INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

Nr IV/4/2016, POLSKA AKADEMIA NAUK, Oddział w Krakowie, s. 1789–1810
Komisja Technicznej Infrastruktury Wsi

DOI: http://dx.medra.org/10.14597/infraeco.2016.4.4.134

ANALYSIS OF EROSION VULNERABILITY OF AGRICULTURAL LAND IN THE CATCHMENT OF LUH STREAM USING THE GIS TOOLS

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Abstract

Utilization of geographic information systems (GIS) for the erosion vulnerability analysis of agricultural land is shown on the example of Luh stream catchment, Czech Republic, district of Vysočina. Evaluation of soil erosion conditions according to the Universal soil loss equation (USLE) was done in ArcGIS 10 Desktop, software product of ArcInfo using a set of integrated software applications ArcMap, ArcCatalog and ArcToolbox user interface with LS-converter and USLE2D programs. The project of erosion control measures and evaluation of their effect on the erosion were parts of the analyses. Erosion control crop rotations with soil protective technologies, that change the value of cover-management factor, were used as erosion control measures.

Key words: water erosion, erosion control crop rotation, USLE, ArcGIS, LS-converter, USLE2D, Luh stream catchment

INTRODUCTION

Soil erosion is a natural process that causes loss of topsoil. Erosion could be induced by natural elements such as water, wind, snow, ice, plants or animals, or could be induced by human activities (above all by agriculture).

The process of erosion generally consists of three distinct actions – soil detachment, movement and deposition. Topsoil, which is high in organic matter, fertility and soil life, is moved to another place, which means decrease in agricultural productivity "on-site". Or is carried "off-site", where causes sedimentation of waterways and eutrophication of water.

Erosion means not only the loss of soil particles but also loss of natural nutrients and possible fertilizers. Seeds can be disturbed or removed and pesticides can be carried off. Loss of soil structure and stability, and negative affecting of soil texture are other problems that can be caused by erosion.

Erosion is a major source of soil degradation, in EU causes annual losses estimated at 14 billion euros (www.soilconservation.eu). In the Czech Republic, there are threatened 50 % of agricultural soils by water erosion; 450,000 hectares (thus more than ten percent) of the agricultural land is damaged seriously. Water erosion washes away about 21 million tonnes of topsoil every year. Another 14 percent of agricultural land is threatened by wind erosion and 45 percent by its compaction (www.vumop.cz).

Water erosion is mainly affected by precipitation, soil erodibilty, topography, vegetative cover and tillage practices.

Simple methods such as the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975), or the Revised Universal Soil Loss Equation (RUSLE) (Renard et al*.,* 1991) are frequently used for evaluation of erosion rates from catchment areas (e.g. Ferro and Minacapilli, 1995; Efe et al., 2000; Zheng et al., 2014). The use of Geographical Information Systems (GIS) methodology is well suited for the quantification of heterogeneity in the topographic and drainage features of a catchment (e.g. Rodda et al*.,* 1999; Bartsch et al., 2002).

GIS tools allow you to quickly and efficiently evaluate the actual vulnerability of agricultural soils to water erosion as well as the effectiveness of erosion control measures proposed through the USLE. The indisputable advantage of the use of GIS is also visualization of the analysis results leading to the calculation of the USLE factors and ultimately soil erosion risks for specific parts of land parcels in the area of interest.

The objective of this research is to use GIS for the evaluation of vulnerability of soil by water erosion before and after design of erosion control measures in the Luh stream catchment.

MATERIALS AND METHODS

Study area

Luh stream catchment is situated in the region of Vysočina, district of Třebíč (Czech Republic) (Fig. 1). The area of the catchment stretches to the cadastral areas of Březník and Kuroslepy. The catchment covers an area of 8.31 km^2. The length of main stream is 5.6 km and flows as a sinistral branch into Oslava river. Altitude of the area is 276–434 m above the sea level. The catchment comes under the fourth category, the number of hydrological order is 4-16-02-082 (Zítek et al., 1965).

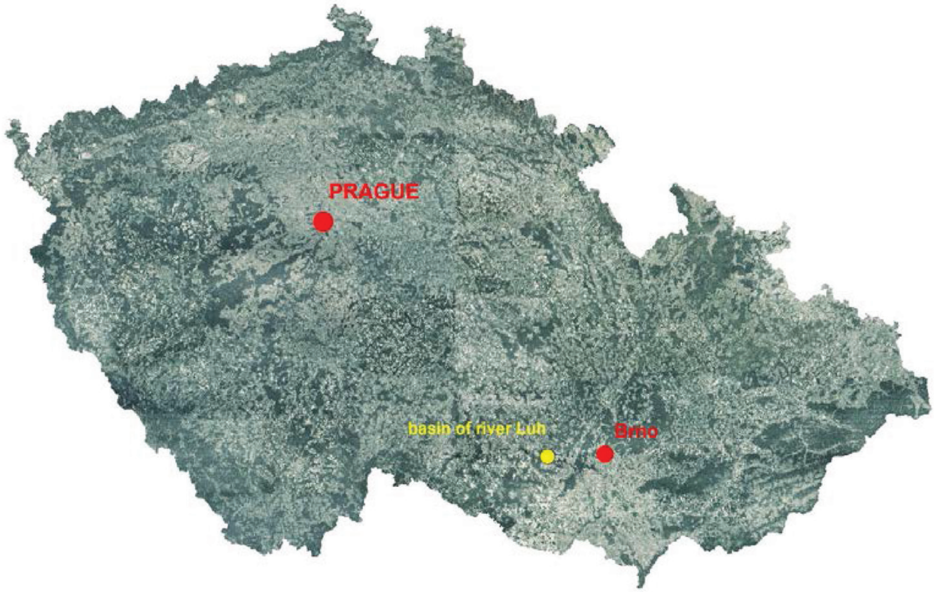

Figure 1. Location of Luh stream catchment, Czech Republic
(data source: orthophotomap – © ČÚZK, www.cuzk.cz)

Climate region of the area is MW7 and MW11 – region with a slightly warm, wet climate with an average annual temperature of 7–9°C. The average annual rainfall for the region is 500 to 550 mm (Tolasz et al., 2007).

