WATER EROSION RISK ASSESSMENT, DIFFERENCES BETWEEN SLOVAK AND POLISH PROCEDURES

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ABSTRACT

Given an example watershed, calculation of the long-term average annual soil loss by the universal soil loss equation (USLE) is analyzed taking into amount the Slovak and Polish approaches. Six factors are considered the rainfall erosivity factor (R), the soil erodibility factor (K), the topographic factors (LS) and the cropping management factors (C and P). Differences in input and methodology are highlighted. The example micro-watershed (the Matny stream basin in the Beskid Wyspowy, the western Carpath, Poland) is located in Poland on the boundary with Slovakia (area 1.47 km^2, the catchment land use structure is dominated by grassland - 73.5%, arable land covers - 14.3%, forests account - 9.5% and urban areas - 2.7%). Mean height of the catchment is 582.66 m asl. Weighted mean slope for the entire catchment is 16.28%. The length of the main watercourse is 2.37 km and its average slope is 5.7%. The results include the calculation of erosion runoff areas by category (none to slight, medium, prominent, very prominent, catastrophal) in both countries.

Keywords: water erosion intensity, erosion risk, universal soil loss equation, USLE, Slovakia, Poland

INTRODUCTION

Erosion soil is the physical process of upsetting and removing part of the earth's surface make by external (exogenous) activity. In contrast to the weathering, whose is the own upsetting, erosion introduces is mainly transport soil [1]. For the first time, he used the term erosion in the translation of the medical text Guilla de Chauliaca "The Questyonary of Cyrurygens" by Robert Copland in 1541. Copland used this term to describe the focuses developed in the throats. Since 1774, the term erosion has also been used outside of medical science when he used Oliver Goldsmith in his "Natural History" book when he wrote about erosion of the earth with water. Soil erosion is a naturally occurring process that affects all landforms. In agriculture, soil erosion refers to the wearing away of a field's topsoil by the natural physical forces of water and wind or through forces associated with farming activities such as tillage [2]. Classification of erosion is based on different criteria. The most widely used classification of soil erosion is by factor (water, wind, glacier, snow, earth, anthropogenic erosion).

Determination of water erosion intensity

The most widely used methods of calculating the soil load by erosive water activity include the Wischmeier-Smith universal soil loss equation [3]. Also known as USLE - Universal Soil Loss Equation. The development of the universal soil loss equation is considered to be one of the most influential works of the twentieth century in the field of soil and water protection.

Under Slovak (SR) conditions, the most vulnerable soil is the degradation by water erosion. The range of erosion (soil loss) is divided into four categories (none to weak, medium, high, and extreme erodibility). Up to 44% of agricultural land (1 066 088 ha) is classified as medium to extreme loss of land. Potential water erosion of agricultural soils in Slovakia (according to the VUPOP) is in the category of medium 9.5%, high 14.6% and 19.8% extreme erodibility.

In Poland (PL), as well as on Slovakia, is soil the most menace to water erosion. The loss of soil is categorized into 5 classes (very weak, weak, medium, strong and very strong erosion). Total water erosion is 20.4% of Poland's area, with a very strong erosion of 7.1%. In comparison with Slovakia there are about half of the smaller values, but the Polish distribution of soil degradation is divided into water (plateau) and river (scratch) erosion, which accounts for up to 37.5% of the total area of Poland [4].

The objective of the contribution is to provide basic information material of determination of water erosion intensity in Slovak and Polish conditions. Provide valuable evidence for experts who are considering re-evaluating the values of some parameters of the universal soil loss equation in water erosion research.

MATERIAL AND METHODS

The example micro-watershed (the Matny stream basin in the Beskid Wyspowy, the western Carpath, Poland) is located in Poland on the boundary with Slovakia area 1.47 km^2. The geological composition of the area consists of Carpathian flysch and volcanic rock. Terrain of area formed by a slight slope with the highest elevation 503,7 in the eastern part and the lowest point 716,3 located in the Matny river. The climate on the territory is a typical montane with variable weather conditions. The average annual air temperature is 7 ° C. Long-term (1995-2014) annual average total precipitation is 960.7 mm. Area is typically agriculturist with a high substitutable of grassland.

