Time Variations of Rainfall Erosivity Factor in the Czech Republic

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Abstract: The ombrographic data have been selected from 24 meteorological stations of the Czech Hydro Meteorological Institute (CHMI), according to the terms of the Universal Soil Loss Equation for calculating the long term loss of soil through water erosion, erosion hazard rains and their occurrence, with their relative amounts and erosiveness, R-factors determined for each month. By comparing the value of the time division of the R-factor in the area of the Czech Republic and in the selected areas of the USA, it has been demonstrated that this division may be applied in the conditions of the Czech Republic.

Keywords: water erosion; rainfall; erosivity factor

In the first half of the 20th century in the USA, a need emerged for the calculation of the soil loss caused by water erosion. For this purpose Cook (1936) identified 3 main factors determining the processes of water erosion: susceptibility (soil erodibility), the potential erosivity of rainfall and runoff, and the soil protection afforded by plant cover. Zingg (1940) published the first empirical model of the erosion process for evaluating average annual losses of soil due to water erosion which he derived from the results of an extensive research into the influence of the steepness and length of a slope on this process. The initial research into the forecasting methods for calculating soil loss due to erosion has been carried out in USA by the following authors: Smith (1941), Musgrave (1947), Browning *et al.* (1948), Smith and Whitt (1948), and others.

Until today, the best description of the quantitative influence of the main factors of water erosion caused by storm rainfall (USLE) was given by Wischmeier (1959). The Universal Soil Loss Equation (USLE) describes the soil loss caused by water (G) as a product of six factors: rainfall-runoff erosivity (R), soil erodibility (K), slope length (L), slope steepness (S), cover and management practices (C), and supporting conservation practices (P).

$$G = R \times K \times L \times S \times C \times P$$

This relatively simple method enables the calculation of the hypothetical long term average annual soil loss caused by water erosion in any given area. It has the advantage of being easily available and simple in the access.

Since its publication in the Agriculture Handbook No. 282 (Wichmeier & Smith 1965) and its revised version published in the Agriculture Handbook No. 537 (Wichmeier & Smith 1978) USLE has become the main planning instrument for the soil protection in the USA and around the world.

By integrating new findings, experiences and a large amount of digitally processed data acquired

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since 1978, which manifested itself also by changes in the calculations of each factor, the so called RUSLE "Revised Universal Soil Loss Equation" was created by Renard *et al.* (1997) and Toy *et al.* (1999), and which uses the same algorithm as USLE.

Aims

The purpose of this study is to compare the occurrence of erosion rainfall, characterised by the R-factor values of each month in the Czech Republic, with the data acquired from the selected meteorological stations in the USA, and to demonstrate the validity of the calculation procedure of the R-factor according to USLE also in our country. The issue has also been dealt with in other European countries, i.e. by Schwertmann *et al.* (1987), Boardman and Poesen (2006), in Bavaria, Austria and Belgium.

The rainfall factor – R, i.e. its erosivity, was formulated in the USA (Wischmeier & Smith 1965). The aforementioned had the largest amount of the necessary data accessible at that time, acquired from a network of meteorological survey stations situated throughout the USA. The rainfall factor used for determining the average annual loss of soil includes the influence of exceptional precipitation events (intensive rainfall) as well as average intensive rains.

Table 1. List of CHMI ombrographic survey stations used in the calculation of the R-factors

	CHMI Survey station	Observation period	Comments	No. of years
1.	Brumov Bylnice	1961–1990	1963 – not measured	29
2.	Desná	1961–2000	1972, 1974 – not measured	38
3.	Deštné	1981–2000	1987 – not measured	19
4.	Doksy	1962–2000		39
5.	Hejnice	1970–2000		31
6.	Horní Bečva	1962–2000		39
7.	Hradec Králové	1961–1994	1987, 1995–1999 – not measured	33
8.	Cheb	1961–2000		40
9.	Liberec	1961–1987, 1991–2000		36
10.	Neumětely	1981–2000		20
11.	Praha-Libuš	1972–2000		29
12.	Přibyslav	1965–2000		36
13.	Přimda	1961–2000	1991 – not measured	39
14.	Raškovice	1962–1985, 1997–2000	1986–1992 – not digitalised	27
15.	Svratouch	1961–2000	1960 – not measured	40
16.	Tábor	1961–1996	1997–2000 – not measured	36
17.	Třeboň	1961–2000	1981, 1997 – unusable	39
18.	Ústí n.Orlicí	1981–2000		20
19.	Varnsdorf	1963–2000		37
20.	Vír	1961–2000		40
21.	Vizovice	1963–1998	further not measured	36
22.	Vranov	1962–2000		39
23.	Zbiroh	1963–2000	1965, 1977 – not measured	36
24.	Židlochovice	1962–1990	1970 – unusable	38

