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ANALYSES OF CALCULATION METHODS FOR DETERMINATION OF RAIN EROSIVITY FOR SLOVAK REPUBLIC

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Abstract. On the basis of provided data from Slovak Hydrometeorlogical Institute were realized the calculation of rain factor for each rain-guage stations. Because provided data were in digital form, we proceeded to digital processing in graphical environment of Microsoft Excel i.e. each minutes of chosen rain were considered for separate rain division. Calculated data were compared with published values of Soil Science and Conservation Research Institute (SSCRI) and also with Methodology for implementation of research results into agricultural practise. From calculated values were created also the lines of exceedance of probability, which give detail information about occurrence of calculated values of rain factor once per 100, 50, 20, 10, 5 and 1 year. Also there were compared the different methodologies of rain factor calculation and kinetic energy of rain and their influence on final values. From calculated values there were found out that on all examined localities are our calculated values several times higher than in listed publications. These differences can be caused by different methods of data processing but also by number of processed years, because values of rain factor in listed publication were calculated for lower number of years. According to calculated values were created the redistribution of rain factor values on particular months of vegetation periods and it was found out that the highest percentage fall on summer months (June, July, August) and on the other hand, the lowest percentage, on the months April and October, therefore it is necessary to attach importance on soil erosion control especially in summer months. Comparison of different methods of data processing (digital vs. graphical) showed up, that differences in final values of rain factor by using of different methods of data processing are minimal, therefore it can be assumed that used methodology is right. Relations for kinetic energy calculation and different methodologies also significantly influenced final values of rain factor. Calculation of rain according different authors showed up that using relation for kinetic energy designed by Marshall, were obtained lower values, which influenced the final value of rain factor i.e. its final values was more closer to pu-

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blished values. Comparison of Hudson (*KE* > 1) and Wischmeier and Smith methodology it was found out that with using Hudson methodology is final value of rain factor almost two times lower than with using Wischmeier and Smith methodology. It was also done the calculations of rain factor which take into account the lack of data. There were used the relations according different authors. These relations calculate only with annual precipitation. The results showed that final values of rain factor is several time higher than with using equations for example of Wischmeier and Smith.

Key words: erosion, erosive effective rainfall, R-factor, Wischmeier and Smith

INTRODUCTION

The simplest definition of soil fertility is the ability of soil to supply plant nutrients. This ability can be significantly disrupted by many factors. One of these factors is soil erosion which is caused by water concretely by rain.

Soil creates the environment for plants, animals and definitely for man and also represents irreplaceable resource for man. World population increased from 2 to 10.000,000 from the beginning of agricultural production 10 to 12.000 years ago, to 6.5 billion in 2006 and may stabilize to 10–12 billion in 2010. This constantly growing numbers lead us to think about the importance of soil protection, which has incalculable value to mankind.

Soil erosion by water is one of the most widespread forms of soil degradation in Europe affecting an estimated 105 million ha, or 16% of Europe's total land area (excluding the Russian federation; EEA, 2003) [The State of Soil in Europe 2012]. In condition of Slovak Republic predominates manifestations of water erosion and potentially is endangered 39,65% (957 173 ha) of agricultural soil [Soil as the Component of Environment in Slovak Republic 2010, 2011]. These alarming numbers invoke detailed need of research of soil water erosion. One of the factors which influenced the rainfall erosion is rainfall erosivity factor R. There are lots of different ways how to calculate rainfall erosivity factor and one of the well know is methodology designed by Wischmeier and Smith [1978].

MATERIAL AND METHODS

Slovak Hydrometeorological Institute in Bratislava provided data about one minute precipitation for chosen meteorological stations situated in area of southwestern Slovakia. Totally were processed data from 5 meteorological stations for different time period. We used the methodology of Wischmeier and Smith [1978] which considers the erosive effective rainfall, those rainfalls, which are higher than 12.5 mm and with intensity higher than 24.00 $mm \cdot h^{-1}$ in one rain division. The main different in this work is that each minute of rain was consider for individual rain division. The following equations were used for calculation of rain factor:

$$R = E \cdot I_{30} \qquad MJ \cdot ha^{-1} \cdot cm \cdot h^{-1}$$

where:

R – rain factor, MJ · ha^{-1} · cm · h^{-1},

E – rain kinetic energy, J · m^{-2} · mm^{-1},

I_{30} – maximal 30-minutes rain intensity, cm · h^{-1}.

$$KE = (11{,}87 + 8{,}73 \cdot \log_{10} I) \cdot H_z \ \mathrm{J \cdot m^{-2} \cdot mm^{-1}}$$

where:

KE – kinetic energy of rain, J · m^{-2} · mm^{-1},

H_z – pecipitation height, mm.

