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Real and Calculated K_{USLE} Erodibility Factor for Selected Polish Soils

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Abstract

The soil erodibility factor according to the USLE method was calculated for selected Polish soils. Data from 10 experimental plots of different soils in black fallow a terrain slope of 10% and in sprinkling conditions, were used for the study.

The comparison of real data and data obtained form equations given by Wischmeier and Smith, as well as by Wiliams, revealed considerable differences in K_{USLE} values of the investigated soils. The statistical investigations were conducted to find the best fitting between observed and numerically predicted K_{USLE} values. The highest correlation (R=0.65) revealed the pair of M_{USLE} and $\ln(K_d/K_w)$ variables, where K_d represents real K_{USLE} values, while K_w K_{USLE} was calculated with Williams equation. The non-linear logarithmic regression model has shown the best fit, reaching the regression of R=0.77 between variables $\ln(K_d/K_w)$, M_{USLE} and outflow coefficient.

Keywords: soil erosion, erodibility factor, simulated rain

Introduction

According to FAO about 1.6 billion hectares of plough land, (i.e. about 13% of the area of continents) come under erosive degradation, over 1 billion hectares under water erosion, and about 550 million hectares under wind erosion [1].

In Poland the potential water erosion appears on about 28% of the country's general area and in this over 700 thousand hectares of grounds became ruined. A major portion is not suitable for agricultural use at all.

The quantitative methods for estimation of erosion spatial structure are suitable only for orientation and gradation of washout threats, not providing any information on the amount of sediment as well as on the locations of deposition areas and transportation paths [2, 3].

Recent investigations on erosion in Poland have been conducted with the use of spatial analyses and digital simulation models. These were mainly models and analyses based on USLE applied in scale of field, or slope, as EPIC [4], or AGNPS [5]. Simultaneously, the investigations on the adaptation of USLE parameters to geographical conditions of Poland, particularly on parameter K, have been conducted. [6, 7]. The hitherto existing research show large divergence of parameter K from expected value, calculated from Wischmaier's and Smith's equation.

The present article presents the results, conducted in simulated conditions aimed at estimation of regression equations for real values of K_{USLE} with regard to K_{USLE} calculated the with equation developed by Wischmeier and Smith [8, 9], as well as that by Wiliams [9, 10].

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Materials and Methods

Model Experiments for Simulated Sprinkling of Soils

For rain simulation a sprinkler was applied, which was designed at the Institute of Soil Science and Plant Cultivation in Pulawy and performed as a prototype at the Polish Academy of Sciences' Institute of Agrophysics in Lublin [11, 12]. Simulated sprinkling were executed in a temporary interval of 30, 40, 45, 50 and 60 minutes. The recorded parameters included: time, amount and intensity of simulated rain, the moisture of soil before sprinkling as well as quantities of runoff and sediment uptake. For every soil type sprinkling was repeated 13 times, in two replicates each. After every simulated rain, the soil material on the studied plot was replenished with spare soil.

Estimation of Indicators of Soil Susceptibility to Water Erosion According to USLE – K_{USLE}

Investigations conducted by Rejman and Usowicz [13] suggested essential differences between K_{USLE} values counted with Wischmeier's and Smith's equation (Kws) [8, 9]:

$$K_{USLE} = Kws = \frac{0.00021 \cdot M^{1.14} \cdot (12 - OM)}{100} + \frac{3.25 \cdot (c_{soilstr} - 2) + 2.5 \cdot (c_{perm} - 3)}{100}$$

where:
M – textural factor; $M = (m_{silt} + m_{vfs}) \cdot (100 - m_c)$,
m_{silt} – silt fraction content (0.002-0.05mm) [%];
m_{vpf} – fine sand fraction content (0.05-0.1mm) [%];
m_c – clay fraction content (<0.002mm) [%].
$c_{soilstr}$ – soil structure code according to USDA;
c_{perm} – profile permeability class according to USDA;
OM – percent organic matter [%].
K_{USLE} – USLE soil erodibility factor [0.013 metric ton m^2 hr/(m^3-metric ton cm)];
and real K_{USLE} values (**Kd**) [8, 9]:

$$K_{USLE} = Kd = \frac{sed}{1.292 \cdot EI_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG}$$

where:
sed – sediment uptake; $[t \cdot ha^{-1} \cdot d^{-1}]$
EI_{USLE} – rain erosion index; $[0.017 \cdot Mg \cdot cm \cdot m^{-2} \cdot h^{-1}]$
K_{USLE} – the USLE soil erodibility factor [0.013 metric ton m^2 hr/(m^3-metric ton cm)]
C_{USLE} – the cover and management factor;
P_{USLE} – the support practice factor;
LS_{USLE} – the topographical factor

