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# Comparison of Different Approaches to LS Factor Calculations Based on a Measured Soil Loss under Simulated Rainfall

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**Abstract**

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Geographic Information Systems (GIS) in combination with soil loss models can enhance evaluation of soil erosion estimation. SAGA and ARC/INFO geographic information systems were used to estimate the topographic (LS) factor of the Universal Soil Loss Equation (USLE) that in turn was used to calculate the soil erosion on a long-term experimental plot near Prague in the Czech Republic. To determine the influence of a chosen algorithm on the soil erosion estimates a digital elevation model with high accuracy (1 × 1 m) and a measured soil loss under simulated rainfall were used. These then provided input for five GIS-based and two manual procedures of computing the combined slope length and steepness factor in the (R)USLE. The results of GIS-based (R)USLE erosion estimates from the seven procedures were compared to the measured soil loss from the 11 m long experimental plot and from 38 rainfall simulations performed here during 15 years. The results indicate that the GIS-based (R)USLE soil loss estimates from five different approaches to calculation of LS factor are lower than the measured average annual soil loss. The two remaining approaches over-predicted the measured soil loss. The best method for LS factor estimation on field scale is the original manual method of the USLE, which predicted the average soil loss with 6% difference from the measured soil loss. The second method is the GIS-based method that concluded a difference of 8%. The results of this study show the need for further work in the area of soil erosion estimation (with particular focus on the rill/interrill ratio) using the GIS and USLE. The study also revealed the need for an application of the same approach to catchment area as it might bring different outcomes.

**Keywords**: geographic information systems; topographic factor; universal soil loss equation; water erosion

More than 80 soil erosion models are nowadays available for the evaluation of a potential soil loss for different spatial and temporal scales (Karydas *et al.* 2014). However, one of the most used models is still the Universal Soil Loss Equation (USLE). The USLE has been widely used all over the world in either the same (Wischmeier & Smith 1978) or a modified form (Renard 1997). When using USLE or RUSLE, the component factors relating to rainfall erosivity (R), slope length and steepness factor (LS), which reflects the influence of terrain on soil erosion, soil erodibility (K), groundcover (C) and soil conservation practices (P) are multiplied together to calculate the average annual soil loss per unit area. Wischmeier and Smith (1978) defined the slope length (L) as: “the distance from the point of origin of the surface flow to the point where each slope gradient (S) decreases enough for the beginning of deposition or when the flow comes to concentrate in a defined channel”.

According to experts (Moore & Burch 1986; Moore *et al.* 1991; Moore & Wilson 1992; Desmet

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& Govers 1996; Mitasova *et al.* 1996; Wilson *et al.* 2000; Kinnell 2008; Zhang *et al.* 2013; Liu *et al.* 2015), the extraction of the LS factor is a key issue in the applications of (R)USLE models (Oliveira *et al.* 2013). This is because the LS factor is the most sensitive parameter of (R)USLE in the soil loss predictions (Truman *et al.* 2001; Tetzlaff & Wendland 2012).

The procedure of obtaining the slope length and slope steepness factors was originally done manually (Wischmeier & Smith 1965, 1978; Moore & Wilson 1992; Renard 1997). Many methods have been developed that attempt to include complex slopes to overcome the restrictions related to equations for LS factor developed by Wischmeier and Smith (1978), common in the context of hydrographic basins. The history of development of the L and S factors equations is described in the work of Garcia Rodriguez and Gimenez Suarez (2010).

To overcome the limitations given by 1-D modelling in the conceptual models, the slope-length factor is substituted by the specific catchment area (Moore & Burch 1986; Moore *et al.* 1991; Desmet & Govers 1996; Mitasova *et al.* 1996), which allows to determine the drainage network, taking into account the direction of the surface runoff and the accumulated flow from the digital elevation model (DEM). Incorporating this concept, Desmet and Govers (1996) modified the equations of Foster and Wischmeier (1974) for an irregular slope. They computed the LS factor in the form of a finite difference in a grid of cells representing a segment of a hillside and compared the GIS-based results with methods of Griffin *et al.* (1988) and manual methods of Foster and Wischmeier (1974). Fu *et al.* (2006) also adopted this contributing area approach to LS factor calculation in their application of the RUSLE and a sediment delivery model to evaluate the impacts of no-till practices on erosion and sediment yield. Another GIS-based simplified equation for calculating the combined LS factor in two-dimensional terrain (Moore & Wilson 1992), based on the unit stream theory, was shown to be an equivalent to the manual RUSLE equations for the LS factor (McCool *et al.* 1989). Other methods have sought to address the potential shortcomings of the aforementioned approaches, such as accounting for the areas of deposition in the landscape that impact slope length (Hickey 2000; Van Remortel *et al.* 2001, 2004).

