Differentiation and Regionalization of Rainfall Erosivity Factor Values in the Czech Republic

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Abstract: The rain erosivity R-factor is one of the main parameters in the Universal Soil Loss Equation (USLE). This paper describes the procedure used to update, differentiate and regionalize the rainfall erosivity R-factor. For the Czech Republic it is recommended to use the average value R = 40.

Keywords: rainfall; rainfall erosivity factor; water erosion

For many years the so-called Universal Equation for calculating the long-term loss of soil due to erosion (USLE), according to Wischmeier and Smith (1965, 1978), has been widely used (including the Czech Republic) for determining soil erosion risks and evaluating the effectiveness of soil conservation measures. The form of the above-mentioned equation is:

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

where:
G – mean annual soil loss
R – rainfall erosivity and runoff factor
K – soil erodibility factor
L – slope length factor
S – slope steepness factor
C – crop management factor
P – erosion control practice factor

A detailed analysis of each factor was done by Wischmeier and Smith (1978). In the Czech Republic a similar analysis was performed by Janeček *et al.* (2005, 2006).

The occurrence of deep rill erosions and large amounts of sediment deposits after extreme or intensive precipitation has led to the conclusion that important erosion events occur in connection with torrential rainfalls and according to maximum intensity. However, according to Wischmeier and Smith (1965), data collected at several locations in the USA have shown that this is not the case.

The data have shown that the R-factor used for average annual soil losses must include the cumulative impact of extreme precipitation events (torrential rains) as well as the impact of precipitation of average intensity. The average annual value of the R-factor is determined on the basis of long-term precipitation observations and represents the sum of the annual erosive impacts of each torrential precipitation event, i.e. precipitation with a total of 0.5 inch at least (12.5 mm), provided that 0.25 inch at least (6.25 mm) have fallen within 15 min.

Rains which occur more than 6 hours after other precipitation events are considered separately. According to Wischmeier and Smith (1965) the R-factor for a specific locality represents the long-term average annual sum of the kinetic energy coefficients (EI) of each torrential rain and its highest 30-min intensity (I_{30}).

In the USA the rainfall erosivity and runoff factor, i.e. erosive impact of rain (R), was assessed for each region in the form of isoerodent lines which were charted on a US map and published in Agriculture Handbook No. 282 (Wischmeier & Smith 1965) and Agriculture Handbook No. 537 (Wischmeier & Smith 1978). Similarly, this factor was regionalized in some other countries (France, Germany, India, etc.). Wischmeier and Smith (1978) indicated coefficient of conversion from US units to SI units 1.735.

In the Czech Republic the Methodical Guidelines for the Protection of Agricultural Soil from Erosion are published periodically with the recommended R-factor = 20. This value was determined on the basis of data assessed by long-term observations of rain gauges at stations of the Czech Hydrometeorological Institute (CHMI) situated in Tábor, Bílá Třemešná and Prague-Klementinum.

Such experimentally acquired data have led to the assumption that surface runoff and soil loss are only caused by rains surpassing half an inch, or 12.5 mm, and this amount was subtracted from the aggregate used for the calculation of the R-factor. The value of the resultant R-factor was smaller than that assessed by using the original method. The small number of stations (3) did not enable the regionalization of the R-factor values.

MATERIALS AND RESULTS

By a systematic assessment of precipitation data, collected from CHMI ombrographic stations in the Czech Republic, the R-factor values of 31 stations are determined, as shown in Table 1, which are expressed as a graph in Figure 1.

In Table 1 and in Figure 1 the R-factor values are listed where assessed precipitation fulfilled the aggregate criterion of over 12.5 mm with intensity of 6.25 in a period of 15 min (erosive rains). Aggregate R-factor values are indicated for the entire observed period (Col. 8), average R-factor values for the number of observed years (Col. 9), and average R-factor values attained for the number of precipitation events (Col. 10).

