Original paper

UPDATING THE DIGITAL LAYER OF R-FACTOR (USLE RAINFALL EROSIVITY FACTOR) FOR THE TERRITORY OF SLOVAKIA

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Abstract

The updated version of USLE erosion prediction model is still an indispensable tool to evaluate the water erosion for the needs of soil conservation due to its simplicity and relative availability of input parameters. The primary objective of this study was to improve the data on R-factor for the territory of Slovakia. This involved two tasks: a) updating the values of rainfall erosivity factor (R-factor) for individual automatic meteorological stations based on one-minute rainfall totals, b) generating the digital layer of R-factor spatial distribution across the entire territory of Slovakia. In 2009 the digital layer of R-factor was created for the USLE model presented on Soil Portal of VUPOP. The previous digital layer of R-factor was based on values calculated by Malíšek (1990, 1992). However, these values are not representative anymore as the medium-term and long-term temporal rainfall dynamics resulted in changing the rainfall means and their spatial distribution patterns during the last few decades. The new calculation of R-Factor was done using a rainfall database of 85 automatic rainfall stations provided by Slovak Hydrometeorological Institute. The resulting updated mean annual R-factor values ranging from 33,55 MJ.ha^{-1}.cm.h^{-1} (Malacky) to 160,91 MJ.ha^{-1}.cm.h^{-1} (Runina, Snina district) were used to generate a new digital layer of rain factor spatial distribution for the whole territory of Slovakia. This digital layer will be an essential input component for the USLE erosion prediction model. It will significantly improve the soil erosion rate estimates generated by USLE model in Slovakia and this will contribute to improving the background information used for supporting soil erosion assessment and soil conservation programs.

Keywords: R-factor (rainfall erosivity factor), spatial distribution of R-factor, USLE, soil erosion, Slovakia

INTRODUCTION

Soil erosion is currently one of the most important environmental problems with a direct impact on agriculture and the environment. The intensity of erosion-accumulation processes caused by water is accelerated if the inappropriate management of agricultural land is applied in an erosion-prone areas (Council of Europe 1972, Eckelmann *et al.* 2006).

Under the soil, climatic and geomorphological conditions of Central Europe soil erosion caused by water (sheet and rill erosion) prevails. Most erosion events result from high intensity and high energy rainfall events. Short-term intensive heavy rains are more harmful than the long-lasting area-wide precipitation with moderate intensities (Onderka *et al.* 2012).

In the year 2022, the land area of potential soil threat from water erosion was generated using the USLE erosion prediction model on area of agricultural land recorded in the GSAA register (the register is managed by the Agricultural Payment Agency). Potential erosion does not consider the protective effect of the current plant cover. Potential erosion area (moderate, high and extremely high endangered soil by potential water erosion) is 954 440.2 ha what represents 52.5 % of the total area of agricultural land. As for the current threat of water erosion to soil (current erosion also considers the protective effect of the

current plant cover), the land areas of the moderate high and extreme high erosion categories decreased to the value of 233 822.7 ha which represents 12.8% of the total area of agricultural land registered in the GSAA register (Kobza *et al*. 2024). This water erosion threat was estimated by an updated version of the USLE erosion prediction model introduced by (Wischmeier & Smith 1978).

In Slovakia, the soil conservation is traditionally based on USLE and although many new models were introduced in last decades, USLE is still preferred in agricultural practice because of its simplicity and availability of input data. Using USLE began in Slovakia in 1980s and early 1990s when basic guidelines and values of some major input parameters were published (Alena 1986, 1989a, b, 1990, 1991, Malíšek 1990a, b, 1991, 1992). The most important achievement at this stage was calculating the rain erosivity factor (R-factor) by Alena (1991) and Malíšek (1990a, b).

The next stage of development started in mid 1990s and peaked in early 2000s, under the EU project *Monitoring Agriculture with Remote Sensing and Environment Related Application* (MARS MERA) which was the first research project initiated by EU in Slovakia and neighboring countries. The GIS approach was introduced to process the values of USLE input parameters, and the erosion estimates for the whole territory of Slovakia ant the first maps of potential and actual soil erosion of Slovakia based on USLE were prepared (Fulajtár *et al.* 1996a, b). Later several updated versions were published (Šúri *et al*. 1997, 2001a, b, 2002a, b, c). The large resolution version of these maps is provided by Fulajtár *et al.* 2000a, b) in *Atlas pôd SR*, which is published in electronic form (maps equivalent to 1:200.000 scale, 100 m pixel resolution) and is available through Soil Portal on website of NPPC VUPOP (www.podnemapy.sk/portal/prave_menu/atlas_pod_sr/Atlas_pod_SR.pdf). The maps present a new concept of potential erosion (erosion rates referring to stable erosion factors and bare land with no vegetation) and actual erosion (reflecting all erosion factors including those which are dynamic such as vegetation, crop and soil conservation measures) and this differentiation enabled to highlight the importance of appropriate land management. These publications present gradual development of USLE application in Slovakia differencing especially in improving the input parameters (for example improving information of LS-factor obtained from improving digital models of terrain (DTM).