Loess, slope sediments of gneisses (light) and slope sediments of other alkaline rocks are prevailing soil-forming substrate of the soils in the Luh stream catchment according to the synthetic soil map of the Czech Republic (Novák et al., 1993). The predominant soil type is brown earth modal with cambisols modal and cambisols eutrophic (geoportal.gov.cz). The main soil units (HPJ) occurring in the area of interest are: HPJ 8, 10, 11, 12, 20, 29, 32, 47, 48, 50 and 56. Their characteristics are listed in the official announcement of Ministry of Agriculture no. 327/1998. These are soils with a depth from medium deep to deep.

Land use is mainly agricultural. Most of the agricultural land is farmed by one collective farm. A detailed description of the land use is shown in the Fig. 2–3.

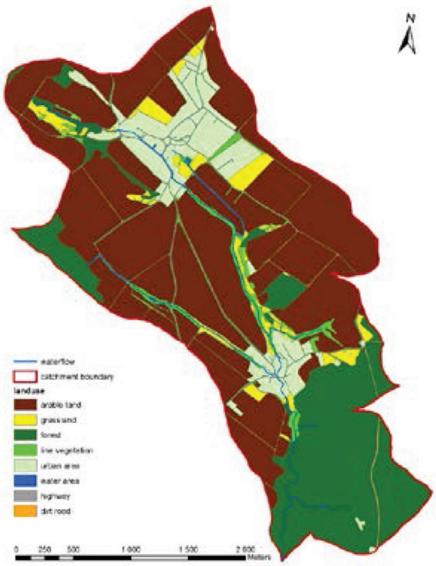

Figure 2. Land use of the Luh stream catchment. Map data: A07_Povodi_IV, A02_Vodni_tok_JU (© VÚV TGM, v.v.i., www.dibavod.cz)

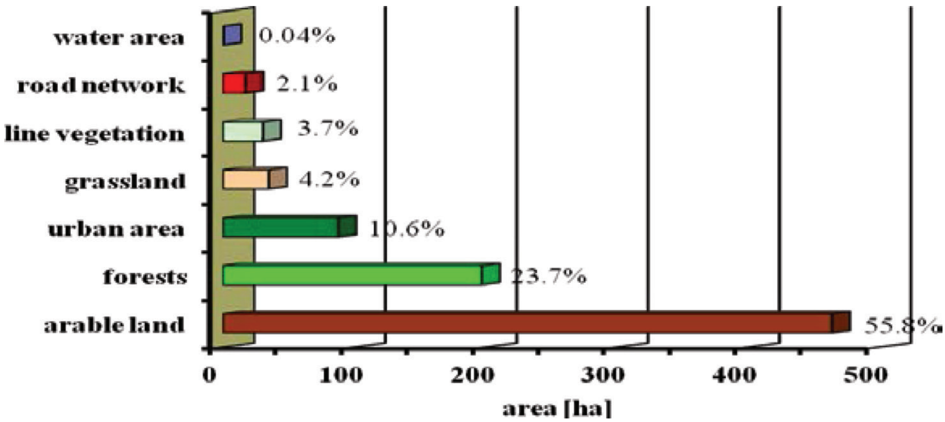

Figure 3. Type of land in the Luh stream catchment and its percentages (data source: orthophotomap – © ČÚZK, www.cuzk.cz)

Methods and input data

Methods such as the USLE have been found to produce realistic estimates of surface erosion over areas (Wischmeier and Smith, 1978). Therefore, soil erosion within a grid cell was estimated via the USLE. The USLE is expressed as (1):

$$A = R \times K \times LS \times C \times P \quad (1)$$

where A is the average annual soil loss [$t.ha^{-1}.yr^{-1}$], R is the rainfall-runoff factor [$MJ.ha^{-1}.cm.h^{-1}$], K is the soil erodibility factor [$t.ha.h.ha^{-1}.MJ^{-1}.cm^{-1}$], LS is the topographic factor (dimensionless), C is the cover-management factor (dimensionless), and P is the supporting practice factor (dimensionless) (these units are used according to Renard et al. (1991).

Preparation, processing of background data and analysis leading to evaluation of erosion risks were made in ArcGIS Desktop 10, software product ArcInfo using a set of integrated software applications ArcMap, ArcCatalog and ArcToolbox user interface, as well as in programs USLE2D and LS-converter.

Data A07_Povodi_IV and A02_Vodni_tok_JU from the digital base of water management data (DIBAVOD) (Map data © WRI, v.v.i., www.dibavod.cz) was used for drawing of watershed divide and hydrographic network. Two layers (landuse and layer of soil blocks) were created to show the current state of land cover using raster base map (ZM10), colour digital orthophotomap (Map data © ČÚZK, www.cuzk.cz) and map of Land Parcel Identification System (LPIS) (Map data © Ministry of Agriculture, www.eagri.cz) using Web Map Service (WMS). A layer *landuse* displays all the types of land and a layer *Soil_Blocks* shows only the blocks of arable land and permanent grassland limitary by roads with ditches, green belts, forests, watercourses, watershed divide or other interruptions of slope length along the fall line. On the basis of these layers, the determined and calculated factors of the USLE were then displayed and then the average annual soil loss by water erosion was calculated, including representation of erosion degrees of individual plots.

