

Contents lists available at ScienceDirect

MethodsX

journal homepage: [www.elsevier.com/locate/mex](http://www.elsevier.com/locate/mex)



## Method Article

# Modification of the RUSLE slope length and steepness factor (LS-factor) based on rainfall experiments at steep alpine grasslands



Simon Schmidt<sup>a,\*</sup>, Simon Tresch<sup>b,c,d</sup>, Katrin Meusburger<sup>e</sup>

<sup>a</sup> Environmental Geosciences, University of Basel, Bernoullistrasse 30, CH-4056 Basel, Switzerland

<sup>b</sup> Department of Soil Sciences, Research Institute of Organic Agriculture (FiBL), Ackerstrasse 113, CH-5070 Frick, Switzerland

<sup>c</sup> Functional Ecology Laboratory, Institute of Biology, University of Neuchâtel, Rue Emile-Argand 11, CH- 2000 Neuchâtel, Switzerland

<sup>d</sup> Biodiversity and Conservation Biology, Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Zürcherstrasse 111, CH-8903 Birmensdorf, Switzerland

<sup>e</sup> Forest Soils and Biogeochemistry, Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Zürcherstrasse 111, CH-8903 Birmensdorf, Switzerland

## A B S T R A C T

The slope length and slope steepness factor (LS-factor) is one of five factors of the Universal Soil Loss Equation (USLE) and its revised version (RUSLE) describing the influence of topography on soil erosion risk. The LS-factor was originally developed for slopes less than 50% inclination and has not been tested for steeper slopes. To overcome this limitation, we adapted both factors slope length L and slope steepness S for conditions experimentally observed at Swiss alpine grasslands. For the new L-factor ( $L_{\text{alpine}}$ ), a maximal flow path threshold, corresponding to 100 m, was implemented to take into account short runoff flow paths and rapid infiltration that has been observed in our experiments. For the S-factor, a fitted quadratic polynomial function ( $S_{\text{alpine}}$ ) has been established, compiling the most extensive empirical studies. As a model evaluation, uncertainty intervals are presented for this modified S-factor. We observed that uncertainty increases with slope gradient. In summary, the proposed modification of the LS-factor to alpine environments enables an improved prediction of soil erosion risk including steep slopes.

- Empirical experiments (rainfall simulation, sediment measurements) were conducted on Swiss alpine grasslands to assess the maximal flow length and slope steepness factor (S-factor).
- Flow accumulation is limited to a maximal flow threshold (100 m) at which overland runoff is realistic in alpine grassland.
- Slope steepness factor is modified by a fitted S-factor equation from existing empirical S-factor functions.

© 2019 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

\* Corresponding author.

E-mail addresses: [simon@simonschmidt.de](mailto:simon@simonschmidt.de), [si.schmidt@unibas.ch](mailto:si.schmidt@unibas.ch), [simon.schmidt@bgr.de](mailto:simon.schmidt@bgr.de) (S. Schmidt), [simon.tresch@frib.org](mailto:simon.tresch@frib.org) (S. Tresch), [katrin.meusburger@wsl.ch](mailto:katrin.meusburger@wsl.ch) (K. Meusburger).

## ARTICLE INFO

Method name:  $L_{alpine}$ ,  $S_{alpine}$ ,  $LS_{alpine}$

Keywords: Revised Universal Soil Loss Equation, Erosion modeling, Switzerland, Terrain features, Maximal, Flow length

Article history: Received 13 November 2018; Accepted 19 January 2019; Available online 26 January 2019

## Specifications Table

Subject area	<i>Environmental Science</i>
More specific subject area	<i>Soil erosion modeling</i>
Method name	<ul style="list-style-type: none"> <li>- <math>L_{alpine}</math></li> <li>- <math>S_{alpine}</math></li> <li>- <math>LS_{alpine}</math></li> </ul>
Name and reference of original method	<p>USLE LS-factor: Wischmeier, W.H., &amp; Smith, D.D. (1978). Predicting rainfall erosion losses. Washington.</p> <p>S-factor: McCool, D.K., Brown, L.C., Foster, G.R., Mutchler, C.K., &amp; Meyer, L.D. (1987). Revised Slope Steepness Factor for the Universal Soil Loss Equation. Transactions of the ASAE, 30, 1387–1396. <a href="https://doi.org/doi:10.13031/2013.30576">https://doi.org/doi:10.13031/2013.30576</a>.</p> <p>S-factor: Smith, D.D., &amp; Whitt, D. (1948). Estimating soil losses from field areas. Agricultural Engineering, 29, 394–396.</p>
Resource availability	<ul style="list-style-type: none"> <li>- SAGA GIS (<a href="http://www.saga-gis.org">http://www.saga-gis.org</a>; [31])</li> <li>- RSAGA (<a href="https://cran.r-project.org/web/packages/RSAGA/index.html">https://cran.r-project.org/web/packages/RSAGA/index.html</a>; [30])</li> </ul>