Another huge progress was achieved in second half of 2000s. A new layer of R-factor was created by Pálka & Styk (2005), using the values calculated by Malíšek (1990, 1992). Malíšek suggested to analyze the time series of rainfall totals with a length of at least 15 years (15–64 years). Updating the R-factor values in Slovak conditions requires working with the long-time series of data of rainfall totals from dense network of rain-measuring meteorological stations (Šúri *et al.* 2002). Malíšek manually processed the data on rainfall totals from 86 ombrographic stations. He used the information recorded in graphic form on ombrographic tapes. He calculated the rain erosivity factor values for all stations in accordance with approach developed by Wischmeier & Smith (1978). The interval of R-factor calculated values range from 5.46 to 37.87 $MJ.ha^{-1}.cm.hod^{-1}$.

This newly updated digital layer was based on soil texture of 17,000 soil profiles from the database of the General Soil Survey of Agricultural Land of Slovakia (Styk *et al*. 2008).

The important update of the prediction erosion model was done in 2009 (Styk & Pálka 2009). They used the following data sources when generated a digital layer of the spatial distribution of R-factor values:

- the layer of elevation, which was derived from the TIN of the SR digital relief model with a grid resolution of 25 × 25 m, which was calculated from contours with a height interval of 10 m from the SVM 50 digital layer;
- the layer of Climatic regions (Lapin *et al.* 2002) as well as Mean annual precipitations totals (Faško & Šťastný 2002) in vector data format, created from cartographic data from the Landscape atlas of the Slovak Republic (Hrnčiarová *et al*. 2002);
- the layer of rain ombrographic stations (86 stations) with R-factor data calculated by Malíšek (1990).

Based on this update an on-line application with detailed maps of erosion rates and USLE erosion factors was developed. It is an interactive tool uploaded on VUPOP website, which is accessible to farmers and agricultural enterprises. The stable erosion factors (R, K, S, and L) are presented as default values,

while the dynamic factor (C) could be selected by operator, so that the farmers could see how the erosion would change if they changed the crops.

The Slovak researchers were involved in European cooperation in erosion assessment using USLE. The R-factor data of Malíšek (1992) were provided for developing the map of R-factor in Europe (Panagos *et al.* 2015). Updated values of R-factor for 95 rain stations were published by Onderka & Pecho (2019). The length of the time series of rainfall totals used in their study varied from 14 years to 49 years between individual rain stations. The output from this work is point digital layer of actualized R-factor values for all hydrometeorological stations.

In recent period (since the last USLE update in 2009) the concern was rising about the representativeness of the R-factor data. The values calculated by Malíšek represent the period of 1971–1990 what is already somewhat obsolete, especially if considering the medium-term and long-term temporal rainfall dynamics. During the last 35 years the rainfall means, and their spatial distribution patterns certainly changed and if considering that the USLE is used especially to provide support for practical implementation of soil conservation, the need of periodical updating of R-factor data is obvious. Recently, a completely new layer of R-factor values was created at VUPOP using the rainfall data from Slovak Hydrometeorological Institute (SHI). SHI provided a database of one-minute rainfall totals for 98 automatic hydrometeorological stations. Some stations were excluded after database modifications, and a final dataset involves 85 automatic hydrometeorological stations. The primary objectives of this study were:

- Updating the values of rainfall erosivity factor (R-factor) for individual automatic meteorological stations based on one-minute rainfall totals
- Generating a digital layer of spatial distribution of updated R-factor values for the entire territory of Slovakia.

MATERIAL AND METHODS

1. Characteristics of the rainfall erosivity factor (R-factor)

The rain energy and its intensity in the specific local soil, climatic and geomorphological conditions have an important influence on formation and course of water erosion. The rainfall erosivity factor is defined as the product of the total energy of the rain and its maximum 30-minute intensity (Wischmeier & Smith 1978). Knowing the local values of the rain factor is essential for the assessment of the water erosion threat of agricultural land. The R-factor is one of the key elements (together with the factors of soil erodibility, relief, soil conserving effect of plants and soil management) forming the basic structure of the USLE erosion model.