The rainfall factor R can vary from year to year, so an average over a number of years is usually used. Of the USLE factors, is the one most exactly computed from input data i.e., rainfall amounts and intensities. However, these data are not always readily available in several areas of the world. Therefore, the rainfall factor, R, is the first factor modified. Published R values represent erosivity during an average year. Rainfall is highly variable from year to year and month to month in a year as some month in a year wettest and some are dry. For these reasons, the R factor needs to be adapted to a climatic region. The simplest method is to use the yearly average of rainfall over number of years as rainfall factor (Hernando and Romana, 2015).

In the USLE, the soil erodibility factor K corresponds to the collective effects of the detachment susceptibility of soil and the sediment transportability as well as the amount and rate of runoff under a given rainfall erosivity (Shabani et al., 2014). The factor K in this work was determined on the basis of the soil ecological units (BPEJ) of the digital layer called *BPEJ* (Map data © VÚMOP, v.v.i.) (Janeček et al., 2012). BPEJ is a unique system that specifies in detail and very precisely the main soil and climatic conditions of the studied area and is listed in numerical and cartographic form in the national database of BPEJ which is ready for territory of the Czech Republic (official announcement of Ministry of Agriculture no. 327/1998). Tool *Extract – Clip* performed cropping of the layer showing the value of factor K in the whole area by layer of *Soil_Blocks*. The output of this was the vector layer *K_factor*. Then the layer *K_factor* had to be converted to raster format for calculation of erosion loss.

The topographic factor LS consists of two sub-factors – a slope gradient factor S and a slope length factor L. Program USLE2D was used for calculation of topographic factor (van Oost and Govers, 2000; geo.kuleuven.be/geography/modelling/erosion/usle2d). USLE2D is designed to calculate the topographic factor from a grid-based Digital Elevation Model (DEM). DEM is a quantitative representation of the Earth's surface that provides basic information about the terrain and allows for the derivation of attributes such as slope, aspect, drainage area and network, curvature, and topographic index (Mukherjee et al., 2014). In a real two-dimensional situation overland flow and the resulting soil loss do not really depend on the distance to the divide or upslope border of the field, but on the area per unit of contour length contributing runoff to that point. The latter may differ considerably from the manually measured slope length, as it is strongly affected by flow convergence and/or divergence. USLE2D overcomes this problem by replacing the slope length by the unit contributing area. USLE2D provides different routing algorithms for calculating the contributing area and various LS-algorithms (Fistikoglu and Harmancioglu, 2002).

The linkage of USLE2D in a GIS offers several advantages to the one-dimensional and/or manual approach; it may account for the effect of flow convergence on rill development and it has advantages in terms of speed of execution and objectivity. The linking of USLE2D with a GIS facilitates the application of the (R)USLE to complex land units, thereby extending the applicability and flexibility of the (R)USLE in land resources management (Panagos et al., 2015).

Program USLE2D requires as input data DEM, as already stated, and layer *Soil_Blocks*. Layer S*oil_Blocks* divides the territory to sub-areas. The calculation is based on the assumption that the boundaries between blocks work as barriers to surface runoff, an interruption of runoff occurs here. The length of the runoff lines and factor L are then reduced. The program USLE2D calculates factor LS separately for each raster element. The length of the runoff line is replaced by a contributing area.

Raster layer of DEM was generated by the tool *Interpolation – Topo to Raster* on the base of vector layer *ZABAGED Altimetry – 3D Contour Lines* (Map data © ČÚZK) and vector file with the boundaries of the area. DEM had to be evened out to remove the imperfections of the resulting surface such as dips and peaks. Even grid (*DMT_Fill*) was created using tool *Hydrology – Fill*.

To get an overview of basic hydrological characteristics, respectively of runoff (layer *LS_factor*), layers *Flow_Direction*, *Flow_Accumulation* and *Flow_Length* were created. The layer *Flow_Direction* was created using tool *Hydrology – Flow Direction* and *DMT_Fill* as a source file. Layers *Flow_Accumulation* and *Flow_Length* were then created on the basis of layer *Flow_Direction* using tools *Hydrology – Flow Accumulation* and *Hydrology – Flow Length.*

The factor C describes the relation between the erosion on bare soil and the erosion on cropped conditions. Factor C was determined on the basis of crop rotations (only on the arable land) for the period of 2010–2014. Five representative crop rotations that were used by collective farm on individual soil blocks were included into the calculation of erosion loss (Tab. 1). Calculations of factors C on the individual blocks were carried out according to the Wischmeier and Smith (1978) in Janeček et al. (2012). The method of calculation of the factor C is an accurate way to quantify the value of factor C, which reflects crop rotation, used agricultural technologies and individual growing periods of each crop, including the period between crop rotation. Vector layer *C_factor* showing the value of factor C of each block was then converted to raster format.