The works of Moore and Wilson (1992), Liu *et al.* (1994, 2000, 2015), Desmet and Govers (1996), Mitasova *et al.* (1996), Nearing (1997), Van Remortel *et al.* (2004) or Fu *et al.* (2006) include some comparison of the computed values for LS and the values obtained by manual methods of Wishmeier and Smith (1978) and McCool (1989). Yitayew *et al.* (1999) performed a study in which they compared several GIS-based approaches to LS calculation. However, they did not explicitly compare any of the GIS-based LS estimates with the field-measured values of LS. Instead, they compared the GIS-based erosion predictions using RUSLE and the observed sediment yield in the watershed.

It could be pointed out that calculating the topographic factor by GIS, although benefitted by automatic generation and spatial distribution (Moore & Wilson 1992; Desmet & Govers 1996; Mitasova *et al.* 1996), remains an object of controversy related to formulation of the applied algorithms (Desmet & Govers 1997; Mitasova *et al.* 1997; Oliveira *et al.* 2013).

The degree to which the available algorithms and equations for deriving the LS factor can influence the model results is the central question of this paper. Therefore, the purpose of this study is to evaluate the effects of alternative algorithms on the erosion model results. The LS factor was modelled and the comparisons of soil loss were made on the basis of seven different algorithms and equations for a fixed hill-length of 11 m. The soil loss was measured under a simulated rainfall.

## MATERIAL AND METHODS

The principle of comparison of different algorithms and/or equations for calculating the LS factor is based on the calculation of the soil loss by the USLE model. The methodology of calculation of the topographical factor in the GIS environment involved the use of a digital elevation model (DEM). Other factors of the USLE were estimated using the experiment rainfall simulations (factors R, C, and P) performed between years 1994–2011. Factor K was gained from the soil surveys. The influences of the DEM resolution (Moore *et al.* 1991; Desmet & Govers 1996), the different flow algorithms (Freeman 1991; Tarboton 1997), and the slope algorithms (Florinsky 1998) on the (R)USLE results have not been considered in this paper. Most of the available LS algorithms are already implemented within GIS softwares, such as IDRISI, SAGA GIS, GRASS, ArcGIS etc. SAGA GIS and the raster calculator in ArcGIS ESRI were the only two GIS softwares used for this study.

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**Experimental plots and field measurements**. The long-term experimental site of the Research Institute for Soil and Water Conservation (RISWC) is situated close to the village of Třebsín (49°51'15''N, 14°27'49''E) about 40 km south-east of Prague. The experimental area consists of 9 experimental plots 35–38 m long and 7 m wide, and another 4 plots 24–26 m long and 2 m wide, with the north exposition and average slope of the plots of 7–8°. They are kept as a permanent fallow land (Figure 1a). The soil is classified as silt with low soil organic matter content identified as Haplic Cambisol (WRB 2006) and without a favourable moisture regime. The soil structure of topsoil corresponds mainly to crumb structure (Kadlec *et al.* 2012; Kovář *et al.* 2012). Specific site properties of the experimental plots are described in more detail by Kadlec *et al.* (2012) and Kovář *et al.* (2012).

A rainfall simulator, construed by the RISWC Prague, was used for experimental testing within 1994–2011. Pipes, 3.0 m in height, are connected to tubes with a wide-angle spraying system formed by four nozzles (fulljet type). Each nozzle covers an area of 104° at a pressure of 34.5 kPa. The size of water drips is close to the size of natural rain drops (Kovář *et al.* 2012). The spraying intensity can vary from 0.5 to 2.0 mm/min. The scheme of the portable rainfall simulator is shown in Figure 1b.

Rainfall simulations were used on a reduced size of the parcel area $A$ = 30 m$^2$ (2.7 × 11 m). The simulator was set over the middle part of the experimental plot at all times and simulated rainfall experiments were run until a constant runoff rate was reached (15–60 min). For each rainfall event with a particular intensity the parameters of the beginning and amount of surface runoff and the rate of water infiltration into soil were recorded. Samples collected in 3-minute intervals were oven-dried at 105°C for 24 h to obtain the soil loss.

