https://doi.org/10.17221/91/2018-SWR

Determination of erosion rainfall criteria based on natural rainfall measurement and its impact on spatial distribution of rainfall erosivity in the Czech Republic

Jiří Brychta, Miloslav Janeček*

Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Prague, Czech Republic
**Corresponding author: brychta.czu@email.cz*

Citation: Brychta J., Janeček M. (2019): Determination of erosion rainfall criteria based on natural rainfall measurement and its impact on spatial distribution of rainfall erosivity in the Czech Republic. Soil & Water Res., 14: 153–162.

Abstract: Rainfall erosivity is the main factor of the USLE or RUSLE equations. Its accuracy depends on recording precision and its temporal resolution, number of stations and their spatial distribution, length of recorded period, recorded period, erosion rainfall criteria, time step of rainfall intensity and interpolation method. This research focuses on erosion rainfall criteria. A network of 32 ombrographic stations, 1-min temporal resolution rainfall data, 35.6-year period and experimental runoff plots were used. We analysed 8951 rainfalls from ombrographic stations, 100 rainfalls and caused soil losses and runoffs from experimental runoff plots. Main parameter which influenced the number of erosion rainfalls was the precondition AND/OR which determines if conditions of rainfall total (H) have to be fulfilled simultaneously with rainfall intensity (I_{15} or I_{30}) or not. We proved that if parameters I_{15} > 6.25 mm/15 min AND H > 12.5 mm were fulfilled, then 84.2% of rainfalls caused soil loss > 0.5 t/ha and 73.7% ≥ 1 t/ha. In the case of precondition OR only 44.6% of rainfalls caused soil loss > 0.5 t/ha and 33.9% ≥ 1 t/ha. If the precondition AND was fulfilled, there were on average 75.5 rainfalls, average R factor for each rainfall was 21 MJ/ha·cm/h (without units below in the text, according international unit: 210 MJ/ha·mm/h) and average annual R factor was 45.4. In the case of precondition OR there were on average 279 rainfalls but average R factor for each rainfall was only 9.1 and average annual R factor was 67.4. Therefore if the precondition OR is used, R factor values are overestimated due to a high number of rainfalls with no or very low erosive potential. The resulting overestimated soil losses calculated using USLE/RUSLE subsequently cause an overestimation of financial expenses for erosion-control measures.

Keywords: erosion rainfall; R factor; rainfall intensity; RUSLE; USLE

The equations USLE (Wischmeier & Smith 1978) and RUSLE (Renard *et al.* 1997) are widely used and accepted methods over the world for calculating average annual soil loss. Development of geoinformation systems (GIS) brings a lot of possibilities for integration with the equations as USLE/RUSLE-GIS method. Using GIS tools different methods for estimating each factor of USLE or RUSLE were developed. These methods can provide different results even when the same equation was used. Rainfall erosivity is the main factor of the USLE or RUSLE equation and highly influences permissible soil loss limits and related financial expenses of erosion-control measures. Brychta and Janeček (2017) presented discrepancies in rainfall erosivity calculation and estimation. Many authors developed different methods of R estimation due to a lack of optimal data for calculation according to original methodology. In general we can divide methods for rainfall erosivity factor (R) calculation into two groups: (1) based on low temporal resolution of rainfall data – yearly, monthly or daily rainfall totals (Schwertman *et*

Supported by the Technology Agency of the Czech Republic, Project No. TAČR TH02030125.

https://doi.org/10.17221/91/2018-SWR

al. 1987; Renard & Freimund 1994; Mikhailova *et al.* 1997; Van der Knijff *et al.* 2000; Loureiro & Countinho 2001; Diodato & Bellochi 2007; Bonila & Vidal 2011; Lee & Heo 2011; Panagos *et al.* 2012; Hermando & Romana 2015; Pretl in Brychta & Janeček 2017), (2) based on high temporal resolution of rainfall data – 1–30 min (Janeček *et al.* 1992, 2006, 2013; Dostál *et al.* 2006; Angulo-Martinez *et al.* 2009; Meusburger *et al.* 2012; Fiener *et al.* 2013; Klik & Konečný 2013; Panagos *et al.* 2015; Hanel *et al.* 2016; Panagos *et al.* 2017; Pretl in Brychta & Janeček 2017; Sokolová in Brychta & Janeček 2017). In the methods based on low temporal resolution data the key aspect of rainfall erosivity – rainfall intensity was not considered. Several problems with the high resolution rainfall data approach were discussed (Panagos *et al.* 2015, 2017; Hanel *et al.* 2016; Brychta & Janeček 2017). These authors defined mainly these uncertainties in the R map creation: formulation of rainfall kinetic energy, number of stations and their spatial distribution, recording temporal resolution, recorded time period, interpolation method and used covariates (cokriging method). Brychta and Janeček (2017) highlighted also uncertainties connected with the type of used recording equipment and especially with determination of erosion rainfall criteria. For the application of a high resolution rainfall data approach long-term continual data from a network of specific rain gauges – pluviographs/ombrographs are necessary. Therefore only a few studies in Europe used this approach. Wischmeier and Smith (1978) and Renard *et al.* (1997) considered 22-year records as a minimum for the representative R fac-

Table 1. Summarization of criteria used for all created R maps for the Czech Republic and some other countries or areas