Table 1. Crop rotations included into the calculation of the factor C

Year/crop rotation	1	2	3	4	5	6	7
2010	winter rape	clover+ grass	winter barley	spring barley	spring barley	winter wheat	winter wheat
2011	winter wheat	clover+ grass	winter wheat	winter wheat	winter wheat	spring barley	maize
2012	alfalfa	maize	winter rape	winter rape	winter rape	maize	spring barley
Year/crop rotation	1	2	3	4	5	6	7
2013	alfalfa	clover+ grass	winter wheat	winter wheat	winter wheat	spring barley	winter wheat
2014	alfalfa	clover+ grass	winter wheat	winter wheat	spring barley	winter wheat	winter rape
C factor	0.093	0.094	0.204	0.210	0.219	0.261	0.267

The factor P represents erosion reducing measures like terraces or ridging/contouring. The P-factor is assigned the value of 1 when no influences from conservation practices are considered. If conservation measures are taken the value will decrease and thereby lower the estimated erosion (Kuok et al., 2013).

In order to apply the USLE in a GIS, every parameter is organized as a thematic layer which is providing a spatial distribution. The layers need to be of the type raster, which means that they are in the form of grid nets (matrixes).

In the spatial distribution of the raster, every grid cell has a unique parameter value and the model is executed by an overlay operation that multiplies all the parameter layers mathematically. This means that every single cell is overlaid (multiplied) with its spatially corresponding cells in the other parameter layers, completing the multiplication of the equation. The output of the model is a combined layer where every single cell value is the product of the equation. Finally, the whole layer is summed and the average annual soil loss per hectare is calculated (Bartsch et al., 2002).

The calculation of average annual soil loss was done using a tool *Map Algebra – Raster Calculator*. Individual factors of the USLE, either in the numerical form (factor R and P) or as raster layers (*K_factor, LS_factor, C_factor*) entered into the equation. A raster layer *A_erosion* was the result, where soil loss values in $t.ha^{-1}.yr^{-1}$ were sorted into seven classes (erosion rates).

Another representation of annual soil loss was created using a tool *Zonal – Zonal Statistics*, when vulnerability of soil by water erosion was expressed by four vulnerability degrees according to the multiple of soil loss tolerance T (erosion light ≤ 1 x T, medium ≤ 2 x T, strong ≤ 3 x T and very strong > 3 x T). Soil loss tolerance is the amount of soil that could be lost without a decline in fertility, thereby maintaining crop productivity indefinitely (Lal, 2006). Soil loss tolerance is determined on the basis of soil depth (Janeček et al., 2012). Soils in the area of interest are moderately deep (30–60 cm) and deep (over 60 cm), the soil loss tolerance is therefore 4 $t.ha^{-1}.yr^{-1}$.

Design of erosion control measures, which included organizational and agronomic measures (change in crop rotations, change in the land organization and proposal of protective grass on the most vulnerable soil blocks) was performed. Subsequently, the recalculation of annual soil loss was done and erosion vulnerability degrees on individual blocks were determined.

More detailed description of operations and analysis in ArcGIS is described in the publications of Dumbrovský et al. (2008), Mašíček (2010), Longley et al. (2011), Geletič et al. (2013), Schmidts (2013), Mašíček and Ždímal (2014).

RESULTS AND DISCUSSION

Calculation of average annual soil loss before design of erosion control measures

The USLE was applied to predict soil loss magnitude and GIS software ArcView and ArcMap was used to simulate the soil loss in spatial distribution. Each one of the USLE-parameters (rainfall erosivity R, soil erodibility K, topography LS, land use C and conservation practice P) were represented by a thematic raster layer in the GIS.

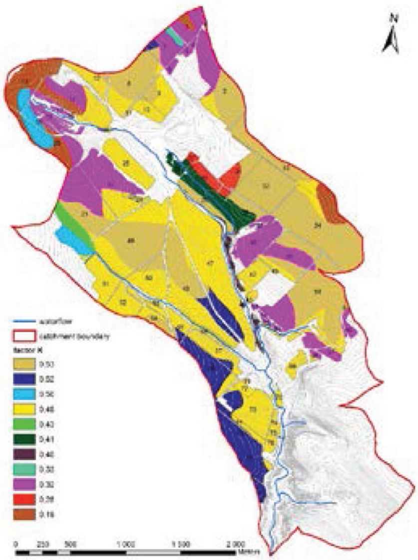

Figure 4. Values of factor K of the Luh stream catchment. Map data: A07_Povodi_IV, A02_Vodni_tok_JU (© VÚV TGM, v.v.i., www.dibavod.cz), ZABAGED Altimetry – 3D Contour Lines (© ČÚZK)

Figure 5. Values of factor LS of the Luh stream catchment. Map data: A07_Povodi_IV, A02_Vodni_tok_JU (© VÚV TGM, v.v.i., www.dibavod.cz), ZABAGED Altimetry – 3D Contour Lines (© ČÚZK)

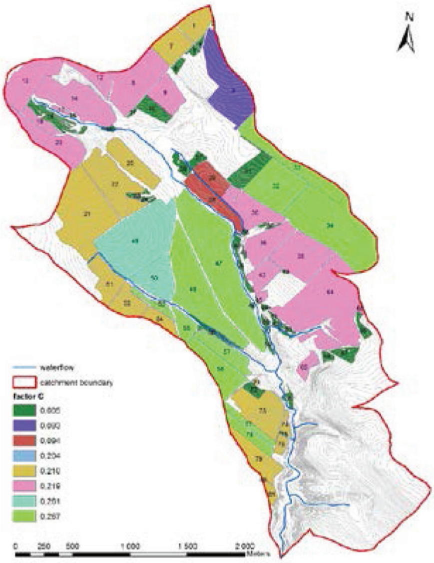

Figure 6. Values of factor C according to the different crop rotations. Map data: A07_Povodi_IV, A02_Vodni_tok_JU (© VÚV TGM, v.v.i., www.dibavod.cz), ZABAGED Altimetry – 3D Contour Lines (© ČÚZK)