## Method details

## Existing approaches for S- and L-factor parametrization

The LS-factor is a product of the slope length (L-) and the slope steepness (S-factor). The most widely used slope length factor represents the ratio of observed soil loss related to the soil loss of a standardized plot (22.13 m). Originally Wischmeier and Smith [1] defined the L-factor as Eq. (1):

$$L = \left( \frac{\lambda}{22.13} \right)^m \quad (1)$$

where  $\lambda$  represents the length of the slope in meters and  $m$  the different slope steepness. Later, Eq. (2) was adapted for the RUSLE-approach to better describe soil loss with increasing slope steepness. Desmet and Govers [2] transformed the original L-factor (Eq. (1)) into a GIS-approach (Eq. (2)) considering the flow accumulation and adding a ratio of rill to interrill erosion (Eq. (3)):

$$L_{ij} = \frac{(A_{ij-in} + D^2)^{m+1} - A_{ij-in}^{m+1}}{D^{m+2} * X_{ij}^m * 22.13^m} \quad (2)$$

where  $A_{ij-in}$  is the flow accumulation in  $m^2$  at the inlet of a grid cell (i,j).  $D$  is the grid cell size in m and  $X_{ij}$  equals to  $\sin a_{ij} + \cos a_{ij}$  where  $a_{ij}$  is the aspect of the grid cell (i,j). The coefficient  $m$  (Eq. (3)) represents the ratio of rill and interrill erosion and is calculated by the  $\beta$ -value (Eq. (4)):

$$m = \frac{\beta}{\beta + 1} \quad (3)$$

with a range between 0 (ratio of rill to interrill erosion close to 0) and 1.

$$\beta = \frac{\frac{\sin\theta}{0.0896}}{[0.56 + 3 * (\sin\theta)^{0.8}]} \quad (4)$$

where  $\theta$  is the slope angle in degrees.

For the S-factor, most often the empiric function proposed by McCool et al. [3] is used to determine the slope steepness factor in the Revised Universal Soil Loss Equation (RUSLE). McCool et al. [3] differentiate the relation between soil loss and slope steepness in radians ( $s$ ) with two functions. One for slopes with an inclination less than 9% and the other greater or equal 9%. The functions are as follows:

$$S = 10.8s + 0.03 \quad \text{for slope steepness in percent} < 9\% \quad (5)$$

$$S = 16.8s - 0.50 \quad \text{for slope steepness in percent} \geq 9\% \quad (6)$$

The S-factor after McCool et al. [3] is particular recommended for areas with low summer rainfall amounts [4]. Many other empirical S-factors were developed since the 1940s (Table 1) but all S-factors have in common that empirical evidence and thus validity is limited to slope gradients less than 50%.

#### *Proposed adaption of the L-factor*

Often, GIS modeled potential flow path length on slopes, expressed as flow accumulation in a GIS-environment, is driven by gravity and theoretically unlimited [13]. In particular cases, these potential flow path lengths can reach many kilometers and enormous runoff volumes. The flow accumulation can be constrained by streets or houses as ending points of the potential flow paths as discussed by Winchell et al. [14].

In 2016, we conducted 19 different rainfall simulation experiments on south facing slopes in an alpine environment (Val Piora, Switzerland) with different conditions regarding soil moisture (dry, moist), steepness ( $36^\circ$ – $82^\circ$ ), and vegetation (low, medium, full vegetation cover) to observe the flow path lengths. The rainfall simulations were realized with an Eijkelkamp mini rainfall simulator (type M1.09.06. E, Eijkelkamp, NL; Fig. 1) for erosion tests with a rainfall intensity of 640 mm/h and an energy of  $4 \text{ J mm}^{-1} \text{ m}^{-2}$ . This rainfall energy is comparable with the average rainfall energy of Val Piora (station Piotta;  $5.6 \text{ J mm}^{-1} \text{ m}^{-2}$ ; [15]). Regardless of the conditions, our observations revealed short surface flow path lengths at the scale of meters with a rapid infiltration into shallow alpine soils (see Appendix A).

Table 1  
Review of selected S-factors (S).

Source	function	Description
Zingg [5]	$S = \left(\frac{s}{g}\right)^{1.4}$	$s$ = slope steepness in percent
Musgrave [6]	$S = \left(\frac{s}{g}\right)^{1.35}$	$s$ = slope steepness in percent
Smith and Whitt [7]	$S = 0.025 + 0.052s^4$	$s$ = slope steepness in percent
Smith [8]	$S = 0.00650s^2 + 0.0453s + 0.065$	$s$ = slope steepness in percent
Smith [8]	$S = 0.044 + 0.10s - 0.00073s^2$	$s$ = slope steepness in percent
Wischmeier and Smith [1]	$S = 65.4\sin\theta^2 + 4.56\sin\theta + 0.0654$	$\theta$ = slope steepness in radians
McCool et al. [9]	$S = \left(\frac{\sin\theta}{0.0896}\right)^{0.6}$	$\theta$ = slope steepness in radians
Foster [10]	$S = 3(\sin\theta)^{0.8} + 0.56$	$\theta$ = slope steepness in radians
McCool et al. [3]	$S = 16.8\sin\theta - 0.5$	$\theta$ = slope steepness in radians
McCool et al. [3]	$S = 10.8\sin\theta + 0.03$	$\theta$ = slope steepness in radians
Nearing [11]	$S = -1.5 + \frac{17}{1 + e^{2.3 - 6.1\sin\theta}}$	$\theta$ = slope steepness in radians
Liu et al. [12]	$S = 21.91\sin\theta - 0.96$	$\theta$ = slope steepness in radians
S <sub>alpine</sub> present study	$S = 0.0005s^2 + 0.1795s - 0.4418$	$s$ = slope steepness in percent



Fig. 1. Different set ups and preconditions of the rainfall simulation experiment on steep slopes in Val Piora, Ticino, Switzerland.

supplementary material). Our measurements and observations show, that potential flow paths without considering infiltration is not realistic for alpine environments and thus, requesting a maximal flow threshold for the estimation of the slope length factor L. McCool et al. [16] and Winchell et al. [14] limited the slope length to a maximal threshold of 333 m (1000 feet) as longer slope length appear only occasionally. According to McCool et al. [16], the usual threshold in many cases is 121 m (400 feet). As a compromise of their suggestion and our observed short flow path lengths in the Swiss Alps, we decided to limit the maximal flow length to 100 m.