Author	Period	RS	SQL	Erosion rainfall criteria		Range R	Ø R
				total (mm)	intensity (mm/*X* min)		
Pretl in Brychta and Janeček (2017)	20 years	9 (1)	OR	> 12.5	> 6.25/15	30–72	–
Toman *et al.*(1993)	20 years	25 (2)	OR	> 10	> 20/60	18–26	22
Sokolová (1992)	15–50 years (3)	21 (3)	OR	> 10	> 20/60	–	19
Janeček *et al.* (1992)	15–50 years (4)	102 (4)	OR	> 10	> 20/60	3–37	20
Banasik *et al.* (2001)	1960–1988	9 (5)	OR	≥ 12.7	> 6.3/15	43–97	64
Dostál 2006	2000–2005	37 (4)	OR	> 12.5	> 24/60	44–85	73
Janeček *et al.* (2006)	1961–2000	13 (4)	AND	≥ 12.5	> 6/15	–	45
Angulo-Martinez *et al.* (2009)	1997–2006	112 (6)	OR	> 12.7	> 6.35/15	4–450	89
Janeček *et al.* (2012)	1971–2000	31 (4)	AND	> 12.5	> 6.25/15	18–113	41
Meusburger *et al.* (2012)	1988–2010	71 (7)	OR	> 12.7	> 8.45/20	12–561	133
Rožnovský in Krása *et al.* (2014)	2003–2012	106 (4)	AND	≥ 12.5	≥ 0.4/1	37–110	69
Fiener *et al.* (2013)	1937–2007	10 (8)	OR	≥ 10	≥ 10/60	45–85	–
Klik and Konečný (2013)	24.5 years	53 (9)	OR	≥ 10	≥ 10/60	27–170	88/98*
Panagos *et al.* (2015)	1961–1999	35 (4)	OR	> 12.7	> 12.7/30	22–109	52
Panagos *et al.* (2015)	17.1 years	1541 (10)	OR	> 12.7	> 12.7/30	5–623	72
Hanel *et al.* (2016)	1989–2003	96 (4)	OR	> 12.7	> 8.5/20	32–152	64
Rožnovský (2016)**	1971–2014	245 (4)	OR	>12.5	> 6.25/15	**	**
Pérez-Sánchez and Senent--Aparicio (2016)	1992–2013	12 (11)	OR	> 12.5	≥ 6.25/15	38–570	60
Brychta and Janeček (2017)	1961–2000	31 (4)	AND	> 12.5	> 6.25/15	29–65	46
Panagos *et al.* (2017)	1961–2013	1890 (10)	OR	> 12.7	> 12.7/30	–	49***

RS – number of rain gauge stations; SQL – precondition AND/OR; *X* min – used time step according to authors 1–60 min; (1) northern and northeastern Bohemia region; (2) south Moravia region; (3) south Bohemia region; (4) Czech Republic; (5) eastern and central Poland; (6) Ebro valley, Spain; (7) Switzerland; (8) western Germany; (9) Austria; (10) Europe; (11) Guadalentín Basin (SE Spain); * Lower Austria/Upper Austria;** not published ongoing research of CHMI; *** information for the European continent

https://doi.org/10.17221/91/2018-SWR

tor calculation due to an apparent cyclical pattern in rainfall data (Hanel *et al.* 2016). Hanel *et al.* (2016) and Foster *et al.* (2003) considered 15 years as sufficient in accordance with Verstraeten *et al.* (2006). Renard *et al.* (1997) recommended longer records than 22 years. According to Verstraeten *et al.* (2006) more than 10-year records should be used. In Table 1 we summarized recorded period lengths used for all created R maps for the CR and some other countries or areas. For the area of the Czech Republic several works were published especially in the last years by Janeček *et al.* (2006, 2013), Hanel *et al.* (2016) or Brychta and Janeček (2017). Janeček *et al.* (2006) highlighted the importance of erosion rainfall criteria – rainfall total and rainfall intensity. This means that the rainfall fulfilling these criteria causes a significant soil loss. We summarized these criteria used by several authors in Table 1. Most of the authors agree with minimal rainfall total of 12.5–12.7 mm. The main difference is in the rainfall intensity criteria. The preconditions OR/AND determine if the rainfall intesity and rainfall total criteria are fulfilled simultaneously or not. Janeček *et al.* (2006) confirmed that both criteria should be fulfilled simultaneously (precondition AND).

METHODS

We used data from 8-year monitoring of experimental runoff plots, which includes total 100 rainfall-runoff events and caused soil losses. The highest temporal resolution (1-min) rainfall data were measured using 2 ombrographs. Parameters of rainfall amount, 15- and 30-min intensity (I_{15}, I_{30}) and antecedent precipitation index (API) were calculated. Dimensions of plots were 25 × 2 m with the slope of 15%. Plots were with bare soil and soil erodibility factor was 0.49. Using level gauges runoff volumes in collecting containers were measured. Experimental plots were cultivated after every rainfall event. After every rainfall event which caused runoff soil losses were analysed. Summarization of measured results is shown in Table 3. According to these results R factor maps with different erosion rainfall criteria were calculated (Table 2).

We used records from a network of 32 ombrographic stations with the highest temporal resolution 1-min rainfall data for the period 1955–2000 with an average length of 35.6 years. Geographic location of used stations is shown in Figure 1. We analysed 8951 rainfall events based on 1-min temporal resolution. For the calculation of R factor values was used methodology according to Wischmeier and Smith (1978) with modification of erosion rainfall parameters according to Table 2 using Eq. (1–3):

Table 2. Parameters of erosion rainfall used for R calculation

Conditions	Rainfall intensity (mm/min)	Precondition	Rainfall total (mm)
1	> 6.25/15	AND	> 12.5
2	> 6.25/15	OR	> 12.5
3	> 6.25/15	–	–
4	–	–	> 12.5
5	> 12.5/30	AND	> 12.5
6	> 12.5/30	OR	> 12.5
7	> 12.5/30	–	–

AND – conditions of rainfall total and rainfall intensity are fulfilled simultaneously; OR – at least one of both conditions is fulfilled; conditions 4 = 6, 5 = 7

$$R = E \times I_{30}/100 \quad (1)$$

where:
R – rainfall erosivity factor (MJ/ha·cm/h)
E – total kinetic energy of rainfall (J/m²)
I_{30} – maximum 30-min intensity (cm/h)

The total kinetic energy of rainfall is:

$$E = \sum_{i=1}^{n} E_i \quad (2)$$

where:
E_i – kinetic energy of rainfall in the *i*-section:

$$E_i = (206 + 87 \log I_{si}) \times H_{si} \quad (3)$$

where:
I_{si} – intensity of rainfall in the *i*-section (cm/h)
H_{si} – rainfall total in the *i*-section (cm)

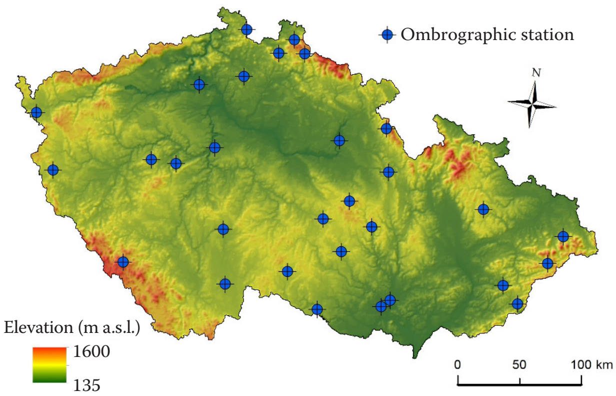

Figure 1. Geographic locations of used ombrographic stations

https://doi.org/10.17221/91/2018-SWR

Note that we used a different unit in comparison with international maps for example by Panagos *et al.* (2015): MJ/ha·cm/h instead MJ/ha·mm/h.