The main difference in this work is that, for the data preparation was design new methodology which is modified Wischmeier and Smith methodology i.e. the chosen effective erosive rainfalls were not divided into rain divisions but each minute of selected rains were considered for individual rain division. This designed methodology eliminates the individual mistakes for choosing of rain divisions.

In the past was also used methodology designed by Wischmeier and Smith, but this methodology used data about precipitation in graphical form. But in the present time are data not only about precipitation recorded in digital form i.e. the data are more detailed and therefore it is better to do calculation with using of these data. The Figure 1 shows the preparation of data for consequent calculation of rain factor.

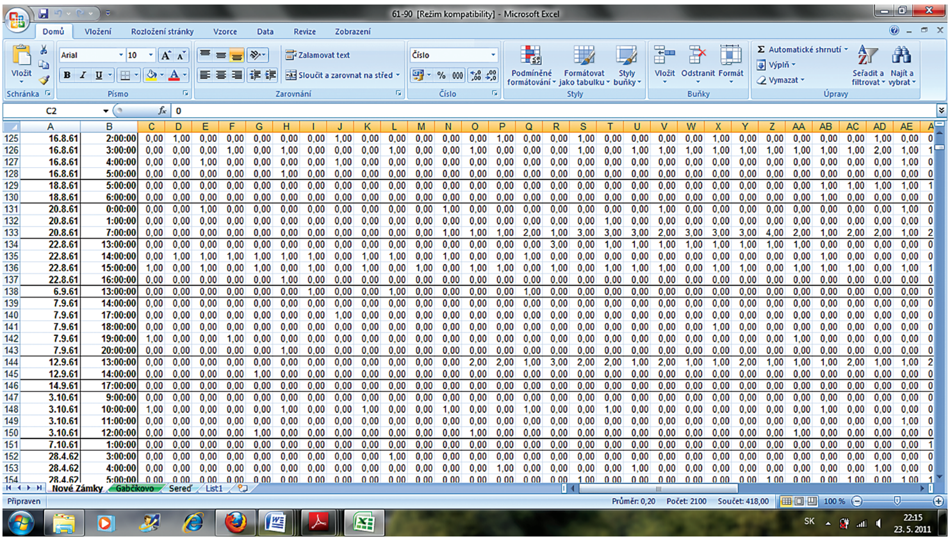

Fig. 1. Provided data in digital form in one – minute step in program MS Excel

For the data preparation was design new methodology i.e. the chosen effective erosive rainfalls were not divided into rain divisions but each minute of selected rains were considered for individual rain division. This designed methodology eliminates the individual mistakes for choosing of rain divisions.

According Hudson [1971] is calculation of EI_{30} and $KE > 1$ the same, but advantage of $KE > 1$ index is that it can be used also for less detailed records about rains. For both these methodologies it is necessary to know rain depth, which fall down and also appropriate intensities. Simple calculation is introduced in Table 1.

Procedure of calculation according this methodology is following:

1. For chosen rain depth is calculated the rain intensity.
2. Then is the rain arrange according intensities shown in the Table 1.
3. For each intensities groups is calculated kinetic energy according following equation:

$$KE = 29{,}8 - \frac{127{,}5}{I} \qquad \mathrm{J \cdot m^{-2} \cdot mm^{-1}}$$

where:

KE – kinetic energy, $\mathrm{J \cdot m^{-2} \cdot mm^{-1}}$,
I – rain intensity, $\mathrm{mm \cdot h^{-1}}$.