The data indicate that, when the factors other then rainfall are held constant, the soil losses in an area are directly proportional to the rainstorm parameter: total storm energy (E) times the maximum 30-min intensity (i_{30}):

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

where:
R – rainfall erosivity factor (MJ/ha × cm/h)
E – total storm energy (cm/h)
i_{30} – maximum 30-min intensity (cm/h)

The total storm energy is:

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

where:
E_i – kinetic energy of rain in the i-section (n – number of rain sections):

$$E_i = (206 + 87 \log i_{si}) \times H_{si}$$

where:
i_{si} – intensity of rain in the i-section (cm/h)
H_{si} – rain fall in the i-section (cm)

The annual value of the R-factor is determined from long term data records of precipitations and represents the aggregate of the erosion impact of each storm rainfall occurring in the given year. Rain showers of less then 12.5 mm (0.5 inch) were omitted from the erosion index, unless at least 6.25 mm (0.25 inch) of rain fell in 15 min. The delay between the rainfalls must be longer then 6 hours in order to consider them as individual rainfalls.

Therefore, the rainfall erosivity factor R depends on the frequency of occurrence, kinetic energy, intensity and amount of rain which fell. In the USA, the values of the R-factor were statistically assessed and presented in the form of an isoerodent maps.

METHODOLOGY

During the calculation of the R-factor for the region of the Czech Republic, the ombrographic data were available, collected from 24 selected survey stations of the CHMI; the method of Wischmeier and Smith (1978) was systematically implemented. Preference was given to the survey stations producing long term ombrographic observation data (Table 1 and Figure 1). The observations were carried out only in the growing season, since most ombrographs are not equipped with heating.

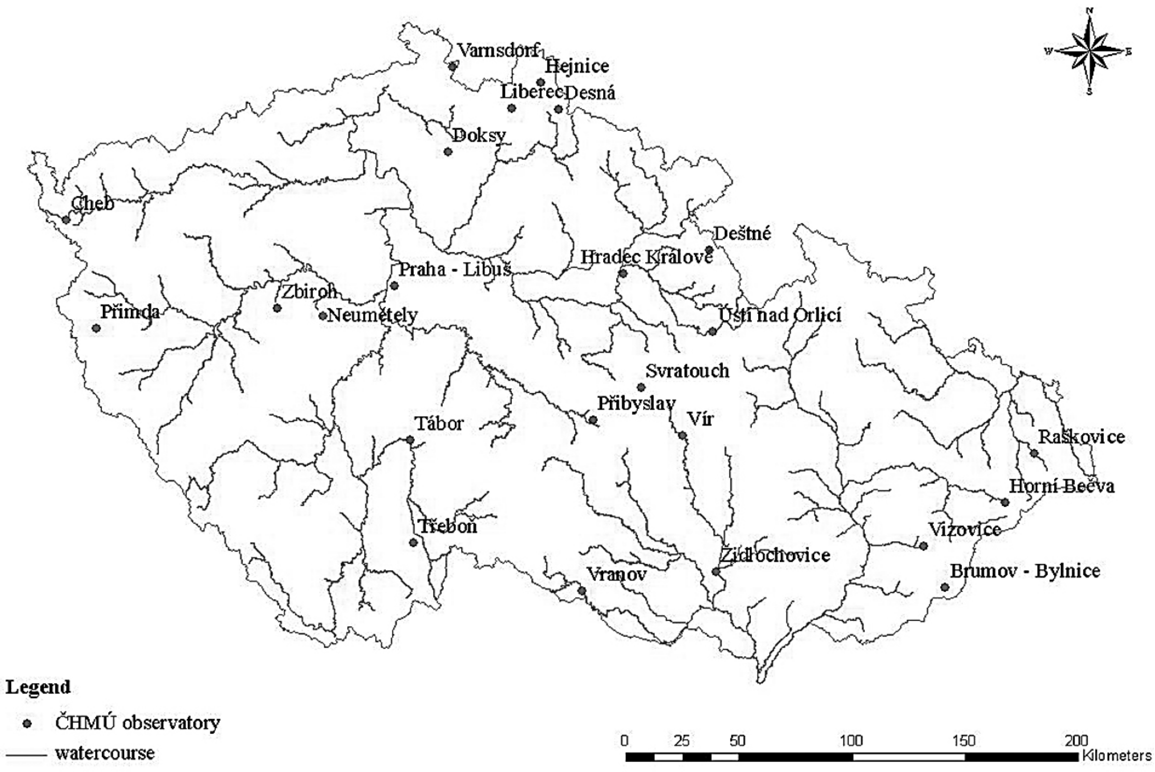

Figure 1. Locations of CHMI ombrographic survey stations used for calculation of R-factors