For the interpolation of R factor values a geostatistical method Empirical Bayesian Kriging was used (Pilz & Spock 2007). Using map algebra in GIS environment all created R maps were compared to figure out differences in R values and their spatial distributions caused by different erosion rainfall parameters.

RESULTS AND DISCUSSION

Results of erosion rainfall criteria verification based on monitoring parameters of 100 rainfall-runoff events and caused soil losses and runoff volume on experimental runoff plots are summarized in Table 3 and 4. We divided rainfalls into 4 categories:

(1) causing runoff > 5 m^3/ha,

(2) causing runoff ≥ 10 m^3/ha,

(3) causing soil loss > 0.5 t/ha = erosion rainfall (ER),

(4) causing significant soil loss ≥ 1 t/ha = significant erosion rainfall (SER),

(5) causing runoff with the concentration of soil particles > 50 g/l.

If only runoff volumes > 5 and ≥ 10 m^3/ha were considered, there is only a 14.6% and 17.9% difference between preconditions OR and AND. If soil losses > 0.5 and ≥ 1 t/ha were considered, there is a 39.6% and 39.8% difference. It means if the precondition AND was fulfilled, there were 73.7% SER and 84.2% ER. For cases where the precondition OR was fulfilled, there were only 33.9% SER and 44.6% ER. It means that significant soil loss usually occurred when both conditions of rainfall total and intensity were fulfilled simultaneously (precondition AND). This is consistent with the statements by Janeček *et al.* (2006, 2013) and Brychta and Janeček (2017). If we focused on each of these parameters individually, there were 38.6% more ER if the rainfall intensity (I_{15}) parameter > 6.25 mm/15 min was fulfilled than if the rainfall total (H) > 12.5 mm was fulfilled. These results proved that significant soil loss occurred if conditions of at least rainfall intensity were fulfilled.

In some cases when the erosion rainfall parameters were not fulfilled, API index was high or API + H > 30 mm and even more the rainfall intensity was very close to 6.25 mm/15 min (Table 5). It means that moisture content in soil can play a very important role. That is why the above-mentioned criteria set by Wishmeier and Smith (1978) do not correspond to R = 0 but approximately R = 4 (Janeček *et al.* 2013).

We tested the influence of moisture content expressed by API index. If API + H > 12.5 mm AND I > 6.25 mm/15 min, there were 71.4% SER and 85.7% ER. If we increased the condition of API + H to 25 mm, the number of erosion rainfalls rapidly decreased. Notice that in every case when the precondition AND or at least intensity was fulfilled, then a high percentage of significant erosion rainfall occurred.

Table 3. Results of experimental rainfall-runoff event monitoring for 15-min intensity

H (mm)	I_{15} (mm/15min)	SQL	N	Q > 5		Q ≥ 10		G > 0.5		G ≥ 1		C > 50	
				(m^3/ha)	(%)	(m^3/ha)	(%)	(t/ha)	(%)	(t/ha)	(%)	(g/l)	(%)
> 12.5	**> 6.25**	**AND**	19	19	100.0	15	78.9	16	**84.2**	14	**73.7**	12	63.2
> 12.5	> 6.25	OR	56	46	82.1	36	64.3	25	44.6	19	33.9	15	26.8
–	**> 6.25**	–	22	22	100.0	17	77.3	18	**81.8**	15	**68.2**	14	63.6
> 12.5	–	–	52	43	82.7	33	63.5	23	44.2	16	30.8	13	25.0
H + API > 12.5	**> 6.25**	**AND**	21	21	100.0	17	81.0	18	**85.7**	15	**71.4**	14	**66.7**
H + API > 12.5	> 6.25	OR	89	57	64.0	43	48.3	30	33.7	23	25.8	19	21.3
H + API > 25	> 6.25	AND	14	14	100.0	12	85.7	12	85.7	9	64.3	8	57.1
H + API > 25	> 6.25	OR	58	38	65.5	32	55.2	25	43.1	23	39.7	15	25.9
API > 12.5	> 6.25	AND	7	7	100	7	100	7	100	5	71.43	5	71.4
API > 12.5	> 6.25	OR	58	45	77.59	35	60.34	26	44.83	22	37.93	18	31.0
H + API > 25	> 3.15	AND	27	26	96.3	23	85.2	18	66.7	14	51.9	11	40.7
H + API > 25	> 3.15	OR	78	54	69.2	42	53.8	29	37.2	22	28.2	18	23.1

H – rainfall total; I_{15} – max. 15-min rainfall intensity; SQL – preconditions AND/OR; N – number of rainfalls; % – percentage of rainfalls fulfilling given criteria; Q – runoff volume; G – soil loss; C – concentration of soil particles in runoff; API – antecedent precipitation index; the best results and therefore the recommended methodology is highlighted in bold

https://doi.org/10.17221/91/2018-SWR

Table 4. Results of experimental rainfall-runoff event monitoring for 30-min intensity

H (mm)	I_{30} (mm/30min)	SQL	N	Q > 5 (m³/ha)	(%)	Q ≥ 10 (m³/ha)	(%)	G > 0.5 (t/ha)	(%)	G ≥ 1 (t/ha)	(%)	C > 50 (g/l)	(%)
> 12.5	**> 12.5**	**AND**	13	13	100.0	10	76.9	11	84.6	8	**61.5**	9	**69.2**
> 12.5	> 12.5	OR	54	44	81.5	34	63.0	23	42.6	17	31.5	13	24.1
H + API > 12.5	> 12.5	AND	9	9	100.0	8	88.9	8	88.9	5	55.6	6	66.7
H + API > 12.5	> 12.5	OR	89	57	64.0	43	48.3	30	33.7	23	25.8	19	21.3
H + API > 25	> 12.5	AND	4	4	100	4	100	4	100	2	50	3	75.0
H + API > 25	> 12.5	OR	55	43	78.2	33	60.0	22	40.0	18	32.7	14	25.5
API > 12.5	> 12.5	AND	13	13	100.0	10	76.9	11	84.6	8	61.5	9	69.2
API > 12.5	> 12.5	OR	53	40	75.47	31	58.49	22	41.51	21	39.62	15	28.3