For the purpose of this study, simulator measurements from the experimental plot No. 4 were processed. Parcel No. 4 was selected on the basis of the most comprehensive available dataset which contains 38 records of rainfall simulations, soil loss, and the description of ground cover, soil management, and soil moisture. A draft of plot No. 4 is depicted in

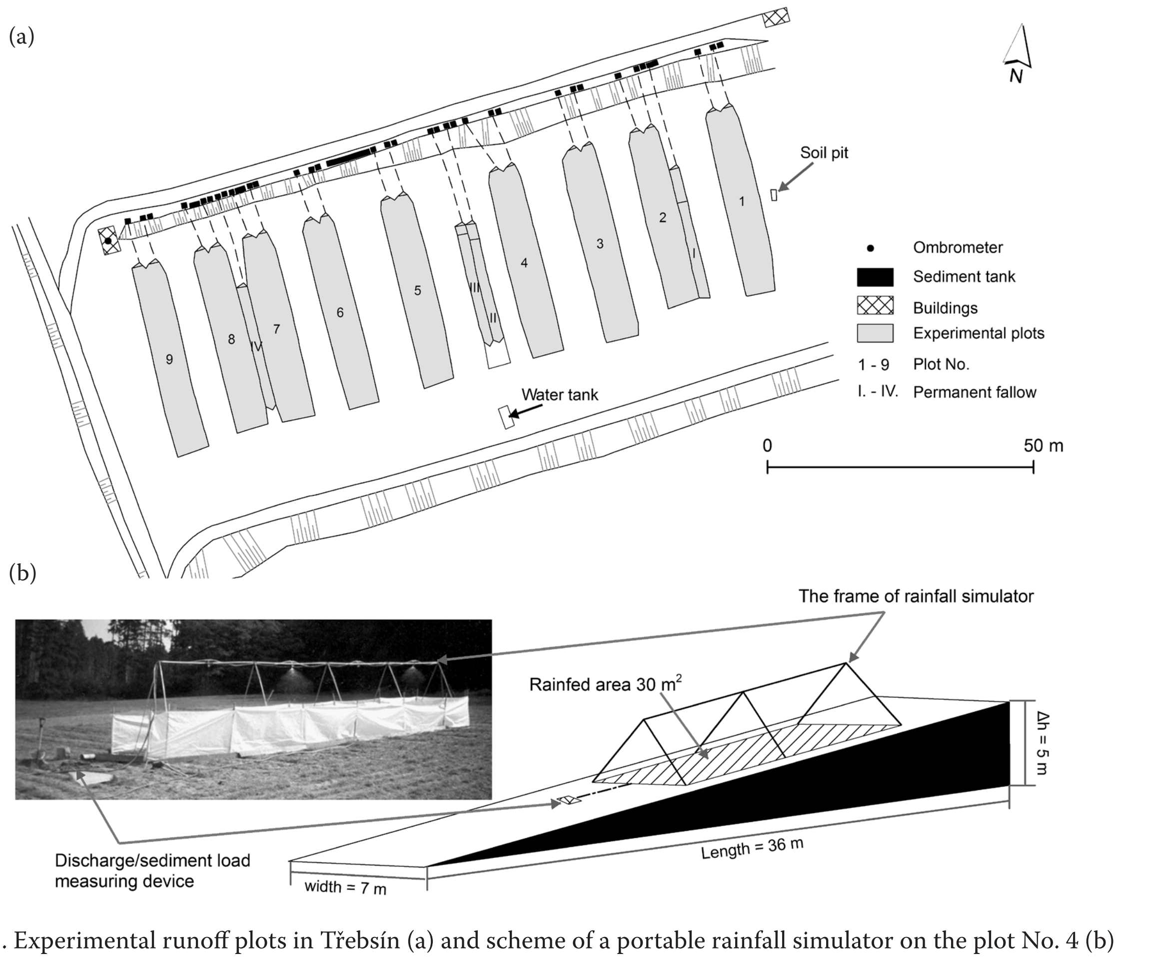


Figure 1. Experimental runoff plots in Třebsín (a) and scheme of a portable rainfall simulator on the plot No. 4 (b)

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Figure 1. The slope of the plot is 8° with a slightly concave profile and a plan curvature. The summary of soil loss measurements under simulated rainfall is available in Table 1.