4. At the end, the sums of each intensity are sum up and the total kinetic energy of rain is calculated

Table 1. Example of calculation according Hudson methodology

Intensity $\mathrm{mm \cdot h^{-1}}$	Precipitation amount mm	Rain kinetic energy $\mathrm{J \cdot m^2 \cdot mm}$	Sums Column 2 × Column 3
0–25	30	–	–
25–50	20	26	520
50–75	10	28	280
>75	5	29	145
Total	65		945 $\mathrm{J \cdot m^{-2}}$

After calculation of kinetic energy of each rain we proceeded according Wischmeier-Smith methodology i.e. maximal 30-minutes intensity was chosen and the values were inducted to the equation for calculation of rain factor.

The results obtained according Wischmeier and Smith methodology was compared with other introduced equations. These equations take into account the lack of data i.e. they calculate with annual precipitation data. Calculation of R-factor according Šabata [1978]:

Šabata expressed rain factor for conditions of Slovak Republic depending on average annual precipitation height:

$$R = 0{,}058 \cdot H_{sa} + 10{,}5 \qquad \mathrm{MJ \cdot ha^{-1} \cdot cm \cdot h^{-1}}$$

where:

H_{sa} – average annual precipitation height, mm.

Expression of rain factor according Zachar [1981]:

$$R = 0{,}068 \cdot Hz{,}r \qquad \mathrm{MJ \cdot ha^{-1} \cdot cm \cdot h^{-1}}$$

where:

Hz,r – average annual precipitation height, mm.

Expression of R-factor according Holý [1978] for whole year, respectively for vegetation period:

$$R = 0{,}0679 \cdot Hs{,}r + 4{,}2793 \qquad \mathrm{MJ \cdot ha^{-2} \cdot cm \cdot h^{-1}}$$

where:

Hs,r – average annual precipitation height, mm.

RESULTS AND DISCUSSION

The first created chart shows the comparison of frequency of precipitation in each years of examined period on the locality Sereď. The both methodology have different criteria for choosing of erosive effective rainfalls.

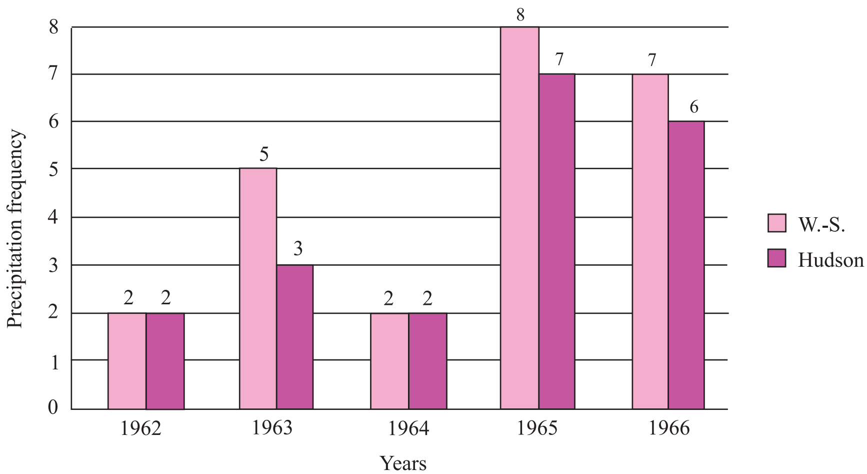

Fig. 2. Comparison of precipitation frequency according Wischmeier and Smith and Hudson, Sereď [1962–1966]

As we can see from created chart, in the years 1963, 1965 and 1966 there occurred the differences in precipitation frequency. In others examined years were number of erosive effective rainfall same for both methodology. According Hudson methodology is number of erosive effective rainfall lower than number of erosive effective rainfalls according Wischmeier and Smith methodology.

The Table 2 shows comparison of *R*-factor values, which was calculated with using both mentioned methodology i.e. Hudson and Wischmeier and Smith methodology for each year of examined period on Sereď locality.

Table 2. Comparison of annual and average

	$R_{\text{annual W.-S.}}$	$R_{\text{annual } KE > 1}$
1962	28.7243	18.3626
1963	32.3413	18.6151
1964	25.3072	18.3626
1965	83.3082	40.3854
1966	65.8864	59.4856
Average	47.1135	31.0423

On the base of calculation method was created following Figure 3, which illustrates comparison of average values of rain factor.