The basic for determination of the intensity of water erosion in the area is:

- topographic objects database (TBD) in scale 1 : 10 000,
- topographic map in scale 1 : 10 000,
- ortophotomap,
- soil complex map in scale 1: 25 000.

The universal soil loss equation makes it possible to predict the average annual soil erosion intensity for all possible combinations of crops, cultivation, soil properties, rainfall ratios and topography [3]. The Wischmeier-Smith universal soil loss equation takes into account the six basic erosion factors. The resulting soil yield is, according to this equation, a function of rain erosivity, soil erodibility, slope length, incline slope, vegetation cover, and countermeasures. The equation has the form (1):

$$SP = R \,.\, K \,.\, L \,.\, S \,.\, C \,.\, P \qquad (1)$$

Sp – loss of soil caused by water erosion [$t.ha^{-1}.rok^{-1}$], R – rainfall-runoff erosivity factor [$MJ.ha^{-1}.rok^{-1}$], K – soil erodibility factor [$t.MJ^{-1}$], L – slope length factor, non-dimensional, S – slope steepness factor, non-dimensional, C – cover management factor, non-dimensional, P – support practice factor, non-dimensional.

Rainfall-runoff erosivity factor (R)

Factor R is calculated as the sum of the total kinetic energy of the rain and its biggest 30 minutes of intensity. The necessary data should be obtained from omrographic rain records for at least 50 years [5] (2).

$$R = E \,.\, I_{30} \qquad (2)$$

R – rainfall – runoff erosivity factor [$MJ.ha^{-1}.cm.h^{-1}$], E – total value kinetic energy of rain [$MJ.ha^{-1}$], I_{30} – 30 minute intensity of rain

SR: For the given localization, the required detailed ombographic record of precipitation from the stations [eg. 1] were not available, we used for computed an approximate value of the R factor by rapport [1] (3):

$$R = 0{,}068 \,.\, H_{d,r} \qquad (3)$$

R – average annual the value erosive efficiency factor of rain [$MJ.ha^{-1}.cm.h^{-1}$], $H_{d,r}$ – average annual rainfall on the exploring localization [mm]

PL: Rain erosivity factor describes drop rain capacity to loosening and transportation of soil bits. It was calculated on the basis of Fournier index in modification [see 6]. The modified Fourier index calculated as the mean from multiyear 1995-2014 from the Obidowa rainfall station, based on (4):

$$F = \frac{1}{m} \cdot \sum_{j=1}^{m} \sum_{i=1}^{12} \frac{p_{i,j}^2}{P_j} \qquad (4)$$

F – Fourier index [mm], m – number of years in a period time, $p_{i,j}$ – rainfall sum in i^{th} month in j^{th} year [mm], P_j – annual rainfall sum in j^{th} year [mm]

Based on calculated value of the Fourier index, the rainfall-runoff erosivity factor changing obtained value, using power relation was determined [7] (5):

$$R = 0{,}2265 \cdot F^{1.2876} \qquad (5)$$

R – the rainfall-runoff erosivity factor for a specific time period [$MJ.ha^{-1}.cm.h^{-1}$]

Soil erodibility factor (K)

Factor K is defined as the soil yield per unit of rain factor R from unit land.

SR: Determination of K factor in Slovak conditions is possible in several ways. The most commonly used is the indicative determination of K factor values by type of soil. We determined the K factor values by assigning the relevant soil type according to the map of the Polish soil complexes of the model territory in the Slovak soil categorization. We have determined the soil species to which we have assigned the appropriate value to the factor.