**Input data, the USLE/RUSLE parameters**. The conservation practices (P) factor values were selected according to the soil management practices at the plot in 1994–2011 (see the notes below Table 1). The P factor equalled 1 for simulations except those in years 1996 and 1997, when corn was planted here parallel to contours. Therefore, the P factor was set as the value 0.7 according to a table by Wischmeier and Smith (1978). The soil erodibility (K) factor was determined on the basis of a research published by Kadlec *et al.* (2012), who estimated the average K factor as the value of 0.046 (t·ha·h/ha·MJ·mm).

The rainfall erosivity index was calculated for each simulation from the records taken during the simulation tests (see Eq. (1)). The R factor was determined by the following relationship from Foster *et al.* (1981) in Renard (1997) – the corresponding version for SI-units of equation developed by Wischmeier and Smith (1978) in the USLE handbook:

$$E_m = 0.119 + 0.0873\log_{10}(i_m) \tag{1}$$

$$\mathrm{R} = \frac{\sum_{i=1}^{j}(EI_{30})_i}{N} \tag{2}$$

where:

$E_m$ – kinetic energy in MJ/ha/mm

$i_m$ – intensity in mm per hour (mm/h)

$I_{30}$ – maximum 30-minute intensity, which in the case of the rainfall simulator equals to an intensity of $i_m$

$EI_{30}$ – for a simulated storm $i$

$j$ – number of simulated events in an $N$-year period

The crop factor (C) was estimated according to the height of the crops (see Table 1), the test date, and other records related to the cover of soil surface. For each simulation, factor C was determined from the handbook by Wischmeier and Smith (1978). Given values of the C factor had to be corrected according to the partition coefficient for rainfall within the year (Wischmeier & Smith 1978). Because simulated rainfall was used for this soil loss evaluation, a uniform distribution of precipitation for the whole growing season was assumed. Therefore, the value of the C factor was corrected by the partition coefficient for a simulated precipitation (0.14). The total C factor was calculated as a sum-up of the average annual C factor of each simulation year.

In order to utilize GIS-based approaches of LS factor calculations, the 5th generation digital elevation model of the Czech Republic (DEM 5G) was used as a regular grid (1 × 1 m). The DEM 5G model is provided by the Czech Office for Surveying, Mapping and Cadastre (CUZK) in a digital form with $X$, $Y$, $H$ coordinates, where $H$ is the altitude (in the Baltic Vertical Datum). The CUZK guarantees the maximum of the average altitudinal error to be 0.18 m in bare soil. However, in the case of our experimental field, the average altitudinal error for bare soil was 0.05 m.

When calculating the LS factor from DEM, the following input parameters and algorithms were used: (*i*) Flow direction algorithm: a multiple flow direction (MFD) algorithm (Quinn *et al.* 1995); (*ii*) Slope algorithm: second order, central finite-difference scheme (Zevenbergen & Thorne 1987); (*iii*) Specific Catchment Area (Upslope Area): contour length dependent on aspect (Desmet & Govers 1996).

The LS factor itself was calculated by the following seven different approaches (where λ is slope length in m, β is slope angle in radians, and $A_s$ is specific catchment area):

(1) A method according to the equations by Wischmeier and Smith (1978):

$$\mathrm{LS} = (\lambda/22.13)^m \times (65.4\sin^2\beta + 4.5\sin\beta + 0.0654) \tag{3}$$

where:

$m = 0.5$ if $\beta > 0.05$

$m = 0.4$ if $0.03 < \beta > 0.05$

$m = 0.3$ if $0.01 < \beta > 0.03$

$m = 0.2$ if $\beta < 0.01$

As a variant 1b, computed in GIS, the slope length λ parameter was replaced by specific catchment area $A_s$.

