Soil erosion modeling in R

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Why?

Preliminary, <u>reproducible</u> assessment of soil erosion almost for every area on Earth with Universal Soil Loss Equation using {rusleR} 📦

rusleR

DOI 10.5281/zenodo.6992394 | R-CMD-check failing | CRAN not published | last change 2022-08-15 | lifecycle experimental | repo status Concept

This package offers an `R` implementation of Universal Soil Loss Equation (USLE). You can find here a collection of functions to estimate main factors: R-factor, K-factor, LS-factor and C-factor. The package uses `terra` and `Rsagacmd` in the background. `SAGA GIS` need to be installed on your machine as well.

UNIVERSAL SOIL LOSS EQUATION (USLE)

$$A = R \cdot K \cdot C \cdot LS \cdot P$$ Estimated soil loss per year [t ha^{-1} yr^{-1}]

R – rainfall erosivity factor [MJ mm h^{-1} ha^{-1} yr $^{-1}$]

K – soil erodibility factor [t h MJ^{-1} mm^{-1}]

C – crop/cover and management factor [dimensionless]

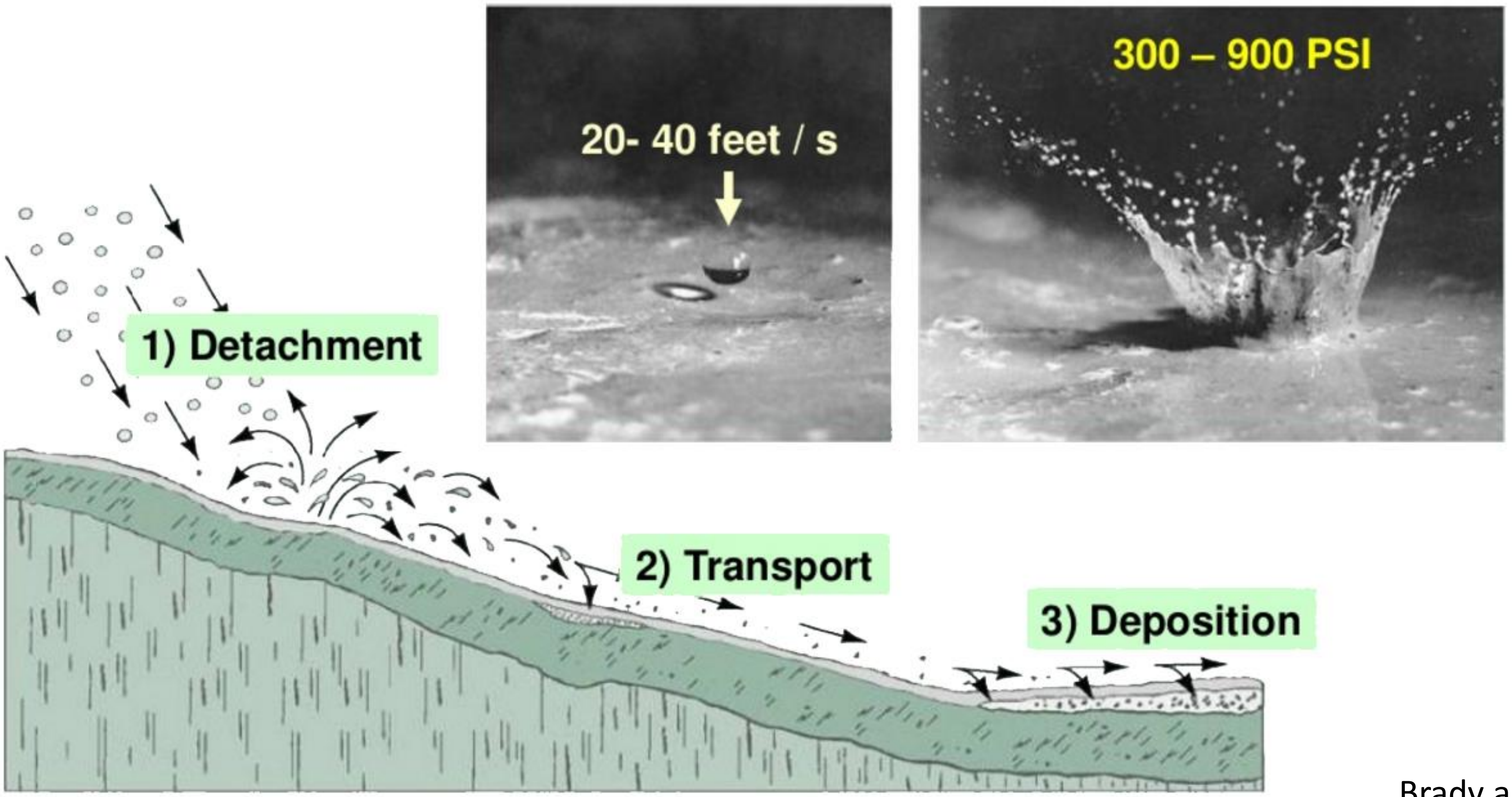
P – conservation/support practice factor [dimensionless]

LS – the slope length and steepness factor (also known as topographic factor)

[dimensionless]

Wischmeir & Smith 1958

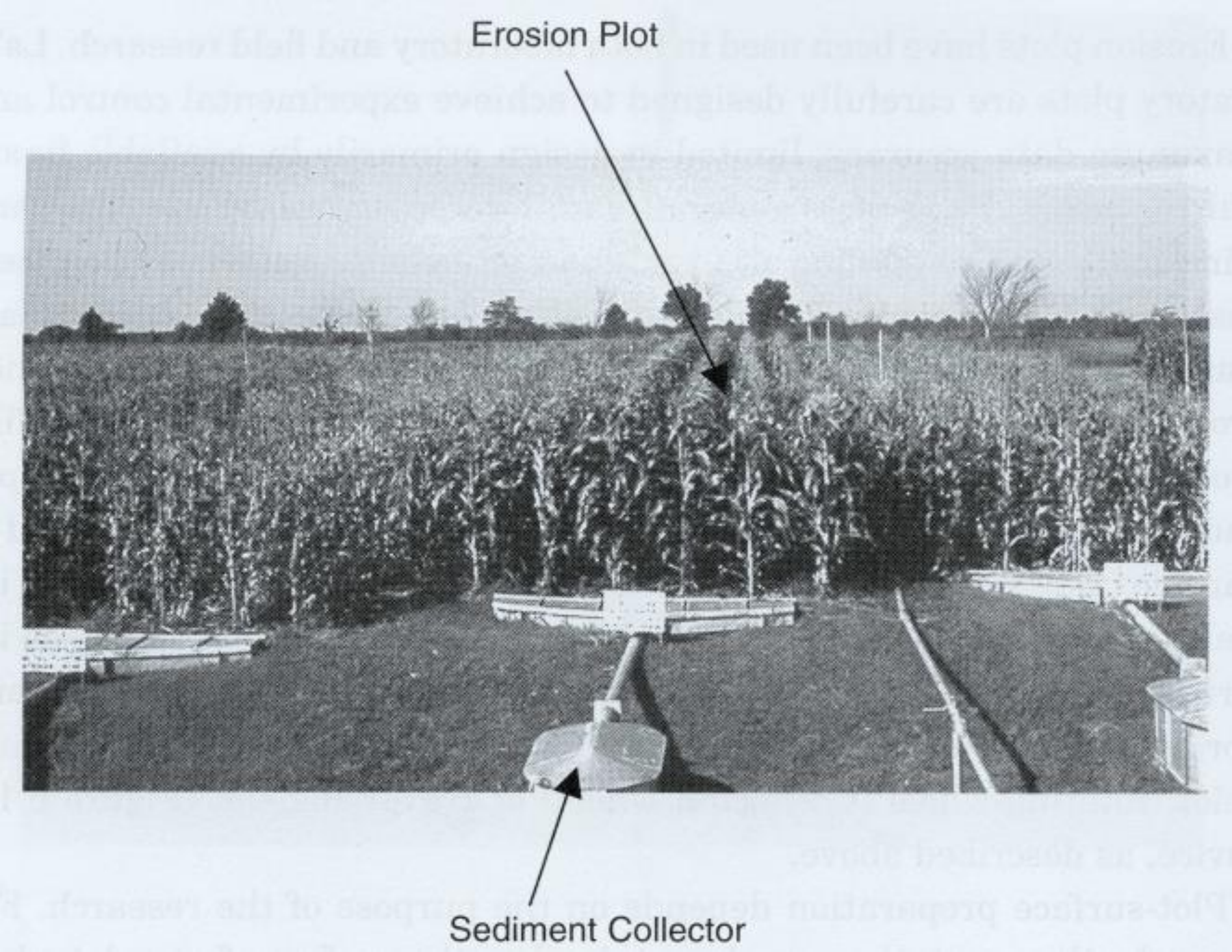
How USLE works?