Table 2. Average number of erosion hazard precipitations in the given months

Relative number of erosion rainfall	Allocation in given months							
	IV	V	VI	VII	VIII	IX	X	XI
Meeting 1 of 2 requirements	2.5	14.9	21.8	21.9	20.0	12.6	5.5	0.8
Aggregate expression of 1 of 2 requirements	2.5	17.4	39.2	61.1	81.1	95.8	99.2	100.0
Meeting both requirements	0.7	10.4	25.1	30.8	25.3	7.2	0.6	0.0
Aggregate expression of both requirements	0.7	11.1	36.2	67.0	92.2	99.4	100.0	100.0

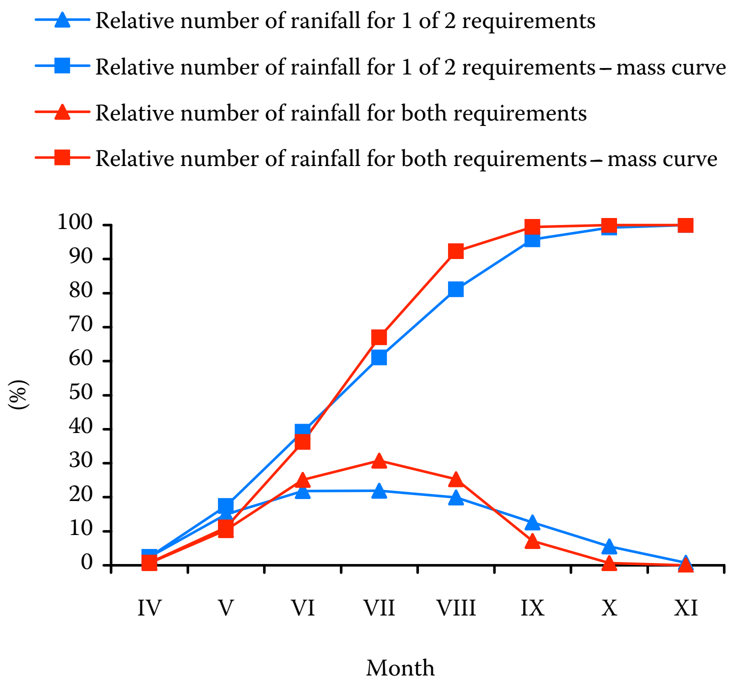

Figure 2. Record of the average occurrence of erosion rainfall during the year

The data records were fed into a text editor in the digital form at time intervals of 1 min, and were adapted from the text document to the Excel chart processor, where R-factor values were subsequently calculated. Prior to that, the calculated data were screened (screening out the precipitation events which did not comply with the above mentioned criteria) and adapted from the text to the Excel chart processor, where R-factor values were subsequently calculated.

RESULTS

Calculations of the R-factors were carried out in 2 variants:

V1. variant – comprised rains which met 1 of the 2 requirements, i.e. when the rainfall was more than 12.5 mm, or when 6 mm fell within a period of 15 min.

V2. variant – comprised rains meeting both requirements, i.e. the rainfall above 12.5 mm and with an intensity above 6 mm in 15 min.

The following data were determined by the survey stations, as indicated in Table 1 and Figure 1:

(a) – relative number of erosion rains which occurred each month, including their aggregate expression,

(b) – R-factors value expressed in the percentage of occurrence in each month and on aggregate.

The number of occurrences of erosion rainfall and their long term variations during the given

Table 3. R-factor values in the given months

R-factor values	Division in given months							
	IV	V	VI	VII	VIII	IX	X	XI
Meeting 1 out of 2 requirements	0.9	10.9	22.3	29.9	25.8	8.3	1.7	0.2
Aggregate expression meeting 1 out of 2 requirements	0.9	11.7	34.1	63.9	89.7	98.0	99.8	100.0
When meeting both requirements	0.5	8.9	22.8	33.5	27.4	6.3	0.5	0.1
Aggregate expression meeting both requirements	0.5	9.4	32.2	65.7	93.1	99.4	99.9	100.0