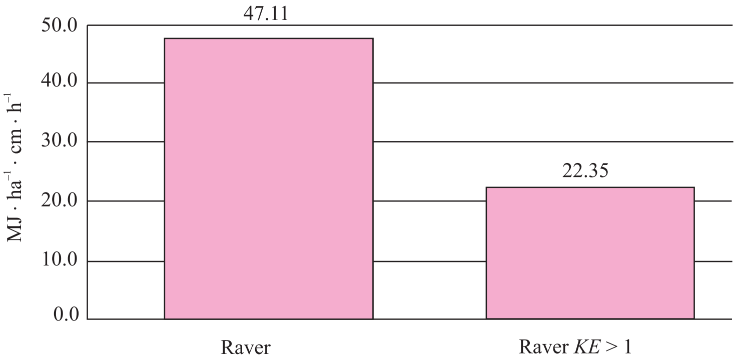

Fig. 3. Comparison of average rain factor values (Wischmeier and Smith and Hudson), Sereď [1962–1966]

As we can see from listed chart, the value, which was calculated according Wischmeier and Smith methodology for meteorological station Sereď for period 1962–1966 is more than 2-times higher than value calculated according Hudson methodology.

Consequently were created charts from obtained values about redistribution of rain factor for each months of vegetation period. This step was necessary because we want to know how different methods of rain factor calculation influenced its redistribution during the vegetation period.

Despite the fact, that values of redistribution of rain factor are different, the highest percentage fall on the same months of vegetation period i.e. on months June, July and August and the lowest on April (when no erosive effective rainfall was observed according both methodologies) and then on September and October.

On the base of listed equation were calculated rain factor and subsequently were created line of exceedance for 50 years, from which were deducted values of rain factor that occur once per 100, 50, 20, 10, 5 and 1 year. These calculated values were compared with values calculated according Wischmeier-Smith formulas. Following tables show calculated values according different methodologies for meteorological stations Myjava and Hurbanovo.

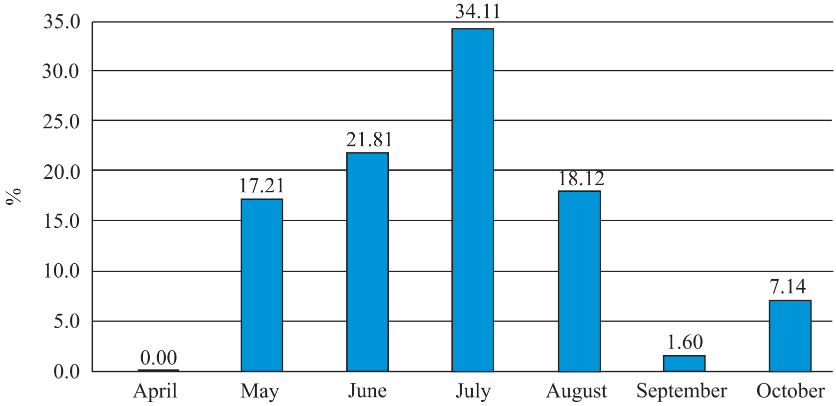

Fig. 4. Redistribution of rain factor according Wischmeier and Smith on the particular months of vegetation period, Sereď [1962–1966]

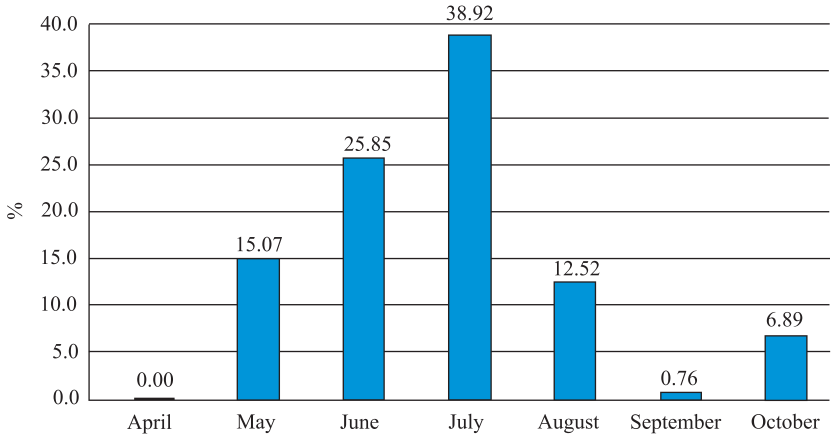

Fig. 5. Redistribution of rain factor according Hudson on the particular months of vegetation period, Sereď [1962–1966]