H – rainfall total; I_{30} – max. 30-min rainfall intensity; SQL – preconditions AND/OR; N – number of rainfalls; % – percentage of rainfalls fulfilling given criteria; Q – runoff volume; G – soil loss; C – concentration of soil particles in runoff; API – antecedent precipitation index; the best results and therefore the recommended methodology is highlighted in bold

If the precondition OR or at least rainfall total was fulfilled, there was a substantially lower percentage of erosion rainfall. The main reason is an overestimation of the number of rainfalls fulfilling the precondition OR which do not cause any soil loss. In all cases if I_{15}> 6.25 mm/15 min and the precondition AND was fulfilled, the runoff volume (Q) >5 m³/ha. But that did not apply in the case of precondition OR (see Table 3 and 4).

Panagos *et al.* (2015, 2017) created R map using REDES database and available rainfall datasets from Europe and from the whole world. These datasets were in different temporal resolution 5–60 min. According to Yin *et al.* (2007) and Williams and Sheridan (1991) R factor is underestimated with the decreasing time step used. As a compromise Panagos *et al.* (2015, 2017) or Ballabio *et al.* (2017) used a 30-min time step of rainfall intensity. In Table 4 we tested also

Table 5. Rainfall parameters causing soil loss > 0.5 t/ha or significant soil loss ≥ 1 t/ha

Date	API + H (mm)	H (mm)	API (mm)	I_{15} (mm)	I_{30} (mm)	Q (l)	q	G (t/ha)	C (g/l)
8.7.	16.20	15.5	0.7	9.6	10.5	6.75	0.44	6.6	101.2
12.5.	34.70	11.9	22.8	10.95	11.7	11.53	0.97	15.4	133.3
21.6.	42.50	39.1	3.4	19.5	21.9	61.86	1.58	19	55.4
22.6.	58.80	19.7	39.1	19.5	19.8	5.98	0.30	0.8	55.4
11.9.	19.90	19.9	0	18	18.9	14.34	0.72	60.2	254
19.6.	24.90	22.6	2.3	15.75	19.5	7.66	0.34	16.2	212
23.7.	53.80	30	23.8	26.85	27	33.39	1.11	118.5	433
19.8.	31.70	23.8	7.9	10.35	15.3	4.43	0.19	4.3	962.4
22.6.	24.00	13	11	5.1	8.7	0.91	0.07	0.6	70.5
24.6.	26.40	5.5	20.9	5.25	5.1	1.69	0.31	1.2	69
9.7.	26.20	21	5.2	17.1	19.2	7.59	0.36	46.9	617.2
28.9.	23.90	23.9	0	14.1	17.7	0.79	0.03	44.3	178.3
8.8.	13.10	13.1	0	6.45	7.2	3.8	0.29	2.8	74.1
10.8.	46.70	25.2	21.5	16.8	20.7	19.4	0.77	12.3	57.5
11.8.	59.00	9.8	49.2	7.2	9.3	1.97	0.20	1.3	63.8
24.8.	31.00	11.4	19.6	6	7.2	1.9	0.17	1.1	57.5
4.7.	12.80	12.8	0	7.95	9	2.25	0.18	4.4	124
7.7.	21.50	5.2	16.3	1.95	2.7	2.25	0.43	1.1	51
8.7.	30.40	8.4	22	4.35	5.1	2.25	0.27	2	82

API – antecedent precipitation index; H – rainfall total; I_{15} – max. 15-min rainfall intensity; I_{30} – max. 30-min rainfall intensity; Q – runoff volume; q – runoff coefficient; G – soil loss; C – concentration of soil particles in runoff

https://doi.org/10.17221/91/2018-SWR

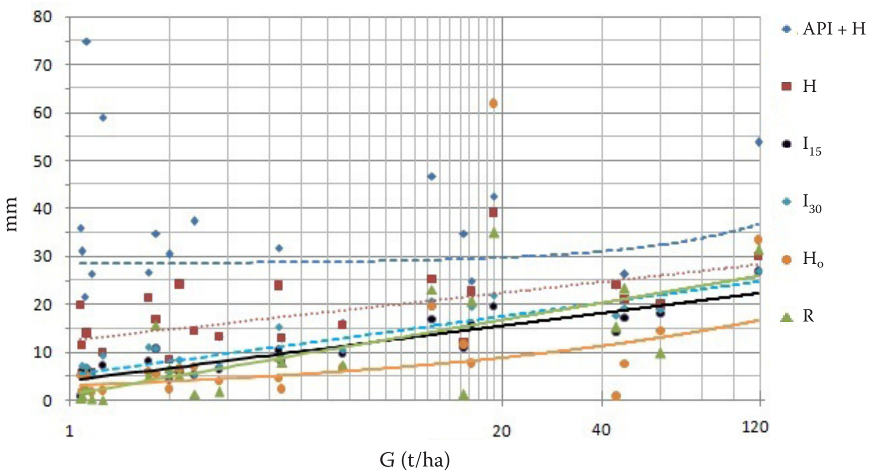

Figure 2. Evaluation of the dependence of observed parameters on soil losses

G – soil loss; API – antecedent precipitation index; H – rainfall total; I_{15} – max. 15-min rainfall intensity; I_{30} – max. 30-min rainfall intensity; H_o – runoff; R – rainfall erosivity (in MJ/ha·cm/h)

preconditions for 30-min rainfall intensity. In this case it is logical that the precondition: I_{30} > 12.5 mm/30 min AND H > 12.5 mm is the same as a simple precondition: I_{30} > 12.5 mm/30 min. Also the precondition: I_{30} > 12.5 mm/30 min OR H > 12.5 mm is the same as the precondition: H > 12.5 mm. The results of I_{15} and I_{30} are similar but I_{30} underestimates the number of erosion rainfalls. In Table 5 are summarized all parameters of rainfalls which caused soil loss > 0.5 t/ha.