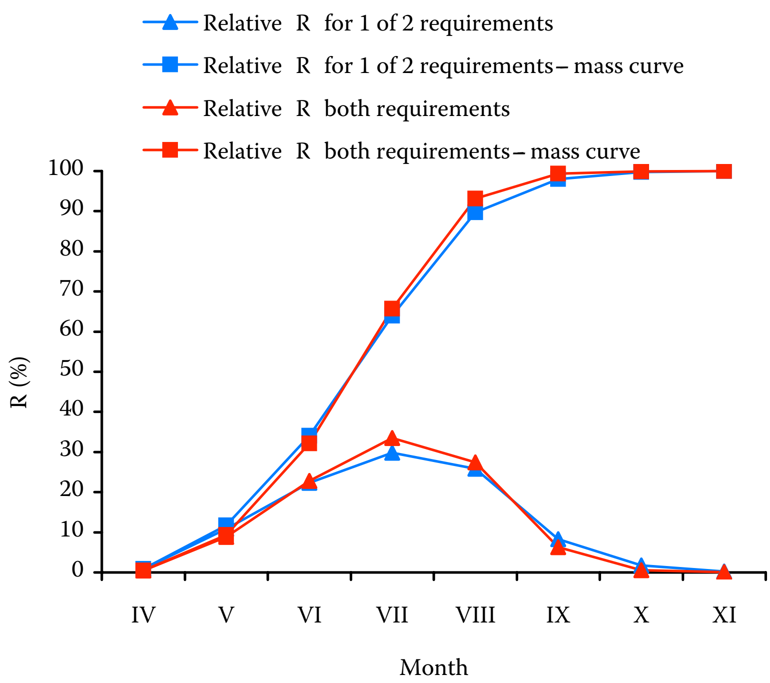

Figure 3. Evolution of R-factor average divisions during one year

Table 4. Comparing the number of erosion rainfall with R-factor values

	Division in given months							
	IV	V	VI	VII	VIII	IX	X	XI
Number of rainfall for 1 out 2 requirements	2.5	14.9	21.8	21.9	20.0	12.6	5.5	0.8
Relative R for out of 2 requirements	0.7	10.4	25.1	30.8	25.3	7.2	0.6	0.0
Number of rainfall for both requirements	0.9	10.9	22.3	29.9	25.8	8.3	1.7	0.2
Relative R for both requirements	0.5	8.9	22.8	33.5	27.4	6.3	0.5	0.1

months were determined from the processed data – see Table 2 and Figure 2.

On the basis of the observed variations in the erosion rainfall during each month, it was confirmed that their highest occurrence took place during the summer months (June–August), see Tables 3, 4, 5 and Figures 3, 4, 5. Significantly increased and decreased numbers of erosion rainfalls occurred during the indicated months in the form of rains meeting both requirements. A similar change was determined in the R-factor division while the difference between both groups was not very significant (up to 2%).

Comparing the respective values of the R-factor division over a year in each month surveyed, as recommended for the practical use in the regions