Brady and Weil (2002)

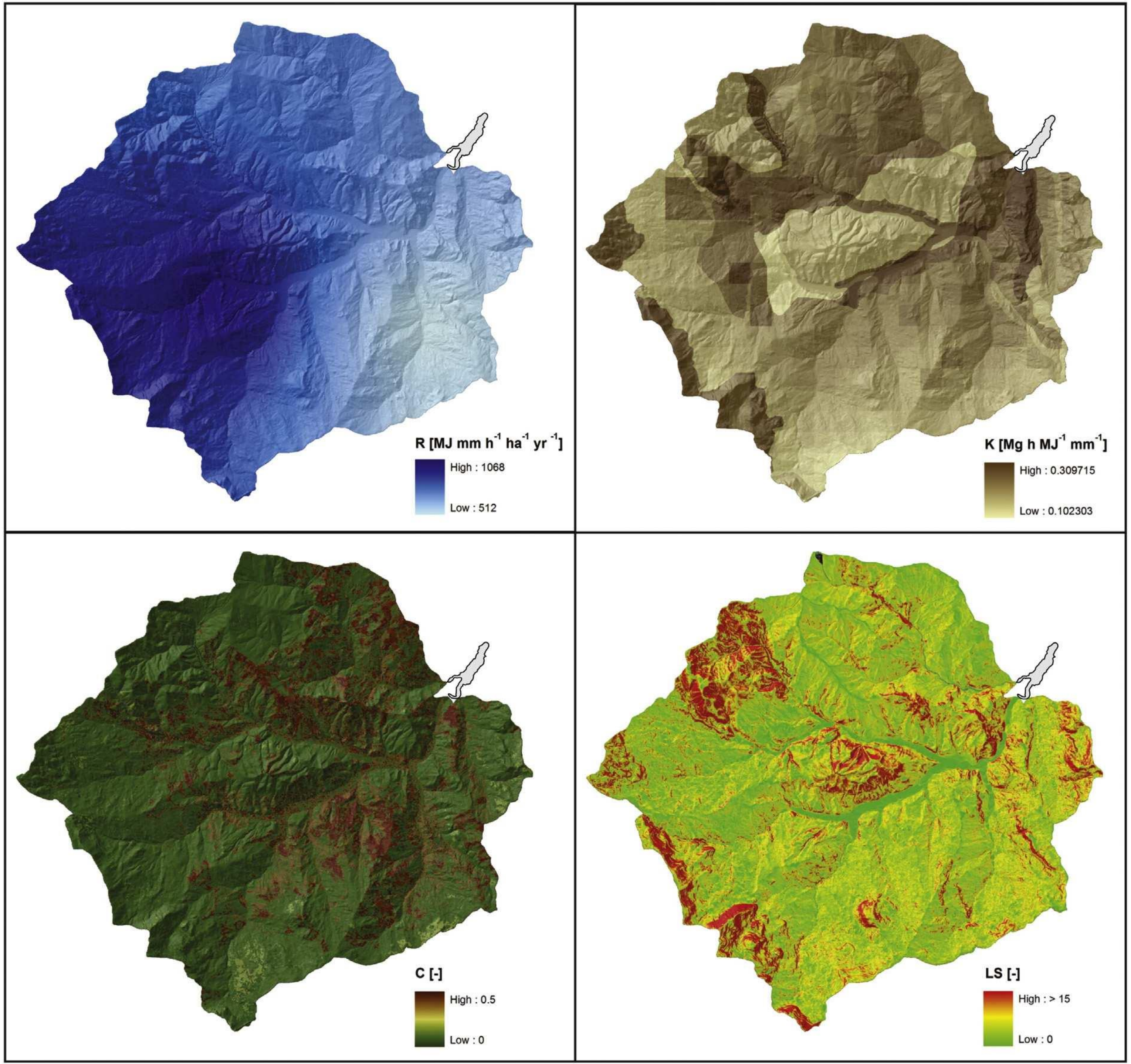
STANDART USLE PLOT

- 22.1m (72.6 ft) long
- 9% slope
- 4m (13.12 ft) wide.