The threshold is implemented as a condition either directly in SAGA GIS or in RSAGA after creating the flow accumulation grid:

$$A_{\text{alpine } ij-in} = \text{ifelse}(A_{ij-in} > \text{thresh}, \text{thresh}, A_{ij-in}) \quad (7)$$

where  $A_{\text{alpine } ij-in}$  is the constraint flow accumulation in  $\text{m}^2$  at the inlet of a grid cell ( $i,j$ ) considering a threshold value  $\text{thresh}$ . That constraint flow accumulation value is inserted into the L-factor equation for the alpine environment (Eq. (8)):

$$L_{\text{alpine } ij} = \frac{\left(A_{\text{alpine } ij-in} + D^2\right)^{m+1} - A_{\text{alpine } ij-in}^{m+1}}{D^{m+2} * X_{ij}^m * 22.13^m} \quad (8)$$

Likewise to Eq. (2), D is the grid cell size in m and  $X_{ij}$  equals to  $\sin a_{ij} + \cos a_{ij}$  where  $a_{ij}$  is the aspect of the grid cell ( $i,j$ ). The coefficient m is the ratio of rill ( $\beta$ -value) to interrill erosion according to the above mentioned Eqs. (3) and (4).

For our calculation of L-factor using a 2 m resolution Digital Elevation Model, the maximal flow length of 100 m, corresponds to a threshold of 50 cells multiplied by the cell size of 2 m (Fig. 2).

Additionally, maximal flow path length was constrained by a field block cadaster. The cadaster defines hydrological units of continuous agricultural land, that are separated by landscape elements acting as flow boundaries (e.g., forests, streets, urban areas, water bodies, or ditches) following the approach of Winchell et al. [14].

#### *Proposed adaption of the S-factor*

In 2014, we conducted a total of 16 rainfall simulations on alpine slopes to assess the soil loss rates related to different slope inclinations (Table 2; [17]). The experiments were conducted at a north and south facing slope both with grassland cover in the mountains of the Urseren Valley, Switzerland. At each slope two transects were selected with slope gradient ranging from 20 to 90%. We used a field hybrid rainfall simulator modified after Schindler Wildhaber et al. [18] with an intensity of  $60 \text{ mm h}^{-1}$ , which is comparable to a high rainfall event in this area.

The experimental sites showed small variation in vegetation cover, soil erodibility, and slope length (due to the effect of slope angle), therefore all experimental plots were normalized to average values of

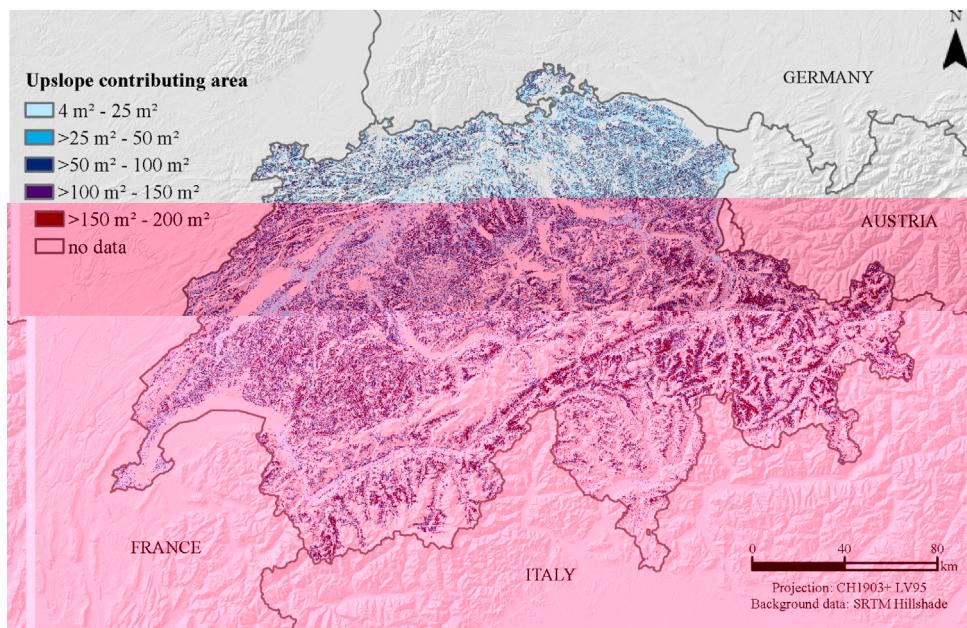


Fig. 2. Constraint flow accumulation grid with a maximal flow path length of 100 m.

**Table 2**  
Rainfall simulation measurements at the two study sites on steep alpine slopes in Switzerland under consideration of different inclinations and vegetation cover.

N°	inclination (°)	vegetation cover (%)	measured sediment rate ( $\text{tha}^{-1} \text{yr}^{-1}$ )	normalized <sup>a</sup> sediment rate ( $\text{tha}^{-1} \text{yr}^{-1}$ )	normalized <sup>a</sup> sediment rate without outliers ( $\text{tha}^{-1} \text{yr}^{-1}$ )
1	17	23	13.8	8.5	8.5
2	22	33	0.6	0.7	0.7
3	11	27	0.0	0.0	0.0
4	27	41	1.2	1.6	1.6
5	31	35	0.2	0.2	0.2
6	35	34	6.8	5.6	5.6
7	42	53	9.4	19.0	19.0
8	39	26	31.0	17.4	17.4
9	11	33	0.6	0.7	0.7
10	17	36	1.4	1.8	1.8
11	22	47	1.3	2.0	2.0
12	27	33	34.3	40.6	
13	31	63	26.1	111.3	
14	35	38	11.1	13.1	13.1
15	39	34	40.2	26.0	26.0
16	42	40	75.4	69.8	