PL: Soil erodibility factor expresses eroded soil mass from the unit of model field. It can be evaluated after [8] (6, 7):

$$K = 0{,}0034 + 0{,}045 \cdot e^{\left[-0.5\cdot\left(\frac{\log D_g + 1.659}{0.7101}\right)^2\right]} \tag{6}$$

$$D_g = e^{\left(0.01\cdot\sum f_i \cdot \ln\frac{d_i + d_{i-1}}{2}\right)} \tag{7}$$

K – soil erodibility factor [Mg.ha^{-1}.MJ.ha^{-1}.cm.h^{-1}], d_i – upper limit of fraction range [mm], d_{i-1} – lower limit of fraction range [mm], f_i – mass fraction content [%]

Topographic factor (LS)

In the revised universal soil loss formula called RUSLE (Revised USLE), which was created for GIS and specified some factors. A significant difference was the connection of S factor and L factor into one common termed topographic factor. The LS factor reflects the ratio of soil loss from the investigated slope to the loss of soil from the unit land. The LS factor value is expressed by:

$$LS = I_d^{0,5} . (0{,}0138 + 0{,}0097 . s + 0{,}00138 . s^2) \tag{7}$$

LS – topographic factor, non-dimensional, I_d – uninterrupted slope length [m]; s – slope slope [%]

SR: With objective to take into account the influence of the drain concentration, the time on the slope was replaced by the contribution (source) area A [9]. The modification of the relation to the LS factor was in the final form derived from [10]. A simpler, continuous form of the equation for calculating the LS factor at r = (x, y) on the slope was derived by [11] in the form (8):

$$LS_{(x,y)} = 1.6 . \left(\frac{A_{(x,y)}}{22{,}13}\right)^{0.6} \cdot \left(\frac{\sin b_{(x,y)}}{0{,}09}\right)^{1.3} \tag{8}$$

$LS_{(x,y)}$ – LS factor for a given raster model cell with coordinates x, y, A – unit ones the contributing (source) area at the cell input [m^2], b – slope cell [°]

PL: In Polish procedure, LS factor is also used according to the revised universal soil loss equation. Expression of LS factor for conditions Poland determined [9]. The topographical equation for methodological calculation methods in Poland is (9):

$$LS = 1{,}4 \,.\, \left(\frac{As}{22{,}13}\right)^{0{,}4} \,.\, \left(\frac{\sin q}{0{,}0896}\right)^{1.3} \qquad (9)$$

LS – topographic factor, non-dimensional, A_s – local upslope contributing area from flow accumulation raster [m²], q – slope [°]

Cover management factor (C)

Factor C is defined as the ratio between the intensity of erosion in the soil with the vegetation cover and the intensity of erosion on the machined eel. The factor of the protective effect of vegetation is also expressed by the applied agrotechnics and the sowing process. In the model basin, we specified 6 types of land.

SR: The attribution of the individual C factor values according to [12] was made according to the type of land in the river basin.

PL: The same way is applied in Polish conditions. The assignment of the C factor value is done by [13].

Support practice factor (P)

The anti-erosion efficiency factor defines the ratio between the intensity of erosion in the area investigated and the applied erosion measures and the intensity of erosion on the same plot of land cultivated. Since there is a lack of land housekeeping data, we have determined P factor = 1 for both Slovak and Polish procedures.

RESULTS AND DISCUSSION

Based on the topographic map and the orthophotomap, we specified 6 types of land use. The largest representation in the analyzed area has grassland with a percentage of up to 72% and arable land with a share of 15%. The solution of the territory is situated in the foothill area, therefore the logical prevalence of the grassland.

Rainfall-runoff erosivity factor (R) - For calculating the rainfall-runoff erosivity factor (R) rainfalls from years 1995-2014 from the Obidowa rainfall station was used. The greatest difference in the comparison and analysis of the universal equation factors USLE has been recorded in the erosive efficiency of the rain. The resulting value of the R factor according to the Slovak procedures is 65.33 $MJ.ha^{-1}.cm.h^{-1}$, which is 40.52 $MJ.ha^{-1}.cm.h^{-1}$ than in the Polish method (105.85 $MJ.ha^{-1}.cm.h^{-1}$).