USLE

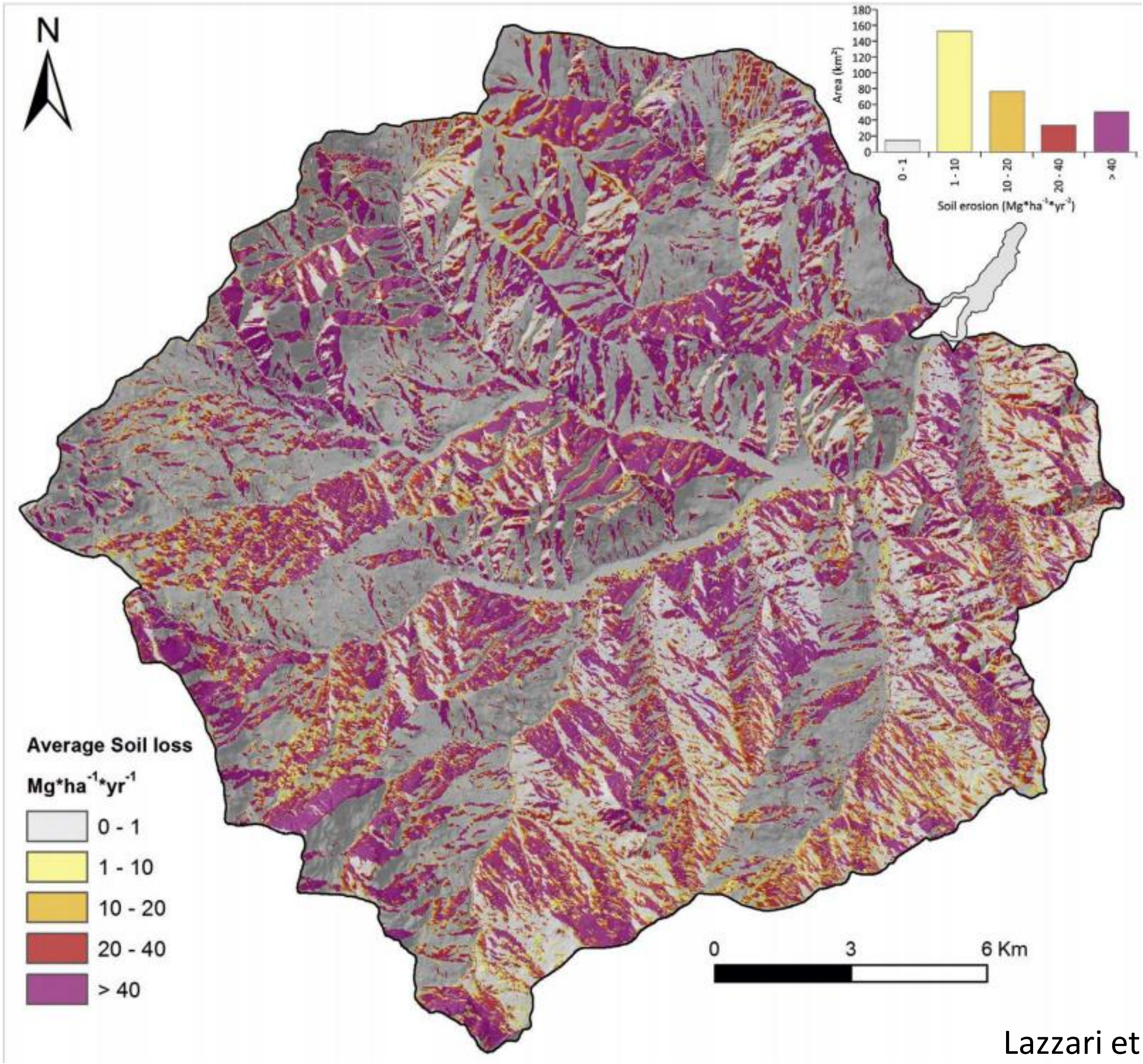
MAPS OF FACTORS



Lazzari et al (2015)

USLE

MAP OF SOIL LOSS



Lazzari et al (2015)

FACTORS COMPUTING: R

$$R = \frac{1}{n}\sum_{j=1}^{n}\left[\sum_{k=1}^{m}(E)(I_{30})_k\right]_j$$

R – rainfall erosivity;

E – total amount of kinetic energy contained within a storm;

I – maximum 30-min intensity of the storm

Wischmeier and Smith also developed the following empirical equation for determining E, the total amount of kinetic energy in a storm that would be used to initiate the motion of sediment particles:

$$E = 916 + 331log_{10}I$$

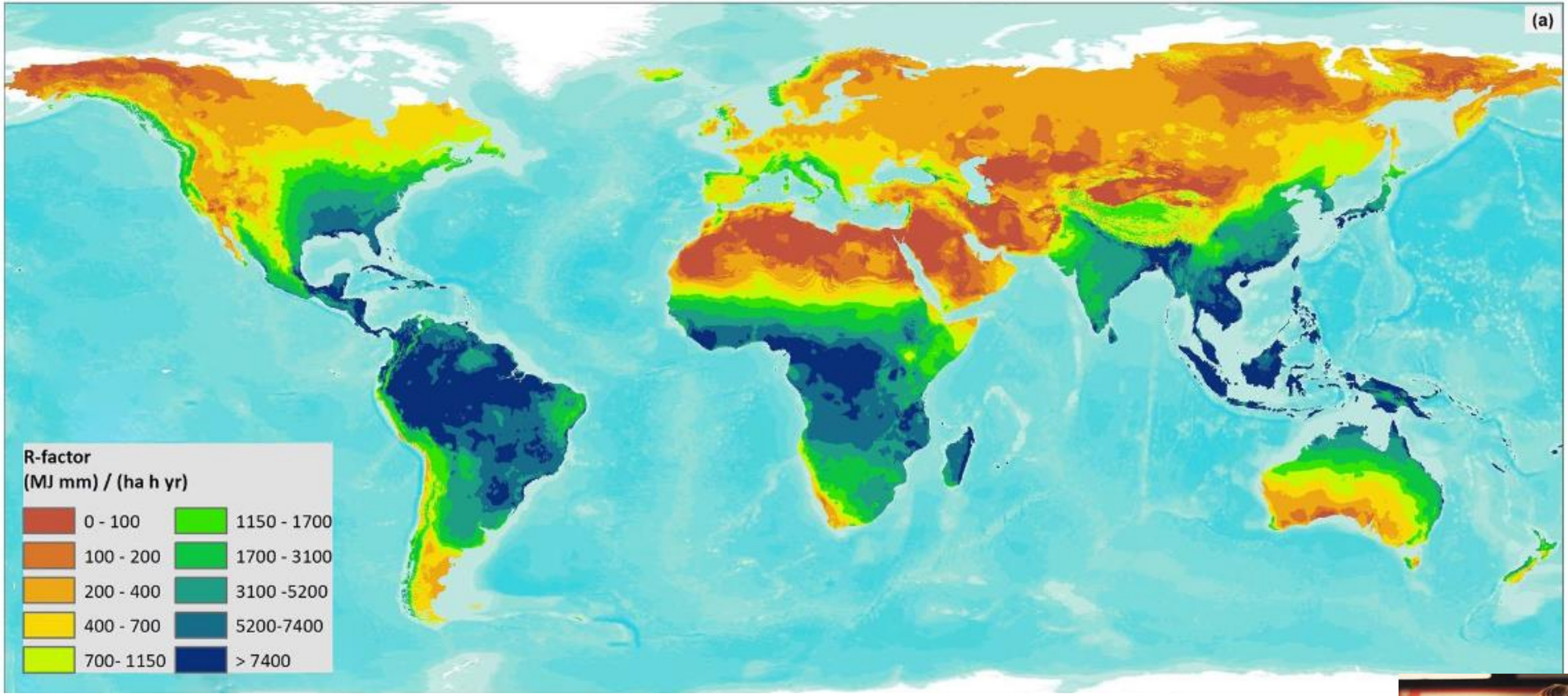
Wischmeir & Smith 1958

FACTORS COMPUTING: R

Model	Parameters	Authors
$R = -102 + 2.91 \cdot I_{1,2} + 30.93 \cdot I_{24,2}$	$I_{1,2}$ and $I_{24,2}$ is rainfall intensity of 1 and 24 hours duration and a return period of 2 years	D'Asaro and Santoro, 1983
$R = 0.21 \cdot z^{-0.1} \cdot \left(\frac{P}{R_{days}} \right)^2$	z elevation (m); R_{days} the mean annual number of rainy days	D'Asaro and Santoro, 1983
$R = 0.524 \cdot \left[\sum_{i=1}^{12} \frac{p^2_{i,j}}{P_j} \right]^{1.59}$	$p_{i,j}$ is the total precipitation (mm) of the generic month i of the year j; P_j, is the total precipitation (mm) of the year j	Ferro et al., 1991
$EI_{30} = k \cdot d \cdot (h_{max})^{1.95}$	d is the daily rain depth (mm); h_{max} is the maximum 60 minutes rain intensity (mm h^{-1}); k is a coefficient set to 0.15	Bagarello and D'Asaro, 1994
$EI_{30-annual} = 0.124 \cdot \left[P^{0.9} + \left(d^{0.85} \cdot h \right) \right]^{1.294}$	d is the annual maximum daily rainfall (mm); h is the annual maximum hourly rainfall (mm)	Grauso et al., 2010

Equation	Author(s)
$R_x = 3.76 \cdot \frac{M_x^2}{P} + 42.77$	Oliveira and Medina (1990)
$R_x = 36.849 \cdot \left(\frac{M_x^2}{P} \right)^{1.0852}$	Morais et al. (1991)
$R_x = (0.66 \cdot M_x) + 8.88$	Oliveira (1988)
$R_x = 42.307 \cdot \frac{M_x^2}{P} + 69.763$	Silva (2001)
$R_x = 0.13 \cdot M_x^{1.24}$	Leprun (1981)
$R_x = 12.592 \cdot \left(\frac{M_x^2}{P} \right)^{0.6030}$	Val et al. (1986)
$R_x = 68.73 \cdot \left(\frac{M_x^2}{P} \right)^{0.841}$	Lombardi Neto and Moldenhauer (1992)
$R_x = 19.55 + (4.20 \cdot M_x)$	Rufino et al. (1993)