<sup>a</sup> By C-factor with 35% vegetation cover, L-factor of 1.2, and K-factor of 0.031.

the respective factors. S-factors were fitted to observed soil loss versus sine of the slope angle using an exponential, power, and polynomial equation to the original dataset with all observation and a dataset excluding one outlier (N° 13), and three outliers (N° 12, 13, 16). The nine regression lines yield  $R^2$  estimates between 0.18 and 0.70, but differ largely with increasing slope steepness. This range of S-factors with increasing steepness is comparable to previous developed empirical S-factor equations (Table 1, Fig. 1). Therefore, we decided that a fitted function ( $S_{\text{alpine}}$  in Table 1, Fig. 3) complying the most important S-factors from the literature would be most suitable to describe the soil loss behavior

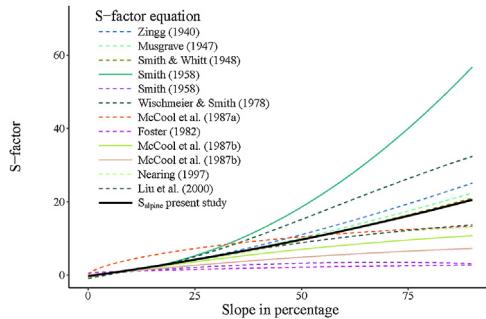


Fig. 3. Review and behavior of different empirical S-factor functions and the fitted function for steep alpine environments ( $S_{\text{alpine}}$ ).

at steep slopes. The aggregated S function and is a quadratic polynomial function with progressive growth (Eq. (9)):

$$S_{\text{alpine}} = 0.0005s^2 + 0.7956s - 0.4418 \quad (9)$$

where  $s$  is the slope steepness in percent.

$S_{\text{alpine}}$  is very close to the empirical normalized function proposed by Musgrave [6] for a slope steepness of 9%.

#### The Swiss LS-factor map including the Alps

The resulting modeled mean  $LS_{\text{alpine}}$ -factor of Switzerland is 14.8. The LS-factor increases with elevation gradient from a mean of 7.0 in the zone  $<1500$  m a.s.l. to 30.4 in the zone  $>1500$  m a.s.l. A cluster of highest mean LS-factors can be found across the Alps (Fig. 4). The lowest mean LS-factors are

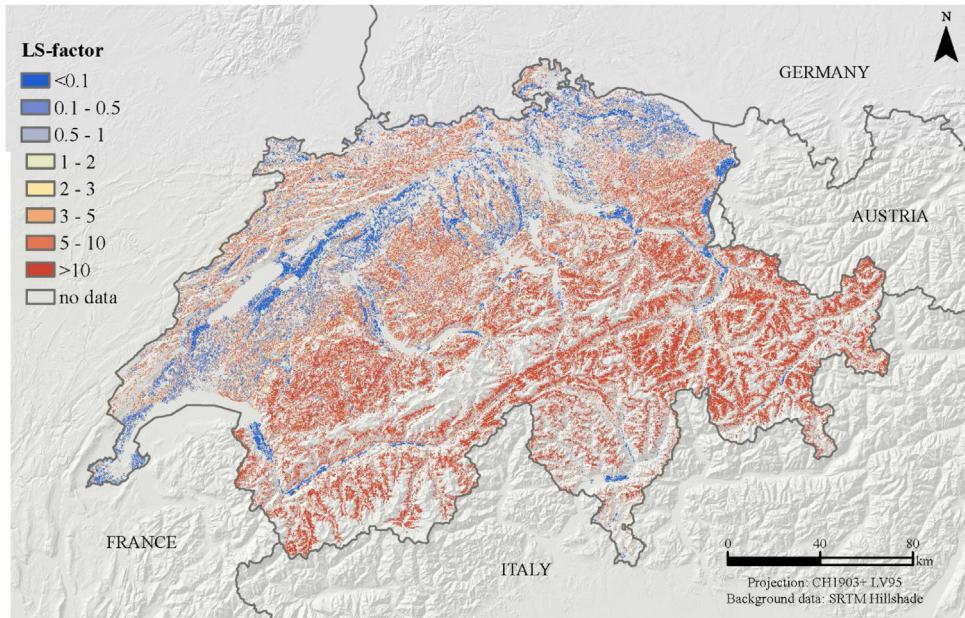


Fig. 4.  $LS_{\text{alpine}}$ -factor map (spatial resolution 2 m) for Switzerland derived by the digital elevation model SwissAlti3D.

in the Swiss lowlands. South-western facing slopes have higher LS-factors (17.6) compared to plain surfaces (0.04) and north facing slopes (12.5).

#### *Quality assessment and method uncertainties*

The original LS-factor has its origin in empirical field experiments and is developed for a maximum slope steepness of 50%. Validation of existing equations for slopes that are steeper than 50% is a challenge. However, while previous studies at inclinations >25% with approximately 20 plot measurements ([19], 24 plots; [20], 19 plots; [12], 9 plots; [21], 22 plots; [18], 6 plots) were successful in delineating and S-factor equation, in our case the variability of the data impeded a unique solution of the S-factor equation. To account for this high variability and still existing uncertainty, the way forward is to include the variability in the LS-factor calculation.