Figure 2 and Table 6 show the evaluation of dependence of all observed parameters on soil losses > 1 t/ha. The best correlation was found in I_{15} with r^2 = 0.82 and I_{30} with r^2 = 0.786. For I_{15} and I_{30} best fits logarithmic function. Parameters H, API+H and H_o exhibit low correlations. R factor based on parameters I_{15} > 6.25 mm/15 min AND H > 12.5 mm shows a statistically significant correlation r^2 = 0.55.

We also focused on rainfall parameters causing the concentration of transported soil particles in runoff volume > 50 g/l. For this purpose the precondition with consideration of also API index: API + H > 12.5 AND I > 6.25 mm/15 min (66.7%) or API > 12.5 mm AND I > 6.25 mm/15 min (71.4%) shows the best fit. All rainfall parameters which caused soil losses and resulted in soil particle concentration > 50 g/l are summarized in Table 5.

Our rainfall data have 1-min temporal resolution. This is a very unique dataset. Moreover, this dataset is for a long-term period of on average 35.6 years. Using

Table 6. Evaluation of the dependence of observed parameters on soil losses

Parameter	Function	r^2
I_{15}	$y = 3.853\ln(x) + 3.917$	0.820
I_{30}	$y = 4.078\ln(x) + 5.167$	0.786
H	$y = 3.335\ln(x) + 12.34$	0.378
H_o	$y = 3.050x^{0.355}$	0.276
H + API	$y = 28.64e^{0.002x}$	0.017
API	$y = -4.06\ln(x) + 21.38$	0.147
R_{AND15}	$y = 5.167\ln(x) + 1.329$	0.550

I_{15} – max. 15-min rainfall intensity; I_{30} – max. 30-min rainfall intensity; H – rainfall total; H_o – runoff; API – antecedent precipitation index; R_{AND15} – R factor calculated using precondition AND with I_{15}

Table 7. Statistics of resulting R values of all 8951 rainfalls from 32 ombrographic stations

Conditions	Rainfall intensity (mm/min)	Precondition	Rainfall total (mm)	Ø R	Ø R_n	Ø N	Ø SD
1	> 6.25/15	AND	> 12.5	45.4	21.0	75.6	22.4
2	> 6.25/15	OR	> 12.5	67.4	9.1	279	14.4
3	> 6.25/15	–	–	46.3	18.2	90	20.9
4	–	–	> 12.5	66.6	9.3	265	14.9
5	> 12.5/30	AND	> 12.5	35.2	30.5	40.6	26.8
6	> 12.5/30	OR	> 12.5	66.6	9.3	265	14.9

Ø R – average of annual average R factors of all stations; Ø R_n – average R factor for all rainfalls fulfilling given criteria 1–6; Ø N – average number of erosion rainfalls; Ø SD – average standard deviation from Ø R; condition 4 = 6

https://doi.org/10.17221/91/2018-SWR

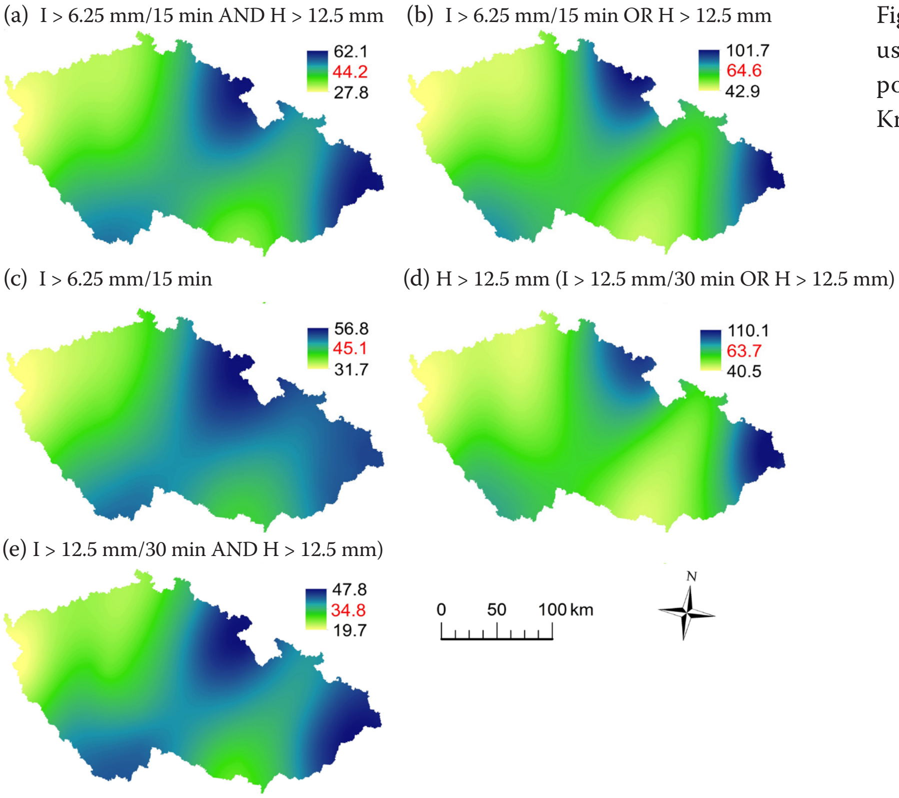

Figure 3. R factor values calculated using different criteria and interpolated using Empirical Bayesian Kriging method

32 ombrographic stations we analysed 8951 rainfalls and the influence of selected rainfall parameters and preconditions (according to Table 2) on the resultant R factor values and their spatial distribution. Results are shown in Table 7, Figure 3 and 4. The main impact of different erosion rainfall parameters is reflected in numbers of rainfalls fulfilling the given criteria. In the case of precondition AND (condition 1 in