Based on the R-factor calculation, according to Wischmeier and Smith (1978) and Renard *et al.* (1997), the average value for the Czech Republic was set at R = 48 MJ/ha × cm/h. Stations in the Czech Republic are not spatially equally distributed. Therefore, the regionalization of the R-factor values for the entire area of the Czech Republic was not conclusive. For this reason, the authors decided to process more data than that available from ombrographic stations. Additional data was used from a total of 257 rain gauge stations of the CHMI from the observation period 1971–2000, i.e. 30 years, and with correction according to the altitude of each station. To justify this step, the

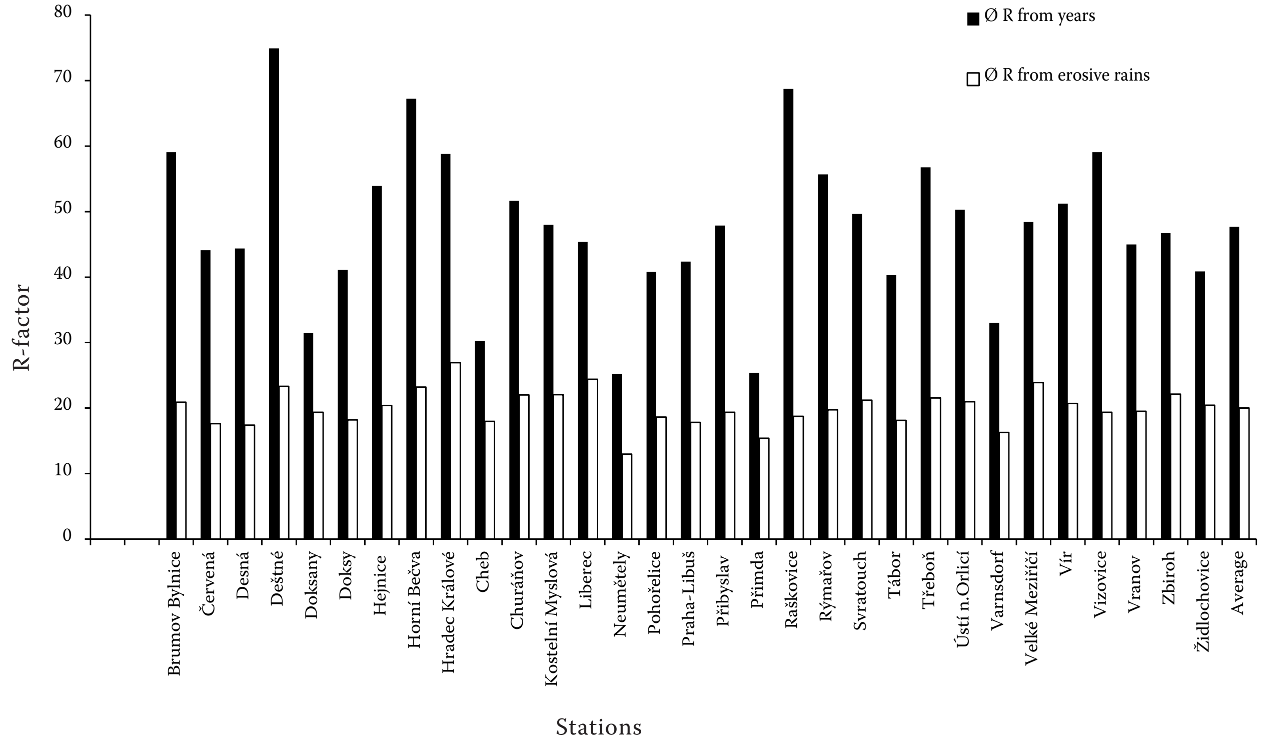

Figure 1. Average values of rainfall erosivity and runoff factor (R-factor) for the number of erosive rains for the years observed

Table 1. R-factor values assessed from data measured at ombrographic stations of the Czech Hydrometeorological Institute (CHMU) (in MJ/ha × cm/h)