We investigated the deviation in percentage of our proposed  $S_{\text{alpine}}$  to a conservative function and a rather progressive function. The conservative function ( $S_{\text{cons}}$ ) is based on the translated and scaled sine functions of Eqs. (5) and (6) by McCool et al. [3] with a proportional and slightly digressive growth. The progressive function ( $S_{\text{prog}}$ ) is a quadratic polynomic function according to Smith and Whitt [7] with a progressive growth, but a higher coefficient than the here presented fitted function  $S_{\text{alpine}}$  (Eq. (10)) for  $S_{\text{alpine}}$ .

$$S_{\text{prog}} = 0.00650s^2 + 0.0453s + 0.065 \quad (10)$$

where  $s$  is the slope steepness in percent.

Low uncertainty has a deviation close to 0%. Higher percentages equals to a higher deviation of  $S_{\text{cons/prog}}$  to  $S_{\text{alpine}}$ .

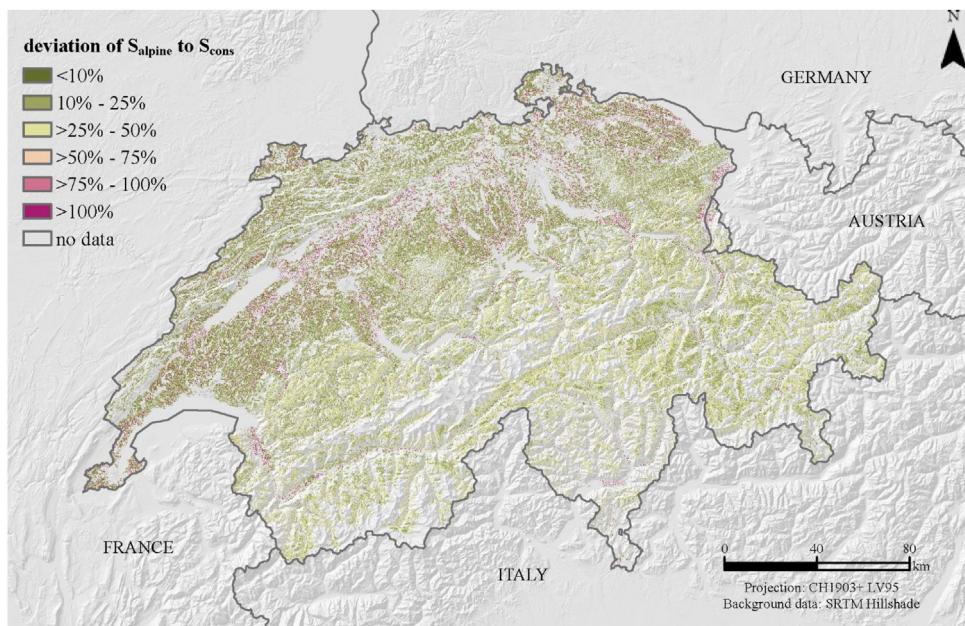


Fig. 5. Deviation in percentage of  $S_{\text{alpine}}$  to  $S_{\text{cons}}$  as an indicator of quality for the proposed  $S_{\text{alpine}}$ -factor.  $S_{\text{alpine}}$  is a lumped S-factor of a total of 12 empiric S-factor equations of the literature (Eq. (9)). It can be seen as an approximation to the high slope gradients in alpine environments.  $S_{\text{cons}}$  complies with the proposed S-factor of McCool et al. [3] (Eqs. (5) and (6)). The deviation is presented in percentage.

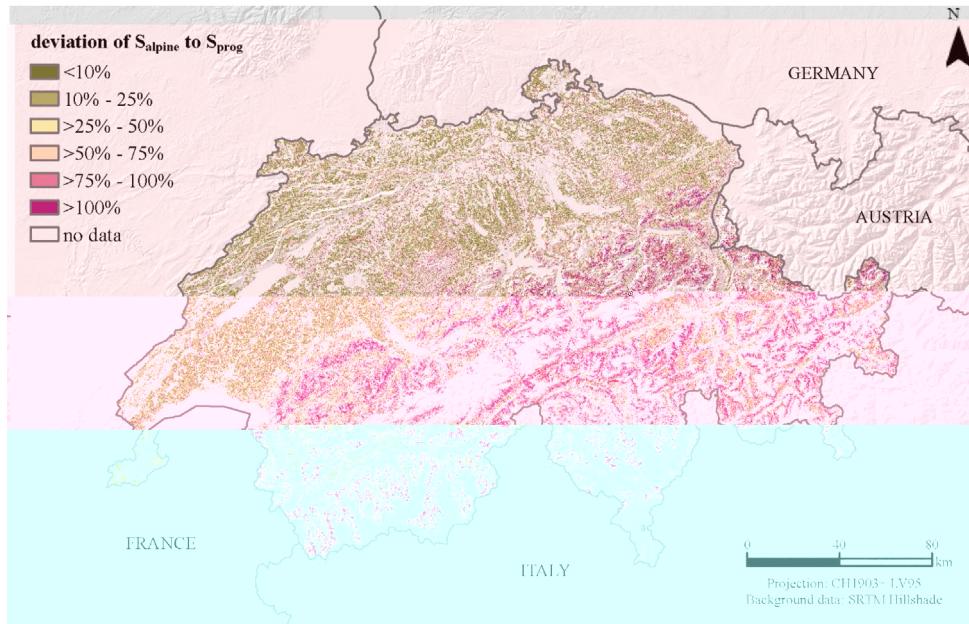


Fig. 6. Deviation in percentage of  $S_{\text{alpine}}$  to  $S_{\text{prog}}$  as an indicator of quality for the proposed  $S_{\text{alpine}}$ -factor.  $S_{\text{alpine}}$  is a lumped S-factor of a total of 12 empiric S-factor equations of the literature (Eq. (9)). It can be seen as an approximation to the high slope gradients in alpine environments.  $S_{\text{prog}}$  complies with the proposed S-factor of Smith and Whitt [7] (Eq. (10)). The deviation is presented in percentage.