Global Rainfall Erosivity (GLOREDa)



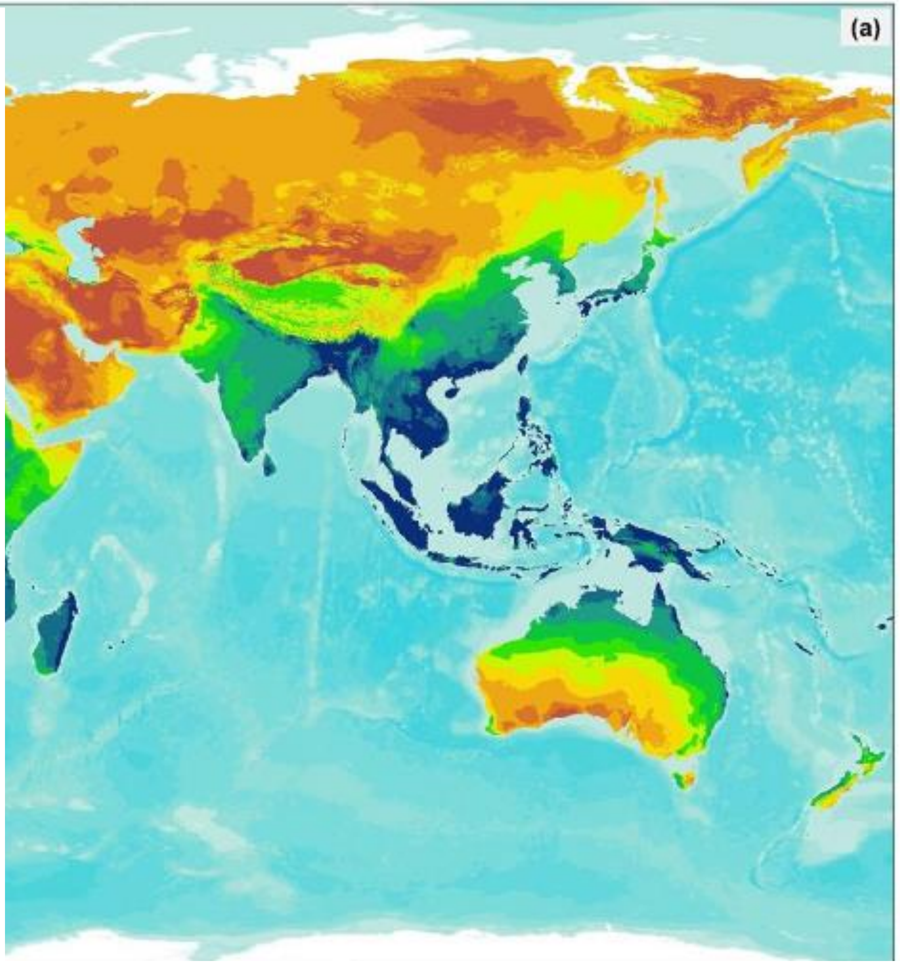
⚠ **Be careful with the temporal range of input data**

Panagos P et al. 2017. Global rainfall erosivity assessment based on high-temporal resolution rainfall records. Scientific Reports **7** : 4175. DOI: 10.1038/s41598-017-04282-8

Global Rainfall Erosivity (GLOREDa)

Country		No. of Stations	(Main) Period Covered	Years per station (average)	(Main) Temporal resolution of rainfall data	Source of high temporal resolution rainfall data
NZ	New Zealand	35	2000–2012	12	10 Min	New Zealand Institute of Water and Atmospheric Research (NIWA)
PL	Poland	13	1961–1988	27	30 Min	Warsaw University of Life Sciences
PT	Portugal	41	2001–2012	11	60 Min	Agência Portuguesa do Ambiente
RO	Romania	60	2006–2013	8	10 Min	Meteorological Administration
RU	Russian Federation	218	1961–1983	23	30 Min	Lomonosov Moscow State University
SE	Sweden	73	1996–2013	18	60 Min	Swedish Meteorological and Hydrological Institute (SMHI)
SI	Slovenia	31	1999–2008	10	5 Min	Slovenian Environment Agency
SK	Slovakia	103	1971–1990	20	60 Min	Slovak Hydrometeorological Institute, Climatological service
SR	Suriname	11	1987–2010	25	60 Min	Meteorological organization of Suriname
TR	Turkey	160	2005–2014	10	1 Min	Ministry of Forest and Water Affairs General Directorate of Combating Desertification and Erosion
UK	United Kingdom	38	1993–2012	20	60 Min	NERC & UK Environ. Change Network(ECN), British Atmospheric Data Centre (BADC)
US	United States of America	92	2006–2016	11	5 Min	U.S. Climate Reference Network (USCRN), NOAA; Diamond *et al.*[58]
ZA	South Africa	5	2001–2005	5	5 Min	Nel and Summer[41]
Total		**3,540**				

Table 2. Overview of the high resolution rainfall data used to estimate global rainfall erosivity. In addition, erosivity information of 85 stations from 13 countries found in the literature[24, 43–56] was included in the global map (not shown in the table).



