Revised Determination of the Rainfall-runoff Erosivity Factor *R* for Application of USLE in the Czech Republic

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Abstract: The evaluation of a series (1961–2000) of ombrographic records from 13 selected stations of Czech Hydrometeorological Institute provided long-term annual summation values and annual peaks of the rainfall-runoff erosivity factor *R* in the USLE. The evaluation indicated that by defining an erosive rainfall event as (a) rainfall ≥ 12.5 mm or (b) rainfall intensity > 6 mm per 15 minutes, there were on average 8 erosive rainfall events per station, varying from 1 to 25. The long-term summation values of *R* factor were in the range of 42 to 106 (average 66) and annual peaks ranged from 19 to 38 (average 29). If the criteria (a) and (b) were to be fulfilled simultaneously, there were on average more than 2 erosive rainfall events per year per station, the number varying from 0 to 12. The long-term summation values of *R* factor ranged from 25 to 67 (average 45), with annual peaks from 17 to 36 (average 27.5). The long-term investigations of soil losses by erosion on experimental runoff plots, near Třebsín (Prague-West district), caused by storms, reveal that these losses were mostly caused by rainfall events satisfying both criteria (a) and (b) at the same time. The results of this investigation suggest that the average value of the erosivity factor *R* = 20 recommended for the Czech Republic until now should be increased to *R* = 45 and/or 66, which in practical terms would necessitate more stringent conservation measures.

Keywords: water erosion; storms; rainfall erosivity (*R*) factor; USLE

To determine the rate of water erosion on agricultural soils and to evaluate the efficiency of appropriate response practices, as in other countries the Universal Soil Loss Equation (USLE) devised by Wischmeier and Smith (1978) is used in the Czech Republic. The Revised Universal Soil Loss Equation (RUSLE), proposed by Renard *et al.* (1997), is at the testing stage. Both empirical models, USLE and RUSLE, are based on the principle of tolerable soil loss per standard plot, the parameters of which are defined and derived from the measurements of standard elementary runoff parcels (plots) 22 m in length and of 9% gradient; the surface of these parcels is kept without vegetation and is mechanically cultivated up or down the slope gradient after each storm. Tolerable soil loss is defined as the maximum soil loss by erosion that permits to maintain a sufficient and sustainable level of soil productivity at acceptable costs. Soil loss is calculated from the equation:

$$G = R \times K \times L \times S \times C \times P \qquad \text{(t/ha/year)}$$

where:

G – average annual soil loss
R – rainfall erosivity factor
K – soil erodibility factor

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L – slope length factor
S – slope steepness factor
C – factor of the conservation effect of canopy cover
P – support practice factor

The erosivity factor R for the USA was derived from a large quantity of data on precipitation. From these data it is possible to deduce that, keeping the factors other than rainfall constant, the soil loss from a cultivated field is directly proportionate to the following characteristics of a storm: the product of total kinetic energy of rainfall (E) and its peak 30-minute intensity (I_{30}):

$$R = E \times I_{30}/100$$

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

$$E = \sum_{i=1}^{n} Ei$$

Ei – kinetic energy of the i-th segment of rainfall (n – number of rainfall segments)

$$Ei = (206 + 87 \log I_{si}) \times H_{si}$$

where:
I_{si} – intensity of the i-th segment of rainfall (cm/h)
H_{si} – rainfall amount in the i-th segment (cm)

The appearance of deep erosion furrows, also called rills, and the amount of accumulated sediment after unusually intensive rainfall events made researchers draw conclusions that significant erosion phenomena were connected with several storms only and were the function of peak intensities. However, according to Wischmeier (1959, 1962), more than 30-year measurements in many localities in the USA indicated that this conclusion does not hold good. Data on the rainfall factor used to determine the average annual soil loss should involve the cumulative effect of both extraordinary rainfall events (intensive storms) and many rainfall events of medium-intensity.

The average annual value of factor R is calculated from long-term records of precipitation, and it is the sum of the annual erosivity of particular storms, whilst not all events are considered; those of smaller precipitation sum than 0.5 inch, i.e. 12.5 mm, separated from preceding and successive rainfall events by rainless periods longer than 6 h, are omitted if at least 0.25 inch (6.25 mm) of rain did not fall in the course of 15 min.