Measuring station	Observation period	Number of years	Number of erosive rains				Total of all R	Ø R from years (all rains)	Ø R from erosive rains
			all cases	Ø per year	min	max			
Brumov Bylnice	1961–1990	29	82	2.8	0	7	1713.2	59.1	20.9
Červená	1961–2000	40	100	2.5	0	10	1763.7	44.1	17.6
Desná	1961–2000	38	97	2.6	0	7	1686.7	44.4	17.4
Deštné	1981–2000	19	61	3.2	0	7	1423.5	74.9	23.3
Doksany	1952–2000	48	78	1.6	0	5	1509.3	31.4	19.3
Doksy	1962–2000	39	88	2.3	0	6	1602.5	41.1	18.2
Hejnice	1970–2000	31	82	2.6	0	6	1671.1	53.9	20.4
Horní Bečva	1962–2000	39	113	2.9	1	12	2622.4	67.2	23.2
Hradec Králové	1961–1994	33	72	2.2	0	7	1940.8	58.8	27.0
Cheb	1960–2000	41	69	1.7	0	6	1239.9	30.2	18.0
Churáňov	1955–2000	46	108	2.3	0	6	2376.7	51.7	22.0
Kostelní Myslová	1961–2000	40	87	2.2	0	7	1919.7	48.0	22.1
Liberec	1961–1987,1991–2000	36	67	1.9	0	4	1633.6	45.4	24.4
Neumětely	1981–2000	20	39	2.0	0	5	505.0	25.3	12.9
Pohořelice	1963–2000	37	81	2.2	0	5	1509.0	40.8	18.6
Praha-Libuš	1972–2000	29	69	2.4	0	6	1228.4	42.4	17.8
Přibyslav	1965–2000	36	89	2.5	0	7	1723.9	47.9	19.4
Přimda	1957–2000	43	71	1.7	0	5	1091.9	25.4	15.4
Raškovice	1962–1968, 1970–1985, 1997–2000	27	99	3.7	1	9	1855.7	68.7	18.7
Rýmařov	1963–2000 (the failure data)	28	79	2.8	0	5	1559.1	55.7	19.7
Svratouch	1956–2000	44	103	2.3	0	9	2184.1	49.6	21.2
Tábor	1961–1996	36	80	2.2	1	5	1450.7	40.3	18.1
Třeboň	1923–1941,1944–1980, 1982–2000	74	195	2.6	0	6	4200.5	56.8	21.5
Ústí n. Orlicí	1981–2000	20	48	2.4	0	6	1006.4	50.3	21.0
Varnsdorf	1963–2000	37	75	2.0	0	6	1221.5	33.0	16.3
Velké Meziříčí	1961–1999	39	79	2.0	0	6	1888.6	48.4	23.9
Vír	1961–2000	40	99	2.5	1	9	2049.0	51.2	20.7
Vizovice	1962–1998	37	113	3.1	0	8	2186.4	59.1	19.3
Vranov	1962–2000	39	90	2.3	0	5	1754.4	45.0	19.5
Zbiroh	1963–2000	36	76	2.1	0	6	1682.3	46.7	22.1
Židlochovice	1962–2000	38	76	2.0	0	5	1552.9	40.9	20.4
Average		36.7	86.0	2.4			1734.0	47.7	20.0

R – rainfall erosivity and runoff factor

Table 2. Distribution of the R-factor values (MJ/ha × cm/h) according to altitudes in the region of Idaho (USA)

Altitude (m a.s.l.)	R-factor value			
	Wischmeier and Smith (1978)		Renard *et al.*(1997)	
	vegetative	year	vegetative	year
1184	21.45	24.34	26.55	28.93
1649	24.34	30.13	28.93	34.04
1454	27.23	36.93	31.49	39.49
1649	30.13	52.59	34.04	51.23
2073	30.13	71.14	34.04	64.17
2164	36.93	92.93	39.49	77.95

authors refer to Wischmeier and Smith (1978) and Renard (1997), who indicated the following distribution of the R-factor values at various altitudes in the region of Idaho (USA) (Table 2).

Two other approaches were chosen which led to two different input sets for further analysis. Set A, for the regression analysis of R-factors, was based on daily totals of precipitation. The set included R-factors calculated at the Faculty of Environmental Sciences of the stations listed in Table 1 (with the exception of Červená and Churáňov stations, at the time of analysis data were not available) from all the years that were available for the station (e.g. Třeboň from 1923 to 2000).

In order to keep the input data consistent, the set of R-factors was adapted in the following way:

(*i*) It is assumed that the R-factor occurs in one day as the only event. As such, more R-factors in one day (4 cases) are taken as one R-factor (sum of partial R-factors). Instead of the number of R-factors, we take the number of days with erosive rain.

(*ii*) R-factors of erosive rains exceeding one day (23 cases) were excluded from the analysis (see ad (*i*))

(*iii*) Days with a rain gauge data aggregate of 12.5 mm or less were also excluded from the analysis (see the definition of erosive rain).

(*iv*) As a result of the above-mentioned steps, one day's R-factors with daily totals of up to 12.5 mm (incl.) were also excluded from the analysis.

