Use of Chosen Methods for Determination of the USLE Soil Erodibility Factor on the Example of Loess Slope

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ABSTRACT

The investigations were carried out on a loess slope in the Brzeźnica village, in the Rudnik commune. Nine points were chosen, in which particular parameters being parts of the examined models, were determined. On the basis of the literature, eight models for the Universal Soil Loss Equation (USLE) erodibility factor determination were designated. The chosen models were the ones proposed by: Wishmeier, Monchareonm, Torii et al. and Walker (all based on texture and organic matter content, Wischmeier and Smith (based on texture organic matter content and additionally on aggregate classes), Wiliams et al. (based on texture and organic carbon content), Renard et al. as well as Stone and Hilborn (both based only on texture). The investigated site was characterized as well. The statistical conclusions were drawn and the obtained results were compared with the results presented in the literature.

Keywords: soil erodibility factor, model USLE

INTRODUCTION

Water erosion, along with salinity [Boroń et al. 2010, Boroń et al. 2016, Klatka et al. 2015], drought, floods and heavy metals contamination, belongs to the most dangerous forms of soil degradation. Soil water erosion can be determined in various ways, including modelling, the approach used most often. Among many published soil erosion models, Universal Soil Loss Equation (USLE) is the most popular. One of the factors used in creating this model is the soil erodibility factor, which depends on the mechanical properties of the soil. The main factors determining it are textural properties (granulometry and sorting), structural properties (presence of stable soil aggregates), the void ratio and soil moisture [Klatka 2020]. The USLE erodibility factor K_{USLE} expresses the mass of eroded soil (Mg·ha^{-1}) from a standard plot per erodibility unit Je (h·ha^{-1}·MJ^{-1}·cm^{-1}). A slope of length 22,1 m, width 1.87 m and 9% inclination was taken as the standard plot in the USLE model [Wischmeier and Smith 1978], assuming that agricultural practices are conducted

along the slope and that there is no plant cover for at least two years prior to measurements. For standard conditions, the coefficients L, S, C and P are defined as 1 [Wischmeier and Smith 1978]. Determination of the soil erodibility factor K_{USLE} is problematic due to the number of elements characterizing the soil cover, so various methods have been developed to quantify it. These methods can be divided into direct (field) and indirect approaches (by means of equations and nomograms). As the field investigations that involve installing measurement systems for effluents on test plots are costly and time-consuming, they are sometimes impossible to be carried out on a large scale [Shabani et al. 2014]. In practice, this coefficient is therefore calculated by means of empirical functions (pedotransfer functions), taking into account various parameters. Such functions describe the relationships between the easily-measurable parameters and the parameters which are more difficult to measure.

Wischmeier presented the first method for determining the K_{USLE} coefficient in 1977 [Torri et al. 1997, Ryczek et al. 2013a]. The method was

based on the 0.1–0.002 mm and < 0.002 mm fractions and organic matter content. Wischmeier and Smith [1978] introduced a modification of the equation [Chodak et al. 2008, Ryczek et al. 2013a, Panagos et al. 2014] involving water permeability, structure and the 0.1 – 2 mm fraction. Monchareon (1982) introduced a nomogram [Bahadur 2009, Ryczek et al. 2013a], and Williams (1984) discussed the organic matter content [Zhang et al. 2008]. Modifications were proposed [Renard et al., 1997; Torri et al., 1997] which reduced the input data only to texture [Drzewiecki and Mularz 2005, Ryczek et al. 2013a, Ryczek et al. 2013b]. Stone and Hilborn [2000] used considerable simplifications concerning the percentage content of organic matter (OM) and soil type. The NRCS [2007] elaborated the method, taking into account the coarse particle content and land use [Ryczek et al. 2013a]. In 2017, Walker [2017] proposed a regression equation that enabled researchers to omit the time-consuming process of determining K_{USLE} based on the Wischmeier and Smith nomogram [1978]. Some investigations [Vaezi et al. 2010] emphasised that K_{USLE} may be influenced by soil structure, and is related to calcium carbonate. In calcareous soil, calcium carbonate influences the formation of soil aggregates, causing increased water permeability and consequently a decrease in K_{USLE} [Shabani et al. 2014]. The K_{USLE} values calculated for such soils may not be appropriate [Vaezi et al. 2010].