Hence the rainfall erosivity factor R depends on the frequency of occurrence of rainfalls, and on their kinetic energy, intensity and amount. The values of the R factor were processed statistically and presented in the form of isoerodent maps. For the Czech Republic, the average rainfall erosivity factor R = 20 MJ/ha.cm/h was calculated from a

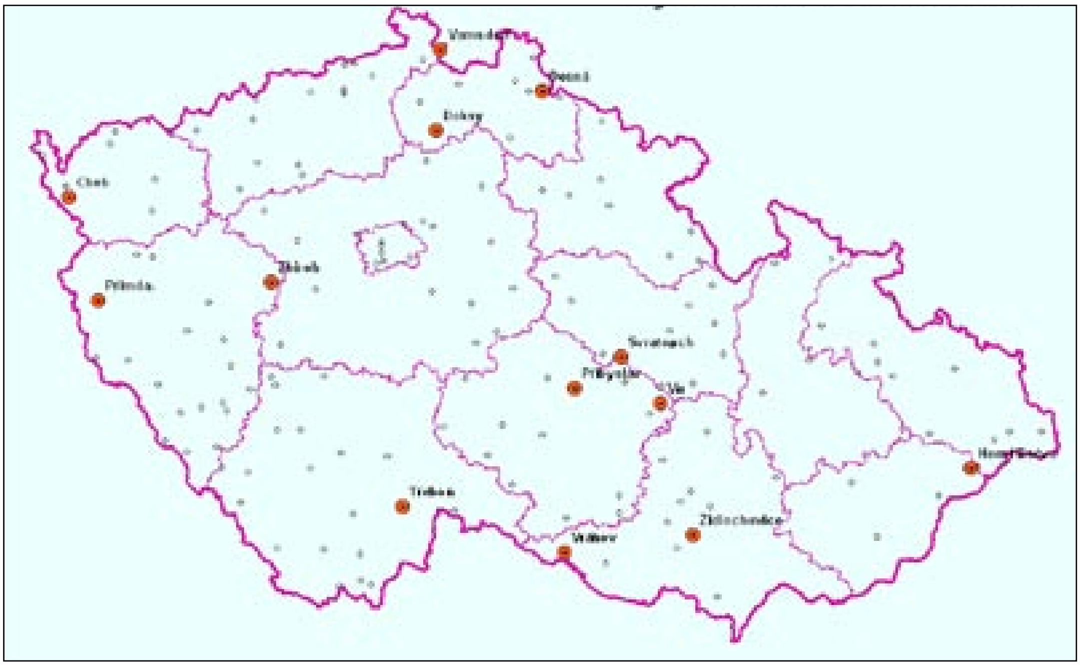

Figure 1. Selected stations of CHMI

long-term series of rainfall observations for the Prague-Klementinum, Tábor and Bílá Třemešná stations of the Czech Hydrometeorological Institute (CHMI) (Janeček 1992). Applying the newly processed long-term series of ombrographic records from other stations of CHMI made it possible to analyse the method of *R* factor determination for the Czech Republic in more detail.

Methodical approach

Ombrographic records for the particular stations of CHMI (Figure 1) with sufficiently long periods of observations were used in a digital form with 1-min time steps. Before the calculation of the *R* factor, the data provided by CHMI were selected according to the criteria defined by Wischmeier and Smith (1978). As the CHMI data on precipitation have numerical codes indicating the record quality, it was possible to evaluate the reliability of these background data, taking into account their completeness, their having or not having been completed a posteriori and the variability of beginnings and ends of records in the particular years.

RESULTS

The values of *R* factor were calculated for 2 variants.

Variant A: for all rainfall events either with the sum > 12.5 mm OR with the intensity > 6 mm per 15 min (Table 1).

Variant B: for all rainfall events with the sum > 12.5 mm AND with the intensity > 6 mm per 15 min (Table 2).

The results for the CHMI stations were used to determine:

– annual sums of the *R* factors over all events in the particular years,
– annual maxima of *R* factors for particular events.

These data for the particular stations were processes further to obtain:

– long-term average annual sums of the *R* factor,
– long-term average annual maximum of the *R* factor.