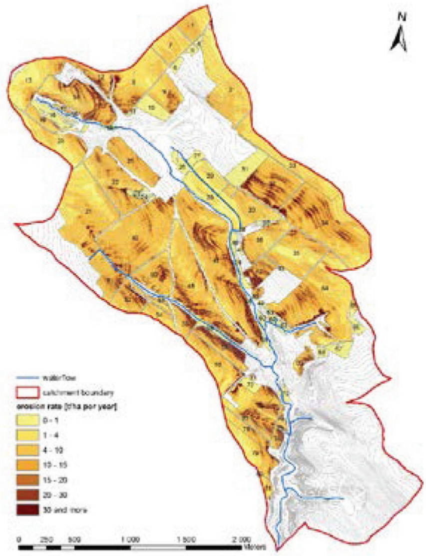

Figure 7. Erosion rate in $t.ha^{-1}.yr^{-1}$ of the Luh stream catchment. Map data: A07_Povodi_IV, A02_Vodni_tok_JU (© VÚV TGM, v.v.i., www.dibavod.cz), ZABAGED Altimetry – 3D Contour Lines (© ČÚZK)

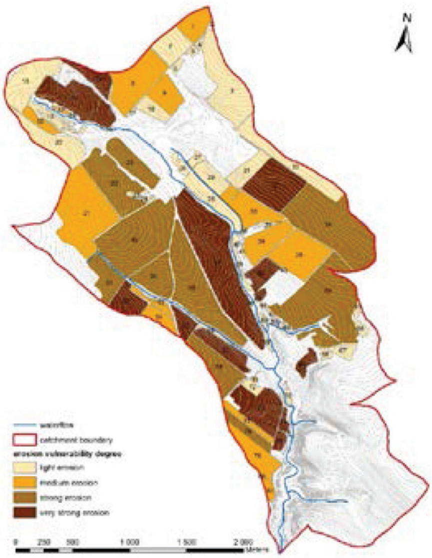

Figure 8. Erosion vulnerability degrees of individual blocks of the Luh stream catchment. Map data: A07_Povodi_IV, A02_Vodni_tok_JU (© VÚV TGM, v.v.i., www.dibavod.cz), ZABAGED Altimetry – 3D Contour Lines (© ČÚZK)

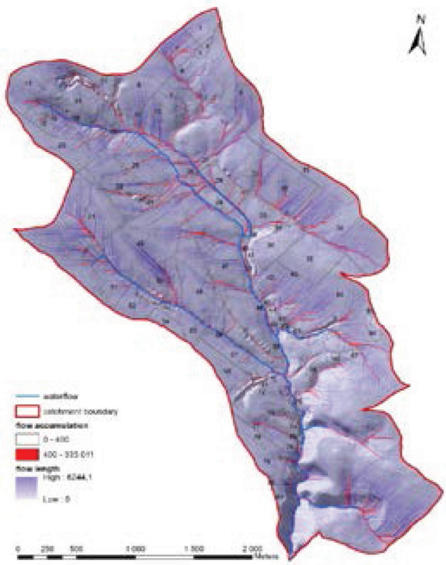

Figure 9. Flow accumulation and flow length of the Luh stream catchment. Map data: A07_Povodi_IV, A02_Vodni_tok_JU (© VÚV TGM, v.v.i., www.dibavod.cz), ZABAGED Altimetry – 3D Contour Lines (© ČÚZK)

Value of the factor R was determined according to the methodology of Janeček et al. (2012) which is based on the method of Wischmeier and Smith (1978). The value of the factor R is 40 $MJ.ha^{-1}.cm.h^{-1}$ for the Czech Republic.

Soil erodibility expressed through factor K is shown in the Fig. 4. Values of the factor K range from 0.19 to 0.53 $t.ha.h.ha^{-1}.MJ^{-1}.cm^{-1}$. The higher the value of factor K, the greater vulnerability of soil to water erosion.

The influence of slope gradient and slope length on the amount of soil loss is expressed by topographic factor LS, which is graphically displayed in the form of raster layer *LS_factor* in the Fig. 5. Some similarities of the graphical representation of LS factor and of the average annual soil loss (Fig. 7) are evident. The intensity of erosion is in a certain correlation with the increasing value of LS factor.

Calculated mean values of factor C differ according to the used crop rotation (Tab. 1). The highest erosion control effect of vegetation was found out in the crop rotation no. 1, on the contrary the crop rotation no. 7 had the worst erosion control effect. The difference is caused by represented crops and their sequence in crop rotation (Fig. 6).

Information on the support practices or factor P values in the site was collected through field observation. P factor value is 1, which indicates no physical evidence of erosion control in the area of interest.

Individual layers were overlaid and multiplied according to the USLE into one combined layer (*A_erosion*) which shows the erosion rate (Fig. 7) and subsequently erosion vulnerability of the area of interest (Fig. 8).

Fig. 7 and 8 show that blocks of arable land are vulnerable to various degrees of erosion, compared to that – blocks with grassland are almost without threat.

