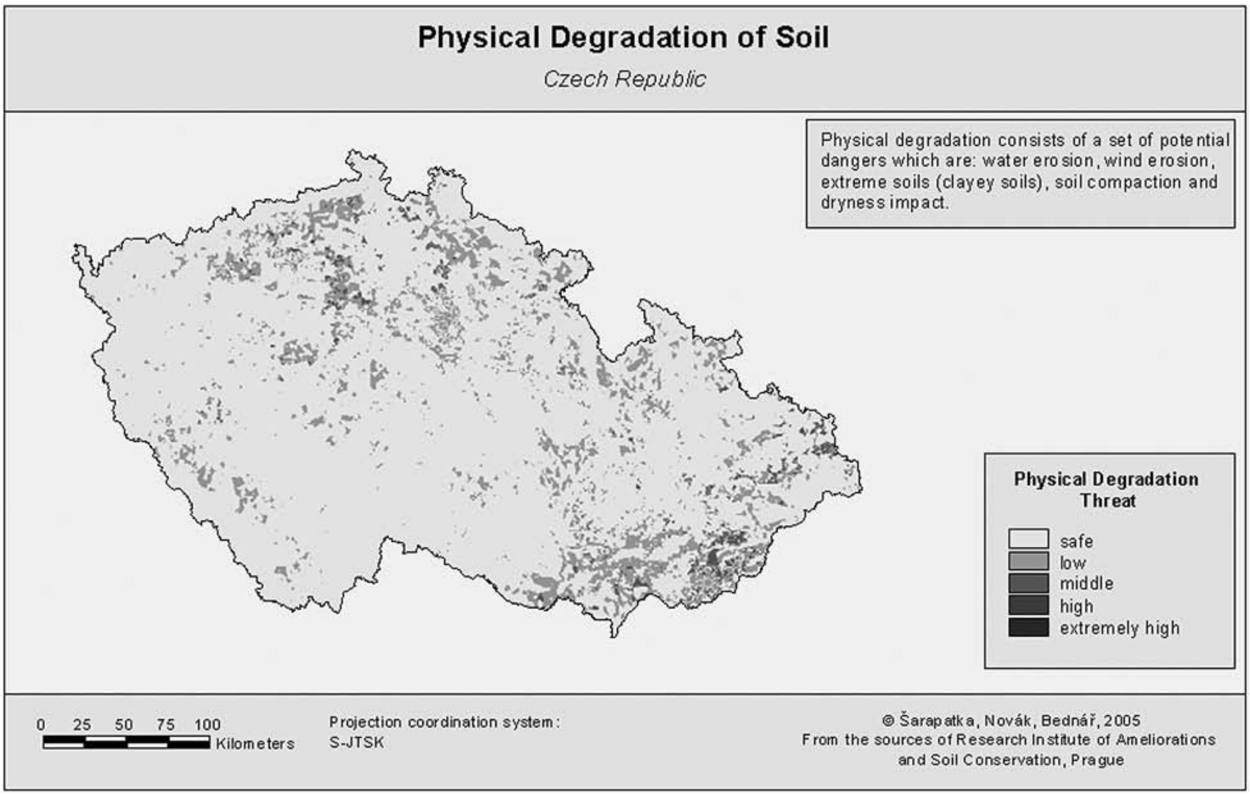

Figure 3. Physical degradation of soil model

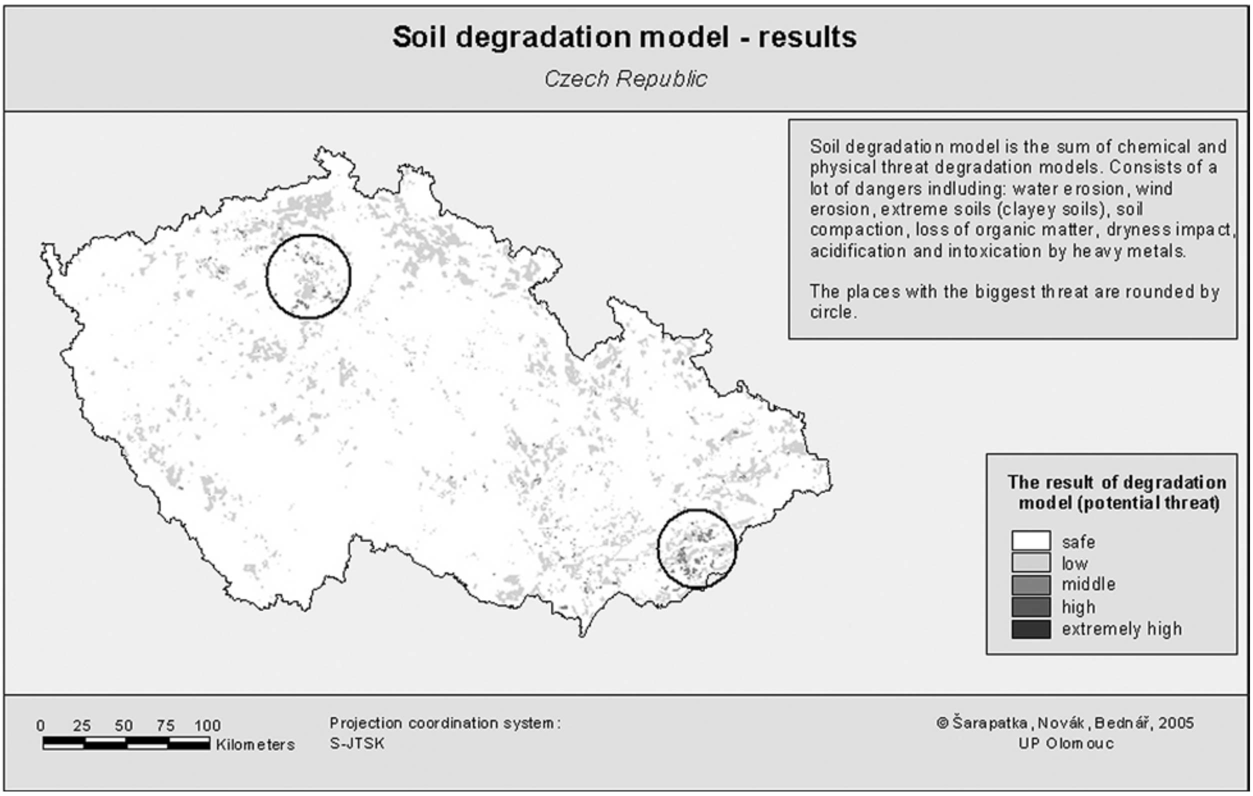

Figure 4. Total soil degradation model (combination of degradation factors)

As we can see from the process functions, all sources in a group were overlaid and superimposed (by the methods of raster analysis map algebra) to obtain the final group raster map which showed the resulting situation in the Czech Republic in terms of the chemical, physical, and finally total endangerment of agricultural areas.

For the purposes of comparison the data concerning the environmental landscape protection was assessed (Figure 2). This data includes the maps of the Protected Areas (CHKO), National Parks, Natura 2000 Bird areas, and areas influenced by Nitrate Directive. These were evaluated and superimposed in the same way as the degradation factors described above to obtain the model of the landscape environmental protection. A diagram follows (Figure 2).

The hypothesis could be expressed by the following sentence: The landscape protected areas should express a lower value of total degradation than the non-protected areas. This was statistically evaluated.

The scale of legends was set up to five classes from safe to extremely high according to the resulting sum of all inputs affecting degradation expressed in degradation units. Maximum possible value of the sum (all input degradation units have their maximum) divided by five (five classes of legend) gives the interval of one class.

RESULTS

The results provided are in the form of maps which show the areas influenced by different rates of degradation processes. Figures 3 and 4 illustrate the results of two degradation models – physical and total degradation. The latter model helps to identify the areas where the total degradation sum involving all the degradation factors has reached a maximum.

Due to the fact that the soil protection management could significantly reduce the level of degradation, we included a map showing both degradation and protection impacts by combining the degradation and environmental protection models.

From the resulting landscape protection model, the hypothesis of the effects of the landscape protected areas on the total sum of degradation was tested. The hypothesis was not proven. The mean degradation is similar for both categories of protected and non-protected land.

CONCLUSION

It can be seen from the results that most problems reside in very intensively used agricultural production areas, which are not included in the less favoured areas (LFA). These are often the soils with signs of desertification (areas affected by dryness, water erosion and loss of humus).

Further investigation will concern organic farming analysis. Considerate systems of agricultural practise will be proposed with respect for the environment (for example organic farming according to EU Council Directive 2092/91) on the basis of the land use, soil degradation, investigation and further points of view including economic and social aspects.

We believe the methodology can quickly address the places with the most problematic soil degradation and can do this more precisely than the human eye. By pinpointing the problem areas, it can show where the environmental protection should be directed to.

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