According to Wischmeier and Smith (1978), the long-term average annual sum of the *R* factor is calculated from long-term precipitation

Table 1. Long-term averages of the sums of annual values of *R* factor and long-term averages of annual peaks of *R* factor for amounts of rains above 12.5 mm or for rain intensity 6 mm/15 min (variant A)

CHMI station	Observations in	Number of years	Number of erosive rains				Average of	
			total	Ø per year	min.	max.	sums of annual *R* factors	peaks of annual *R* factors
Desná	1961–1971, 1973, 1975–2000	38	496	13.1	4	23	87.38	28.54
Doksy	1962–2000	39	263	6.7	1	17	61.36	30.92
Horní Bečva	1962–2000	39	462	11.9	5	25	106.29	38.12
Cheb	1960–2000	41	241	5.9	1	11	42.75	20.57
Přibyslav	1965–2000	36	314	8.7	3	15	61.29	28.19
Přimda	1957–1990, 1992–2000	43	298	6.9	2	10	42.44	19.13
Svratouch	1956–1959, 1961–2000	44	421	9.6	4	17	78.25	30.01
Třeboň	1923–1941, 1944–1980, 1982–1996, 1998–2000	74	581	7.9	2	15	75.13	36.60
Varnsdorf	1963–1966, 1968–2000	37	306	8.3	2	14	50.97	23.23
Vír	1961–2000	40	300	7.5	2	15	68.16	31.23
Vranov	1962–2000	39	290	7.4	2	14	60.73	30.11
Zbiroh	1963–1964, 1965–1976, 1978–2000	36	266	7.4	2	15	65.18	31.72
Židlochovice	1962–1969, 1971–2000	38	257	6.8	2	13	55.93	29.53
CR		544	4495	8.3	1	25	65.84	29.06

Table 2. Occurrence of erosive rains on experimental runoff plots near Třebsín (Prague-West district)

Year	Number of erosive rains – variant		Sum of annual *R* factors – variant		Annual peaks of *R* factor	Number of rains that caused	
	A	B	A	B		soil losses by erosion	significant losses
1997	9	4	89.8	82.7	48.0	5	5
1998	4	1	16.8	12.9	12.9	3	2
1999	6	2	18.5	8.3	4.5	4	2
2000	5	4	37.7	35.3	15.5	3	1
2001	6	1	21.7	7.5	7.5	4	3
2002	15	6	164.3	134.5	72.7	9	9
2003	7	4	101.7	90.7	46.7	6	4
2004	4	1	28.6	20.6	20.6	2	1
2005	7	2	36.3	17.6	13.2	2	1
1997–2005	63	25	515.4	410.1	241.6	38	28
Ø per year	7	2,8	57.3	45.6	26.8	4.2	3.1
Min.	4	1	16.8	7.5	4.5	2	1
Max.	15	6	164.3	134.5	72.7	9	9

records. Each year, the sum of erosivity of individual storms excluding rainfall events with sums less than 12.5 mm (except for those during which at least 6.25 mm fell in the course of 15 min). Hence the annual value of *R* factor should be the sum of the values of the *R* factor for all rains that exceeded 12.5 mm, i.e. including long-duration rains with relatively low intensities or short-term rainfalls with relatively small sums but with intensities exceeding > 6.25 mm per 15 min.

The evaluation of data from 13 stations for more than 30 years indicated that applying the criterion of the variant A, there were on average 8 erosive rainfall events per station, the number varying from 1 to 25. The long-term average annual sums of the *R* factor were in the range 42 to 106 (average 66), the long-term average annual maxima ranging from 19 to 38 (average 29) for individual stations. Applying the criterion of the variant B, there were on average 2 erosive rainfall events per station per year, the number varying from 0 to 12. The long-term average annual sums of the *R* factor ranged from 25 to 67 (average 45), with the long-term average annual maxima ranging from 17 to 36 (average 27.5) for individual stations (Tables 1 and 2).

The long-term 9-year observations (1997–2005) of rains and consequent soil losses from the standard runoff parcels in Třebsín (Prague-West district), characterised by the soil erodibility factor *K* between 0.47 and 0.52, indicated that out of the 63 rainfall events satisfying at least one of the criteria (i.e. selected according to the variant A), 38 caused soil losses by erosion on the bare soil parcels and, out of these, 28 events caused significant losses. In most cases, the significant soil loss occurred when both conditions were satisfied simultaneously as required by the variant B.