The map in Fig. 8 shows four erosion vulnerability degrees determined on the basis of calculated annual soil loss A and soil loss tolerance T, which is 4 $t.ha^{-1}.yr^{-1}$ for moderately deep and deep soils in the area. It means that 21.4 % of the land area is threatened by light erosion, 21.5 % by medium erosion, 34.8 % by strong erosion and 22.3 % by very strong erosion. The results show a strong and very strong vulnerability of large areas of arable land to water erosion, and therefore a need of a draft of appropriate erosion control measures.

The map in Fig. 9 brings an idea of the runoff, which can be a basis for the design of erosion control technologies in individual plots. The map shows paths of concentrated runoff, runoff lengths and directions on the basis of shaded digital elevation model.

Calculation of average annual soil loss after design of erosion control measures

Design of erosion control measures was based on a valid methodology (Janeček et al., 2012), which states that care should be taken not only to maximize the effect of the proposed soil conservation measures, but also should ensure their feasibility and integration into agricultural practices. That means, as Polách et al. (1987) say, that the managing subject should, in their own interest, respect and strive to adopt the proposed erosion control measures. As well as, a draft of erosion control measures should correspond with the needs and interests of farming cooperatives. In accordance with the above mentioned, the design of organizational and agrotechnical character was done. Technical measures were not designed due to their cost and the difficulty of integrating into the conventional practice of farming cooperatives.

Agronomic measures were focused on the shortening of the time period when the land is without vegetation cover or protective effect of crop residues. These measures are characterized by lower economic demands and technical requirements (Vlčková, 2015). Within the measures design, the existing representation of cultivated crops in the area was respected corresponding with the economic effect, which the current cropping brings. Crops of current crop rotation were not substituted with crops more resistant, but only identification of the most problematic ones in terms of their effectiveness against erosion was done, where minimizing tillage with using of harvest residues was proposed. Harvest residues not only provide protection of the soil surface, but also have improving effect on its structure and content of organic matter (Badalíková and Hrubý, 2009).

Following agrotechnical erosion control measures were proposed – sowing of maize into plowed soil with left straw after harvesting cereal forecrop (crop rotation no. 6 and 7) or sowing of maize into sod of perennial forage crops that was killed by herbicides (crop rotation no. 2), summer no-tillage sowing of winter rape into the stubble (crop rotation no. 4, 5 and 7) or into stubble with left straw after harvesting cereal forecrop (crop rotation no. 3), sowing of spring barley into plowed soil with straw after harvest of winter wheat (crop rotation no. 4, 5 and 6), sowing of winter wheat into plowed soil with left straw after harvest spring barley (crop rotation no. 5) and shift of plowing to the period with a lower occurrence of torrential rains in the event of liquidation of alfalfa crop (crop rotation no. 1).

The main reason of the design of the measure consisting in the summer no-tillage sowing of winter rape into the stubble was to reduce soil erosion vulnerability in period of heavy rainfall, when, as stated Podhrázská and Dufková (2005) fields ready for sowing and fields sown by summer intercrops and winter rape are particularly heavily threatened by water erosion. Mentioned authors find the solution in summer no-tillage sowing of winter rape. Janeček et al. (2012) states that winter rape sown into stubble compensates germination and yield of winter rape sown in traditional tillage. Procházková et al. (2011), however, mention certain restrictions with using of minimization technologies which are related mainly to regulation of second growth and leaving the straw on the field. It is very important to crush the straw well, evenly spread it out over the soil, adjust the C:N ratio and immediately incorporated the straw into the soil when leaving the straw on the field before sowing winter rape, and all this due to the very short intervegetation period and generally higher requirements of winter rape on the quality of sowing. Even when following these precautions associated with leaving the straw in the field, it is necessary to expect the inhibitory effect of straw and second growth, while more serious problems occur within the cultivation of winter rape after spring barley than after winter wheat.

Reduction in number of tillage was achieved once per crop rotation (no. 3, 4, 5 and 7) by sowing of winter rape into the stubble. It would be the best to completely eliminate plowing from the erosion point of view, but it is not the best solution. For example, Pivnička (2002) points out the importance of plowing. He states that plowing turns the soil, blends it, loosens it and crumbles it, which means increasing of the porosity, permeability to water, the amount of air in the soil and the dynamics of its replacement, while the specific gravity of the softened soil decreases. Weakening and destruction of weeds, incorporation of manure and crop residues are also the important functions of plowing. Pivnička (2002) also states that the importance of farmyard manure, which is incorporated into the soil during the plowing, lies in the fact that the soil is supplied with organic matter and certain amount of humus.

Usefulness of manure for soil appears in many other ways. For example, Mašíček et al. (2013) examined the effect of adding manure to the soil on the water infiltration velocity. The research, which was carried out on arable land with vegetation of spring wheat during the growing season of 2012, showed that average higher rate of infiltration was found out on the fertilized plot compared to unfertilized one during the whole growing season.

Table 2. Values of original factor C (without erosion control measures) and factor C after draft of erosion control measures

Crop rotation	1	2	3	4	5	6	7
Without erosion control measures	0.093	0.094	0.204	0.21	0.219	0.261	0.267
After design of erosion control measures	0.089	0.01	0.182	0.19	0.177	0.203	0.214

Pivnička (2002) also states that water erosion rate is proportional also to the quantity of humus in the soil, whose amount is increasing with delivery of matured manure into the soil. From this fact, it is possible to deduced substantiation for the inclusion of both no-tillage, as well as traditional techniques with tillage into crop rotations on vulnerable plots. A suitable combination of these techniques could thus probably achieve effective long-term agricultural production in the areas threatened by water erosion.