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FACTORS COMPUTING: K

Soil erodibility

Wischmeir & Smith 1958

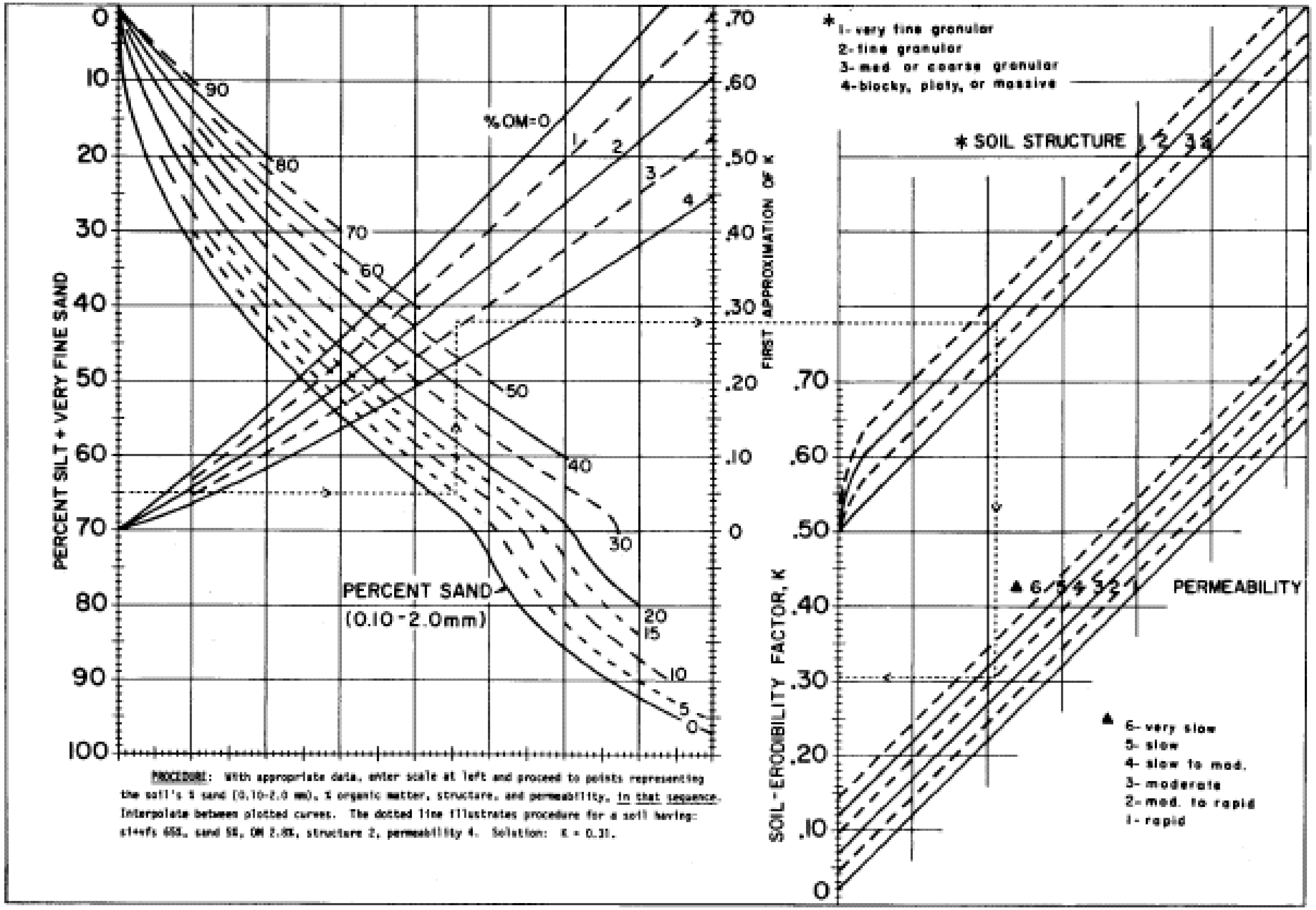


FIGURE 3.—The soil-erodibility nomograph. Where the silt fraction does not exceed 70 percent, the equation is $100\,K = 2.1\,M^{1.14}\,(10^{-4})\,(12 - a) + 3.25\,(b - 2) + 2.5\,(c - 3)$ where $M =$ (percent si + vfs) (100 − percent c), a = percent organic matter, b = structure code, and c = profile permeability class.

Variables that affect the K factor

Variable	Description and Function	Effect on erosion	Management Implications
Soil texture	- size and distribution of the available soil particles - smaller particles, *once detached*, are easily transported - texture of a soil influences runoff amount and rate	- erodibility increases with silt plus very fine sand content (particles easily detached, readily form crusts which decrease infiltration, increase runoff (see Table 3.2)	- type of soil may limit: - agricultural uses - crops that can be grown - management systems
Organic matter content	- amount of humus present - organic material helps to bind the soil particles together - affects water-holding capacity of soil, influences infiltration/runoff amounts	- soils with high organic matter content more erosion resistant, hold more water - low organic matter = low erosion resistance	- maintenance of adequate organic matter levels (through residue and/or manure management) reduces erosion risk, increases fertility (which in turn can increase crop vigour/cover, increase soil protection...)
Structure	- the arrangement of soil particles and aggregates - gives an indication of how strongly the soil particles "bind" together to resist erosion	- soils which do not break down easily yet allow infiltration more erosion-resistant	
Permeability	- affects the amount of water that will infiltrate into the soil as opposed to flowing downslope or ponding on the surface	- better infiltration = less runoff, less erosion (e.g. medium and coarse sand)	- practices which lead to the development of consolidated, impermeable layers or ploughpans increase the risk of soil erosion
Seasonality	- soil characteristics that may vary on a seasonal basis and affect erodibility include water content, bulk density, structure, permeability, biological activity, and drainage	- soils tend to be most susceptible in spring (especially during thaw conditions - saturated, less dense soils over frozen soils with low permeability) - least erodible in fall (dry, consolidated after growing season)	- better cover (standing and/or residue), rougher surfaces in spring can help stabilize soil, reduce erosion

FACTORS COMPUTING: K

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

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

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

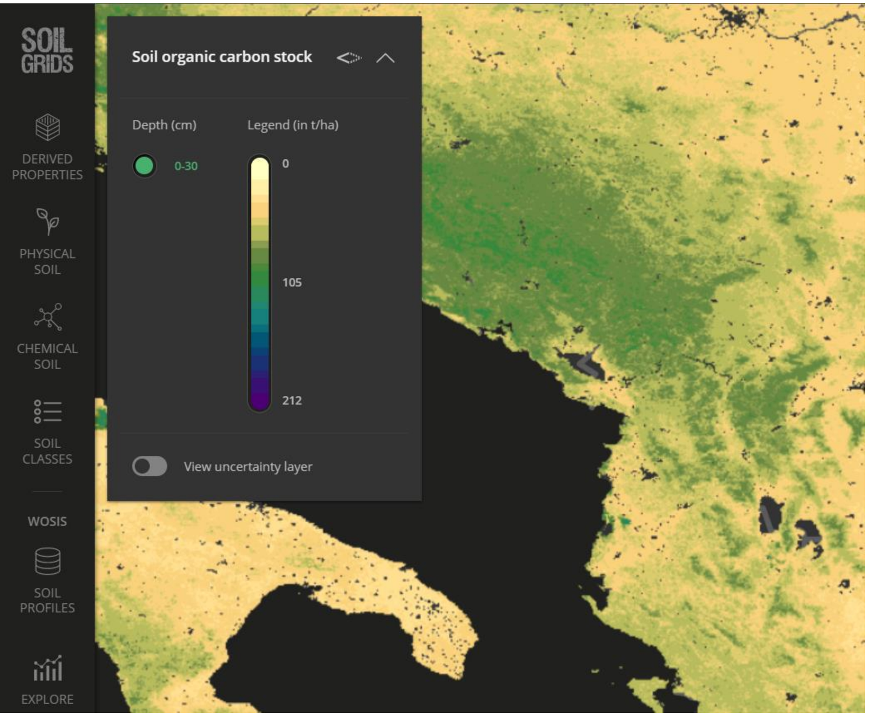
$$f_{orgc} = \left(1 - 0.0256 \times \frac{orgC}{orgC + \exp\left(-5.51 + 22.9 \times \left(1 - \frac{m_s}{100}\right)\right)}\right)$$

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

Williams 1983

FACTORS COMPUTING: K

PLOS | ONE



RESEARCH ARTICLE

SoilGrids250m: Global gridded soil information based on machine learning

Tomislav Hengl[1] *, Jorge Mendes de Jesus[1], Gerard B. M. Heuvelink[1], Maria Ruiperez Gonzalez[1], Milan Kilibarda[2], Aleksandar Blagotić[3], Wei Shangguan[4], Marvin N. Wright[5], Xiaoyuan Geng[6], Bernhard Bauer-Marschallinger[7], Mario Antonio Guevara[8], Rodrigo Vargas[8], Robert A. MacMillan[9], Niels H. Batjes[1], Johan G. B. Leenaars[1], Eloi Ribeiro[1], Ichsani Wheeler[10], Stephan Mantel[1], Bas Kempen[1]

Landuse/Landcover Factor — C

Table 7. *C*-factor equations that use NDVI.