The soil erodibility factor remains the subject of tests and verifications, so despite the extensive literature on the topic, the best method of calculation remains an open question. In Poland, similar investigations were carried out by Ryczek et al. [2013a] among others, within the 48.54 km² Kasińczanka basin. The authors analysed nine methods for 52 sampling points located within the basin, with soil textures including loam, sandy clay loam, clay loam and silt loam. The organic matter content was between 1.85 and 4.28%, while water permeability was between $0.84 \cdot 10^{-3}$ and $4.87 \cdot 10^{-1}$ m·d⁻¹. The following calculation methods were used: Wischmeier [1977], Wischmeier and Smith [1978], Monchareon (1982), Williams et al. (1984), Renard et al. [1997], Torri et al. [1997], and Stone and Hilborn [2000] as well as the NRCS K_w and the NRCS $\underline{K}_f$ [2007] models. Baryła [2012] carried out the investigations on the soil mass eroded in the area of the Agricultural Farm Puczniew (Łódź province). The arable lands of the farm consist mostly of loam and

sand. The K_{USLE} coefficient was determined by use of the Wischmeier and Smith [1978] nomogram. Święchowicz [2016] investigated the K_{USLE} factor in the Łazy village located on the Brzesko Foreland, in the area of the Agricultural Pilot Plant of the Jagiellonian University 'Łazy'. The texture was uniform and the sand content was low (below 10%), with high silt content (50–70%) and clay content (8–18%). The organic matter content in the humus horizon was between 0.5 and 1.6%. Relief was characterised by the occurrence of curved hilltop hummocks with sections of flattened surfaces, and mainly low-gradient (3–10°) concavo-convex slopes.

Kruk [2016] investigated the soil loss in the mountain basin of the Mątny stream, which has an area of 1.47 km². Soil texture was determined for 47 points, with results showing sandy clay loam, clay loam, loam and silty clay in the study area. The author used the Wischmeier and Smith [1978] and Renard et al. [1997] methods. Ryczek et al. [2013b] carried out investigations in the Smugawka stream basin, located in the Island Beskid region with an area of 5.40 km². The K_{USLE} parameter was determined using the Renard et al. method [1997]. The soils in the basin included clay loam, loam, sandy loam and silty clay. The K_{USLE} factor can also be determined by mapping the K_{USLE} distribution, as elaborated by Panagos et al. [2014], who determined the K_{USLE} based on the Wischmeier and Smith [1978] method for 25 countries including Poland.

The aim of this work was to compare these methods for determination of the soil erodibility factor, K_{USLE}, for use in the USLE model.

Study site

The study site was an area located in the province of Silesia, Racibórz administrative district, Rudnik commune. The investigated site is geomorphologically part of the Silesia Plain subprovince, covering all of the western and middle parts of the Racibórz administrative district in the Oder river valley. Two mesoregions occur within the commune, Głubczyce Plateau and Racibórz Valley [Kondracki 2000]. According to the Gumiński agricultural-climatic province categories, the area belongs to the Sub Sudety–XVIII province. Masses of wet air from the Atlantic Ocean reach the area often, with rarer masses of dry continental air from the east. Total rainfall is 650 mm per year, and there are approximately 40–55 days

with snow cover each year. The mean yearly temperature is 8.0°C. The warmest month is July (mean temperature about 18°C), and lowest temperatures are recorded in January (mean –2.1°C). There are typically 30 frosty days and 120 days with ground-frost each year. The growing season starts early, in the second week of March, and lasts an average of 210–220 days. Southern and western winds prevail over the area [Radomski 1987, Woś 1993]. The study site was covered by winter wheat during fieldwork on 20 June 2017. Before sowing, traditional tillage was used.

Methods

Field experimentation was carried out on 20 June 2017. Nine measuring points were chosen (Fig. 1a). Three replicates for each sample were taken from the upper part of soil, using 100 cm³ rings for determination of physical properties (Fig. 1b) and using plastic bags for the remaining analyses. The following soil properties were analysed: texture by means of the Casagrande method [PN-R-04032 1998], bulk density (ρ_o), solid phase density (ρ_s), total porosity (n) [Mocek et al. 1997, 2015], organic matter content (OM), organic carbon content (C) [Oleksynowa et al. 1991] and saturated hydraulic conductivity (k) [Twardowski and Drożdżak 2006] (Table 1).

The K_{USLE} coefficient was calculated using 8 methods, which depend on various soil properties. In this work, the models proposed by Wischmeier [1997], Wischmeier and Smith [1978], Monchareon (1982) [Bahadur 2009], Williams et al. (1984) [Zhang et al. 2008], Renard et al. [1997], Torri et al. [1997], Stone and Hilborn [2000] and Walker [2017] (Table 2) were used. All

the results were presented in units of Mg·ha·Je⁻¹. The statistical analyses were performed using the Statistica 13.0 software package, using the Least Significant Difference (LSD) test and basic statistical analysis (Tukey and Fischer-Snedecor procedures). The LSD method allowed determining which differences are statistically significant. In the case where the absolute value of the difference between the means is greater than LSD $|\bar{X}i - \bar{X}| \geq NIR$, it is assumed that differences are significant. The LSD values were calculated using the Tukey test, based on the Student t-distribution. The mathematical model is described as:

$$x_{i,j} = \mu + \rho_i + \tau_j + \varepsilon_{i,j} \tag{1}$$

where: $x_{i,j}$ is the hypothetical value of the investigated feature of replicate i (i = 1, 2, …..) and object j (j = 1, 2, …..),
μ is the state value estimated by the mean of all observations,
ρ_i is the block component (influence of affiliation to the i-th block),
τ_j is the object component (influence of j-th object),
$\varepsilon_{i,j}$ is the random component (error),
r is the number of repetitions (blocks), and
k is the number of factor objects.

The mean value for each group and object mean (from all data), total sum of squares (total variability), total sum of squares between groups (from all data) and sum of squares within each group (intragroup variability) were determined. The F-statistics were then calculated and compared with the table values. The results are presented in Table 3.
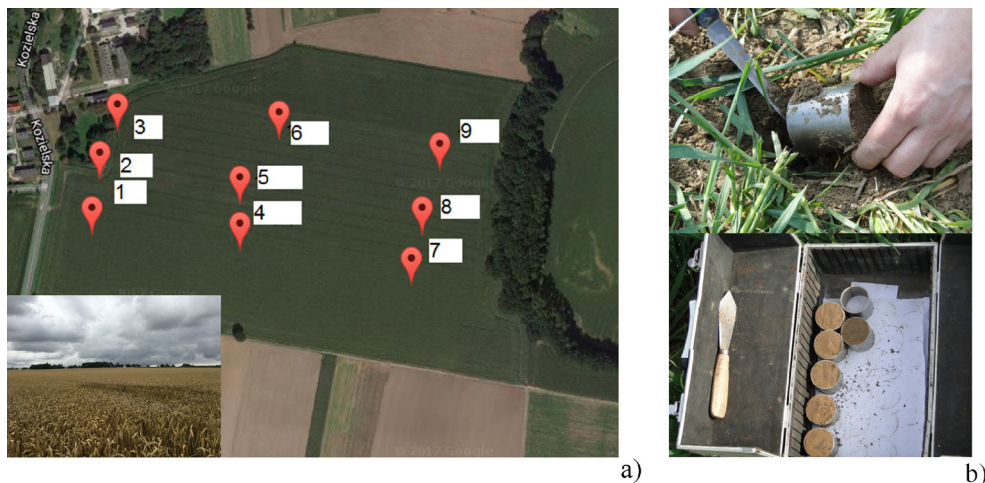

Figure 1. Location of the points measured in the study site

Table 1. Soil properties

Parameter	Method	
Bulk density (ρ_o), Mg·m^{-3} Internal ring volume (V_p), m^3	$\rho_0 = \frac{m_{mt} - m_t}{V_p}$ $V_p = \frac{\pi \cdot d^2}{4}$	m_{mt} – dry soil mass with a ring, Mg; m_t – mass of a ring, Mg d – internal ring diameter, m
Solid phase density (ρ_s), Mg·m^{-3}	$\rho_s = \frac{m_{mt} \cdot \rho_w}{P_w + g - P_{w.g}}$	P_w – mass of a picnometer with distilled water, Mg $P_{w.g}$ – mass of a picnometer with distilled water and soil, Mg ρ_w– water density, Mg·m^{-3}
Total porosity (n), –	$n = 1 - \frac{\rho_o}{g_s}$	ρ_o – bulk density, Mg·m^{-3}, ρ_s – soil phase density, Mg·m^{-3},
Organic matter content, (*OM*), %	The Turin method [Oleksynowa et al. 1991], depending in oxidation of organic matter by potassium dichromate (Cr^{6+}). Organic matter content was calculated according to the equation:	
	$OM = \frac{(a-b) \cdot f \cdot 0,10344}{q}$	a – amount of 0,2 n FeSO$_4$ for titration of blind sample, b – 0,2 n FeSO$_4$, f – amount of 0,2 n FeSO4, q – mass of dry soil
Organic carbon content (*C*), %	% OM = % C · 1,724	1,724 – converting coefficient
Saturated hydraulic conductivity (*k*), m·d^{-1} Empirical coefficient, *C*	k = C·d$_{10}^2$ C = 400+40·(*n*-26)	d$_{10}$ – diameter of particles, that mass with the mass of lower diameter is 10% of sample mass, n – total porosity,%