The deviation of  $S_{\text{alpine}}$  to  $S_{\text{cons}}$  shows higher deviations in areas with less slope gradients (parts of Swiss midland) (Fig. 5). The steep slope areas in the Alps have deviations of 25%–50%. Both functions,  $S_{\text{alpine}}$  and  $S_{\text{cons}}$  predict the steep alpine environment in a comparable way. The deviation of the progressive S-factor ( $S_{\text{prog}}$ ) and  $S_{\text{alpine}}$  diverge much more in the Alps whereas the equations are rather fitting in flatter regions (Fig. 6). A sharp edge of low divergence to high divergence is marked by the northern Alpine foothill with increasing slope gradients.

This relationship of deviation and slope gradient is not surprising as the uncertainty of many equations rises with slope steepness (cf. Fig. 3). García-Ruiz et al. [22] identified an increasing trend of uncertainty for 624 measured erosion rates and slope gradients across the world for slope steepness  $>11^\circ$ .

The LS-Factor map of the Swiss agricultural land use unit is visually compatible with the LS-factor maps of the European Union provided by Panagos et al. [23] (Fig. 7). In contrast to the modeling of the total country area by Panagos et al. [23] we constrained the LS-factor to agricultural soils incl. grasslands using a field cadaster. The main differences are found on steeper slopes  $>50\%$ , which have been excluded in the European approach. Furthermore, the European map relies on the conservative Eqs. (5) and (6) by McCool et al. [3]. Additionally, different spatial resolutions of Digital Elevation Models (2 m versus 25 m) are influencing the slope and aspect mapping and thus the LS-factor [24–26].

It should be considered that the number of rainfall experiments for the L-factor ( $n = 19$ ) and the S-factor ( $S = 16$ ) is short and limited only to grasslands which are the predominant land use at Swiss alpine slopes [27]. Rainfall simulations in alpine environments are difficult to conduct due to the harsh terrain and climate conditions. Often, the temporal period for measurements is limited by the late melt out of snow cover and the short vegetation period [28]. To better model the S-factor for steep

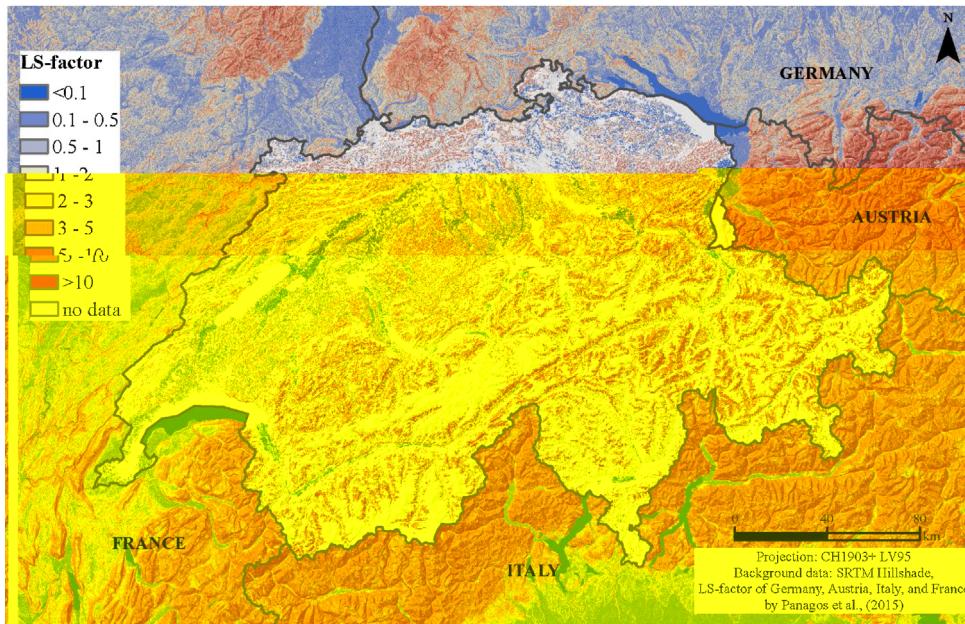


Fig. 7. LS-factor for the Swiss agricultural area (incl. Liechtenstein) embedded in the European Union's LS-factor map (for total country area) by Panagos et al. [23].

alpine slopes further measurements (e.g., rainfall simulation experiments) are needed to constrain S-factor assessment for steep slopes.

#### Additional information

##### *Introduction*

The slope length factor L and slope steepness factor S, often lumped together as the topographic factor LS. The LS-factor is one of the factors (R rainfall erosivity, C cover and management factor, K soil erodibility, P support practices) of the Universal Soil Loss Equation (USLE) and its revised version (RUSLE) [1,29]. LS is a factor that describes the influence of the topography to the soil erosion risk by considering the length of a slope and the influence of surface runoff which can be active on eroding soil material before it infiltrates or continues as interflow. Furthermore, it includes the steepness of a slope as runoff on steeper slopes has a higher gravity and therefore is more relevant for erosion.

With the availability of Digital Elevation Models the calculation of LS-factors in GIS environments was made possible even for large-scale erosion modeling approaches. Winchell et al. [14] revealed a reasonable agreement of GIS-based LS-factor and field measured LS-factors of the US Natural Resource Inventory database for the Mississippi Catchment.