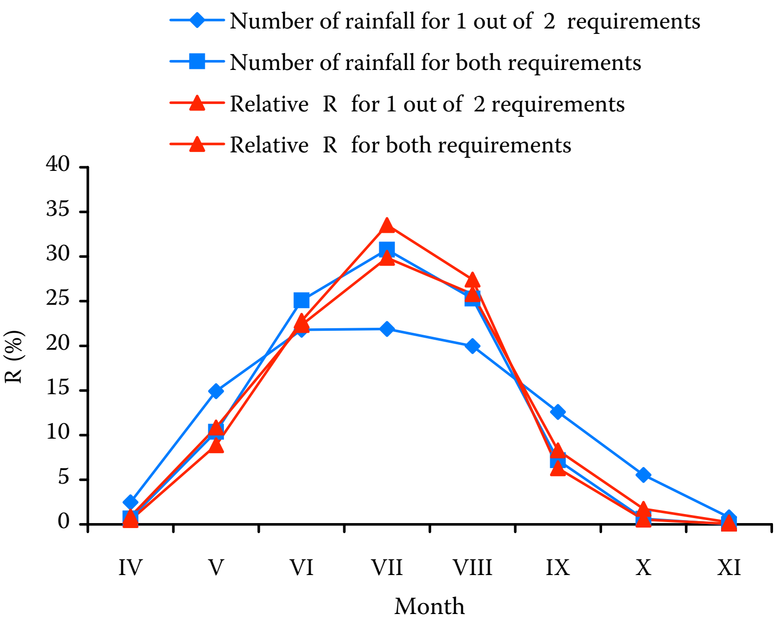

Figure 4. Evolution of the number of erosion rainfall and R-factor values

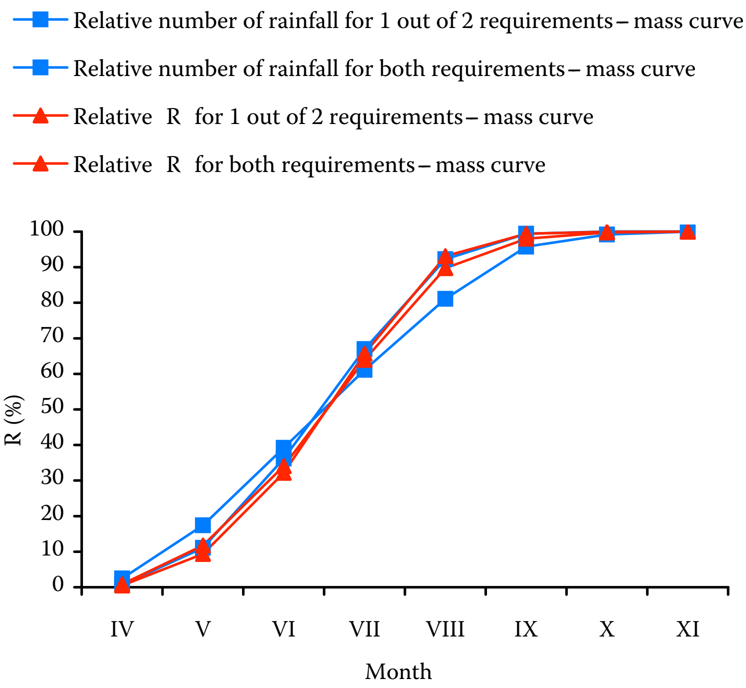

Figure 5. Total curves of number of erosion rainfall with R-factor values

Table 5. Aggregate expression of the number of rainfall with R-factor values

	Division in given months							
	IV	V	VI	VII	VIII	IX	X	XI
Relative number of rainfall for 1 out of 2 requirements	2.5	17.4	39.2	61.1	81.1	95.8	99.2	100
Relative number of rainfall for both requirements	0.7	11.1	36.2	67.0	92.2	99.4	100.0	100
Relative R for 1 out of 2 requirements	0.9	11.7	34.1	63.9	89.7	98.0	99.8	100
Relative R for both requirements	0.5	9.4	32.2	65.7	93.1	99.4	99.9	100