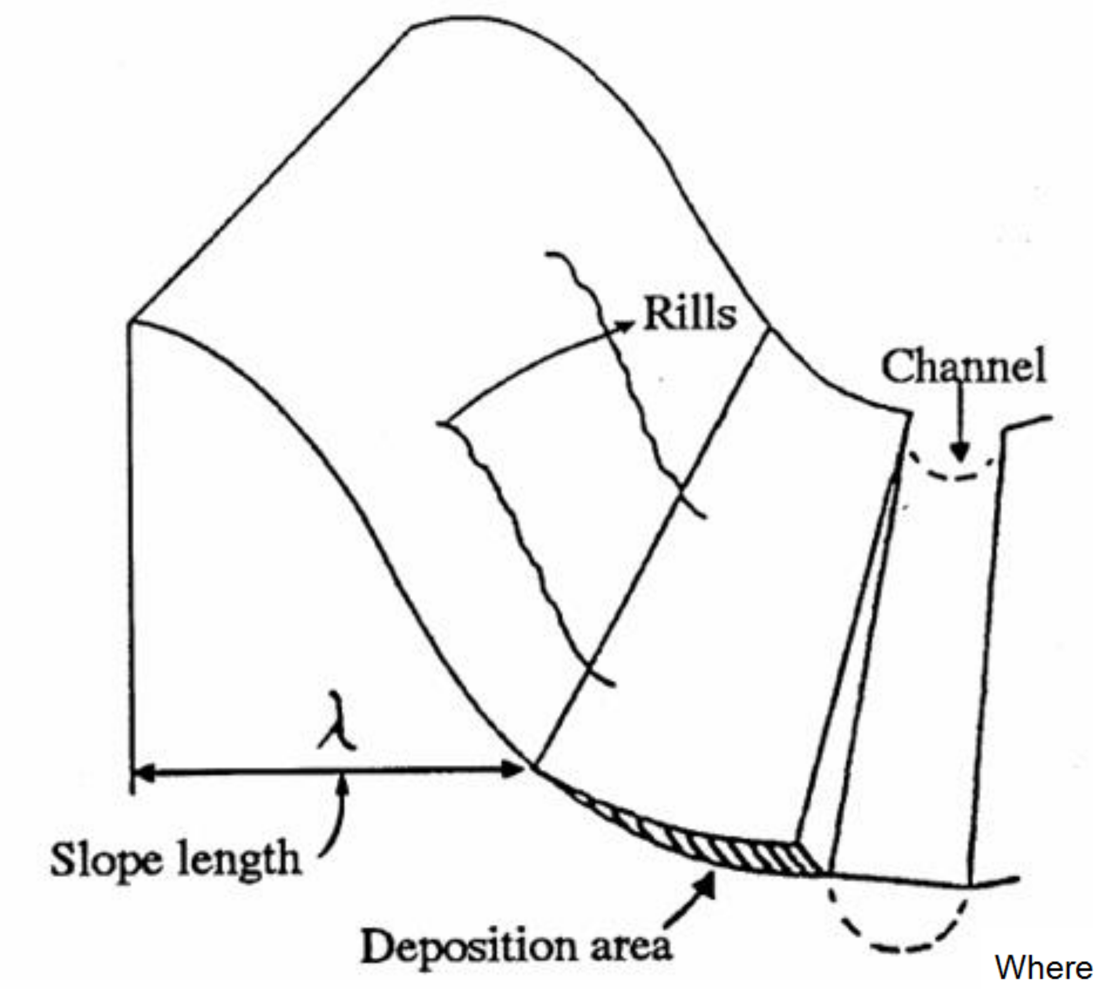
No.	Author	Original location	Equation
1	Van der Knijff et al. (2000)	Europe	$C = \exp\left[\propto \left(\frac{\text{NDVI}}{\beta - \text{NDVI}}\right)\right]$ $\alpha = 2$ $\beta = 1$
2	Ma et al. (2010) as cited in Li et al. (2014)	China	$f_g = \frac{\text{NDVI} - \text{NDVI}_{\text{min}}}{\text{NDVI}_{\text{max}} - \text{NDVI}_{\text{min}}}$ $C = \begin{cases} 1 & f_g = 0 \\ 0.6508 - 0.343 \times \log?(f_g) & 0 < f_g < 78.3\% \\ 0 & f_g \geq 78.3\% \end{cases}$

Table 8. *C* factors for general types of land cover compiled from various sources.

Cover	Dymond (2010) (New Zealand)	David (1988) (Philippines)	Morgan (2005) (various)	Fernandez et al. (2003) (USA)	Dumas and Fossey (2009) (Vanuatu)	Land Development Department (2002) as cited in Nontananandh and Changnoi (2012)
Bare ground	1	1	1			
Urban		0.2		0.03	0	0
Crop				0.128	0.01	0.255–0.525
Forest	0.005	0.001–0.006	0.001	0.001	0.001	0.003–0.048
Pasture	0.01		0.1			
Scrub	0.005	0.007–0.9	0.01	0.003	0.16	0.01–0.1

Benavidez R, Jackson B, Maxwell D, Norton K. 2018. A review of the (Revised) Universal Soil Loss Equation ((R)USLE): with a view to increasing its global applicability and improving soil loss estimates. *Hydrology and Earth System Sciences* **22** (11): 6059–6086 DOI: https://doi.org/10.5194/hess-22-6059-2018

FACTORS COMPUTING: LS



Ratio of soil loss under given conditions to that at a site with the "standard" slope and slope length.

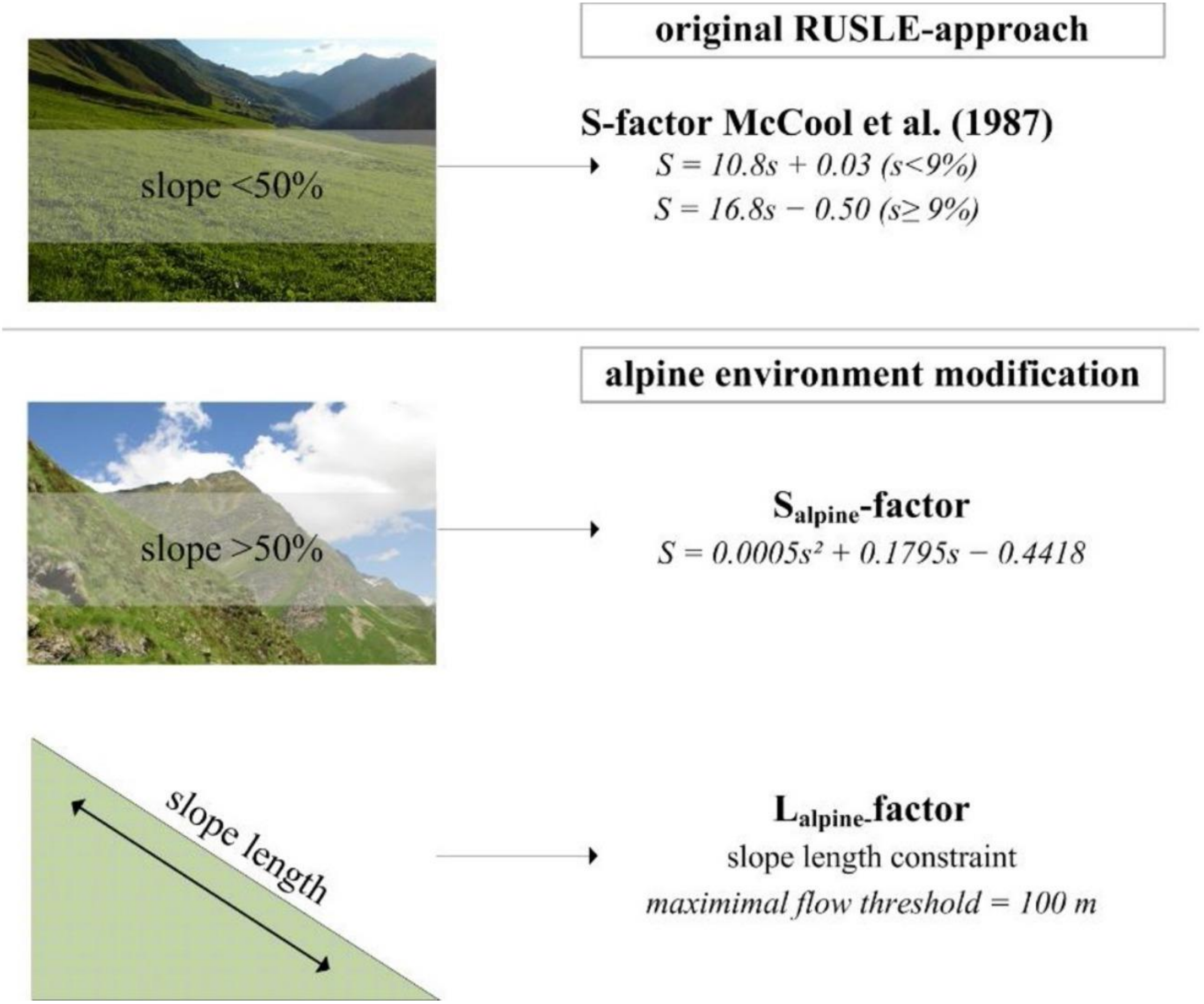
$$LS = \left(\frac{\lambda}{22.1}\right)^m (65.41 \sin^2\theta + 4.56 \sin\theta + 0.065)$$