(2) A method according to McCool *et al.* (1989):

$$\mathrm{LS} = (\lambda/22.13)^m \times \begin{cases} (10.8\sin\beta + 0.03) & \text{if } \beta < 0.09 \\ (16.8\sin\beta - 0.5) & \text{if } \beta \geq 0.09 \\ (3\sin0.8\beta + 0.56) & \text{if } \lambda < 4.5\ m \end{cases} \tag{4}$$

$$m = F/(1 + F) \tag{5}$$

where

$$F = \frac{\sin\beta/0.0896}{\sin^{0.8}\beta + 0.56} \quad \text{or}$$

$F = 0$ when there is deposition if $\lambda \leq 4.5\ m$

As a variant 2b, computed in GIS, the slope length λ parameter was replaced by specific catchment area $A_s$.

(3) The L factor according to Desmet and Govers (1996), and S factor according to Nearing (1997):

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Table 1. Soil loss measurements by the rainfall simulator at the plot No. 4 in 1994–2011

| No. | Year | Crop | Soil moisture | Crop height (cm) | Duration of rainfall (min) | Total rainfall (mm) | Intensity (mm/min) | Start of the surface runoff (s) | Surface runoff (mm) | Infiltration (mm) | Soil loss (t/ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1994 | maize | dry | NA | 62.35 | 41.56 | 0.67 | 750 | 3.32 | 38.36 | 0.054 |
| 2 | 1995 | barley | dry | NA | 31.07 | 12.94 | 0.42 | 249 | 2.87 | 10.20 | 0.447 |
| 3 | 1995 | barley | dry | NA | 54.60 | 23.65 | 0.43 | 699 | 2.62 | 21.11 | 0.278 |
| 4 | 1996 | maize[1] | NA | NA | 45.61 | 37.67 | 0.83 | 1780 | 1.35 | 36.45 | 0.078 |
| 5 | 1997 | maize[1] | NA | 15 | 29.97 | 24.79 | 0.83 | 420 | 3.20 | 21.76 | 0.307 |
| 6 | 1998 | maize[2] | dry | NA | 20.12 | 18.20 | 0.90 | 220 | 7.37 | 11.17 | 3.070 |
| 7 | 1999 | maize | dry | NA | 29.88 | 23.64 | 0.79 | 48 | 10.58 | 13.47 | 2.110 |
| 8 | 1999 | maize | dry | NA | 30.05 | 24.43 | 0.81 | 120 | 8.93 | 16.90 | 1.227 |
| 9 | 2000 | fallow | dry | NA | 29.97 | 24.20 | 0.81 | 443 | 7.83 | 16.60 | 6.566 |
| 10 | 2001 | fallow | dry | NA | 45.00 | 38.97 | 0.87 | 1240 | 3.17 | 36.07 | 0.443 |
| 11 | 2001 | fallow | dry | NA | 44.92 | 37.34 | 0.83 | 1490 | 1.97 | 35.48 | 0.166 |
| 12 | 2002 | maize[3] | dry | NA | 30.17 | 25.85 | 0.86 | 120 | 7.40 | 18.75 | 0.262 |
| 13 | 2002 | maize[3] | dry | NA | 30.00 | 25.70 | 0.86 | 83 | 12.83 | 13.70 | 3.556 |
| 14 | 2004 | sunflower | dry | NA | 30.00 | 27.79 | 0.93 | 140 | 5.80 | 21.99 | 0.603 |
| 15 | 2004 | sunflower | dry | NA | 22.00 | 18.98 | 0.86 | 135 | 4.10 | 14.88 | 0.260 |
| 16 | 2007 | sunflower[4] | dry | 70 | 15.75 | 15.22 | 0.97 | 165 | 2.23 | 13.05 | 0.113 |
| 17 | 2007 | sunflower[4] | wet | 70 | 15.67 | 14.52 | 0.93 | 100 | 4.67 | 10.12 | 0.096 |
| 18 | 2007 | sunflower[4] | dry | 75 | 14.53 | 13.92 | 0.96 | 152 | 3.63 | 10.75 | 0.155 |
| 19 | 2007 | sunflower[4] | wet | 75 | 15.13 | 14.15 | 0.94 | 68 | 5.90 | 8.68 | 0.137 |
| 20 | 2008 | maize[4] | dry | 52 | 15.00 | 17.36 | 1.16 | 90 | 4.53 | 13.09 | 1.472 |
| 21 | 2008 | maize[4] | wet | 52 | 15.00 | 16.39 | 1.09 | 35 | 7.27 | 9.45 | 2.151 |
| 22 | 2008 | maize[4] | dry | 155 | 15.13 | 16.28 | 1.08 | 128 | 4.67 | 11.85 | 1.475 |
| 23 | 2008 | maize[4] | wet | 155 | 15.00 | 20.72 | 1.38 | 39 | 6.17 | 14.89 | 1.792 |
| 24 | 2008 | maize[4] | dry | 170 | 15.00 | 16.41 | 1.09 | 60 | 7.07 | 11.31 | 1.654 |
| 25 | 2008 | maize[4] | wet | 170 | 15.00 | 13.94 | 0.93 | 20 | 9.4 | 5.14 | 2.801 |
| 26 | 2009 | maize[4] | dry | 90 | 15.00 | 12.47 | 0.83 | 95 | 5.77 | 8.2 | 0.971 |
| 27 | 2009 | maize[4] | wet | 90 | 15.00 | 12.87 | 0.86 | 43 | 7.43 | 6 | 1.534 |
| 28 | 2009 | maize[4] | dry | 140 | 15.00 | 11.67 | 0.78 | 140 | 10.80 | 2.13 | 2.178 |
| 29 | 2009 | maize[4] | wet | 140 | 15.00 | 11.47 | 0.76 | 130 | 7.83 | 4.3 | 1.346 |
| 30 | 2009 | maize[4] | dry | 205 | 15.00 | 8.13 | 0.54 | 68 | 4.13 | 4.13 | 1.202 |
| 31 | 2009 | maize[4] | wet | 205 | 15.00 | 9.33 | 0.62 | 26 | 6.17 | 3.4 | 2.596 |
| 32 | 2010 | maize[4] | dry | 53 | 15.00 | 14.70 | 0.98 | 100 | 3.60 | 11.43 | 3.666 |
| 33 | 2010 | maize[4] | wet | 53 | 15.00 | 14.80 | 0.99 | 43 | 5.83 | 9.37 | 3.938 |
| 34 | 2010 | maize[4] | wet | 135 | 14.92 | 13.90 | 0.93 | 55 | 5.47 | 8.9 | 0.673 |
| 35 | 2011 | maize[4] | dry | 160 | 15.00 | 13.47 | 0.89 | 50 | 7.33 | 6.6 | 4.510 |
| 36 | 2011 | maize[4] | wet | 160 | 15.00 | 13.80 | 0.92 | 36 | 8.73 | 5.93 | 2.820 |
| 37 | 2011 | maize[4] | dry | 200 | 15.00 | 13.66 | 0.91 | 40 | 9.37 | 5.02 | 1.344 |
| 38 | 2011 | maize[4] | wet | 200 | 15.00 | 13.57 | 0.90 | 25 | 10.30 | 3.83 | 1.214 |