Soil erodibility factor (K) - The soil composition in the studied area is represented by 37% sandy clay loam and loam (36%). They are further represented in the territory sandy loam (22%) and silt loam (1%). Values of soil susceptibility to water erosion factor (K) that were estimated for analyzed studied area varied from 0,17 to 0,39 following methodological standards for Slovakia. The range of values to a factor of determining the susceptibility of the Polish soil water erosion is from 0.19 to 0.45.

Topographic factor (LS) - The calculation procedure for the determination of the Polish and Slovak LS factor is very similar to. One significant difference is the failure to calculate the contributing area to interrupt the slope length of the barrier in the Polish LS Factor determination method. In Slovak conditions are considered as barriers waterways, roads, built-up areas and forests. The topographic factor value is 0 - 63 with an average of 2.23. When calculating the Polish way, this value is the range of half the size and 0.36, but with approximately the same average value of 2.32.

Cover management factor (C) - Based on the land cover and land use map, the values of factor C were determined. For Slovak procedures, the average annual C factor values for field crops: Arable land: Common wheat – 0.1; Potatoes – 0.45; Spring oats – 0.1; Grassland – 0.005; Water areas, urban areas, roads and non-forest woody vegetation were identified as barriers. Polish C factor values: Arable land: Common wheat – 0.124; Potatoes – 0.229; Spring oats – 0.104; Grassland – 0.015; Forest (non-forest woody vegetation) – 0.002; Water areas, urban areas and roads – 0.00.

Mean annual soil loss (A)

As a result of conducted modelling of water erosion, information about spatial distribution of soil losses size in the tested study area was obtained (Fig. 1), according to Slovak and Polish procedures. Mean quantity of eroded soil in the study area was calculated following Slovak procedures and amounted 1.85 $t.ha^{-1}.year^{-1}$ and Polish procedures it was 2.32 $t.ha^{-1}.year^{-1}$.

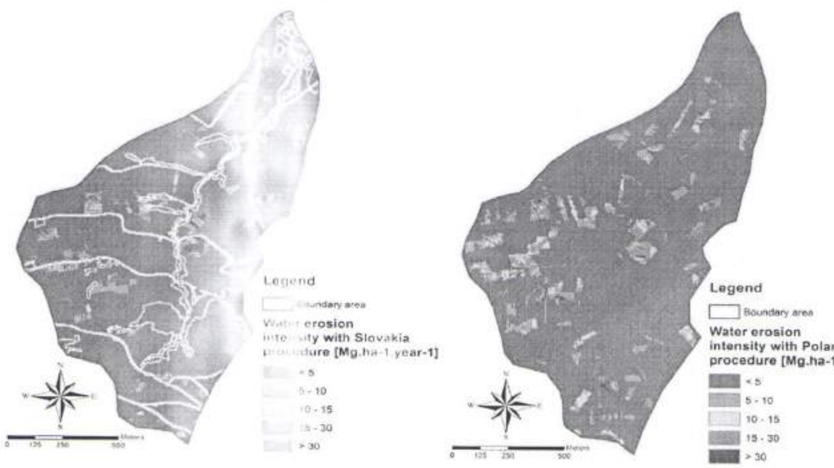

Fig. 1 Predicted soil loss on model area

Total annual mass of eroded soil from the model area calculated after Slovak procedures (271.,95 Mg. $year^{-1}$) is almost 25% bigger than the values obtained by means of polish formula (341,04 $Mg.year^{-1}$). It results from different way of factor R, C and non-inclusion into the LS factor barrier determination.

On the basis of predicted soil loss, research area division into water erosion risk zones was performed on the grounds of criteria proposed by [14]: lack or very small, mild, high, very high and catastrophic erosion risk (Table 1).