There is also an equation for estimating K_{USLE} values given by Wiliams' [8, 10]:

$$K_{USLE} = K_w = f_{csand} \cdot f_{cl-si} \cdot f_{orgc} \cdot f_{hisand}$$

where:
f_{csand} is a factor, that lowers the K indicator in soils with high coarse-sand content and higher for soils with little sand; f_{cl-si} gives low soil erodibility factors for soils with high clay-to-silt ratios; f_{orgc} reduces K values in soils with high organic carbon content, while f_{hisand} lowers K values for soils with extremely high sand content:

$$f_{csand} = \left(0.2 + 0.3 \cdot \exp\left[-0.256 \cdot m_s \cdot \left(1 - \frac{m_{silt}}{100}\right)\right]\right)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3}$$

$$f_{orgc} = \left(1 - \frac{0.25 \cdot orgC}{orgC + \exp[3.72 - 2.95 \cdot orgC]}\right)$$

$$f_{hisand} = \left(1 - \frac{0.7 \cdot \left(1 - \frac{m_s}{100}\right)}{\left(1 - \frac{m_s}{100}\right) + \exp\left[-5.51 + 22.9 \cdot \left(1 - \frac{m_s}{100}\right)\right]}\right)$$

where:
m_s – the sand fraction content (0.05-2.00 mm diameter) [%];
m_{silt} – the silt fraction content (0.002-0.05 mm diameter) [%];
m_c – the clay fraction content (<0.002 mm diameter) [%];
orgC – the organic carbon (SOC) content [%].

The assumptions used to calculate **Kw** and **Kws** values are presented in Table 1.

Parameters of model micro-plot, assumed in the estimations of K_{USLE} in simulated conditions (**Kd**): L_{hill}=2m, α_{hill}=6°, C_{USLE}=1, P_{USLE}=1.

Results

On the basis of investigations conducted with the presented methodology, the values of indicators of soils' susceptibility to water erosion according to USLE as well as derivative coefficients Kd/Kws and Kd/Kw for all studied soils have been obtained (Table 2, Fig. 2).

The correlation matrix for dependent variables of Kd indicates the highest correlation between its derivative variable ln(Kd/Kw) and variables: M_{ULSE} (0.62) and USDA_SIL (0.56). The remaining correlation coefficients connected with difference Kd/Kws as well as Kd/Kw are generally higher for variable Kw than for variable Kws. Yet variable Kw shows weaker direct correlation with variable Kd (0.44) than variable Kws (0.52).

On the basis of correlation analysis of pairs of dependent variables: Kd, Kw and Kws and their derivative variables, we conducted the estimation of function in logarithmic model, binding the variables ln(Kd/Kw) with the independent M_{USLE} variable. We obtained linear function with the following formula:

Table 1. Soil parameters for the estimation of soil susceptibility to erosion according to USLE **Kw** and **Kws** [8].

Soil*	Characteristics of soil kinds								
	SOM	orgC	m_{silt}	m_s	m_{vfs}	m_c	$C_{soilstr}$	C_{perm}	M
	%	%	%	%	%	%			
pl	0.39	0.23	0.5	98.5	1.0	1.0	1	1	148.5
ps	1.4	0.81	12.0	84.5	14.5	3.5	2	1	2557.3
pgl	1.13	0.66	20.0	77.0	12.0	3.0	2	2	3104.0
pgm	1.89	1.10	28.0	68.0	10.0	4.0	3	2	3648.0
gl	1.55	0.90	30.5	60.5	11.5	9.0	3	2	3822.0
gs	2.29	1.33	25.5	64.0	3.5	10.5	3	3	2595.5
plz	1.72	1.00	52.5	44.5	12.0	3.0	3	2	6256.5
plg	1.33	0.77	70.5	19.5	12.0	10.0	3	2	7425.0
gc	1.78	1.03	28.5	46.0	3.0	25.5	3	3	2346.8
pgmp	1.39	0.81	38.5	53.0	16.5	8.5	3	3	5032.5

*pl – loose sand; ps-weak loamy sand; pgl-light loamy sand; pgm-strong loamy sand; gl-light loam; gs-average loam; plz-oridinary silt; plg-loess; gc-heavy loam; pgmp-strong loamy silty sand.

Table 2. Descriptive statistics for raw variables: Kd, Kws, Kw and their derivative variables: Kd/Kws i Kd/Kw for the whole population of investigated soil kinds.

Variable	Statistical parameters			
	Mean	Range		SD
		Minimum	Maximum	
Kd	0.144	0.000	1.256	0.192
Kws	0.285	0.003	0.612	0.168
Kw	0.159	0.071	0.249	0.044
Kd/Kws	0.612	0.002	5.095	0.842
Kd/Kw	0.806	0.002	6.972	1.038

Explanation: **Kd** – K_{USLE} calculated from sprinkling; **Kws** – K_{USLE} calculated with Wischmeier's and Smith's equation; **Kw** – K_{USLE} calculated with Wiliams' equation; **Kd/Kws** – **Kd** to **Kws** proportional factor; **Kd/Kw** – **Kd** to **Kw** proportional factor.