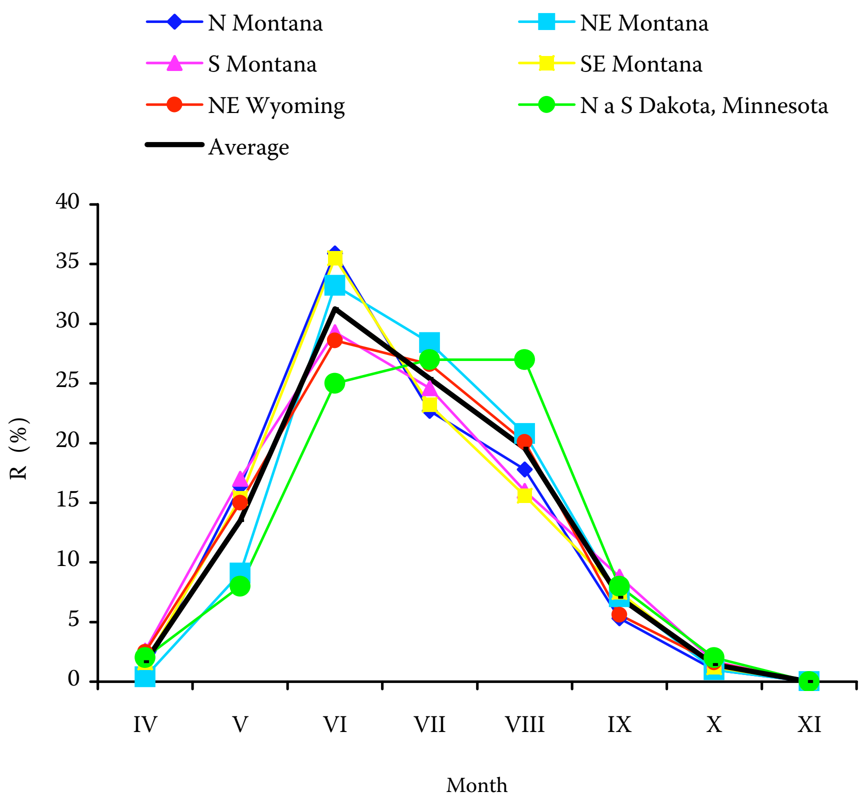

Figure 6. Annual variations of the R-factor in the North West regions of the USA

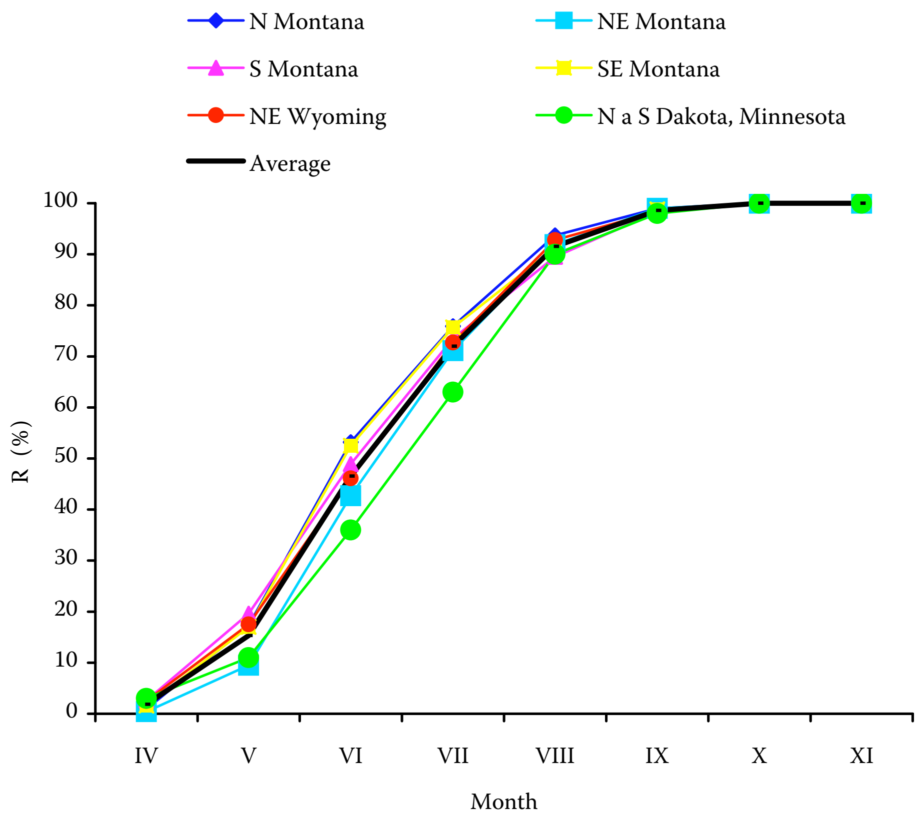

Figure 7. Total curves of the relative values of R-factors for the selected regions in the North West of the USA

Table 6. Monthly division of the R-factors for 6 meteorological survey stations in the North West of the USA

Survey station	Percentage division of the R-factor							
	IV	V	VI	VII	VIII	IX	X	XI
N Montana	0.9	16.4	35.9	22.7	17.8	5.3	1.0	0
NE Montana	0.4	9.1	33.2	28.4	20.8	7.1	1.0	0
S Montana	2.6	17.0	29.3	24.6	16.0	8.8	1.7	0
SE Montana	1.6	15.4	35.5	23.1	15.6	7.5	1.2	0
NE Wyoming	2.5	15.0	28.6	26.6	20.1	5.6	1.6	0
N a S Dakota, Minnesota	2.0	8.0	25.0	27.0	27.0	8.0	2.0	0
Average	1.7	13.5	31.3	25.4	19.6	7.1	1.4	0

Table 7. Total curves of the R-factor division for 6 meteorological survey stations in the North West of the USA

Survey station	Percentage division of the R-factor							
	IV	V	VI	VII	VIII	IX	X	XI
N Montana	0.9	17.3	53.2	75.9	93.7	99.0	100.0	100.0
NE Montana	0.4	9.5	42.7	71.1	91.9	99.0	100.0	100.0
S Montana	2.6	19.6	48.9	73.5	89.5	98.3	100.0	100.0
SE Montana	1.6	17.0	52.5	75.7	91.3	98.8	100.0	100.0
NE Wyoming	2.5	17.5	46.1	72.7	92.8	98.4	100.0	100.0
N a S Dakota, Minnesota	3.0	11.0	36.0	63.0	90.0	98.0	100.0	100.0
Average	1.8	15.3	46.6	72.0	91.5	98.6	100.0	100.0

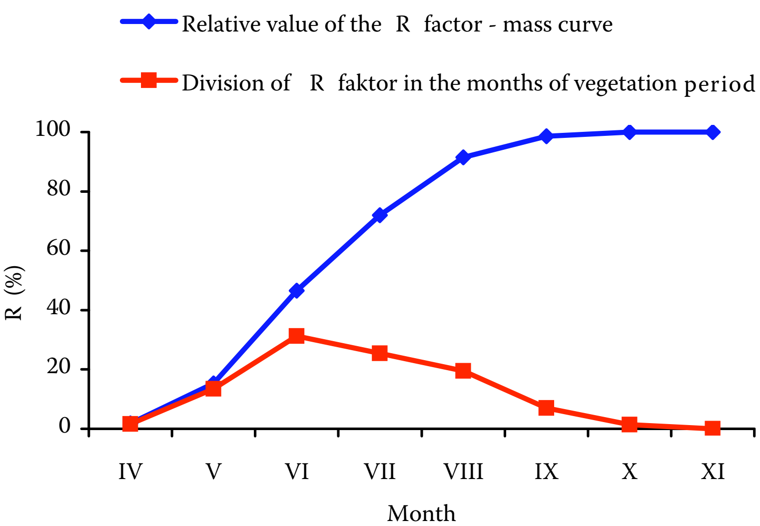

Figure 8. Evolution of the average monthly division of the R-factor in the North and the North West of the USA