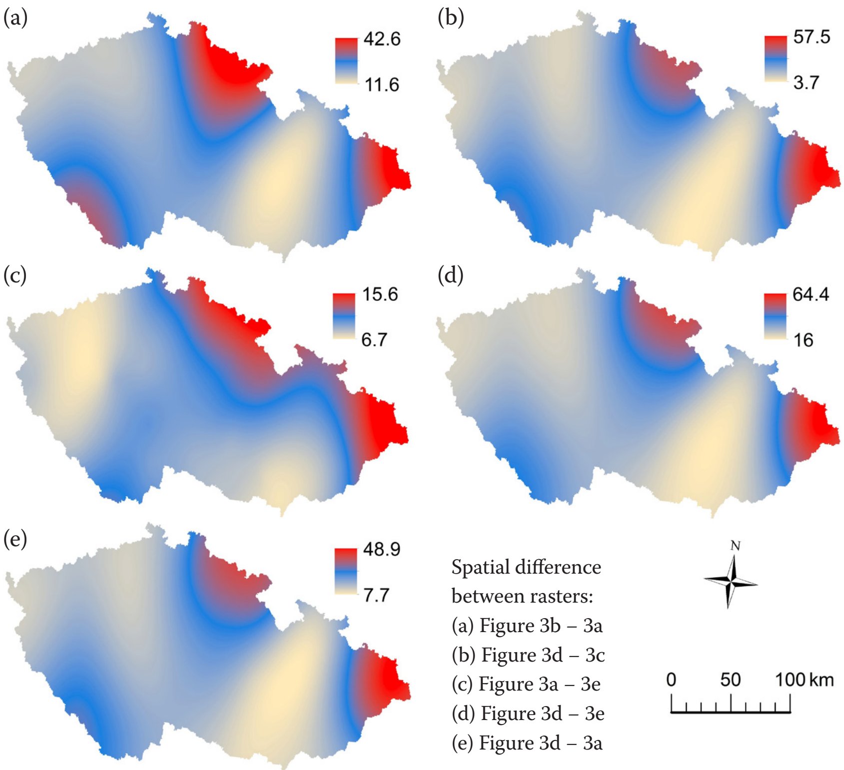

Figure 4. Evaluation of spatial differences caused by erosion rainfall parameters

Table 8. Statistical results of spatial analyses of differences caused by erosion rainfall parameters

Spatial analysis	Conditions*	Ø	SD	Min	Max
Figure 4a	2–1	20.5	6.2	11.6	42.6
Figure 4b	4–2	18.6	10.9	3.7	57.5
Figure 4c	1–5	9.3	1.9	6.7	15.6
Figure 4d	5–6	28.9	9.8	16.0	64.4
Figure 4e	5–1	19.6	8.3	7.7	48.9

*For details see Table 7; Ø – average difference caused by erosion rainfall parameters; SD – standard deviation

Table 9. Correlation analyses of R factor values calculated by different erosion rainfall parameters

Relation	Function	r^2
AND_{15}–AND_{30}	$y = 0.442x^{1.145}$	0.951
AND_{15}–OR_{30}	$y = 22.07e^{0.023x}$	0.803
AND_{15}–OR_{15}	$y = 24.69e^{0.021x}$	0.747
I_{15}–I_{30}	$y = 0.489x^{1.112}$	0.806
I_{15}–H	$y = 24.05e^{0.020x}$	0.631

AND_{15}–OR_{15} (conditions 1 and 6 in Table 7); I_{15}–H (conditions 3 and 4 in Table 7); AND_{15}–AND_{30} (conditions 1 and 5 in Table 7); I_{15}–I_{30} (conditions 3 and 5 in Table 7); AND_{15}–OR_{30} (conditions 1 and 2 in Table 7)

Table 7) there were on average 75.6 rainfalls per station resulting in average annual R = 45.4 MJ/ha·cm/h (without units below in the text), but with high standard deviation (SD = 22.4 MJ/ha·cm/h) and high average R of all rainfalls (R = 21 MJ/ha·cm/h). If the precondition OR was fulfilled, there were much more rainfalls – on average 279 per station resulting in average annual R = 67.4 with lower SD = 14.4. The precondition OR exhibits particularly lower average R of all rainfalls R = 9.1. It means that a high number of rainfalls was with low erosion potential and according to our results from Table 3 they did not cause any significant soil losses. Conditions 3 and 5 according to Table 7 have similar results like condition 1 but in the case of condition 5 the number of erosion rainfalls is highly underestimated (more than twice). Conditions 4 and 6 are equal and are also almost the same as condition 2. Using all above-mentioned conditions R factor values were calculated for all 32 stations and interpolated using the Empirical Bayesian Kriging method (Figure 3).

We can observe from Figure 3 that maps (a), (c) and (e) have a similar spatial distribution of R but with the above-mentioned differences. Maps (b) and (d) have almost the same spatial distribution and also R values. For each map an average for the whole country (red colour number) is shown. The comparisons in more detail are presented in Figure 4. We can see the high R values in border mountain areas in all cases. The main aspect resulting from Figure 4 is a high overestimation of the number of rainfalls fulfilling the precondition OR resulting in an even twofold overestimation of R values especially in mountain areas.

In Figure 4 are shown differences caused by the given erosion rainfall parameters (Figure 3 and Table 7). Results are summarized in Table 8. These spatial analyses show differences between the precondition OR/AND (Figure 4a, d) and H – I_{15} (Figure 4b). There are significant differences increasing in mountain localities where annual rainfall totals are higher. In Figure 4c are demonstrated differences between the used intensity criteria I_{15}–I_{30}. In this case in the northeastern mountain area R factor is underestimated due to a lower number of erosion

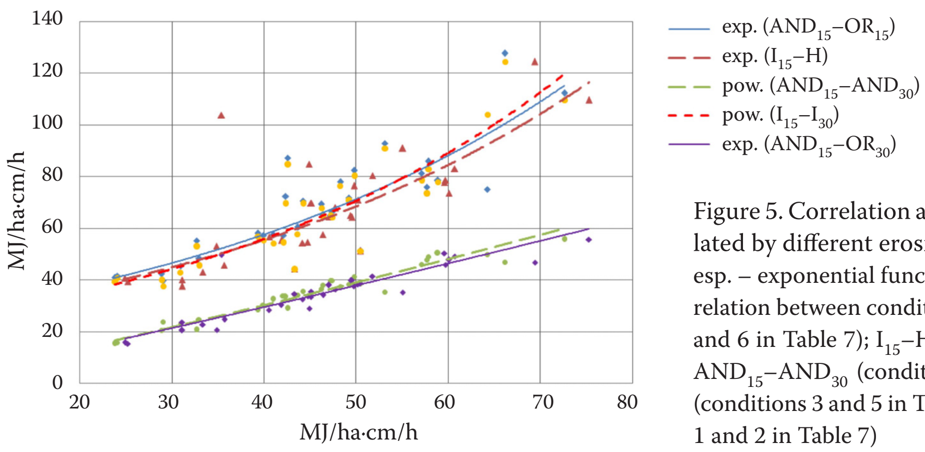

Figure 5. Correlation analyses of R factor values calculated by different erosion rainfall parameters

