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COMPARISON OF METHODS FOR DETERMINATION OF SOIL ERODIBILITY FACTOR (*K*-USLE) ON THE EXAMPLE OF THE KASIŃCZANKA STREAM BASIN

PORÓWNANIE METOD OZNACZANIA WSPÓŁCZYNNIKA EROZYJNOŚCI GLEBY (*K*-USLE) NA PRZYKŁADZIE ZLEWNI POTOKU KASIŃCZANKA

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Abstract. Comparison of various methods for *K*-USLE soil erodibility factor determination was the purpose of this work. The used methods were: Wischmeier's, Wischmeier's and Smith's, Monchareonm's, Wiliams et al., Renard's et al., Torii's et al., Stone's and Hilborn's, and two methods NRCS. Calculations were carried out for mountainous basin of the Kasińczanka stream, tributary of the Raba river in the Western Carpathians. The obtained results shows that methods used for soil erodibility factor determination differ considerably. Mean values obtained by analyzed methods fluctuated between 0,138 and 0,354 Mg · ha^{-1} · Je^{-1}.

Streszczenie. Celem pracy było porównanie różnych metod wyznaczania współczynnika erozyjności gleby do modelu USLE. Wybranymi metodami były metody: Wischmeiera, Wischmeiera i Smitha, Monchareonma, Wiliamsa i in., Renarda i in., Toriiego i in., Stonea i Hilborna oraz dwie metody NRCS. Porównanie zostało przeprowadzone dla górskiej zlewni potoku Kasińczanka, dopływu Raby w Karpatach Zachodnich. Otrzymane wyniki pokazują, że metody dają znacznie różniące się rezultaty. Średnie wartości otrzymane zastosowanymi metodami wahały się pomiędzy 0,138 i 0,354 Mg · ha^{-1} · Je^{-1}.

Key words: model USLE, soil erodibility factor, GIS

Słowa kluczowe: model USLE, współczynnik podatności erozyjnej gleby, GIS

INTRODUCTION

Soil erosion is essential problem from the point if view of environmental protection and country management. This phenomenon is investigated by various methods both

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direct and indirect ones. The modeling methods are most popular. One of the most often used and cited in literature all over the world is USLE (Universal Soil Loss Equation). It is an empirical equation describing soil loss as a result of surface and rill erosion, elaborated in the United States by Wishmeier and Smith in 1978 based upon multiyear research on test plots. One of the parameter creating USLE model is soil erodibility factor (*K*), connected with soil cover.

Determination of soil erodibility factor encounters many problems, because of many elements characterizing soil cover. In practice this factor is calculated by many methods taking into account various properties. Wischmeier [Poesen et al. 1997, Torii et al. 1997] developed in 1977 equation based on particles size fractions 0,1–0,002 and below 0,002 mm as well as organic matter content. In 1978 Wischmeier and Smith [Rejman et al. 1998, Moehansyah et al. 2004, Wawer et al. 2005] modified equation introducing following properties as: water conductivity, structure and fraction 0,1–2 mm. For soils with fraction 0,002–0,1 mm content above 70% the nomograph was elaborated in which rock fragments were included. The succeeding modifications were developed by Wiliams in 1984 [Nam 2003] introducing organic carbon content and Renard et al. in 1997 [Drzewiecki i Mularz 2005] reducing data maximum and minimum grain diameters and their mass share. Torii et al. [1997], introduced mean geometric distribution of ground particles instead of their content. Monchareonm in 1982 [Bahadur 2009] proposed nomograph of triangle shape with sides corresponding with sand, silt and clay fractions content. Stone i Hilborn [2000] applied significant simplification using only organic matter content and information of soil type. National Resources Conservation Service [NRCS 2007] based methods for *K* determination on skeleton particles content and land use. The aim of the work was comparison of chosen methods for soil erosion erodibility determination and possibility of use of GIS methods for necessary properties estimation on the example of the Kasińczanka stream basin.

STUDY AREA

Investigated basin is located in the Beskid Wyspowy of the Western Carpathians [Kondracki 1998]. Southern border creates hill-slides of the Lubogoszcz Mountain (967 m a.s.l.), eastern the Śnieżnica Mountain (1005 m a.s.l.) while northern one the Wierzbanowska Mountain (774 m a.s.l.) and Dzielec Mountain (607 m a.s.l.). From the west the basin is closed by the Kiczara Mountain sopes (755 m a.s.l.). The basin belongs to the Podkarpacka agricultural-climatic province [Gumiński 1948], characterized by mean annual precipitation sum of 800–1000 mm and growing season lasting 200–220 days.