[1]Contour tillage; [2]shallow aeration (3 cm) in each row 70 cm in the distance; [3]without manure; [4]green manure with white mustard (*Sinapsis alba*) as a winter cover; NA – not available data

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$$L_{(i,j)} = \frac{(A_{(i,j),in} + D^2)^{(m+1)} - A_{(i,j),in}^{(m+1)}}{x_{(i,j)}^m \times D^{(m+2)} \times 22.13^m} \quad (6)$$

$$S = -1.5 + \frac{17}{(1 + e^{(2.3 - 6.1\sin\beta)})} \quad (7)$$

where:

$D$ – grid cell size (meters)

$x_{i,j} = \sin a_{i,j} + \cos a_{i,j}$

$a_{i,}$ – aspect direction of the grid cell $(i, j)$

$m$ – related to the $F$ ratio of the rill to interill erosion (McCool *et al.* 1989)

(4) A method according to Moore and Burch (1986) and Moore and Wilson (1992):

$$LS = (A_s/22.13)^m \times (\sin\beta/0.0896)^n \quad (8)$$

where:

$m$ = 0.4 (value range 0.4–0.6)

$n$ = 1.3 (value range 1.22–1.3)

(5) The point method of Griffin *et al.* (1988) for the L factor, and of Moore and Wilson (1992) for the S factor:

$$L = (m + 1) \times (A_s/22.13)^m \text{ and } S = (\sin\beta/0.0896)^n \quad (9)$$

where:

$m$ = 0.4 (value range 0.2–0.6)

$n$ = 1.3 (value range 1.0–1.3) (Mitasova *et al.* 1996)

## RESULTS AND DISCUSSION

The basic parameters characterizing the erosion processes were calculated from simulated rainfall events with a particular intensity and applied to different vegetation covers during 15 years. A summary of the three USLE factor calculations (R, C, P) and measured soil loss from the experimental plot No. 4 summed up for each particular year of measuring are given in Table 2. Table 2 also presents the average annual values of these factors as well as the measured average annual soil loss. They are used for the final evaluation of the influence of the different LS factor calculations on the USLE model results.