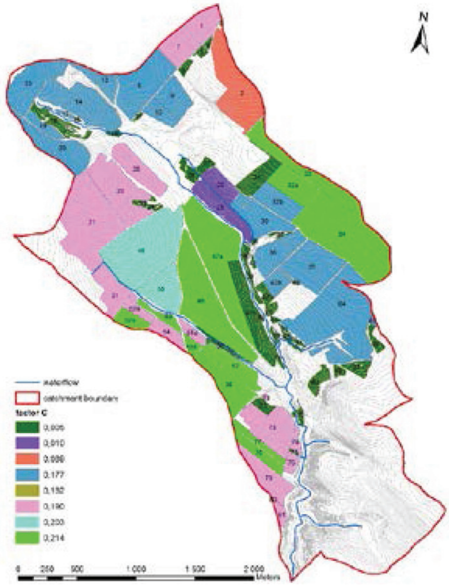

Figure 10. Values of factor C after erosion control measures design. Map data: A07_Povodi_IV, A02_Vodni_tok_JU (© VÚV TGM, v.v.i., www.dibavod.cz), ZABAGED Altimetry – 3D Contour Lines (© ČÚZK)

Partition of the selected soil blocks to smaller ones (32b, 52b and 55a) was proposed because of the application of more suitable crop rotation, the most vulnerable parts of land (42b, 45, 47b and 69) were proposed for grassing. Conversely, as partial compensation for the land covered with grass, one parcel with grass (10) was converted to arable land. In the case of parcels associated with the relocation of crop rotations or grassing proposal, it was simultaneously taken into account the spatial proximity of field blocks (or their parts) with the same (similar) crop rotation and their mechanization availability. After the proposed partition of soil blocks, their number has increased from the original number of 81 to 86. The original layout of crop rotations, which are based on knowledge of local conditions, was fully respected, except of divided soil blocks and the land converted from grassland to arable land. Soil blocks divided according crop rotation or grassland have the same numerical signification in the project, with distinction using small letter of the alphabet. Following plots were divided: 32 (32a, 32b), 42 (42a, 42b), 47 (47a, 47b), 52 (52a, 52b) and 55 (55a, 55b).

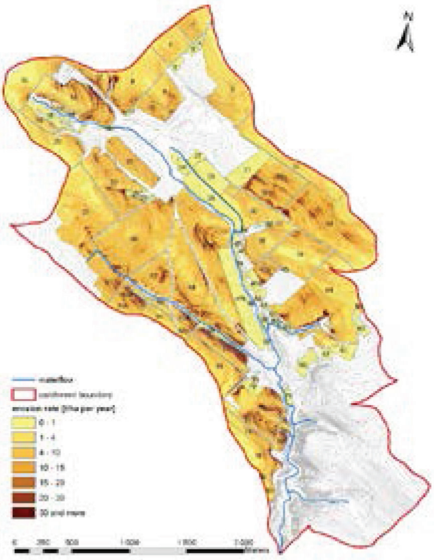

Figure 11. Erosion rate in $t.ha^{-1}.yr^{-1}$ after erosion control measures design. Map data: A07_Povodi_IV, A02_Vodni_tok_JU (© VÚV TGM, v.v.i., www.dibavod.cz), ZABAGED Altimetry – 3D Contour Lines (© ČÚZK)

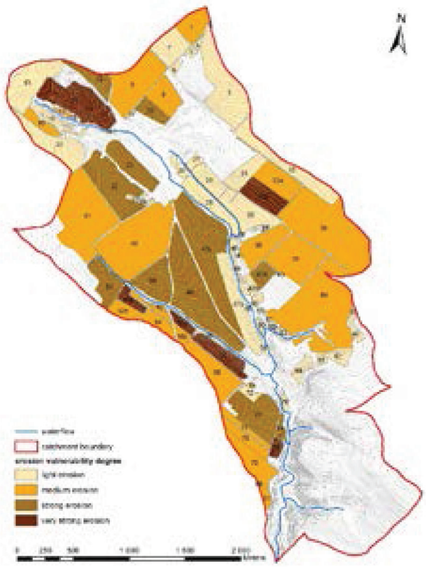

Figure 12. Erosion vulnerability degrees after erosion control measures design. Map data: A07_Povodi_IV, A02_Vodni_tok_JU (© VÚV TGM, v.v.i., www.dibavod.cz), ZABAGED Altimetry – 3D Contour Lines (© ČÚZK)

The protective grassing was proposed only in essential cases and on the locations (the most sloping) most threatened by erosion. Grassing of large areas is in fact incompatible with the practice of farming agricultural cooperatives, and cannot therefore be applied to all arable land, as stated Podhrázská (2009), and it should be done only on plots which, in terms of soil loss by erosion, can no longer be used as arable land (Janeček et al., 2012).

The result of the proposed soil conservation technologies, as reflected in various crop rotations, was decrease in value of factor C (Tab. 2, Fig. 10), and thus the average annual soil loss at areas endangered by erosion (Fig. 11). Erosion vulnerability degrees after erosion control measures design is shown on the map in Fig. 12.

Acreage of the agricultural land in each category of erosion vulnerability degrees before and after the first draft of erosion control measures is shown in Tab. 3. The table shows that there was a reduction in the area threatened by very strong erosion from 111 ha to 35.5 ha and threatened by strong erosion from 173.6 ha to 114.9 ha. Soil blocks threatened by very strong erosion have, after draft of erosion control measures, an area of 7.1 % of agricultural land in study catchment, compared to the initial 22.3 %; and soil blocks threatened by strong erosion have 23.1 % compared to the initial 34.8 %. Whereas less than half (42.9 %) of the area of soil blocks come under 1st and 2nd degree of erosion vulnerability before erosion measures design, the increasing of areas with these degrees to 69.8 % would happen assuming implementation of erosion control measures.