The basin area is 48,54 km^2. It is highly elongated, barrow and low compact. The length attains 11,05 km, mean breadth is 4,39 km and perimeter 37,53 km. The mean height amounts 570,75 m a.s.l. The highest point is located at 1031,1 m a.s.l., while the lowest 398,50 m a.s.l. Mean basin slope is 16,12%. Slopes of 10–20% (31% of the area) and 20–30% (29% of the area) prevail.

The Kasińczanka stream is right side tributary of the Raba river. River network is strongly ramified into many streams, from which the Węglówka is the longest. The length of main stream attains 17,74 km. The slope of main stream is 5,49%, drainage density 2,21 km · km^{-2}.

Regarding texture in the upper part of basin occur sandy clay loam, loam and silt loam. Western and south-western slopes are covered mainly by loam, steep northern and south-eastern slopes by sandy clay loam. In south-western part of the basin occur loamy sand, silt loam and sandy loam.

MATERIALS AND METHODS

There are many methods for determination of soil erodibility factor. In this work various parameters were obtained as a result of overlaying of maps worked out using the GIS methods. Soils of study area were classified based upon soil map 1 : 25000 and field investigations. Soils textural classes were classified according to USDA [Soil Survey Staff 1975]. Basin use structure was worked out by use of ortophotomaps obtained from satellite IRS panchromatic picture. Overlays were elaborated by use of MapInfo Professional 8.0. For determination of soil erodibility factor there were chosen 9 methods:

• Wischmeier (1977) [Torii et al. 1997]

$$K = (12 - OM) \cdot (P \cdot (100 - C))^{1,14}, \ \ \mathrm{Mg \cdot ha^{-1} \cdot Je^{-1}}$$

where:

OM – organic matter content, %,
C – content of fraction <0,002 mm, %,
P – content of fraction 0,002 – 0,1 mm, %.

• Wischmeier and Smith [1978]

$$100K = 2,1 \cdot M^{1,14} \cdot 10^{-4} \cdot (12 - a) + 3,25 \cdot (b - 2) + 2,5 \cdot (c - 3), \ \ \mathrm{Mg \cdot ha^{-1} \cdot Je^{-1}}$$

where:

M – relation of percentage of fraction 0,002–0,1 mm to percentage fraction 0,002–2,0 mm,
a – organic matter content, % (if OM > 4%, OM is 4),
b – aggregates class,
c – water permeability class.

• Monchareonm (1982) [Bahadur 2009]

Soil erodibility factor is determined from nomograph based upon content of sand, silt and clay fractions content.

• Wiliams et al. (1984) [Nam 2003]

$$K = \left\{0,2 + 0,3\exp\left[-0,0256 san \frac{(1 - sil)}{100}\right]\right\}\left(\frac{sil}{cla + sil}\right)^{0,3} \cdot \left(1,0 - \frac{0,25C}{C + \exp(3,72 - 2,95C)}\right)$$

$$\cdot \left(1,0 - \frac{0,7sn1}{sn1 + \exp(-5,51 + 22,9sn1)}\right), \quad \mathrm{Mg \cdot ha^{-1} \cdot Je^{-1}}$$

where:

san – sand fraction content, %,
sil – silt fraction content, %,
cla – clay fraction content, %,
$sn1 = \frac{1-san}{100}$, %
C – organic carbon content, %.

• Renard et al. (1997) [Drzewiecki and Mularz 2005]

$$K = 0,034 + 0,0405 \cdot \exp\left[-0,5\left(\frac{\log D_g + 1,659}{0,7101}\right)^2\right], \text{ Mg} \cdot \text{ha}^{-1} \cdot \text{Je}^{-1}$$

where:

$$D_g = \exp\left(0,01 \cdot \sum f_i \cdot \ln \frac{d_i + d_{i-1}}{2}\right)$$

d_i – upper limit of interval in *i*-th fraction class, mm,
d_{i-1} – lower limit of interval in *i*-th class, mm,
f – mass content of *i*-th fraction, %.

• Torii et al. [1997]:

$$K = 0,0293(0,65 - D_G + 0,24D_G^2) \cdot$$
$$\cdot \exp\left\{-0,0021\frac{OM}{C} - 0,00037\left(\frac{OM}{C}\right)^2 - 4,02C + 1,72C^2\right\}, \text{ Mg} \cdot \text{ha}^{-1} \cdot \text{Je}^{-1}$$

where:

$$D_G = \sum f_i \ln \sqrt{d_i d_{i-1}}$$

d_i – maximum grain diameter in a given class, mm,
d_{i-1} – minimum grain diameter in a given class, mm,
OM – organic matter content, %,
C – content of fraction < 0,002 mm, %.