Next to the R-factors, the set A included all daily ombrographic totals collected at the above-mentioned stations and years, which were in the input set of R-factors (i.e. including aggregates from days where the R-factor equalled zero).

Set B, used for the regression analysis of R-factors, was based on rain events, separated by daily precipitation totals of up to 2 mm or days with snow. One event is understood as one case:

- All rain events were assessed, daily ombrographic totals were added together, all R-factors of the event and their occurrences in the event (several R-factors in one day were included in the numbers of R-factors of the events actual number).
- Events with 12.5 mm and maximum daily total of 6.5 mm (see the definition of erosive rain) were excluded, provided that the highest thirty minutes intensity was not in the period of two days, which was achieved with a reserve in all cases.

Due to time limitations, and due to the fact that out of the aggregate number of 2445 erosive rains there were only 23 cases of erosion rains

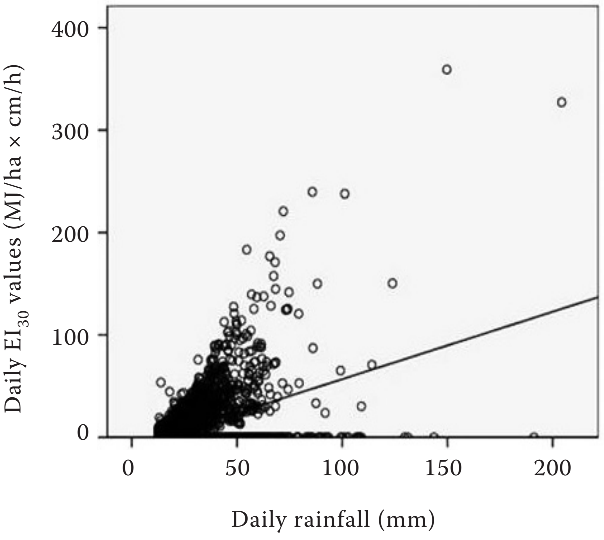

Figure 2. Dependence of daily EI$_{30}$ values in set A on daily rainfall of 12.5 mm and more

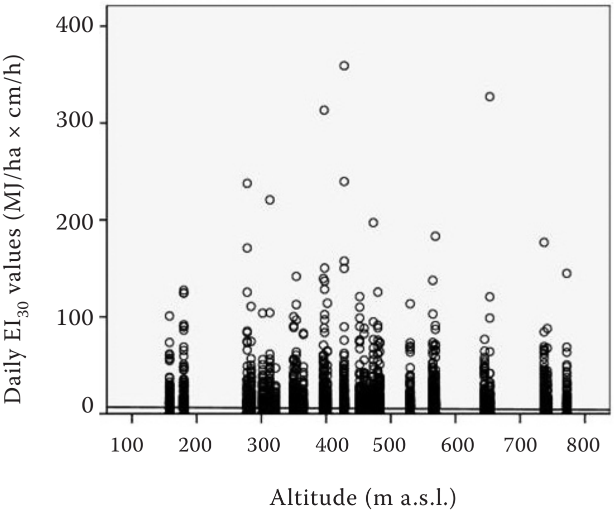

Figure 3. Dependence of daily EI_{30} values on altitude in set A for daily rainfall of 12.5 mm and more

which lasted several days, the subsequent evaluations were reduced to finding the best estimate of the R-factor on the basis of daily precipitation aggregate of 12, 5 mm or more, i.e. to the set A.

Further attention was paid only to the analysis and estimate of the annual sum of R-factors. The nature of the problem allows us to consider the R-factor as an analogy to the cumulated temperature exceeding the given limit. Therefore the term cumulative R-factor can be used.

In the first stage, a regression analysis was performed of the dependence of the daily EI_{30} sums of the set A on daily ombrographic aggregates. The coefficient of determination of the assessed dependence amounts to 24.1%. It is clear from Figure 2 that only some rains satisfy both the above-mentioned conditions to be considered erosive rains. The dependence of the above-mentioned EI_{30} on altitude is illustrated in Figure 3. The coefficient of determination is only 0.2% and the dependence is not tight enough, and thus it was not necessary to apply a regressive equation.

For the purpose of the regionalization of R-factors, the average for the periods was calculated from all 257 stations for the period 1971–2000 (Figure 4). Only days with liquid precipitation were applied (Figure 4).