The topographic factor (LS) was calculated separately. The results of applying different algorithms of S factor calculation are shown in Table 3. The values of the S factor have similar range and there is no significant difference. Although the algorithm for the L factor is the same for all methods (except for method 5), it differs in the $m$ exponent. The influence of this exponent on the results is clearly visible

Table 2. The USLE factors (R, C, and P) calculated according to the recorded data from simulations and measured soil loss, summed up for the particular years when simulations were performed

| Year | No. of measurements | R factor (MJ·mm/(ha·h)) | C factor (–) | P factor (–) | Measured soil loss (t/ha) |
|---|---|---|---|---|---|
| 1994 | 1 | 430.15 | 0.036 | 1 | 0.054 |
| 1995 | 2 | 226.96 | 0.036 | 1 | 0.725 |
| 1996 | 1 | 498.35 | 0.105 | 0.7 | 0.078 |
| 1997 | 1 | 328.62 | 0.105 | 0.7 | 0.307 |
| 1998 | 1 | 267.13 | 0.105 | 1 | 3.070 |
| 1999 | 2 | 615.21 | 0.105 | 1 | 3.337 |
| 2000 | 1 | 312.02 | 0.140 | 1 | 6.566 |
| 2001 | 2 | 1041.91 | 0.140 | 1 | 0.609 |
| 2002 | 2 | 711.15 | 0.105 | 1 | 3.818 |
| 2004 | 2 | 683.02 | 0.105 | 1 | 0.863 |
| 2007 | 4 | 893.75 | 0.105 | 1 | 0.501 |
| 2008 | 6 | 1928.72 | 0.105 | 1 | 11.344 |
| 2009 | 6 | 782.81 | 0.105 | 1 | 9.827 |
| 2010 | 3 | 687.19 | 0.105 | 1 | 8.277 |
| 2011 | 4 | 803.79 | 0.105 | 1 | 9.888 |
| Year average | – | 680.72 | 0.100 | 0.95 | 3.950 |
| Total | 38 | – | – | – | 59.260 |

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Table 3. Values of S and L factor based on different approaches (min, max, mean, standard deviation, range, and standard error of the mean)

| Method | Min | Max | Mean | SD | Range | SEM | References |
|---|---|---|---|---|---|---|---|
| **S factor** | | | | | | | |
| 1a (manual) | – | – | 1.97 | – | – | – | Wischmeier and Smith (1978) |
| 1b (GIS) | 1.72 | 2.61 | 2.12 | 0.29 | 0.89 | 0.051 | Wischmeier and Smith (1978) |
| 2a (manual) | – | – | 1.84 | – | – | – | McCool *et al.* (1989) |
| 2b (GIS) | 1.65 | 2.28 | 1.94 | 0.20 | 0.63 | 0.036 | McCool *et al.* (1989) |
| 3 (GIS) | 1.56 | 2.17 | 1.83 | 0.20 | 0.61 | 0.035 | Nearing (1997) |
| 4, 5 (GIS) | 1.60 | 2.23 | 1.88 | 0.21 | 0.64 | 0.037 | Moore and Wilson (1992) |
| **L factor** | | | | | | | |
| 1a (manual) | – | – | 0.71 | – | – | – | Wischmeier and Smith (1978) |
| 1b (GIS) | 0.33 | 0.77 | 0.58 | 0.12 | 0.44 | 0.021 | Wischmeier and Smith (1978) |
| 2a (manual) | – | – | 0.62 | – | – | – | McCool *et al.* (1989) |
| 2b (GIS) | 0.21 | 0.72 | 0.48 | 0.14 | 0.50 | 0.024 | McCool *et al.* (1989) |
| 3 (GIS) | 0.41 | 0.65 | 0.56 | 0.07 | 0.24 | 0.012 | Desmet and Govers (1996) |
| 4 (GIS) | 0.41 | 0.82 | 0.64 | 0.11 | 0.40 | 0.019 | Moore and Wilson (1992) |
| 5 (GIS) | 0.58 | 1.14 | 0.90 | 0.15 | 0.56 | 0.027 | Griffin *et al.* (1988) |