Table 3. Comparison of rain factor values calculated according different formulas, Myjava

Repetition probability %	1	5	10	20	50	100	Average
Precipitation occurence once per *N* years	100	50	20	10	5	1	
Zachar $MJ \cdot ha^{-1} \cdot cm \cdot h^{-1}$	2.11	49.40	51.63	53.53	55.00	57.19	45.46
Holý $MJ \cdot ha^{-1} \cdot cm \cdot h^{-1}$	36.34	53.61	55.84	57.73	59.19	61.39	49.67
Šabata $MJ \cdot ha^{-1} \cdot cm \cdot h^{-1}$	37.88	52.63	54.54	56.16	57.41	59.28	49.27
W.-S. $MJ \cdot ha^{-1} \cdot cm \cdot h^{-1}$	4.41	40.44	48.08	55.04	60.92	69.74	30.03

As we can see from Table 3, the values which were calculated according Wischmeier and Smith methodology and subtracted from line of exceedance of probability for locality Myjava are approaching to values which were calculated according equations which take into account the lack of data, despite the fact that rain factor calculation according Wischmeier and Smith was calculated only for 10 years period.

Table 4. Comparison of rain factor values calculated according different formulas, Hurbanovo

Repetition probability %	1	5	10	20	50	100	Average
Precipitation occurence once per *N* years	100	50	20	10	5	1	
Zachar $MJ \cdot ha^{-1} \cdot cm \cdot h^{-1}$	41.12	53.54	55.30	56.79	57.97	59.75	50.60
Holý $MJ \cdot ha^{-1} \cdot cm \cdot h^{-1}$	45.34	57.74	59.50	60.98	62.17	63.94	54.81
Šabata $MJ \cdot ha^{-1} \cdot cm \cdot h^{-1}$	45.58	56.17	57.67	58.93	59.94	61.46	53.66
W.-S. $MJ \cdot ha^{-1} \cdot cm \cdot h^{-1}$	0.68	72.68	95.37	117.02	136.27	165.14	48.16

For locality Hurbanovo was also created table (Table 4) with calculated values. On this locality is situation quite different as on the locality Myjava. Values which were subtracted from line of exceedance of probability for repetition time 100, 50, 20, 10, 5 and 1 year are very different. For example precipitation occurrence once per 100 years is value calculated according Wischmeier-Smith up to 67 times lower than values calculated according Zachar [1981], Holý [1978] and Šabata [1978]. But the situation is different when we look at average values of rain factor. The most is average value calculated according Wischmeier-Smith methodology (48,16 $MJ \cdot ha^{-1} \cdot cm \cdot h^{-1}$) approximate to average value of rain factor calculated according Zachar (50,60 $MJ \cdot ha^{-1} \cdot cm \cdot h^{-1}$).

CONCLUSION

Comparing the methodology of Hudson [1973] ($KE > 1$) and methodology of Wischemeier and Smith [1965], it was found out that the Hudson methodology used for the calculation and the calculated values of R-factor are almost 2-times lower than with using the methodology of Wischmeier and Smith. Also it was found out that aside from used methodology the redistribution of rain factor for individual months of vegetation period is the same. The mentioned fact has very important influence on prevention measures against erosion caused by rain, because especially in this period is soil endangered by erosion, so it is very important to design right anti-erosion measures. This fact point at re-evaluation of used methodology for calculation of rain factor in our conditions.