A separate problem is the designation, i.e. what rains falling on top of the snow cover should be included in the R-factor calculations. It is not possible to determine a uniform yearly interval, because this depends on the geographical location of the station (in the conditions of the Czech Republic it depends mainly on its altitude) and on the specific weather in the given year. Days with snow were not taken into account but only days with liquid precipitation with a daily aggregate of 1.5 mm and more. Nevertheless, in the climatic conditions of the Czech Republic there are many days with significant liquid precipitation falling on top of the snow cover.

Depending on the altitude and on the aggregate amount of water contained in the snow cover as well as in the amount of liquid precipitation for

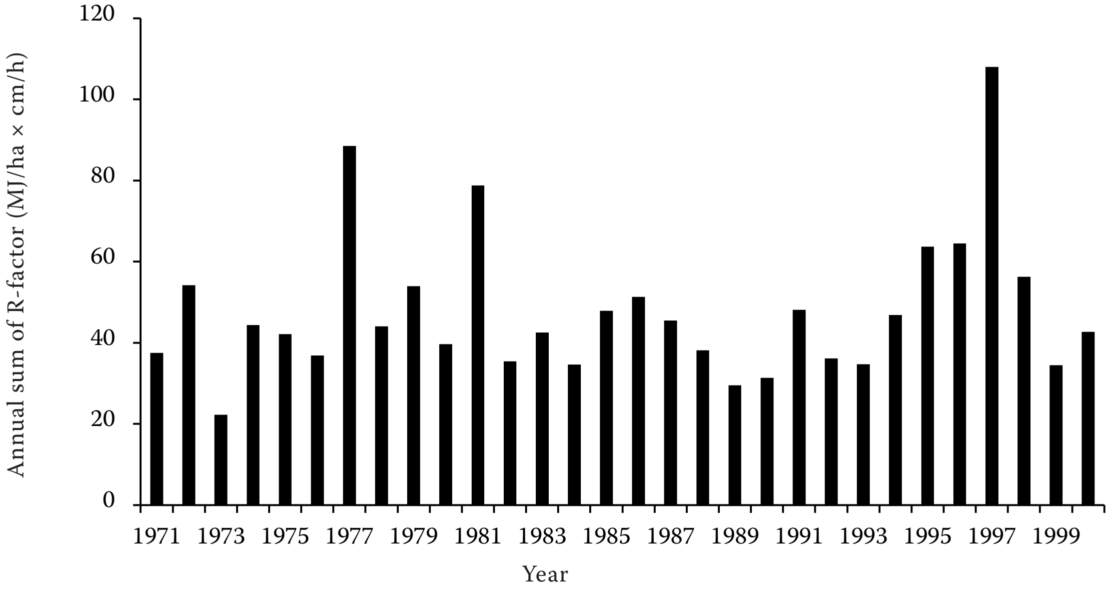

Figure 4. The progression of the annual sum of rainfall erosivity and runoff factor (R-factor) (MJ/ha × cm/h) during the period 1971–2000