esp. – exponential function; pow. – power function; correlation between conditions: AND_{15}–OR_{15} (conditions 1 and 6 in Table 7); I_{15}–H (conditions 3 and 4 in Table 7); AND_{15}–AND_{30} (conditions 1 and 5 in Table 7); I_{15}–I_{30} (conditions 3 and 5 in Table 7); AND_{15}–OR_{30} (conditions 1 and 2 in Table 7)

https://doi.org/10.17221/91/2018-SWR

rainfalls caused by lower time steps of rainfall intensity. Approaches based on precondition AND with 15-min intensity and precondition OR with 30-min intensity exhibit large differences (Figure 4e).

In Figure 5 we tested a dependence of R factors calculated by the above-mentioned different approaches. All tested relations exhibit statistically significant correlations. Results are summarized in Table 9. Using these equations R values can be converted to the method AND_{15}: $I_{15} > 6.25$ mm/15 min AND H > 12.5 mm.

CONCLUSION

We analysed erosion rainfall parameters based on 100 casual rainfalls and caused soil losses and runoffs from experimental runoff plots. Parameters I_{15}, I_{30}, H, API, API+H and the precondition OR/AND were evaluated. Only parameters I_{15} and I_{30} exhibit a significant correlation with soil loss ≥ 1 t/ha (I_{15} with $r^2 = 0.82$ and I_{30} with $r^2 = 0.786$). The main parameter which influenced the number of erosion rainfalls was the precondition AND/OR which determines if conditions of rainfall total H or soil moisture expressed by API have to be fulfilled simultaneously with rainfall intensity (I_{15} or I_{30}) or not. Definition of erosion rainfalls was divided into 2 categories: rainfall causing soil loss > 0.5 t/ha and significant soil loss ≥ 1 t/ha. We proved that if parameters $I_{15} > 6.25$ mm/15 min AND H > 12.5 mm were fulfilled, then 84.2% of rainfalls caused soil loss > 0.5 t/ha and 73.7% caused soil loss ≥ 1 t/ha. In the case of precondition OR only 44.6% rainfalls caused soil loss > 0.5 t/ha and 33.9% caused soil loss ≥ 1 t/ha. In some cases the results were influenced by soil moisture. We expressed soil moisture by API index and if parameters $I_{15} > 6.25$ mm/15 min AND API+H > 12.5 mm were fulfilled, then 85.7% of rainfalls caused soil losses > 0.5 t/ha and 71.4% caused soil losses ≥ 1 t/ha. This condition also exhibits the highest percentage (66.7%) of rainfall-runoff events that caused the concentration of soil particles in runoff volume > 50 g/l. In the case of 30-min intensity similar results were obtained. If the parameter $I_{30} >$ 12.5 mm/30 min, then 84.6% of rainfalls caused soil loss > 0.5 t/ha and 69.2% caused soil loss ≥ 1 t/ha. If $I_{30} > 12.5$ mm/30 min AND API > 12.5 mm, then 61.5% of rainfalls caused the concentration of soil particles in runoff volume > 50 g/l.

These results can be summarized as follows: the precondition OR overestimates the number of rainfalls in all cases in calculation of R factor. But the high percentage of these rainfalls does not cause any significant soil loss. We analysed 8951 rainfalls from 32 ombrographic stations with 1-min temporal resolution. If the precondition AND was fulfilled, there were on average 75.5 rainfalls, average R factor for each rainfall was 21 MJ/ha·cm/ha (without units below in the text) and average annual R factor was 45.4. In the case of precondition OR there were on average 279 rainfalls but average R factor for each rainfall was only 9.1 and average annual R factor was 67.4. Therefore if the precondition OR is used, R factor values are overestimated due to a high number of rainfalls with no or very low erosive potential. The resulting overestimated soil losses calculated using USLE/RUSLE subsequently cause an overestimation of financial expenses for erosion-control measures.

References

Angulo-Martinez M., Lopez-Vincente M., Vincente-Serrano S.M., Bergueira S. (2009): Mapping rainfall erosivity at a regional scale: A comparison of interpolation methods in the Ebro Basin (NE Spain). Hydrology and Earth System Sciences, 13: 1907–1920.

Ballabio C., Borrelli P., Spinoni J., Meusburger K., Michaelides S., Beguería S., Klik A., Petan S., Janeček M., Olsen P., Aalto J., Lakatos M., Anna Rymszewicz A., Dumitrescu A., Tadićm M.P., Diodato N., Kostalova J., Rousseva S., Banasik K., Alewell Ch., Panagos P. (2017): Mapping monthly rainfall erosivity in Europe. Science of the Total Environment, 579: 1298–1315.

Banasik K., Gorski D., Mitchell J.K. (2001): Rainfall erosivity for East and Central Poland. In: Int. Symp. Soil Erosion Research for the 21st Century, Honolulu, Jan 3–5, 2001: 279–282.

Bonila A.C., Vidal L.K. (2011): Rainfall erosivity in Central Chile. Journal of Hydrology, 410: 126–133.

Brychta J., Janeček M. (2017): Evaluation of discrepancies in spatial distribution of rainfall erosivity in the Czech Republic caused by different approaches using GIS and geostatistical tools. Soil and Water Research, 12: 117–127.

Dostál T., Vrána K., Krása K., Jakubíková A., Schwarzová P., Uhlířová K., Bečvář M., Veselá J., Kavka P., Zandler D., Rosendorf P. (2006): Partial Final Report of Project COST No. 1P04OC634.001 Methods and Ways of Predicting Surface Runoff, Erosion and Transport Processes in the Landscape. Prague, ČVUT. (in Czech)

Diodato N., Bellocchi G. (2007): Estimating monthly (R) USLE climate input in Mediterranean region using limited data. Journal of Hydrology, 345: 224–236.

https://doi.org/10.17221/91/2018-SWR

Fiener P., Neuhaus P., Botschek J. (2013): Long-term trends in rainfall erosivity – analysis of high resolution precipitation time series (1937–2007) from Western Germany. Agriculture and Forest Meteorology, 171: 115–123.