Originally, the LS-factor was assessed on a 9% steep slope with a length of 22.13 m (72.6 feet) [1]. Owing to its empirical character, LS-factors are usually limited to a maximum slope angle of 50% ( $26.6^\circ$ ) [3,12]. As Switzerland is a country with a high elevation gradient from 192 m a.s.l. to 4633 m a.s.l. (mean elevation 1288 m a.s.l.) and a mean slope gradient of up to 36% ( $20^\circ$ ), a not negligible fraction of slopes (4.7%) exceeds the limitation of 50%. Yet, no uniform equation to assess the LS-factor for steep slopes like in the alpine environment of Switzerland was presented to the scientific community. Only a few studies are dealing with LS-factors on steep slopes (e.g. [12]). For example, slopes >50% were disregarded in the most recent European Union's LS-factor map by Panagos et al. [23].

To overcome that limitation in LS-factor modeling on steep slopes, we (i) limited the potential flow path length to a maximal flow and (ii) choose the most representative equation for Swiss steep slopes.

## Data statement

Raw data were generated at Swisstopo and provided only for scientific purposes. Derived data supporting the findings of this study are available from the corresponding author SS on request.

## Acknowledgments

This work was supported by the Swiss Federal Office for the Environment (FOEN) (grant numbers N° N222-0350 and N° P182-1535). The authors would like to thank Christine Alewell for the methodological support and Pascal Bircher for the advice in data handling with SAGA GIS/RSAGA and the upgrade of the existing field block cadaster of Switzerland. Our thank goes to M. Schulthess, C. Keller, N. Bongni, S. Rothenbühler, and A. Aeschbach for the support in the field and the footage. The authors thank Swisstopo for making their data available for this research. The authors would like to thank two anonymous referees for their valuable comments and suggestions to improve the quality of the paper.

## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.mex.2019.01.004>.

## References

- [1] W.H. Wischmeier, D.D. Smith, Predicting Rainfall Erosion Losses Washington, (1978) .
- [2] P.J.J. Desmet, G. Govers, A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units, *J. Soil Water Conserv.* 51 (1996) 427–433.
- [3] D.K. McCool, L.C. Brown, G.R. Foster, C.K. Mutchler, L.D. Meyer, Revised slope steepness factor for the universal soil loss equation, *Trans. ASAE* 30 (1987) 1387–1396, doi:<http://dx.doi.org/10.13031/2013.30576>.
- [4] K. Auerswald, Eignung der Hangneigungsfaktoren verschiedener Erosionsmodelle unter bayerischen Anbauverhältnissen, *Zeitschrift für Kulturtechnik und Flurbereinigung* 27 (1986) 218–224.
- [5] A. Zingg, Degree and length of land slope as it affects soil loss in run-off, *Agric. Eng.* (1940) 59–64.
- [6] G.W. Musgrave, The quantitative evaluation of factors in water erosion—a first approximation, *J. Soil Water Conserv.* (1947) 133–138.
- [7] D.D. Smith, D. Whitt, Estimating soil losses from field areas, *Agric. Eng.* 29 (1948) 394–396.
- [8] D.D. Smith, Factors affecting rainfall erosion and their evaluation, *Int. Assoc. Sci. Hydrol. Publ.* 43 (1958) 97–107.
- [9] D. McCool, L. Brown, G.R. Foster, C. Mutchler, L. Meyer, Revised slope steepness factor for the universal soil loss equation, *Trans. ASAE* 30 (1987) 1387–1398.
- [10] G.R. Foster, Modeling the erosion process, in: I.C.T. Haan, H.P. Johnson, D.L. Brakensiek (Eds.), *Hydrologic Modeling of Small Watersheds*, St. Joseph, 1982, pp. 297–382.
- [11] M.A. Nearing, A single, continuous function for slope steepness influence on soil loss, *Soil Sci. Soc. Am. J.* 61 (1997) 917, doi:<http://dx.doi.org/10.2136/sssaj1997.03615995006100030029x>.
- [12] B.Y. Liu, M.A. Nearing, P.J. Shi, Z.W. Jia, Slope length effects on soil loss for steep slopes, *Soil Sci. Soc. Am. J.* 64 (2000) 1759, doi:<http://dx.doi.org/10.2136/sssaj2000.6451759x>.
- [13] S. Orlandini, G. Moretti, M.A. Corticelli, P.E. Santangelo, A. Capra, R. Rivola, J.D. Albertson, Evaluation of flow direction methods against field observations of overland flow dispersion, *Water Resour. Res.* 48 (2012) 412, doi:<http://dx.doi.org/10.1029/2012WR012067>.
- [14] M.F. Winchell, S.H. Jackson, A.M. Wadley, R. Srinivasan, Extension and validation of a geographic information system-based method for calculating the revised universal soil loss equation length-slope factor for erosion risk assessments in large watersheds, *J. Soil Water Conserv.* 63 (2008) 105–111, doi:<http://dx.doi.org/10.2489/jswc.63.3.105>.
- [15] MeteoSwiss, Automatic Monitoring Network, (2018) . <https://www.meteoswiss.admin.ch/home/measurement-and-forecasting-systems/land-based-stations/automatisches-messnetz.html>.
- [16] D.K. McCool, G. Foster, G. Weesies, Slope length and steepness factor (LS), Chapter 4, in: K.G. Renard, G.R. Foster, G.A. Weesies, D.K. McCool, D.C. Yoder (Eds.), *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)*, USDA, Washington, D.C, 1997, pp. 101–142.
- [17] S. Tresch, Influence of the Slope Steepness on Soil Erosion Modelling Measured with Rainfall Simulations in the Urseren Valley. Master Thesis Basel, (2014), doi:<http://dx.doi.org/10.13140/RG.2.2.15260.54409>.
- [18] Y. Schindler Wildhaber, D. Bänninger, K. Burri, C. Alewell, Evaluation and application of a portable rainfall simulator on subalpine grassland, *Catena* 91 (2012) 56–62, doi:<http://dx.doi.org/10.1016/j.catena.2011.03.004>.
- [19] A.W. Kilinc, E.V. Richardson, Mechanics of Soil Erosion from Overland Flow Generated by Simulated Rainfall, Colorado State University, 1973.
- [20] B.Y. Liu, M.A. Nearing, L.M. Risso, Slope gradient effects on soil loss for steep slopes, *Trans. ASAE* 37 (1994) 1835–1840.