Where λ is the horizontally measured plot length,
θ is the slope angle, and
m is a variable plot exponent adjustable to match terrain and soil variants. m varies between 0.5 (slopes of 5% or more) and 0.2 (slopes of $< 1\%$)

FACTORS COMPUTING: LS

LS factor for mountain topography:

- Flow accumulation threshold!
- Various equations for various slopes



Schmidt S, Tresch S, Meusburger K. 2019. Modification of the RUSLE slope length and steepness factor (LS-factor) based on rainfall experiments at steep alpine grasslands. MethodsX 6 : 219–229. DOI: 10.1016/j.mex.2019.01.004

FACTORS COMPUTING: LS

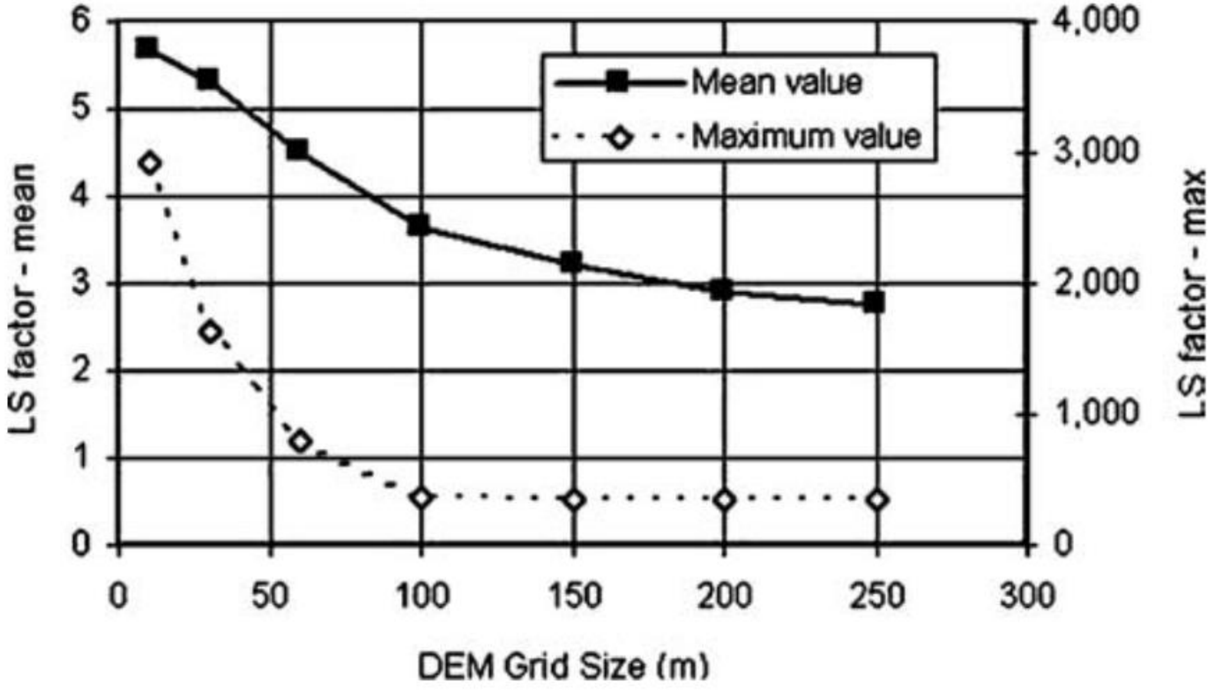


Figure 4. The *LS* factor versus DEM grid size.

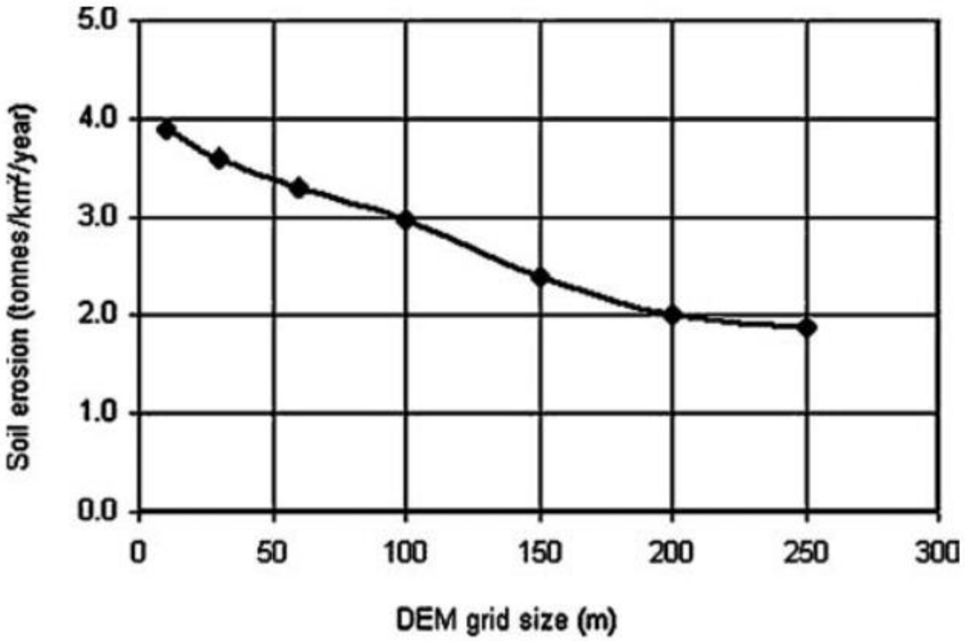


Figure 6. Soil erosion estimates at different DEM resolutions.

Wu S, Li J, Huang G. 2005. An evaluation of grid size uncertainty in empirical soil loss modeling with digital elevation models. *Environmental Modeling & Assessment* **10** (1): 33–42 DOI: 10.1007/s10666-004-6595-4

So? Why R?

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Table 3
Parameters of the truncated normal distribution of C factor values for each land use class in the Mortes River basin.