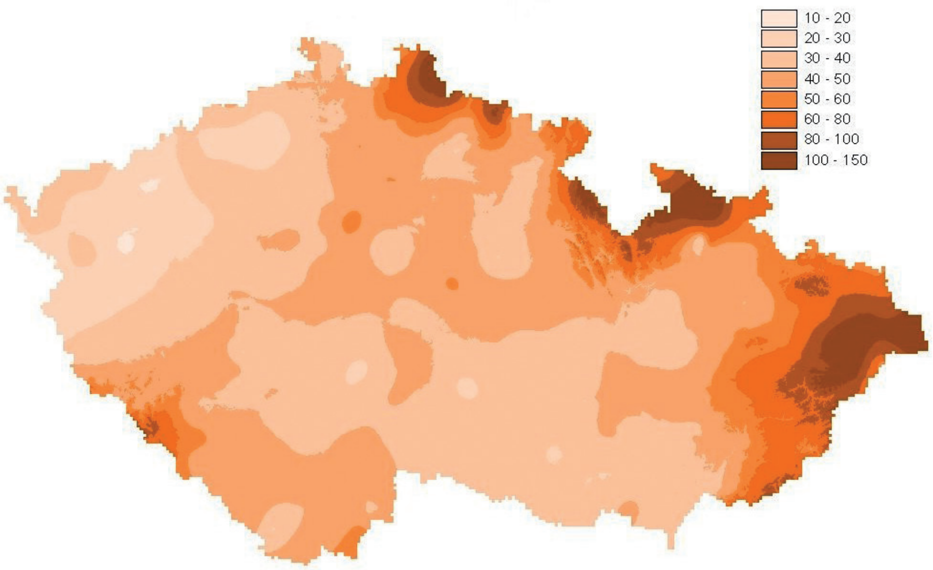

Figure 5. Area distribution of the average annual sum of rainfall erosivity and runoff factors (R-factors) in the Czech Republic, 1971–2001

some rains, some rains considered as erosive by estimate do not have to be erosive in reality. The authors therefore performed the initial estimate of a possible impact of this factor. For a reduction of the number of days included in the calculations of the estimated regressive factor we assume that the water value of the entire snow cover is 0.5 and at the most a half of the remaining precipitation infiltrates in it, i.e. (1–0.5)/2 = 0.25, the rest of the precipitation can then have an erosive impact provided that its aggregate value is 12.5 mm. The total snow cover of 5 cm seeps 12.5 mm and the daily precipitation aggregate must have the value of 25 mm at least in order to be included in the processing. With this reduced estimate the calculation was done for the above-mentioned technical scale. On average, the annual estimate at all 257 stations and for the period was smaller by 0.96 MJ/ha × cm/h than the initial estimate. The most significant differences were found at medium and higher altitudes, which is not surprising. It is evident that these differences, which do not appear in a substantial amount in the average of

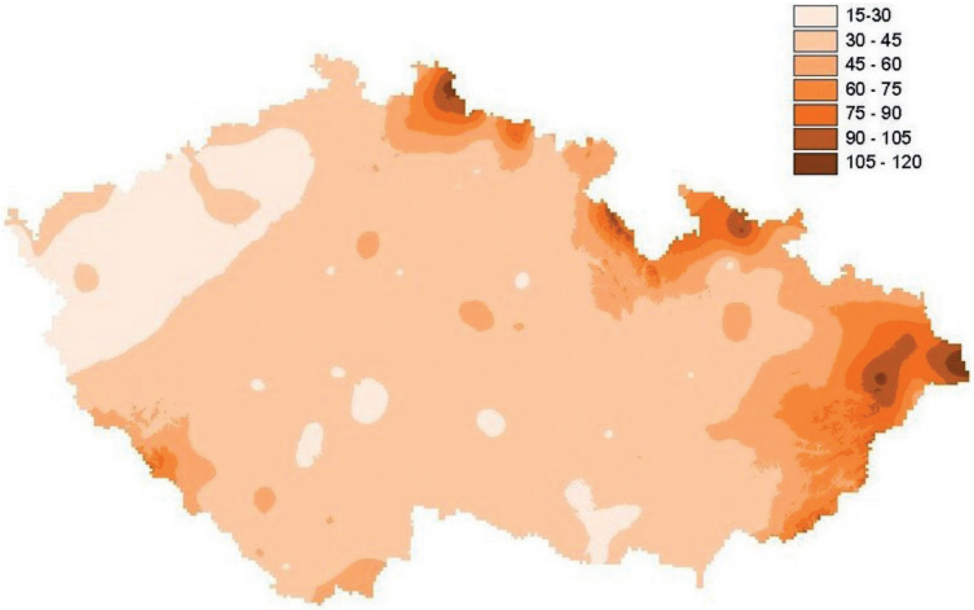

Figure 6. Area distribution of the truncated mean estimate (minus the 2 lowest and the 2 highest annual sums for each station) of rainfall erosivity and runoff factors (R-factors) in the Czech Republic in 1971–2001

Table 3. Minimum and maximum values of the truncated mean (minus the 2 lowest and the 2 highest values for the period) R-factors (MJ/ha × cm/h) for 1971–2000