Significant soil losses were caused by only 12 rainfall events below 12.5 mm during which the intensity exceeded 6.25 mm in 15 min, but in these cases the soil had been previously saturated or the previous rainfall exceeded 12.5 mm and its intensity was close to the 6.25 mm limit. In the remaining 26 such events (below 12.5 mm with intensities above 6.25 mm in 15 min) the soil losses were very small or none. The annual *R* factor sums according to the variant A ranged from 16.8 to 164.3, with an average of 57.23, and according to the variant B from 7.5 to 134.5, with an average of 45.6. The annual maxima ranged from 4.5 to 72.7 (average 26.8) – Table 3.

Table 3. Long-term averages of the sums of annual values of *R* factors and long-term averages of annual peaks of *R* factors for amounts of rains above 12.5 mm and rain intensity higher than 6 mm/15 min (variant B)

CHMI station	Number of years	Peak *R* factor determined over the years of observations	Number of erosive rains				Average of sums of annual *R* factors	Average of annual peaks of *R* factors
			Total	Ø per year	min.	max.		
Desná	38	144.8	97	2.6	0	7	44.39	24.16
Doksy	39	149.8	89	2.3	0	6	44.93	29.79
Horní Bečva	39	137.7	113	2.9	1	12	67.24	36.23
Cheb	41	72.7	66	1.6	0	6	30.24	19.05
Přibyslav	36	113.5	90	2.5	0	7	47.89	26.69
Přimda	43	88.0	71	1.7	0	4	25.39	17.41
Svratouch	44	176.9	103	2.3	0	9	49.64	27.99
Třeboň	74	359.1	195	2.6	0	6	56.76	35.77
Varnsdorf	37	83.2	75	2.0	0	6	33.01	20.90
Vír	40	125.6	99	2.5	1	9	51.23	30.60
Vranov	39	141.7	90	2.3	0	5	44.98	29.47
Zbiroh	36	197.2	76	2.1	0	6	46.73	30.09
Židlochovice	38	127.5	76	2.0	0	5	40.86	29.36
CR	544	147.5	1240	2.3	0	12	44.87	27.50

DISCUSSION AND CONCLUSIONS

The evaluation of *R* factor for 13 stations of CHMI shows that on average per station there are more than two erosive rainfall events per year at each station, the number varying from none to 12 events per year (Horní Bečva) when both conditions (according to the variant B) were satisfied, and that the long-term averages annual sums of the *R* factor for individual stations range from 25 (Přimda) to 67 (H. Bečva), with the average for the Czech Republic being 45. This is more than

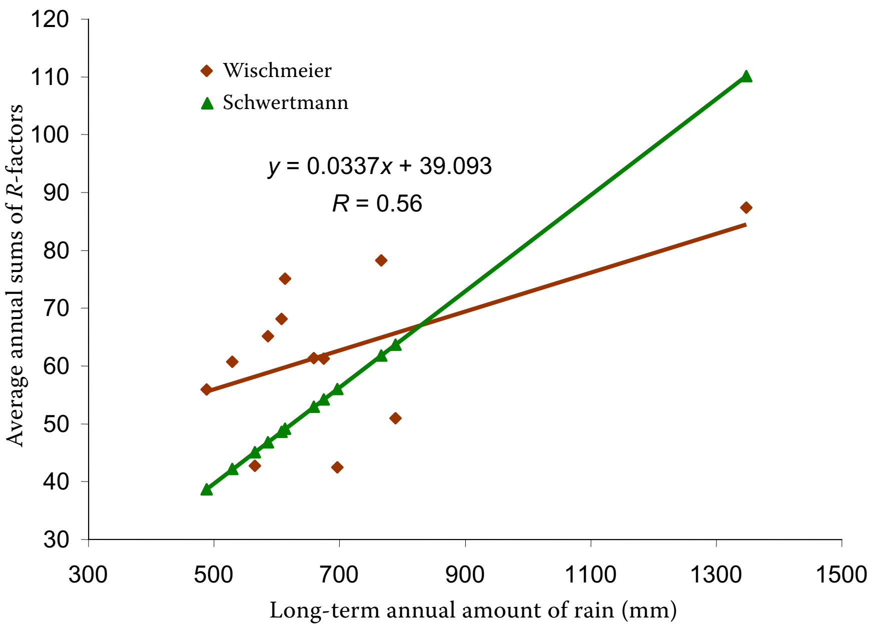

Figure 2. Relation between average annual sums of *R*-factors and long-term annual precipitation sums