Land use	Mean	Standard dev.	Minimum	Maximum
Bare	0.8	0.2	0.6	1
Cropland	0.088	0.045	0.02	1
Eucalypt	0.015	0.03	0.0005	1
Forest	0.001	0.003	0.0001	1
Pasture	0.01	0.02	0.001	1
Rupestrian vegetation	0.001	0.005	0.0001	1

Batista PVG, Laceby JP, Davies J, Carvalho TS, Tassinari D, Silva MLN, Curi N, Quinton JN. 2021. A framework for testing large-scale distributed soil erosion and sediment delivery models: Dealing with uncertainty in models and the observational data. Environmental Modelling & Software **137** : 104961. DOI: 10.1016/j.envsoft.2021.104961

Are we sure in factor values?

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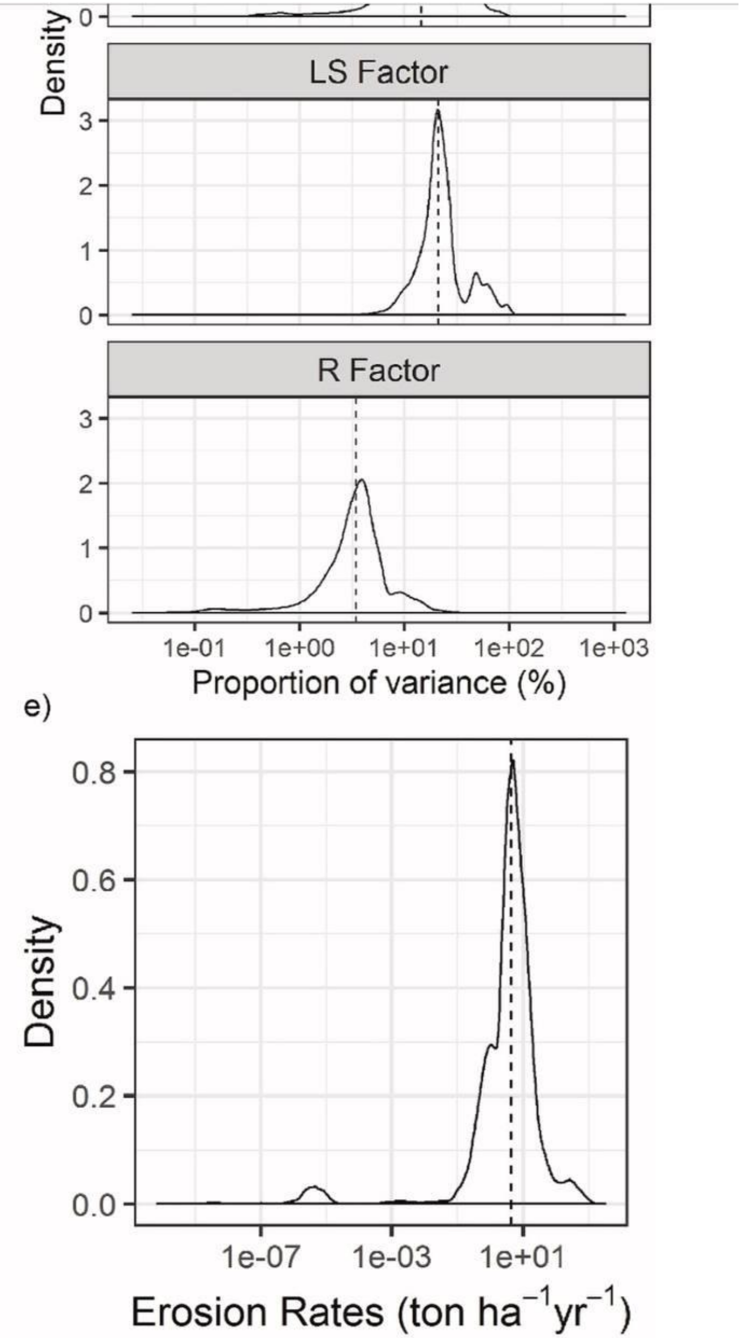

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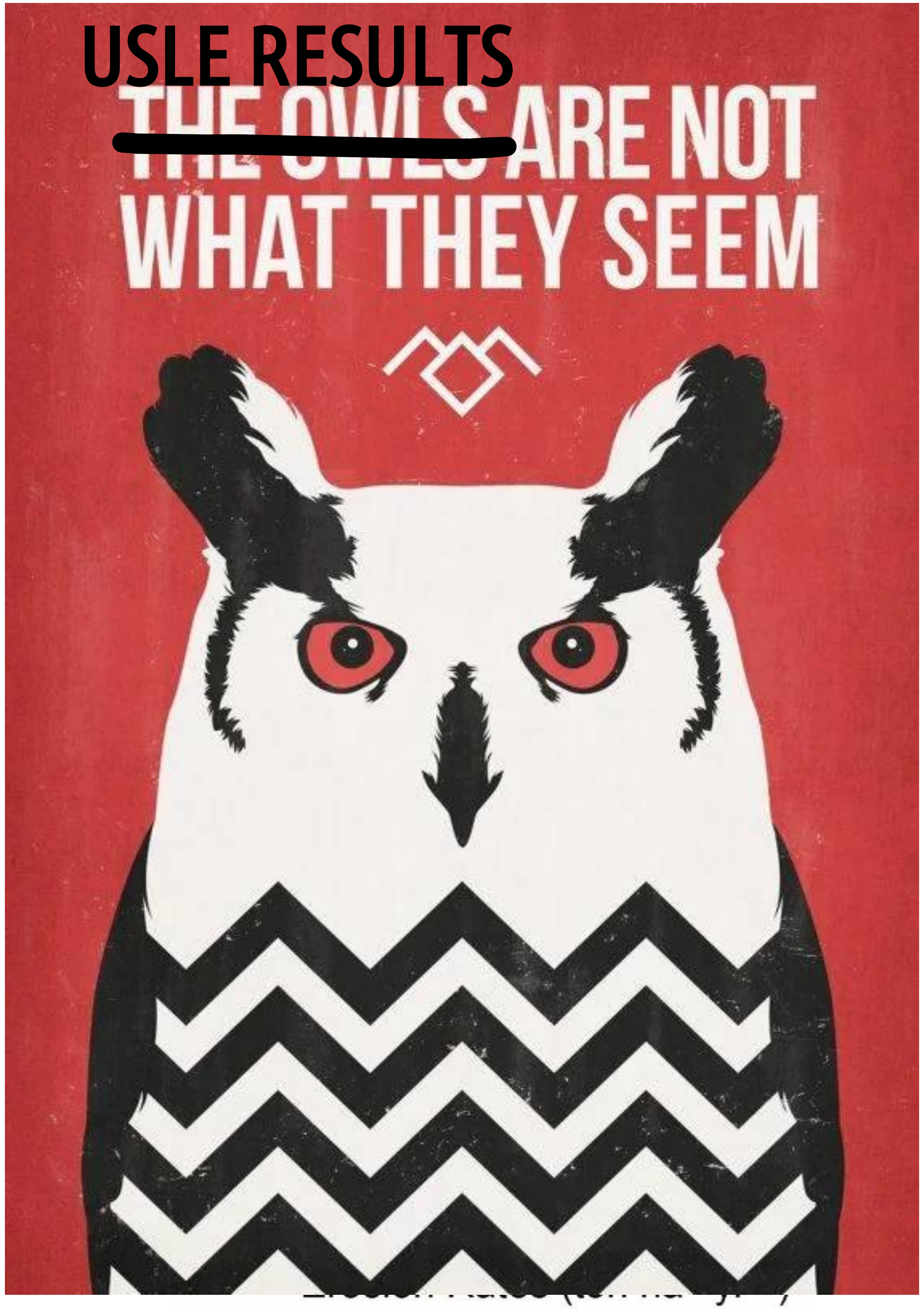

Thank you!

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