The total sum of squares (*G*) was calculated according to the equation

$$G = \sum_{i=1}^{a} \sum_{j=1}^{n} y_{i,j}^2 - \frac{Y_{..}^2}{an} \qquad (2)$$

the sum of squares of factors (*T*) was calculated according to the equation

$$T = \frac{1}{n} \sum_{i=1}^{a} y_{i,j}^2 - \frac{Y_{..}^2}{an} \qquad (3)$$

and the sum of block squares (*R*) was calculated according to the equation

$$R = \sum_{j=1}^{n} y_{i,j}^2 - \frac{Y_{..}^2}{an} \qquad (4)$$

Correction *P* is calculated according to the equation

$$P = \frac{Y_{..}^2}{an} \qquad (5)$$

$$Y_i = \sum_{j=1}^{n} y_{ij} \qquad (6)$$

$$Y_j = \sum_{i=1}^{a} y_{ij} \qquad (7)$$

$$Y_{..} = \sum_{i=1}^{a} \sum_{j=1}^{n} y_{ij} = \sum_{i=1}^{a} Y_i = \sum_{j=1}^{n} Y_j \qquad (8)$$

The sum of squared errors (*E*) is calculated according to the equation

$$E = G - T - R \qquad (9)$$

LSD was calculated as a product of the standard deviation of the means difference s_D (based on error due to variance) and the t_D–value of the dependent variable in relation to significance level *α,* degrees of freedom for the error (*v*) and the number of compared means (*m*):

$$NIR = t(\alpha; k, N - k) S_e \sqrt{\frac{1}{n}} \, [\text{-}] \qquad (10)$$

where: $t(\alpha; k, N – k)$ is the critical value of the standardised Student t-test range. The standard deviation of the difference between the means was calculated as:

$$s_D = \sqrt{\frac{2s_E^2}{r}} \, [\text{-}] \qquad (11)$$

RESULTS AND DISCUSSION

The soil texture was analysed for 9 sample locations, based on the PN-R-04032 [1998] standard (table 4). The concentrations

Table 2. Values of the soil erodibility factor K_{USLE}

Method	Equation	
Wischmeier [1977],	$K = (12 - OM) \cdot [p(100 - C)]^{1,14}$	*OM* – organic matter content, %, *C* – content of fraction <0,002 mm [%], *p* – content of fraction 0,002 - 0,1 mm, %
Wischmeier and Smith [1978]	$100K = 2,1 \cdot M^{1,14} \cdot 10^{-4} \cdot (12 - a) + 3,25 \cdot (b - 2) + 2,5 \cdot (c - 3)$	

The *Wischmeier andi Smith nomogram [1978]for soil of silt and fine sand content (0,002 – 0,2 mm)*

M – product of the percentage of grains with a diameter of 0,002 to 0,1 mm and grains from 0,002 to 2,0 mm:

$$M = \int_{0,002}^{0,1} (100 - \int_{0}^{0,002}) \ [-]$$

a – organic matter content OM,%,
b – soil aggregate class; 1: <1 mm, 2: 1-2mm, 3: 2-5 mm or 5-10mm, 4: >10 mm;
c – soil water permeability class [USDA, 1951]; 6 – very low, 5 – low, 4 – medium low, 3 – medium, 2 – medium high, 1 - high

Method	Equation	
Wiliams et al. [1984]	$K = \{0,2 + 0,3 \exp \left[-0.0256 san \dfrac{(1 - sil)}{100} \right]\} \cdot \left(\dfrac{sil}{cla + sil}\right)^{0,3} \cdot \left(1,0 - \dfrac{0,25C}{C + \exp(3,72 - 2,95C)}\right) \cdot \left(1,0 - \dfrac{0,7sn1}{sn1 + \exp(-5,51 + 22,9sn1)}\right)$	
	san – sand fraction content [%], *sil* – silt fraction content [%], *cla* – clay fraction content [%], *sn1* – ratio calculated as: $sn1 = \frac{1-san}{100}$ [%], *C* – organic carbon content [%]	
Renard et al. [1997]	$K = 0,0034 + 0,0405 \cdot exp \left[-0,5 \left(\dfrac{logD_g + 1,659}{0,7101} \right)^2 \right]$	
	$D_g = exp \left(0,01 \cdot \sum f_i \cdot ln \dfrac{d_i - d_{i-1}}{2} \right)$	d_i – maximum diameter of a grains in a given class [mm], d_{i-1} – minimum diameter of a grain in a given class [mm], *f* – mass share [%].
Torii et al. [1997]	$K = 0,0293(0,65 - D_G + 0,24D_G^2) \cdot exp \left\{ -0,0021 \dfrac{OM}{C} - 0,00037 \left(\dfrac{OM}{C} \right)^2 - 4,02C + 1,72C^2 \right\}$	
	$D_G = \sum f_i ln \sqrt{d_i d_{i-1}}$	d_i – maximum diameter of grains in a given class; d_{i-1} – minimum diameter of grains in a given class, mm; *OM* – organic matter content, %; *C* – content of fraction <0,002 mm,%
Walker [2017]	Regression equation with parameters to be determined based on readings at least 3 values of *K* obtained based on the presented above nomogram	
	$K = a \cdot X + b \cdot Y + c \cdot Z$	a, b, c – parameters of linear regression determined based on 3 chosen points, *X* – % sum of fractions 0,05-0,002 mm and 0,05-0,1 mm, *Y* – % content of sand fraction (2 – 0,1 mm), *Z* – % organic matter content.