Region	Minimum					Maximum				
	zone of altitudes (marked highest limit of the zone in m a.s.l.)									
	400	600	800	1000	1600	400	600	800	1000	1600
Ústí n. L.	18.8	18.4	18.4	18.3	20.4	40.9	41.2	41.6	39.9	24.0
Liberec	29.5	26.5	33.1	45.6	48.0	104.1	110.2	111.8	111.7	111.9
Hradec Králové	27.0	26.4	39.4	41.5	44.3	57.6	78.9	93.2	105.6	112.7
Karlovy Vary	19.0	17.8	17.8	18.9	20.3	28.6	34.7	38.8	38.8	35.5
Central Bohemia	25.1	25.2	28.4	36.8		50.7	45.7	40.3	37.2	
Ostrava	41.8	38.8	37.3	34.8	25.2	115.8	115.3	112.4	111.2	106.8
Plzeň	23.8	19.7	19.5	25.3	38.6	42.8	56.7	69.5	80.1	94.1
Praha	28.2					44.8				
Pardubice	27.1	31.5	33.7	70.9	77.4	53.3	73.6	87.0	98.4	83.1
Olomouc	30.2	28.6	33.1	29.6	24.9	67.2	85.1	86.1	85.3	83.4
Bohemian-Moravian Highlands	28.0	26.2	27.2	34.0		46.7	45.7	44.8	37.1	
South Bohemia	28.1	26.4	27.6	29.6	36.9	45.2	48.2	49.5	49.6	49.4
South Moravia	29.0	29.1	34.3			47.1	45.8	41.8		
Zlín	33.2	36.4	64.8	64.8	100.3	90.1	100.6	105.3	107.9	111.2
Czech Republic	18.8	17.8	17.8	18.3	20.3	115.8	115.3	112.4	111.7	112.7

the Czech Republic, may have a significant impact at medium and higher altitudes. The mean value for the period is influenced to a large extent by extreme values which occurred at some stations in the above-mentioned period and which have the character of more than one hundred years values.

Using a spatial analysis in GIS environment and taking into account the altitude a map of the arithmetic average of R-factors for the period 1971–2000 (Figure 5) and a map of the trimmed arithmetic average of R-factors (average for 26 years) (Figure 6) were produced.

In Table 3 and 4 the area values of Figure 6 are indicated for regions and altitude zones (marked the highest limit of the range in m a.s.l.).

DISCUSSION

The applied R-factor calculation is very sophisticated when we have data in minute intervals. Currently, this calculation is based on the processing of minute ombrographic values which were measured and digitalised by the CHMI. We particularly focused on the analysis and estimation of the R-factor annual aggregate.

While searching for the area disposition of the R-factor we encounter many problems related to the insufficiently dense network of the assessed R-factors from minute values and to the inconsistent observation period. In the set of assessed R-factors there remain many questions. Besides the problem of unassessable ombrographic data, there is a problem of categorisation; what rains should be included in the calculations of the R-factors.

It is not possible to set a consistent annual interval proposed for the measurement of snow cover because it depends on the geographic location of the station (mainly on its altitude in the conditions of the Czech Republic) and on the specific weather in the given year.

During warm years this period will be longer, during cold years it will be shorter. At higher altitude it will be shorter than at lower altitudes. During the elaboration of the map the assessed days of the year were defined in such a way that they must be days with rain, not with snow. At some stations there are instruments with a heated rain gauge.

Table 4. Means and standard deviations of the truncated mean (minus the 2 lowest and the 2 highest values for the period) R-factors (MJ/ha × cm/h) for 1971–2000

Region	Arithmetic mean					Standard deviation				
	zone of altitudes (marked highest limit of the zone in m a.s.l.)									
	400	600	800	1000	1600	400	600	800	1000	1600
Ústí n. L..	29.0	30.3	29.4	27.4	21.8	4.4	6.4	5.4	5.7	1.0
Liberec	46.1	53.8	70.9	86.5	71.9	11.8	17.7	18.0	17.9	19.5
Hradec Králové	38.4	47.4	66.5	78.1	78.6	4.5	9.1	15.6	17.8	13.3
Karlovy Vary	23.7	25.8	25.4	31.0	26.7	2.6	3.6	5.0	5.1	3.8
Central Bohemia	37.6	35.3	35.7	37.0		4.1	3.5	2.4	0.1	
Ostrava	68.5	63.2	63.0	72.1	60.1	15.0	22.3	21.2	19.4	21.7
Plzeň	34.5	34.9	38.9	58.3	55.1	2.5	7.4	13.2	9.8	13.2
Praha	37.0					4.2				
Pardubice	38.5	44.3	48.5	80.3	79.3	4.7	8.2	15.0	5.8	1.3
Olomouc	45.0	44.3	52.7	60.0	49.3	8.1	9.2	14.0	17.5	18.6
Bohemian-Moravian Highlands	35.3	34.9	34.9	36.0		5.8	3.4	2.9	1.2	
South Bohemia	35.4	36.4	40.3	42.5	41.7	4.5	4.2	4.9	3.2	1.7
South Moravia	34.7	37.4	37.7			4.1	3.5	2.3		
Zlín	49.5	70.9	83.7	87.5	104.9	10.9	10.7	7.4	12.1	5.7
Czech Republic	41.1	39.8	43.7	51.7	55.5	12.6	13.2	18.7	21.8	19.6