- [21] A. Merz, C. Alewell, E. Hiltbrunner, D. Bänninger, Plant-compositional effects on surface runoff and sediment yield in subalpine grassland, *J. Plant Nutr. Soil Sci.* 172 (2009) 777–788, doi:<http://dx.doi.org/10.1002/jpln.200800231>.
- [22] J.M. García-Ruiz, S. Beguería, E. Nadal-Romero, J.C. González-Hidalgo, N. Lana-Renault, Y. Sanjuán, A meta-analysis of soil erosion rates across the world, *Geomorphology* 239 (2015) 160–173, doi:<http://dx.doi.org/10.1016/j.geomorph.2015.03.008>.
- [23] P. Panagos, P. Borrelli, K. Meusburger, A new european slope length and steepness factor (LS-factor) for modeling soil erosion by water, *Geosciences* 5 (2015) 117–126, doi:<http://dx.doi.org/10.3390/geosciences5020117>.
- [24] K.-t. Chang, B.-w. Tsai, The effect of DEM resolution on slope and aspect mapping, *Cartogr. Geogr. Inf. Syst.* 18 (1991) 69–77, doi:<http://dx.doi.org/10.1559/152304091783805626>.
- [25] M.F. Ramli, M.K. Yusoff, S. Mustapha, T.S. Hiang, The effect of digital elevation model scale factor on soil erosion studies. Case study in Cameron Highlands, Malaysia, *J. Environ. Hydrol.* 14 (2006) 1–9.
- [26] Q. Zhu, X. Yang, Q. Yu, Assess the topographic resolution impact on soil loss, 2016 IEEE International Geoscience and Remote Sensing Symposium (IGARSS) (2016) 6055–6058.
- [27] S. Schmidt, C. Alewell, K. Meusburger, Swiss national grassland map and change (1996–2015) of permanent grasslands extent in Switzerland, *Data Brief* 20 (2018) 1992–1998, doi:<http://dx.doi.org/10.1016/j.dib.2018.09.039>.
- [28] S. Schmidt, C. Alewell, K. Meusburger, Mapping spatio-temporal dynamics of the cover and management factor (C-factor) for grasslands in Switzerland, *Remote Sens. Environ.* 211 (2018) 89–104, doi:<http://dx.doi.org/10.1016/j.rse.2018.04.008>.
- [29] K. Renard, G. Foster, G. Weesies, J. Porter, RUSLE. Revised universal soil loss equation, *J. Soil Water Conserv.* 46 (1991).
- [30] A. Brenning, D. Bangs, M. Becker, Package 'RSAGA', (2018) . <https://cran.r-project.org/web/packages/RSAGA/RSAGA.pdf>.
- [31] O. Conrad, B. Bechtel, M. Bock, H. Dietrich, E. Fischer, L. Gerlitz, J. Wehberg, V. Wichmann, J. Böhner, System for automated geoscientific analyses (SAGA) v. 2.1.4, *Geosci. Model. Dev. Discuss.* 8 (2015) 1991–2007, doi:<http://dx.doi.org/10.5194/gmd-8-1991-2015>.

Update

**MethodsX**

Volume 8, Issue , 2021, Page

DOI: <https://doi.org/10.1016/j.mex.2021.101588>



ELSEVIER

Contents lists available at ScienceDirect

MethodsX

journal homepage: [www.elsevier.com/locate/mex](http://www.elsevier.com/locate/mex)



## Corrigendum

### Corrigendum to “Modification of the RUSLE slope length and steepness factor (LS-factor) based on rainfall experiments at steep alpine grasslands” [MethodsX 6 (2019), 219–229]



Simon Schepер<sup>a,b,\*</sup>, Simon Tresch<sup>c</sup>, Katrin Meusburger<sup>d</sup>

<sup>a</sup> Environmental Geosciences, University of Basel, Bernoullistrasse 30, Basel CH-4056, Switzerland

<sup>b</sup> Dr. Simon Schepер – Research | Consulting | Teaching, Eickhorst 3, Dähre 29413, Germany

<sup>c</sup> Institute for Applied Plant Biology, Benkenstrasse 254a, Witterswil 4108, Switzerland

<sup>d</sup> Forest Soils and Biogeochemistry, Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Zürcherstrasse 111, Birmensdorf CH-8903, Switzerland

---

#### ARTICLE INFO

Article history: Available online 23 November 2021

---

The authors regret that a typing error was introduced in Eq. (9). The correct equation for  $S_{alpine}$  is the following:

$$S_{alpine} = 0.0005s^2 + 0.1795s - 0.4418$$

It is correctly written in the graphical abstract and Table 1 of the article, however in Eq. (9) accidentally 0.7956 s instead of 0.1795 s was written.

---

DOI of original article: [10.1016/j.mex.2019.01.004](https://doi.org/10.1016/j.mex.2019.01.004)

\* Corresponding author.

E-mail addresses: [simonscheper@simonscheper.com](mailto:simonscheper@simonscheper.com) (S. Schepер), [simon.tresch@iap.ch](mailto:simon.tresch@iap.ch) (S. Tresch), [katrin.meusburger@wsl.ch](mailto:katrin.meusburger@wsl.ch) (K. Meusburger).