Method	Stone and Hilborn [2000]			
Monchareonm [1982]				

Text. group [2008]	OM [%]	Fractions PTG [2008]	OM [%]
clay	0.22	loamy sand	0.39
clay loam	0.30	sand	0.02
coarse sandy loam	0.07	sandy clay loam	0.20
fine sand	0.08	sandy loam	0.13
fine sandy loam	0.18	loamy clay silt	0.38
silty clay	0.17	silty loam	0.26
loam	0.30	silty clay loam	0.32
fine sandy loam	0.11	very fine sand	0.43
loamy sand	0.04	loamy very fine sand	0.35

of sand (2.0–0.05 mm), coarse silt (0.05–0.02), fine silt (0.02–0.002 mm) and clay (<0.002 mm) are presented in Table 4. The classification of granular groups was performed according to the methods of PTG [2008].

The analysis of the results showed that the soils in the study area are not differentiated by texture, but rather are all loamy silt. The sand content was 13–18%, the silt content was 70–79% and the clay content was 5–12%. Three replicate measurements of bulk density (ρ_o), solid phase density (ρ_s), organic matter content (*OM*), organic carbon content (*C*) and total porosity (*n*) were carried out for each point, with results presented in Table 5. Bulk density (ρ_o) varied between 1.41 and 1.57 Mg·m^{-3}, while solid phase density (ρ_s)

varied between 2.52 and 2.75 Mg·m^{-3}. *OM* varied from 0.85 to 1.35%, and *C* fell between 0.52 and 0.78%. Total porosity (n) was between 40 and 46% (table 5).

Saturated hydraulic conductivity varied between 0.003111 and 0.009097 m·d^{-1}. Saturated hydraulic conductivity plays an important role in forming surface runoff. High values show low surface runoff, while low values indicate higher-intensity runoff. Saturated hydraulic conductivity was classified as very low, $k < 3.0 \cdot 10^{-5}$ [USDA Soil Survey Manual 1951], in all samples. These results show that high runoff can occur in the study area. Figure 2 shows soil material transported as a result of runoff on the day of field investigations (20 July 2017).

Results of calculations of the K$_{USLE}$ soil erodibility factor

Table 6 presents the values of parameters used to determine the value of K$_{USLE}$. For the Wischmeier method [1977], the required percentage content of grains in the size range 0.1–0.002 mm was determined based on the grain size distribution

Table 3. Analysis of variance [Rudnicki 1992]

Source of variability	Degree of freedom	Sum of squares	Mean squares s^2	F$_{cal}$
Blocks	r – 1	R		$\frac{s_T^2}{s_E^2}$
Factor	k – 1	T	T / (k-1)	
Error	(r-1) (k-1)	E	E / [(r-1)(k-1)]	
Total	rk – 1	G		

Table 4. Soil texture at sampling locations

Point	% share of separates of diameter [mm]				
	sand	silt			clay
	2,00 – 0,05	0.05 – 0,02	0.02 – 0,005	0.005 – 0,002	< 0.002
1	17	40	24	9	10
2	17	40	25	8	10
3	18	37	27	6	12
4	13	41	26	8	12
5	15	39	25	10	11
6	15	38	26	10	11
7	14	40	31	5	10
8	14	42	29	8	7
9	16	44	26	9	5

Table 5. Bulk density (ρ_o), solid phase density (ρ_s), organic matter content (*OM*), organic carbon content (*C*), total porosity (*n*) and saturated hydraulic conductivity (*k*)