• Stone i Hilborn [2000]:

Stone and Hilborn [2000] proposed method based on organic matter content and fractions content presented in tables.

• NRCS [2007]:

The NRCS methods cover parameters K_w and K_f. Parameter K_w is determined based on skeleton particles content and basin use while K_f concerns fractions < 0,2 mm.

RESULTS AND DISCUSSION

Texture

In the basin occurs loam (42,1%), sandy clay loam (20,1%), clay loam (19,7%) and silt loam (18,1%) (table 1). Content of skeleton particles amounted between 3 and 37%.

Table 1. Texture and percentage of textural groups in the basin
Tabela 1. Skład granulometryczny i udział grup granulometrycznych w zlewni

Textural group Grupa granulometryczna	Mean content of fractions, % Średnia zawartość frakcji, %				Percentage in the basin, % Zawartość w zlewni, %
	2–0,05 mm	0,01–0,05 mm	0,05–0,002 mm	< 0,002 mm	
loam glina	45	19	16	20	42,1
sandy clay loam glina piaszczysto-ilasta	64	8	6	22	20,1
clay loam glina ilasta	32	21	15	32	19,7
silt loam glina pylasta	22	26	33	19	18,1

Land use

In land use structure prevail forests – 50,19 %, mainly they are coniferous ones located in the upper part of the basin and in streams valleys. Agricultural uses occupy 41,7%, mainly that are grasslands – 29,0%, occurring at streams, in valleys and in the upper part between forests. Arable lands – 12,7%, are scattered through the whole basin area. Intensive individual farming predominates.

Organic matter

Organic matter content fluctuated between 1,85 and 4,28% and is connected mainly with land use and soil subtype.

Saturated hydraulic conductivity

Saturated hydraulic conductivity varied between $0,84 \cdot 10^{-3}$ and $4,87 \cdot 10^{-1}$ $m \cdot d^{-1}$. Obtained results show possibility of high surface runoff on the basin area.

Soil erodibility factor *K*-USLE

• Wischmeier (1977) [Torii et al. 1997]

Values of soil erodibility factor determined by use of this method amounted 0,072–0,253 $Mg \cdot ha^{-1} \cdot Je^{-1}$. Mean value was 0,138 $Mg \cdot ha^{-1} \cdot Je^{-1}$. This method gave rather low values in comparison with other methods (table 2).

• Wischmeier and Smith [1978]

Values of soil erodibility factor fluctuated between 0,160–0,520 Mg · ha^{-1} · Je^{-1}. Mean value attained 0,306 Mg · ha^{-1} · Je^{-1}. This method in turn gave high values (table 2).

• Monchareonm (1982) [Bahadur 2009]

Soil erodibility factor attained values of 0,140–0,560 Mg · ha^{-1} · Je^{-1}. Mean value was rather high – 0,301 Mg · ha^{-1} · Je^{-1} (table 2).

• Wiliams et al. (1984) [Nam et al. 2003]

Soil erodibility factor was between 0,097 and 0,196 Mg · ha^{-1} · Je^{-1}. Mean value was the lowest in comparison with other used methods – 0,138 Mg · ha^{-1} · Je^{-1}.

• Renard et al. (1997) [Drzewiecki and Mularz 2005]

Values of soil erodibility factor using this method factor fluctuated between 0,0092–0, 439 Mg · ha^{-1} · Je^{-1}. Mean value attained 0,354 Mg · ha^{-1} · Je^{-1} and was the highest from all the methods used.

• Torii et al. [1997]

Soil erodibility factor was between 0,0091 and 0,285 Mg · ha^{-1} · Je^{-1}. Mean value determined by use of this method was equal to 0,220 Mg · ha^{-1} · Je^{-1}.

Table 2. Mean values of soil erodibility factor (Mg · ha^{-1} · Je^{-1}) for examined methods and LSD analysis

Tabela 2. Średnie wartości współczynnika podatności erozyjnej gleby (Mg · ha^{-1} · Je^{-1}) dla badanych metod i analiza NIR

Parameter Parametr	Method Metoda								
	Renard et al. (1997)	Wischmeier and Smith [1978]	Monchareonma (1982)	NRCS [2007] $H - K_w$	Stonea and Hilborna [2000]	NRCS [2007] K_f	Torii et al. [1997]	Wischmeier (1977)	Wiliams et al. (1984)
Mean Średnia	0,354	0,306	0,301	0,289	0,251	0,242	0,220	0,138	0,138
Maximum Maksimum	0,092	0,160	0,140	0,130	0,099	0,100	0,095	0,072	0,097
Minimum Minimum	0,439	0,520	0,560	0,460	0,412	0,430	0,285	0,253	0,196
$LSD_{0,05}$ $NIR_{0,05}$	0,042								
Symbols Symbole	a	b	b	bc	c	c	c	d	d

• Stone and Hilborn [2000]

Values of soil erodibility factor were between 0,099–0,412 Mg · ha^{-1} · Je^{-1}, and mean value 0,251 Mg · ha^{-1} · Je^{-1}.