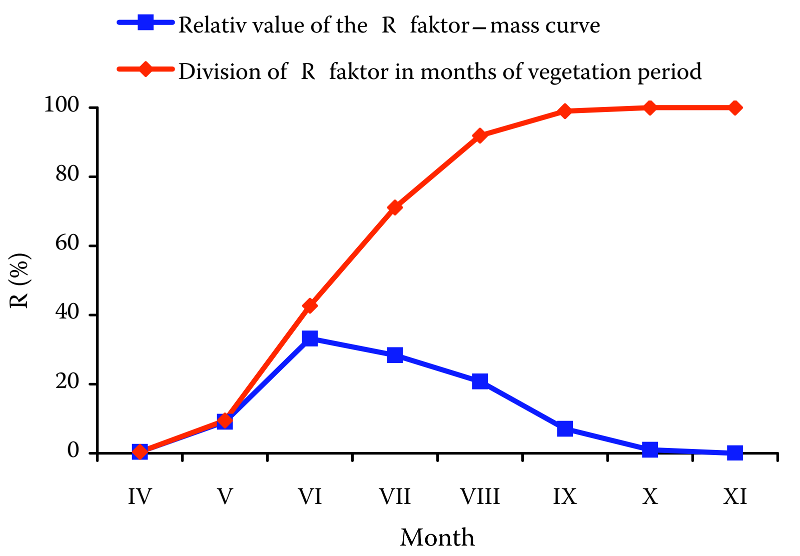

Figure 9. Evolution of the R-factor division during the vegetation period months for the North East of Montana

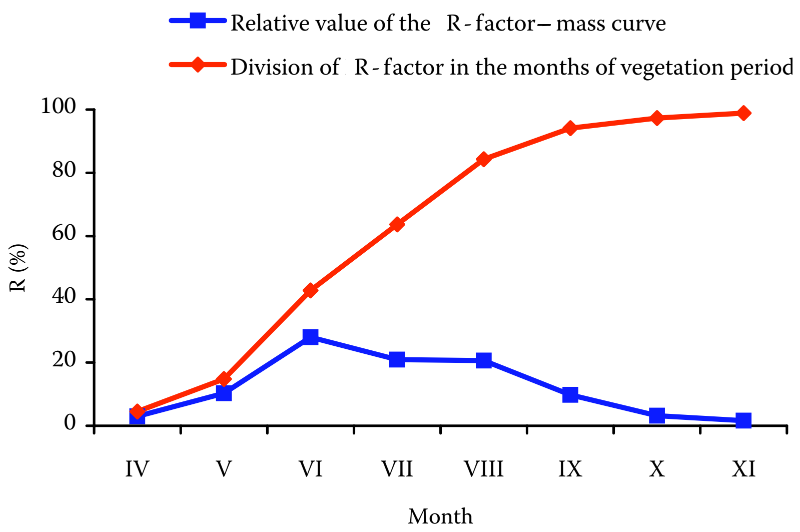

Figure 10. Evolution of the average R-factor division during the given months in Bavaria

Table 8. Average division of the R-factor in given months for the North and the North West of the USA, North East part of Montana and Bavaria

Month	IV	V	VI	VII	VIII	IX	X	XI
Percentage of R-factor for the North West USA	1.7	13.5	31.3	25.4	19.6	7.1	1.4	0
Percentage of R-factor for the North East Montana	0.4	9.1	33.2	28.4	20.8	7.1	1.0	0
Percentage of R-factor for Bavaria	3	10.3	28	20.9	20.6	9.8	3.2	1.6

Table 9. Comparative values of R-factor division for the Czech Republic, the USA and Bavaria

Factor values	Division in given months							
	IV	V	VI	VII	VIII	IX	X	XI
R division for the Czech Republic	0.9	10.9	22.3	29.9	25.8	8.3	1.7	0.2
R division for the USA	1.7	13.5	31.3	25.4	19.6	7.1	1.4	0.0
R division for Bavaria	3	10.3	28.0	20.9	20.6	9.8	3.2	1.6