Such data, of course, do not provide any information on the type of precipitation. The influence of the height of snow cover on the days included in the calculation must also be considered. It may be assumed that in the relation between liquid precipitation and the total mass of snow cover, the infiltration of rain water is allowed without erosive impact. It must be evaluated separately within the process of snow melting. As far as the extent of the work goes, it was only possible to formulate the basic estimate of the extent of a possible impact. In the future the problem of the time sequences of erosive rains must be addressed. Also, the problem of the influence of soil saturation on the accuracy of the calculation methods of each R-factor should be addressed.

While evaluating the mean erosion impact in each region of the Czech Republic it should be considered that the station average in a given period may include extreme rains, e.g. Ústí nad Orlicí in 1988, floods in Moravia in 1997, which have a very small periodicity of recurrence. This problem was solved in the framework of the project by means of a truncated mean which omits the two lowest and the two highest annual values at each station. The area truncated mean of the year by estimating the sum of the R-factors in the Czech Republic in the period 1971–2000 amounted to 41.1 MJ/ha × cm/h, with area variations from 17.8 to 112.7 MJ/ha × cm/h.

The highest values were assessed in mountainous regions, where the inclusion of liquid precipitation in the high snow cover also plays a role. The above-mentioned truncated mean was approximately 4 MJ/ha × cm/h (Table 4) lower for the given period than the standard arithmetic mean for that period, whilst at least the gross estimate of the total snow cover leads on average for the Czech Republic to another diminution of approximately 1 MJ/ha × cm/h. In the future it could be useful to consider the norm of erosive risk based on the values of equal periodicity (e.g. 50 years), and not for the same period. The indicated R-factor time distribution in the Czech Republic corresponds approximately to the distribution of R-factor on the isoerodent map for the state of Montana (USA), from 35 to 61 MJ/ha × cm/h. For this US state it was assessed (Kubátová *et al.* 2009) that the distribution and occurrence of erosive rains is very similar to the Czech Republic.

Provided that we do not assess mountainous areas with R-factor of 60 to 120 where the share of agricultural and particularly arable land is very small and the influence of the snow cover is greater, we can conclude from Figure 6 that the R-factor for the majority of the lands used for agricultural purposes in the Czech Republic varies between 30 and 40, except in the area of rain shadow where R = 15 to 30 and low mountain areas with R-factor from 45 to 60. With reference to the above-mentioned problems making the determination of R-factor difficult we may conclude that it does not appear so useful to regionalize the R-factor for the Czech Republic (which, amongst others, corresponds to the exactness of the identification of isoerodent lines for the USA) and it may be better to be satisfied – for the vast majority of the agricultural lands in the Czech Republic – with the mean value of the R-factor = 40. When using this value, it may be assumed that in the area of the rain shadow somewhat higher resultant values of soil loss due to erosion will be assessed, with lower values in the low mountains.

If there is a need to determine the soil erosion risk and to implement soil protection in mountainous areas, usually forested or with permanent grassland and thus protected from erosion, it is possible to use higher values indicated on the map, considering longer-lasting snow cover.

CONCLUSION

The available set of R-factors, calculated from ombrographic data, is an original method for estimations of the annual aggregate of R-factors from daily precipitation. The method provides satisfactory results compared with experimental data, although it would surely be good to expand the scope of the set and to solve open questions, as mentioned in the discussion. It may be concluded from the results that for the majority of the agricultural lands in the Czech Republic the value of R = 40, the double of the value proposed so far, could be recommended. This decision will surely result in higher demands on soil conservation measures and will contribute significantly to a reduction of land losses due to erosion in the Czech Republic.

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