• NRCS [2007]

Values of soil erodibility factor K_w fluctuated between 0,136 and 0,460 Mg · ha^{-1} · Je^{-1}, and mean value 0,289 Mg · ha^{-1} · Je^{-1}, while K_f between 0,100 and 0,430 Mg · ha^{-1} · Je^{-1} and mean value 0,242 Mg · ha^{-1} · Je^{-1}.

Analysis of LSD shows that Renard's method (group a) based on maximum and minimum grain diameter and their percentage content gives the highest values and strays stastistically from others methods. In turn Wischmeier's and Wiliam's methods based on silt and clay separates content and organic matter or organic carbon content give the lowest values and statistically strays from others methods (group d). Methods that produce similar results are methods: NRCS (based on separate content), Stone's and Hilborn's as well as Tori's (based upon separate content and organic matter content).

CONCLUSIONS

1. Review of subject literature show that proper determination of soil erodibility factor (*K*-USLE) is very complicated problem.
2. Results of investigations indicate that GIS technology may be effective tool for Carry out space analysis concerning soil erosion, highly activating calculations.
3. Detailed statistical analysis of results obtained by use of various methods points out high difference between Renard's, Wischmeier's and Wiliam's methods in comparison to the others ones.
4. The most similar values of soil erodibility factor were obtained my means of methods: NRCS, Stone'a and Hilborn's as well as Tori's.
5. In this paper nine empirical models for evaluation of *K*-USLE soil erodibility factor were used. The results were compared by use of LSD method.

REFERENCES

Atlas klimatu Polski, 2005. Instytut Meteorologii i Gospodarki Wodnej. Warszawa.

Bahadur K., 2009. Mapping soil erosion susceptibility using remote sensing and GIS: a case of the Upper Nam Watershed, Nan Province, Thailand. Environ. Geol. 57, 695–701.

Drzewiecki W., Mularz S., 2005. Model USPED jako narzędzie prognozowania efektów erozji i depozycji materiału glebowego. Rocz. Geomat. 3(2), 5–9.

Gumiński R. 1948. Próba wydzielenia dzielnic rolniczo-klimatycznych w Polsce. Przegl. Met. Hydrol. 1, 7–20.

Kondracki J., 1998. Geografia regionalna Polski. Wyd. Naukowe PWN Warszawa.

Moehansyah H., Maheshawari B.L., Armstrong J. 2004. Filed evaluation of selected soil erosion models for catchment management in Indonesia. Biosyst. Engineer. 88(4), 498–499.

Nam P.T., Yang D., Kanae S., Oki T., Musiake K., 2003. Global soil loss estimate using rusle model: the use of global spatial datasets on estimating erosive parmeters. Geoinformatics 14(1), 49–51.

NRCS (National Resources Conservation Service), 2007. Part 618 – Soil Properties and Qualities. US Department of Agriculture, http://soils.usda.gov/technical/handbook/contents/part618.html#55.

Rajurkar M.P., Kothyari U.C., Chaube U.C., 2002. Artificial neural networks for daily rainfall-runoff modelling. Hydrol. Sci. J. 47(6), 865–877

Rejman J., Turski R., Paluszek J., 1998. Spatial and temporal variations in erodibility of loess soil. Soil Tillage Res. 46, 66–67.

Soil Survey Staff. 1975. Soil Taxonomy. USDA Washington, 17–754.

Stone R.P., Hilborn D., 2000. Universal soil loss equation (USLE). Ministry of Agriculture, Food and Rural Affairs Ontario.

Torri D., Poesen J., Borselli L., 1997. Predictability and uncertainty of the soil erodibility factor using a global dataset. Catena 31, 1–22.

Wawer R., Nowocień E., Podolski B., 2005. Real and Calculated K_{USLE} Erodibility Factor for Selcected Polish Soils. Pol. J. Environ. Stud. 14(5), 655–658.

Wischmeier W.H., Smith D.D., 1978. Predicting Rainfall Erosion Losses. A Guide to Conservation Planning. Agriculture Handbook 282. US Department of Agriculture Washington.

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