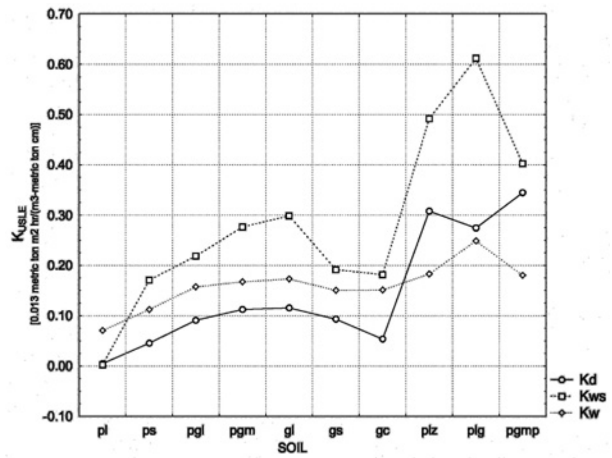

Fig. 1. Kd, Kw and Kws average values for investigated soil kinds on the base of simulated sprinkling. Abbreviation of soils, see Table 1.

Explanation: **Kd** – K_{USLE} calculated from sprinkling; **Kws** – K_{USLE} calculated with Wischmeier's and Smith's equation; **Kw** – K_{USLE} calculated with Wiliams' equation

$$\ln(Kd/Kw) = -3.92 + 0.051 * M_{USLE}^{0.5}$$

and a correlation coefficient R = 0.651.

The further analysis of ternaries of dependent variable ln(Kd/Kw) show the best fitting for dependent variables: M_{USLE} and outflow coefficient. Estimated function with the general formula

$$z = a + bx*\ln x + c*(\ln y)^2$$

is characterized with coefficient R = 0.7689 as well as relatively good relationship between observed and predicted values (Fig. 2).

Discussion

The ranking of studied soils according to increasing susceptibility to superficial rainwash in conditions of simulated

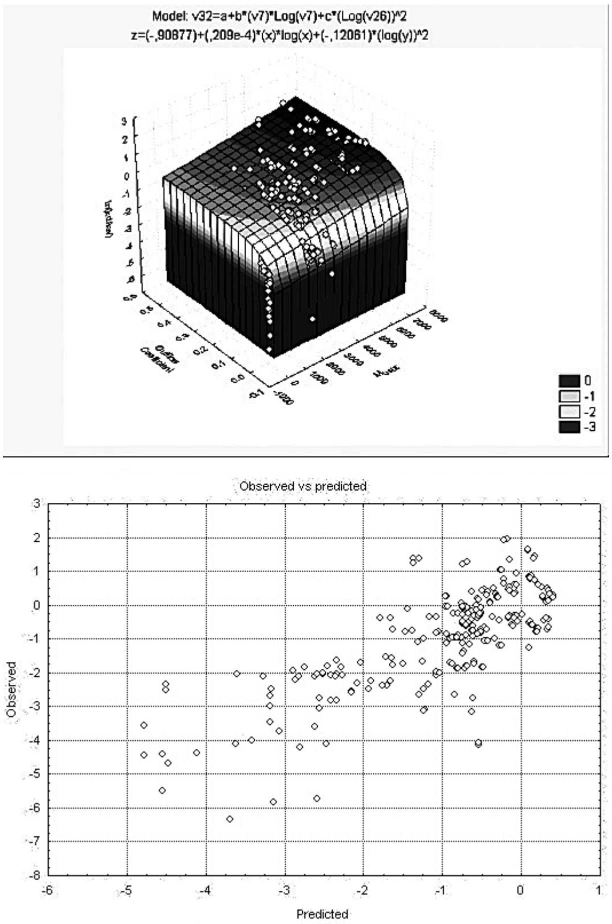

Fig. 2. Best fit 3D equation for estimation of the relationship between Kd and Kw (R=0.7689) and the chart of its fitting quality

rain was as follows: loose sand, weak loamy sand, heavy loam, average loam, light loamy sand, strong loamy sand, light loam, loess, oridinary silt, strong loamy silty sand. This result confirmed differences among respective soils received by other researchers as well as the legitimacy of the general indexing into classes of susceptibility on erosion [14].

It was ascertained that the values of the coefficient K_{USLE} calculated from simulated research, differ essentially from the values calculated with the equations of Wischmeier and Smith [8, 9] as well as Wiliams [8, 10]. The chart of arithmetical averages of affirmed and counted K_{USLE} indicators (Fig. 1) reveals generally uniform differentiation among investigated soil, showing divergence only in the case of loess soil. By virtue of high silt content in loess soils, exceeding 70%, it is not recommended to apply the formula of Wischmeier and Smith for K_{USLE} calculation for these soils [8, 10].

The analysis of correlation of raw pairs of variables for the dependent variable Kd show essential dependences with: Kws, $M_{USLE,}$ USDA_SIL, USDA_FS, H_{init}, USDA_WILG, E_{pcp} and Kw. However, the most correlated variable is Kws.

The analysis of derivative variables have shown the high dependency between variable ln(Kd/Kw) and the M_{USLE} coefficient reaching R=0.6178.

The non-linear estimation of ternary of variables ln(Kd/Kw), M_{USLE} and outflow coefficient allowed to improve the fitting to R=0.7689 as well as to introduce the dependence of parameter Kd from hydrological parameters.

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