Point	ρ_o [Mg·m^{-3}]	ρ_s [Mg·m^{-3}]	OM [%]	C [%]	n [%]	k (m·d^{-1})
1	1.43	2.65	1.05	0.61	46	0.004806
2	1.53	2.63	1.35	0.78	42	0.004132
3	1.45	2.58	1.05	0.61	44	0.003214
4	1.57	2.75	0.90	0.52	43	0.003111
5	1.41	2.52	0.85	0.49	44	0.003635
6	1.57	2.72	1.15	0.67	42	0.003406
7	1.56	2.73	1.15	0.67	43	0.004297
8	1.48	2.52	1.00	0.58	41	0.009097
9	1.52	2.53	1.05	0.61	40	0.008047

curves. For sample sites 1, 2, 4, and 6, this value was 82%; for site 3, 80%; for site 5, 81%; for site 7, 83%; for site 8, 86%; and for site 9, 87%. The estimated K_{USLE} values were 0.27–0.31 t·ha^{-1}·Je^{-1}. The values of the 2.0 – 0.1 mm grain size fraction content for the Wischmeier and Smith method [1978] were 8% for sites 1–3, 5, and 9, 6% for site 4, and 7% for sites 6–8. The values of the *a* parameter were between 0.85 and 1.35%; in all samples the value of parameter *b* was found to be 2 (indicating that aggregates have a fine aggregate structure (1 – 2 mm)), and parameter *c* was found to be 6 (indicating that the ground has very low permeability). The values of the K_{USLE} parameter were found to be between 0.63 and 0.75 t·ha^{-1}·Je^{-1}. The values of K_{USLE} determined based on the Monchareon (1982) method (based on the geometric mean between 3 neighbouring values) were between 0.55 and 0.57 t·ha^{-1}·Je^{-1}. The K_{USLE} values determined with the Williams method (1984), taking into account texture, organic matter (*OM*)

and organic carbon content *(C)*, fell between 0.16 and 0.18 t·ha^{-1}·Je^{-1}. The values of K_{USLE} calculated using the Renard et al. method [1997] were between 0.41 and 0.43 t·ha^{-1}·Je^{-1}. In the analysis using the Torri et al. equation [1997], calculations were carried out assuming that the lowest grain size value of separates is 0.000005 mm; the results fell between 0.27 and 0.29 t·ha^{-1}·Je^{-1}. For the Stone and Hilborn [2000] method, the granular subgroups were distinguished based on the division of mineral deposits into groups and subgroups according to PTG [2008], and it was found that for all 9 points K_{USLE} equalled 0,41 t·ha^{-1}·Je^{-1}. Because of the lack of variability in the calculated results, the distribution isolines were not generated. During determination of the regression equation for the Walker method [2017], 3 random sampling points were chosen (1, 5, 9). This method produced the equation $K = 0.0074 \cdot S + 0,0044 \cdot C - 0,0925 \cdot OM$, with K_{USLE} values ranging between 0.52 and 0.58 t·ha^{-1}·Je^{-1}. According

Figure 2. Accumulation of soil material dislocated as a result of runoff

Table 6. K_{USLE} determinations for statistical analysis

Point	Methods							
	A	B	C	D	F	G	H	I
	Wischmeier [1977]	Wischmeier and Smith [1978]	Monchareonm [1982]	Wiliams [1984]	Renard et al. [1997]	Torii et al. [1997]	Stone and Hilborn [2000]	Walker [2017]
1	0.28	0.67	0.55	0.17	0.42	0.28	0.41	0.54
2	0.27	0.65	0.55	0.17	0.42	0.28	0.41	0.52
3	0.27	0.63	0.55	0.17	0.42	0.28	0.41	0.53
4	0.28	0.66	0.56	0.16	0.43	0.29	0.41	0.55
5	0.28	0.66	0.55	0.17	0.43	0.28	0.41	0.56
6	0.28	0.65	0.56	0.17	0.43	0.28	0.41	0.53
7	0.28	0.67	0.56	0.17	0.43	0.29	0.41	0.54
8	0.31	0.73	0.57	0.17	0.42	0.28	0.41	0.57
9	0.31	0.75	0.56	0.18	0.41	0.27	0.41	0.58
Mean	0.28	0.67	0.56	0.17	0.42	0.28	0.41	0.55
Mean for methods	0.42							
Median	0.41							

to these authors' suggestion, the K_{USLE} parameters for all 9 sampling locations were recorded based on the Wischmeier and Smith [1978] method. The percentage content of separates with grain sizes 2–0.1 and 0.1–0.002 mm, and the percentage content of organic matter (*C*) were used in the first approximation. In order to understand variability in the resulting K_{USLE} values, a second approximation was made, taking into account soil structure and its permeability (Fig. 3). The results fell between 0.44 and 0.51 t·ha^{-1}·Je^{-1} for the first approximation, and between 0.52 and 0.58 t·ha^{-1}·Je^{-1} for the second approximation. The isolines of spatial distribution for the K_{USLE} values calculated by these methods are presented in Figure 3. The statistical analyses were carried out based on Table 7, which shows the collected results of the K_{USLE} calculations, with their mean values and object and block sums.