in Table 3, where $m$ = 0.5 was used for method 1, $m$ = 0.69 for method 2a, the mean value was $m$ = 0.72 for methods 2b and 3, and $m$ = 0.4 for method 4. Liu *et al.* (2000) stated that the $m$ = 0.5 exponent is better adapted for accentuated slopes. With the slope increase from 9 to 60%, the $m$ exponent increases from 0.5 to 0.71. Therefore, the exponent $m$ continues to increase with slope inclination in Eq. (5) (McCool *et al.* 1989), and thus, the slope length effect is a function of the erosion ratio of rill to interrill.

Desmet and Govers (1996) stated that the LS values predicted by the GIS method are generally higher by 10–50% than those obtained by manual approach, which contradicts the results shown in Table 4. However, the authors derived the LS factor based on the grid with a resolution of 50 $m$ and evaluated their algorithm for a catchment scale. Therefore, the effect of convergent and divergent flow on erosion was more significant than here, on hillslope scale (Walling 2005; Hengl & Reuter 2008). Further, it is also necessary to consider the effect of C factor, one of the sensitive parameters of the model as well, on the overall model (Tetzlaff & Wendland 2012). In this study, the LS values generated by the GIS method were generally lower by 10–30% than those obtained by the manual method of Wischmeier and Smith (1978), while LS values resulted from Griffin's point method yielded higher by 22%. However, if we compare the GIS method with the manual method of McCool *et al.* (1989), the difference is more or less

Table 4. The calculated LS factors, predicted average annual soil loss, and its difference from the measured average annual soil loss from the plot No. 4

| Methods | Calculated average soil loss (t/ha/year) | Difference from measured average (t/ha/year) | Difference (%) | LS factor |
|---|---|---|---|---|
| 1a (manual) | 4.17 | 0.22 | 5.48 | 1.39 |
| 1b (GIS) | 3.69 | –0.26 | –6.66 | 1.23 |
| 2a (manual) | 3.42 | –0.53 | –13.50 | 1.14 |
| 2b (GIS) | 2.81 | –1.14 | –28.79 | 0.94 |
| 3 (GIS) | 3.08 | –0.87 | –21.98 | 1.03 |
| 4 (GIS) | 3.63 | –0.32 | –8.00 | 1.21 |
| 5 (GIS) | 5.09 | 1.14 | 28.80 | 1.69 |

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10% for all methods (except Griffin's point method). The findings of this study are in agreement with the conclusions of Yitayew *et al.* (1999) stating that the mean annual erosion was mostly under-predicted by the GIS methods. As can be observed from Table 4, the spatial variations in length-slope factors by the different procedures have significant effects on the total erosion calculation. All the methods, except for those of Wischmeier (1a) and Griffin (5), led to higher values of the average annual soil loss than those obtained by manual approach. However, the best results yielded Wischmeier's method, where slope-length was replaced by a specific catchment area, and Moore's method. Values of the LS factor calculated by these two methods are almost equal (LS = 1.23 for method 1b and LS = 1.21 for method 4).

## CONCLUSION

The analysis and acquisition of the topographic factor conducted in the digital environment have become a norm in erosion modelling, because they enable systematic analyses of a given area. In this study various methods of the LS factor calculation were presented. Various uncertainties are related to the results which may be e.g. DEM resolution, methods of the flow estimation or computation of a specific catchment area. The study has proved the disposal of GIS-based LS factor calculation methods on hillslope scale providing results with an acceptable level of compliance with the measured data. Particularly Moore's method or Wishmeier and Smith's method, where the slope-length λ replaced by specific catchment area $A_s$ can be used as an alternative to manual methods. However, a comparison of the two above-mentioned methods conducted on a larger number of hillslopes of different shapes and lengths should be conducted. The best method for LS factor estimation on hillslope scale is the original manual method of the USLE, which predicted the average soil loss with a 6% difference from the measured soil loss. The second method is the GIS-based method that concluded a difference of 8%.

To conclude, further research in the area of soil erosion estimation (with particular focus on the rill/interrill ratio) using GIS and USLE methods is needed. The presented study revealed that the same method applied to a catchment area might yield different outcomes.

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