At the same time, it is also necessary to mention that decrease in soil loss by water erosion was even recorded in those soil blocks, where the change of degree of erosion vulnerability has not been directly observed.

Table 3. Acreage of the agricultural land in each category of erosion vulnerability degrees before and after erosion control measures design

Erosion vulnerability degree	Before erosion control measures design – acreage		After erosion control measures design – acreage	
	Ha	%	ha	%
1. light erosion	106.6	21.4	127.7	25.6
2. medium erosion	107.3	21.5	220.3	44.2
3. strong erosion	173.6	34.8	114.9	23.1
4. very strong erosion	111.0	22.3	35.5	7.1
	498.5	100	498.5	100

Increase or decrease in the degree of erosion vulnerability of individual soil blocks before and after the erosion control measures design is shown in Fig. 13. The positive values indicate an increase in the vulnerability degree after the erosion control measures design in comparison with the current state, while negative values indicate the decrease. The value of zero means no change in vulnerability degree, despite the fact that the reduction of soil loss was achieved, as mentioned above. The increasing of the vulnerability degree was observed in one soil block, where change from permanent grassland to cropland was proposed. The reason was to compensate the reduction in crop production, caused by grassing of other parts of the area. The design of erosion control measures enables to reduce the vulnerability degree on 17 soil blocks, of which three (42b, 47b and 69) achieved a significant reduction in soil loss of three degrees, and on soil blocks 32a, 52b and 55b by two degrees.

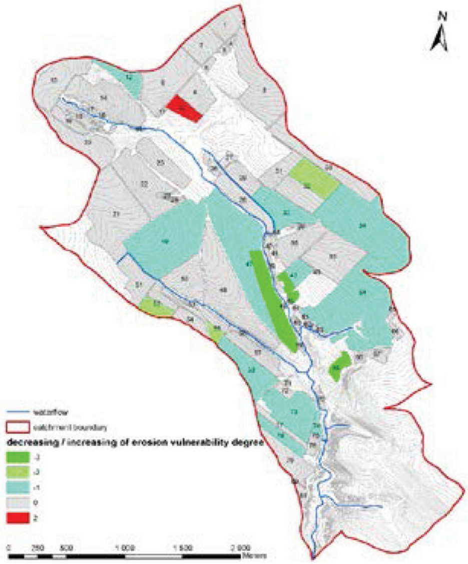

Figure 13. Change in soil erosion vulnerability degrees. Map data: A07_Povodi_IV, A02_Vodni_tok_JU (© VÚV TGM, v.v.i., www.dibavod.cz), ZABAGED Altimetry – 3D Contour Lines (© ČÚZK)

CONCLUSION

Evaluation of the vulnerability of agricultural land by water erosion, including the erosion control measures design, was done using GIS on example of the Luh stream catchment. The proposed measures should improve the current situation and also contribute to preservation of agricultural activity in this area in a form close to the current situation.

The importance of GIS consists in the fact that they allow rapid and accurate quantification of physical-geographical characteristics of large areas in combination with efficient and accurate way of the USLE calculation. Graphical representation of the factors of K, LS, C and of the result of USLE itself in the individual map layers provides a quick orientation in erosion conditions of the study area. Individual erosion control measures can be specifically applied through these outputs and alternative solutions of soil erosion protection with immediate presentation of the effect of the proposed measures on specific plots can be proposed.

Significant losses exceeded tolerable soil loss of study area according to the calculation of USLE factors and determination of annual average soil loss. It has been shown, before proposing of erosion control measures, that 22.3 % of the agriculture soil is threatened by very strong erosion, 34.8 % by strong erosion, 21.5 % by medium erosion, and 21.4 % of the land area is threatened by light erosion. On the basis of these results, proposal of erosion control measures was made, consisting in the introduction of no-tillage technologies for the cultivation and planting mainly of crops such as maize, winter rape, winter wheat and spring barley. Changes in crop rotations were proposed in three cases, protective grassing of part or whole plots were proposed in four cases. Recalculation of the annual average soil loss after erosion control measures proposal showed a significant effect of these measures on water erosion decrease in the study area. The area of land threatened by very strong erosion was reduced to 7.1 % of agricultural land, strong erosion to 23.1 %, area of land threatened by medium erosion increased to 44.2.0 % and light erosion to 25.6 %.

Erosion control measures proposal, which has to serve effectively to man, soil and landscape, cannot be done for its own sake and only by the austere rules, but always needs to be the most appropriate to incorporate all the determinants of a particular area with its capabilities, but also limitations, both natural and anthropogenic. Only with such an approach to the landscape, which is based on its understanding and long-term development, it is possible to propose measures that will serve well for current and future generations.

Finally, it is necessary to consider the importance of the issue of soil protection and overall the state of the environment, not only on a regional scale. Soil is one of nonrenewable natural resources, is an indispensable part of the environment, life on earth would not exist without it. Therefore, it is necessary to protect the soil and particularly in expectation of climate change to prevent the further degradation through appropriate measures.

ACKNOWLEDGMENT

The paper was elaborated with the support of the Institutional Plan of Mendel University in Brno no. 13.9 “Innovation of the subject Computer Design – the practical use of GIS within hydrological analyses solving”.

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Received: 10.11.2016
Accepted: 07.12.2016