The calculated value of the *F* coefficient (2880,000) is higher than the value indicated by the Fischer-Snedecor distribution tables (2,180), which suggests that statistically significant differences exist between all the means. The LSDs between the particular methods were calculated using the *q* Tukey test (Table 8). The value of the *q* Tukey parameter, according to the distribution tables (at $\alpha = 0{,}05$; $v = 56$; $m = 8$) is equal to 4.44. LSD is equal to 0.02.

From the LSD analysis results, it was found that the Wischmeier and Smith [1978] method (B) (group *a*), based on water permeability, structure and content of the 0.1–2 mm size fraction, differs statistically significantly from the other methods, as does the Williams (1984) method (D) based on the organic matter content method, among other parameters, belonging to group *e*. The B and D methods should be rejected. The Monchareon (1982) method (C), based on the nomogram with the information on the percentage content of sand, silt and clay separates, and the Walker [2017] method (I), based on the regression equation, make up one group (*b*) and do not differ statistically. This is similar to the Renard

et al. [1997] (F) and Stone and Hilborn [2000] (H) methods which make up group *c*, based on maximum and minimum grain diameters and their mass share (I), percentage organic matter content and soil type information (H). The Wischmeier [1977] method (A) and the Torri et al. [1997] method (G), which together compose group *d* and are based on the 0.1–0.002 and < 0.,002 mm grain size fractions and organic matter content, do not differ statistically from each other. However, they do differ from the other methods. Methods F and H both give the values closest to the mean (0.42 t·ha^{-1}·Je^{-1}) and median values (0.41 t·ha^{-1}·Je^{-1}), and thus can be taken as most reliable. This study was carried out on a low-inclination slope with uniform soil texture, and the site was covered by uniform plants and consisted of arable land; it can be therefore assumed that disagreement due to random factors was reduced to a minimum.

Comparing the obtained results with the values from the literature, one can see that Ryczek et al. [2013a] obtained the values in the range 0.072–0.253 Mg·ha·Je^{-1} using the Wischmeier [1977] method; 0.160 – 0.520 Mg·ha·Je^{-1} using the Wischmeier and Smith [1978] method; 0.140–0.560 Mg·ha·Je^{-1} using the Monchareon [1982] method; 0.097–0.196 Mg·ha·Je^{-1} using the Williams et al. [1984] method; 0.092–0.439 Mg·ha·Je^{-1} using the Renard et al. [1997] method; 0.091–0.285 Mg·ha·Je^{-1} using the Torri et al. [1997] method; and 0.099–0.412 Mg·ha·Je^{-1} using the Stone and Hilborn [2000] method. Baryła [2012] used the Wischmeier and Smith [1978] method to obtain a K_{USLE} value of 0.390 t·ha^{-1}·Je^{-1}. Ryczek et al. [2013] used the Renard et al. [1997] method for the Smugawka stream basin and obtained the values of 0.141–0.430 Mg·ha·Je^{-1} (0.141 Mg·ha·Je^{-1} for clay loam, 0.430 Mg·ha·Je^{-1} for silty clay, 0.354 Mg·ha·Je^{-1} for light loam, 0.279 Mg·ha·Je^{-1} for sandy clay loam and 0.248 Mg·ha·Je^{-1} for loam). Święchowicz [2016] obtained a mean value of 0.377 Mg·ha^{-1}·Je^{-1} from direct measurements, and a value of 0.738 Mg·ha^{-1}·Je^{-1} by

Table 7. Analysis of variability F (0.05;7;56)

Source of variability	Degree of freedom	Sum of squares	Mean squares s²	F_{cal}	F_{tab} $\alpha=0,05$
Blocks	8	0.01			
Method	7	3.60	0.514286	2880.000	2.180
Random error	56	0.01	0.000179		
Total	72	1.82			