Comparison of equation which calculate only with annual precipitation with modified Wischmeier and Smith methodology brought conclusion that using of formulas which take into account only annual precipitation are proper only in rare cases because the values calculated according Zachar [1981], Holý [1978] and Šabata [1978] for localities Hurbanovo and Myjava were only in rare cases approaching to values calculated according Wischmeier and Smith modified methodology. We recommend using these formulas only in the case of lack of data because the final values are several times higher and therefore anti-erosion measurements designed according these results (formulas by Zachar, Holý and Šabata) are excessive and expensive. On the other hand in the case of lack of data could be these formulas useful.

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ANALIZY METOD OBLICZENIOWYCH OKREŚLAJACYCH EROZYJNOŚĆ DESZCZOWĄ DLA REPUBLIKI SŁOWACKIEJ

Streszczenie. Na podstawie danych uzyskanych ze Słowackiego Instytutu Hydrometeorologicznego przeprowadzono obliczenia współczynnika wydajności deszczu dla każdej stacji pomiaru opadów. Ze względu na to, że wszystkie dane miały formę cyfrową, przeprowadzono ich cyfrowe przetworzenie w środowisku graficznym Microsoft Excel, to znaczy każda z minut podczas wybranego deszczu była rozważana dla osobnego rozdziału deszczowego. Obliczone dane zostały porównane z wartościami podanymi przez Soil Science and Conservation Research Institute (SSCRI), a także z Metodologią wdrażania wyników badań do praktyki rolniczej. Z obliczonych wartości utworzono również linie przekroczeń prawdopodobieństwa, które dostarczają szczegółowych informacji o występowaniu obliczonych wartości współczynnika wydajności deszczu raz na 100, 50, 20, 10, 5 lat oraz 1 rok. Porównano także różne metodologie obliczeń tego współczynnika i energii kinetycznej deszczu oraz ich wpływ na końcowe wyniki. Obliczenia wykazały, że we wszystkich badanych lokalizacjach obliczone wartości były kilkakrotnie wyższe niż w wymienionych wcześniej publikacjach. Różnice mogą być spowodowane zarówno przez różne metody przetwarzania danych, jak i liczbę analizowanych lat, gdyż wartość współczynnika wydajności deszczu w wymienionych pracach była obliczana na podstawie mniejszej ilości lat. Obliczone dane posłużyły do redystrybucji wartości współczynnika wydajności deszczu w poszczególnych miesiącach wegetacji, co doprowadziło do stwierdzenia najwyższych procentowo opadów w miesiącach letnich (czerwiec, lipiec, sierpień), a z drugiej strony najniższego odsetka w miesiącach kwietniu i październiku, i dlatego konieczne jest zwrócenie uwagi na kontrolowanie erozji gleb szczególnie w miesiącach letnich. Porównanie różnych metod przetwarzania danych (cyfrowych kontra graficznych) wykazało, że różnice w końcowych wartościach współczynnika wydajności deszczu obliczonych odmiennymi metodami przetwarzania danych są minimalne i dlatego można przyjąć, że wykorzystana metodologia była właściwa. Relacje obliczeń energii kinetycznej i różnych metodologii także znacząco wpłynęły na ostateczne wartości współczynnika wydajności deszczu. Obliczenia te według różnych autorów wykazały, że wykorzystanie powiązań energii kinetycznej określonych przez Marshalla doprowadziło do uzyskania niższych wartości, co miało wpływ na końcową wartość współczynnika wydajności deszczowej, a więc jego wartości były ostatecznie bliższe tym ogłoszonym. Porównanie metodologii Hudsona ($KE > 1$) i Wischmeier-Smitha wykazało, że przy użyciu metodologii Hudsona wartość współczynnika wydajności deszczu jest prawie dwukrotnie wyższa niż ta, która była obliczona według metodologii Wischmeier-Smitha. Wykonano też obliczenia tego współczynnika, biorąc pod uwagę brak danych. Użyto powiązań wykazanych przez różnych autorów. Relacje te były liczone jedynie w oparciu o opady roczne. Wyniki badań wykazały, że końcowe wartości współczynnika wydajności deszczu są wielokrotnie wyższe niż obliczane na podstawie równań, na przykład wzoru Wischmeier-Smitha.

Słowa kluczowe: erozja, erozyjne opady rzeczywiste, współczynnik R, Wischmeier-Smith

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