Foster G.R., Yoder D.C., Weesies G.A., McCool D.K., McGregor K.C., Bingner R.L. (2003): Draft User's Guide, Revised Universal Soil Loss Equation Version 2 (RUSLE-2). Washington, D.C., USDA-Agricultural Research Service.

Hanel M., Máca P., Basta P., Vlnas R., Pech P. (2016): Rainfall erosivity factor in the Czech Republic and its uncertainty. Hydrology and Earth System Sciences, 20: 4307–4322.

Hermando D., Romana G.M. (2015): Estimating the rainfall erosivity factor from monthly precipitation data in the Madrid region (Spain). Journal of Hydrology and Hydromechanics, 63: 55–62.

Janeček M., Pasák V., Bohuslávek J., Sokolová I., Toman F., Fuxa Z., Švehla F. (1992): Methodology Protection of Agricultural Land from Erosion. Prague, UVTIZ. (in Czech)

Janeček M., Kubátová E., Tippl M. (2006): Revised determination of the rainfall-runoff erosivity factor R for application of USLE in the Czech Republic. Soil and Water Research, 1: 65–71

Janeček M., Květoň V., Kubátová E., Kobzová D. (2013): Values of rainfall erosivity factor for the Czech Republic. Journal of Hydrology and Hydromechanic, 61: 97–102.

Klik F., Konečný F. (2013): Rainfall erosivity in north-eastern Austria. Transactions of the ASABE, 56: 719–725.

Krása J., Středová H., Dostál T., Novotný I. (2014): Rainfall erosivity research on the territory of the Czech Republic. In: Rožnovský J., Litschmann T. (eds.): Mendel and Climatology, Brno, Sept 3–5, 2014: 182–196.

Lee J.H., Heo J.H. (2011): Evaluation of estimation methods for rainfall erosivity based on annual precipitation in Korea. Journal of Hydrology, 409: 30–48.

Loureiro N.D., Coutinho M.D. (2001): A new procedure to estimate the RUSLE EI_{30} index, based on monthly rainfall data and applied to the Algarve region, Portugal. Journal of Hydrology, 250: 12–18.

Meusburger K., Steel A.B., Panagos P., Montarella L., Alewell C. (2012): Spatial and temporal variability of rainfall erosivity factor for Switzerland. Hydrology and Earth System Sciences, 16: 167–177.

Mikhailova E.A., Bryant R.B., Schwager S.J., Smith S.D. (1997): Predicting rainfall erosivity in Honduras. Soil Science Society of America Journal, 61: 273–306.

Panagos P., Karydas C.G., Gitas I.Z., Montanarella L. (2012): Monthly soil erosion monitoring based on remotely sensed biophysical parameters: A case study in Strymonas river basin towards a functional pan-European service. International Journal of Digital Earth, 5: 461–487.

Panagos P., Ballabio C., Borrelli P., Ballabio C., Borrelli P., Meusburger K., Klik A., Rousseva S., Tadiće M.P., Michaelides S., Hrabalíková M., Olsen P., Aalto J., Lakatos M., Rymszewicz A., Dumitrescu A., Beguería S., Alewell Ch. (2015b): Rainfall erosivity in Europe. Science of the Total Environment, 511: 801–814.

Panagos P., Borrelli P., Meusburger K., Yu B., Klik A., Li K.J., Yang J.E., Ni J., Miao Ch., Chattopadhyay N., Sadeghi S.H., Hazbavi Z., Zabihi M., Larionov G.A., Krasnov S.F., Gorobets A.V., Levi Y., Erpul G., Birkel Ch., Hoyos N., Naipal V., Oliveira P.T.S., Bonilla C.A., Meddi M., Nel W., Al Dashti H., Boni M., Diodato N., Van Oost K., Nearing M., Ballabio C. (2017): Global rainfall erosivity assessment based on high-temporal resolution rainfall records. Scientific Reports, 7: 4175.

Pérez-Sánchez J., Senent-Aparicio J. (2016): Estimating rainfall erosivity in semiarid regions. Comparison of expressions and parameters using data from the Guadalentín Basin (SE Spain). Soil and Water Research, 11: 75–82.

Pilz J., Spock G. (2007): Why do we need and how should we implement Bayesian Kriging methods. Stochastic Environmental Research and Risk Assessment, 22: 621–632.

Renard K.G., Freimund J.R. (1994): Using monthly precipitation data to estimate the R-factor in the revised USLE. Journal of Hydrology, 157: 287–306.

Renard K.G., Foster G.R., Weesies G.A., McCool D.K., Yoder D.C. (1997): Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). USDA Agriculture Handbook No. 703, Washington D.C., USDA-ARS.

Schwertmann U., Vogel W., Kainz M. (1987): Bodenerosion durch Wasser. Stuttgart, E. Ulmer Gmbh.

Toman F., Sanetrník J., Filip J. (1993): The influence of climatic conditions on the factor of erosion efficiency of torrential rains. In: Proc. Agro-meteorological Conf. 93, Brno, Nov 25–26, 1993: 67–69. (in Czech)

Van Der Knijff J.M., Jones R.J.A., Montanarella L. (2000): Soil Erosion Risk Assessment in Europe. European Soil Bureau, Joint Research Centre, Space Applications Institute.

Verstraeten G., Poesen J., Demaree G., Salles C. (2006): Long-term (105 years) variability in rain erosivity as derived from 10-min rainfall depth data for Ukkel (Brussels, Belgium): implications for assessing soil erosion rates. Journal of Geophysical Research, 111: 22.

Williams R.G., Sheridan J.M. (1991): Effect of measurement time and depth resolution on EI calculation. Transactions of the ASAE, 34: 402–405.

Wischmeier W.H., Smith D.D. (1978): Predicting Rainfall Erosion Losses – A Guide to Conservation Planning. USDA Agricultural Handbook No. 537, Washington D.C., USDA-ARS.

Yin S., Xie Y., Nearing M.A., Wang C. (2007): Estimation of rainfall erosivity using 5- to 60- minute fixed-interval rainfall data from China. Catena, 70: 306–312.

Received for publication May 3, 2018
Accepted after corrections, October 15, 2018
Published online February 25, 2019