Tab. 1 Classification of erosion risk criteria according to [14]

Risk class	Water erosion risk	Annual soil loss [t.ha^{-1}. year^{-1}]	Comparison of risk classes [%]	
			SR	PL
1	lack or very small	< 5	94	89
2	mild	5 - 10	3	5
3	high	10 - 15	1	3
4	very high	15 - 30	1	3
5	catastrophic risk	> 30	1	0

CONCLUSION

USLE model used in the present research is commonly applied in the world method of soil erosion risk evaluation. Its usage prevalence enables possibility to compare gathered results of modelling with the other world methodics researches results which were conducted in different parts of the country or the world [15]. On the basis of conducted modelling, following conclusions can be presented:

1. Significantly lower value of the factor R in Slovak conditions.
2. Significant differences in factor C values for given crops.
3. Does not include barriers to the application of Polish methodologies for setting LS factor values.
4. Significant differences in K factor comparison for the same soil subtype.
5. Results of erosion prognosis by means of USLE method after Slovak methodics are by 25% higher than values evaluated after Polish methodics.
6. Eroded soil mean mass from area unit during the year is estimated at the level of 1,85 a 2,32 Mg.ha^{-1}, depending on accepted computable method.
7. Total mass of eroded soil which can annually flow into the Mściwojów water reservoir is evaluated at 271,95 and 341,04 Mg.year^{-1}, depending on computable method used in that country.

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REFERENCES

[1] Antal J., Protierózna ochrana pôdy, Nitra, 2005.

[2] Muchová Z., Leitmanová M., Petrovič F., Possibilities of optimal land use as a consequence of lessons learned from land consolidation projects (Slovakia), Ecological engineering, vol. 90, pp. 294-306, 2016.

[3] Wischmeier W.H., Smith D. D., Predicting fall erosion losses – a guide to conversation planning, Washington, 1978.

[4] Józefaciu, A., Józefaciuk CZ, Mechanizm I wskazówki metodyczne badania procesów erozji, Warszawa, 1996.

[5] Mališek A., Zhodnotenie faktora eróznej účinnosti prívalové zrážky, Geographic journal, vol. 42, pp. 410 – 422, 1990.

[6] Licznar P., Łomotowski J., Rojek M., Zintegrowany system pomiarów opadów atmosferycznych dla potrzeb badań nad erozją wodną, Acta Agrophysica, vo. 5, no 2, pp. 335–344, 2005.

[7] Wężyk P., Pierzchalski M., Szafrańska B., Korta G., Aktualizacja mapy gleboworolniczej z wykorzystaniem klasyfikacji obiektowej (OBIA) zobrazowań teledetekcyjnych oraz analiz przestrzennych GIS. Archiwum Fotogrametrii, Kartografii i Teledetekcji, vol. 23, pp. 477–488, 2012.

[8] Renard K. G., Freimund J. R., Using monthly precipitation data to estimate R-factor in the revised USLE, Journal of Hydrology, vol. 157, pp. 287-306, 1994.

[9] Moore I.D., Grayson R.B., Ladson A.R., Digital terrain modelling: a review of hydrogical, geomorphological, and biological applications, Hydrol. Proc., vol. 5, 1991.

[10] Desmet P.J., Govers G.,. A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units, Journal of Soil and Water Conservation, vol. 51, 1996.

[11] Mitášová H., Hofierka J., Zlocha M., Iverson L. R., Modelling topographic potential for erosion and deposition using GIS, International Journal of GIS, vol. 10, pp. 629 – 641, 1996.

[12] Alena F., Stanovenie straty pôdy eróznym splachom pre navrhovanie protieróznych opatrení, Bratislava, 1986.

[13] Koreleski K. Próby oceny nateženia erzji wodnej, Sesja Naukowa, vol. 35, 1992.

[14] Marks R., Muller M.J., Leser H., Klink H.J., Anleitung zur Bewertung des Leistungsvermogens des Landschaftshaushaltes, Forschungen zur Deutschen Landeskunde, 1989.

[15] Muchová Z., Leitmanová M., Petrovič F., A more detailed approach to the assessment of the water erosion threat for a territory. SGEM, 2015, 1st ed. 738, pp. 3-10.