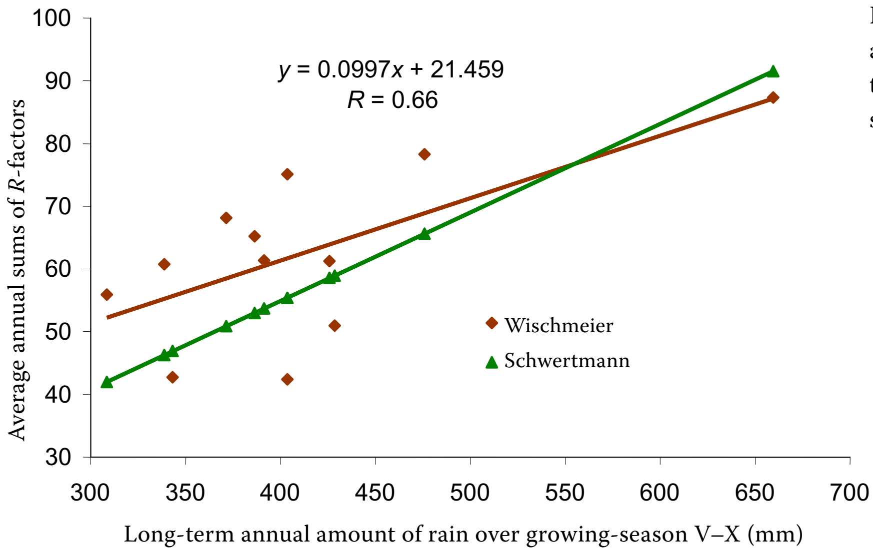

Figure 3. Relation between average annual sums of *R*-factor and long-term growing-season precipitation sums

a double of the value of the *R* factor previously recommended for the Czech Republic. The long-term annual maxima of the *R* factor vary from 17 (Přimda) to 36 (H. Bečva), with the average for the Czech Republic being 27.50. The latter figure is not far from the previously recommended average value (20).

However, considering the finding of WISCHMEIER (1962) that the *R* factor used to determine the average annual soil loss by erosion must involve the cumulative effect not only of the storms with maximal *R* but also of the other, medium-intensity rains satisfying the criteria defined above, we think that the results obtained according to the variant A should be regarded as more indicative. These results tell us that on average there were 8 erosive rains per year per station, varying from 1 to 25, and the long-term average annual sums of the *R* factor for individual stations ranged from 42 (Přimda) or 43 (Cheb) to 106 (H. Bečva) with the

Table 4. Long-term annual amounts of rain and amounts of rain for the growing season (V–X) for CHMI stations (1961–2000)

CHMI stations	Height above sea level (m)	Long-term annual amount of rain (mm)	Long-term amount of rain over the growing season (V–X) (mm)
Desná	772	1348	659.5
Doksy	279	658.9	391.3
Cheb	471	564.5	343.1
Přibyslav	530	674.4	425.9
Přimda	742	696.5	403.5
Svratouch	737	766.2	475.8
Třeboň	429	613.3	403.5
Varnsdorf	338	788.7	428.4
Vír	480	607.3	371.6
Vranov	354	529.4	338.8
Zbiroh	480	585.3	386.4
Židlochovice	180	487.8	308.5
CR average	482.7	693.4	411.4

whole-country average 66. This average is more than three times the value of the *R* factor value recommended previously – Janeček (2005).

Therefore, it is necessary to reassess the value of the *R* factor recommended hitherto for the practical application of USLE in the Czech Republic; namely *R* = 20. Our results indicate that *R* = 45 or *R* = 66 should be used, depending on the criteria used for selection of the erosive rain events. These revised values of the standard *R* factor correspond more closely with the values specified for the parts of Germany adjacent to the Czech Republic (Schwertmann *et al.* 1987). On the other hand, the regression (recommended by Schwertmann *et al.* 1987) between the values of *R* factor and the average precipitation sums over the growing season (May to October) or the average annual precipitation sums were not found to be statistically significant for the CHMI stations studied (Table 4, Figure 2 and 3). In addition, the number of stations (13) studied is not sufficient to generate regional values of the *R* factor for the Czech Republic. Therefore, the revised *R* factor values should be proposed as constitutive standards for the whole country. This change will result in more efficient conservation practices and will lead in future to better protection of soil from erosion.

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