means of the Wischmeier and Smith [1978] method. Kruk [2016] carried out investigations in the Mątny stream basin, obtaining the K_{USLE} values of 0.14 – 0.57 Mg·ha⁻¹·Je⁻¹ using the Wischmeier and Smith [1978] method, and the K_{USLE} values of 0.19 – 0.44 Mg·ha⁻¹·Je⁻¹ using the Renard et al. [1997] method. Lower values of K_{USLE} using the first method (0.14–0.26 Mg·ha⁻¹·Je⁻¹) were due to sandy clay loam and clay loam (0.17 Mg·ha⁻¹·Je⁻¹). For loam, the values fall within the range 0.27 – 0.52 Mg·ha⁻¹·Je⁻¹; values > 0.52 Mg·ha⁻¹·Je⁻¹ were obtained mostly from silty clay. Lower values (≤0.41 Mg·ha⁻¹·Je⁻¹) obtained using the second method were mainly from sandy clay loam and loam. The values > 0.41 Mg·ha⁻¹·Je⁻¹ almost all occurred in silty clay.
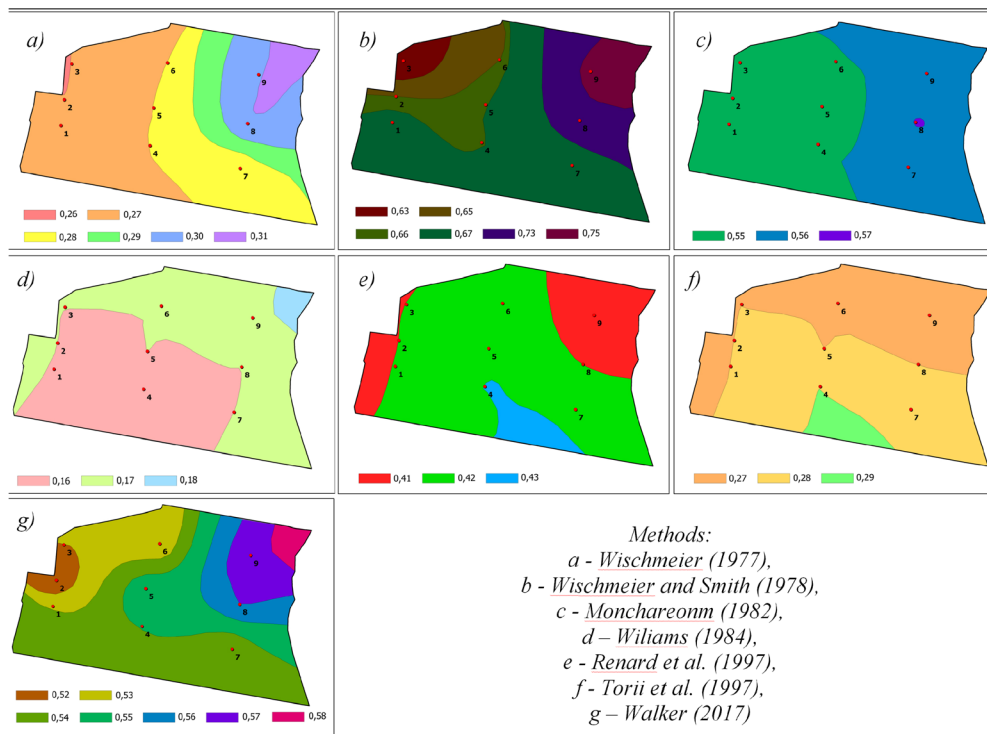

Figure 3. Isolines of the K_{USLE} distribution calculated according to the following methods: *a* – Wischmeier, *b* – Wischmeier and Smith, *c* – Monchareon, *d* – Williams, *e* – Renard et al., *f* – Torri et al., and *g* – Walker

Table 8. List of means in decreasing order (triangle of differences between means)

Method	Means		Triangle of differences between means						
B	0.67								
		0.11							
C	0.56		0.12						
		0.01		0.25					
I	0.55		0.14		0.26				
		0.13		0.15		0.39			
F	0.42		0.14		0.28		0.39		
		0.01		0.27		0.28		0.50	
H	0.41		0.14		0.27		0.39		
		0.13		0.14		0.38			
A	0.28		0.13		0.25				
		0.00		0.24					
G	0.28		0.11						
		0.11							
D	0.17								
Means	0.67	0.56	0.55	0.42	0.41	0.28	0.28	0.17	
	a								
		b	b						
				c	c				
						d	d		
								e	

a–e – uniform groups

The map of K_{USLE} factor distributions across Europe produced by Panagos et al. [2014], based on the Wischmeier and Smith [1978] method, shows that the mean K_{USLE} values for Europe averaged 0.320 Mg·ha^{-1}·Je^{-1}. The mean value for Poland was 0.299 Mg·ha^{-1}·Je^{-1}. For the Brzeźnica village, this value was between 0.46 and 0.55 Mg·ha^{-1}·Je^{-1}.

CONCLUSIONS

Different methods of calculating the USLE soil erodibility factory (K_{USLE}) produce differing results. The maps of the K_{USLE} distribution indicate that this coefficient shows high spatial variability. The proper determination of the K_{USLE} coefficient is a very real, complicated and important problem. Detailed statistical analysis of the results obtained with various methods showed noticeable differences between the results calculated by means of the Wischmeier and Smith, and Williams methods, and between the Wischmeier, and Torri et al. methods. The Wischmeier and Smith method gives overly high values, while the Williams, Wischmeier and Torri et al. methods give lower values in comparison to other ones. They should be used in limited contexts. The most reliable methods are the ones proposed by Renard et al., and Stone and Hilborn, because they give the values that fall within the ranges of mean and median values obtained for all the methods.

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