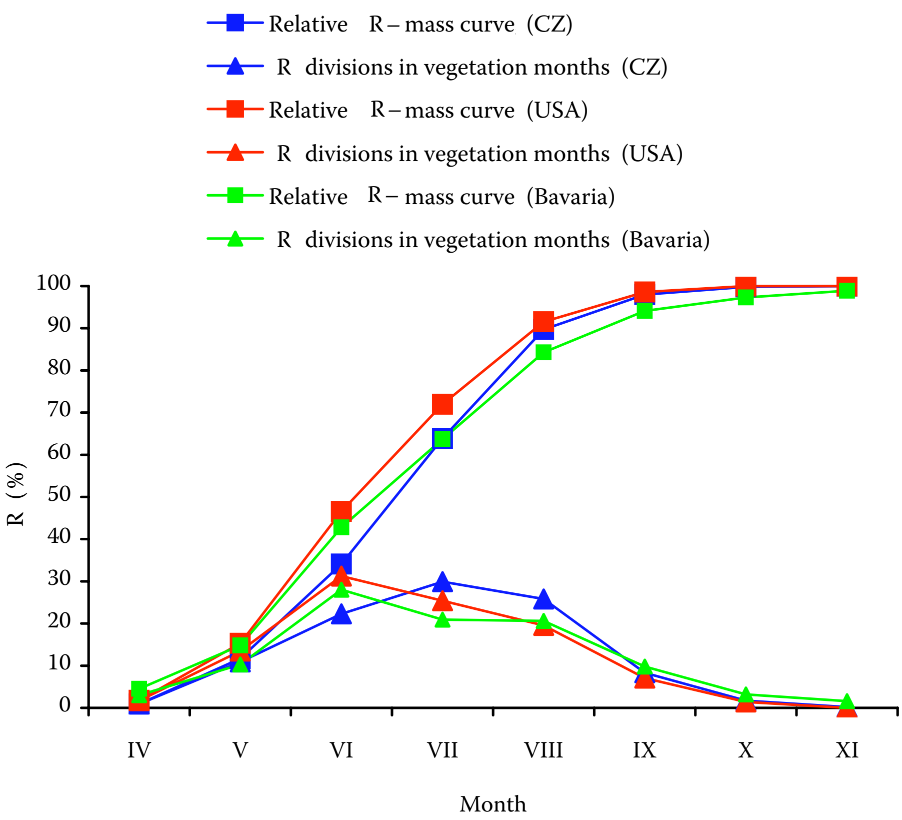

Figure 11. Long term evolution of the average R-factor by months in the Czech Republic, the USA, and Bavaria

of Bohemia and Moravia in previous publications by Janeček *et al.* (2005, 2007), no significant variation has been found.

DISCUSSION

For the purpose of comparing the results of the average division of R-factors in the given months in the Czech Republic, we used the mass curve of average annual E_i parameter values from 140 meteorological survey stations situated in the USA (Renard *et al.* 1997).

Out of these stations, 6 had been selected with regard to climatic conditions similar to those in the Czech Republic. These stations are situated in the North and North West of the USA (Montana, North and South Dakota, Wyoming and Minnesota). For these selected stations, the percentage division of the R-factor in the given months is shown in Table 6 and Figure 6, and the relative R-factors expressed by mass curves are shown in Table 7 and Figure 7. From the data supplied the average percentage division of the R-factor in the North and North West has been calculated – see Table 8 and Figure 8.

Table 10. Comparing long term evolution of monthly values of R-factors in the Czech Republic, the USA and Bavaria

Factor values	Division in given months							
	IV	V	VI	VII	VIII	IX	X	XI
R division for the Czech Republic	0.9	11.7	34.1	63.9	89.7	98.0	99.8	100.0
R division for the USA*	1.8	15.3	46.6	72.0	91.5	98.6	100.0	100.0
R division for Bavaria**	4.5	14.8	42.8	63.7	84.3	94.1	97.3	98.9

*Division of R-factor begins with third month; **division of R-factor covers whole year

To specify further, the data from the survey stations in the North East parts of Montana have been processed showing the greatest similarities with the R-factor values measured in the Czech Republic – see Table 8 and Figure 9. Furthermore, the data from18 meteorological survey stations from neighbouring Bavaria were used for comparison (Schwertmann et al. 1987) – see Table 8 and Figure 10. The overall comparison of these values for Montana, Bavaria, and our country is indicated in Tables 9 and 10, and in Figure 11.

CONCLUSION

The comparison of long term monthly occurrences of erosion rainfall characterised by the divisions of R-factor values for the Czech Republic and selected survey stations in the USA indicates the occurrence of erosion rainfall in our conditions at the end of spring and the beginning of summer (VII–VIII). The results indicated conformity of their division in the Czech Republic and the selected regions of the USA. Therefore, it may be considered that the use of the R-factor in the USLE complies with our conditions.

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