The mountainous relief of Slovakia significantly affects the local climate variability which is also influenced by different ways of air flow either from the Atlantic Ocean or the Mediterranean Sea. Slovakia is divided into 17 climatic districts located in warm, moderately warm and cold regions of Slovakia (Lapin *et al.* 2002). Rainfall totals are increased with increasing altitude, on average about 50-60 mm for every 100 meters of altitude. The largest amount of precipitation (40% of the total annual amount) falls in summer (June to August), 25% in spring, 20% in autumn and the remaining 15% in winter (Onderka & Pecho 2019). The mean annual rainfall totals across the territory of Slovakia range from 500 mm in the Danube Lowland (the driest region of Slovakia) to 2 000 mm in the High Tatras (Faško & Šťastný 2002).

The recent climate changes are manifested by the changed ability of atmosphere to retain larger volumes of water vapor, which grow exponentially due to the increasing air temperature. It is the main cause of the increasing frequency and intensity of extreme precipitation events. In the last three decades an increase of extreme precipitation has been recorded. The short-term rainfall intensity (15-30 min) is often higher than the ability of the soil to effectively absorb the volume of water that falls during this time in the form of precipitation. Such torrential rainfall events in our climate conditions most often occur during the growing season from April to October (Alena 1986).

Onderka *et al.* (2019) evaluated the trend of erosive rain occurrence during the period from 1961 to 2009 at six selected sites. Their conclusions showed that erosive rain occurred on average 2.55 to 4.71

times per year in the monitored territories. The occurrence of all rainfall events (including non-erosive events) in the warm part of the year (April–October) increased in average by 16%, from 44 events in 1962 to 51 events in 2009.

The water erosion risk can occur if surface runoff is formed. The most common causes of surface runoff are following:

- The entire soil profile is completely saturated with rainwater and the soil is no longer able to absorb infiltrating rainwater
- The rainfall intensity exceeds the soil permeability

2. Selecting rainfall with the potential to cause surface runoff

Not every rainfall event has a harmful effect on soil because not every rain has erosion potential. Rainfall events with a high intensity (so-called torrential rains) during which the formation of surface runoff occurs are necessary to initiate water erosion. Various authors have similar opinion on the limit values of the threshold intensity and amount of precipitation, when the formation of surface runoff begins, and water erosion processes start. Wischmeier & Smith (1978) consider as erosion efficient rains those rains, which have their rainfall totals higher than 12.5 mm and the maximum intensity (in at least one time section) exceeding 24 mm per hour. Individual rain must be separated from each other by a break of 6 or more hours. Hrnčiarová (2001) and Janeček *et al.* (2012) reported similar threshold values for erosive efficient rain (rainfall total higher than 12.5 mm, maximum intensity of precipitation in at least one time section exceeding 25 mm per hour). Renard *et al.* (1997), Ganasri. & Ramesh. (2016) in their RUSLE handbook for erosive rain considers the rain with total amount exceeds 12.7 mm and their highest 15-minute intensity exceeds 24.13 mm per hour. Erosive rain in the soil-climatic and geomorphological conditions of Slovakia is considered a rainfall event equal to or greater than 30 mm i.e. 30 liters of precipitation falling on 1 m^2 per 1 hour (Jambor & Ilavská 1998). Low intensity rains, in which small drops with low kinetic energy predominate, almost never cause erosion.

Formation of surface runoff begins on the basis of difference between the intensity of rain and its infiltration into the soil profile (Fulajtár & Janský 2001). Only a certain part of the rain (so-called the efficient rain episode) is the main cause of the surface runoff formation and erosion processes follow if the runoff mobilizes detached soil particles (Alena 1986, Antal 2005).

To identify the erosive efficient rains in order to calculate the values of rainfall erosivity factor the method defined by Wischmeier & Smith (1978) was used. We have worked with the dataset of information provided to us by the Slovak Hydrometeorological Institute (SHI) in 2020. SHMI provided data of one-minute rainfall totals. to generate the digital layer of potential water erosion distribution on agricultural soils for Report on the state of implementation of the Council directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources in the Slovak Republic (Cibulka *et al.* 2020). Specifically, it is a database of one-minute rainfall totals for a period of 10 years and more from 98 automatic hydrometeorological stations located throughout Slovakia. Belasri & Lakhouili (2016) also used 10-year time period to calculate the R-factor in their work.

Our objective was to obtain data from a longer time period (data time series of at least 15-30 years), but it is not possible because we processed data from automatic hydrometeorological stations which came into operation only in the last decade. The database contains data on one-minute rainfall totals. We define erosive efficient rains based on the selection of the obtained data in accordance with the conditions of the USLE erosion prediction model. Individual rains must be separated from each other by a time interval at least 6 hours or more. If this condition does not apply, it is taken as one continuous rain.

Rain is classified as erosive efficient when it meets the following criteria (in accordance with the methodology of Wischmeier & Smith 1978):

a) the threshold value of rainfall total has to be 12.5 mm or more;
b) the intensity of precipitation in at least one precipitation section must be more than 24 mm. $hour^{-1}$ (or 6.00 mm per 15 min, or 0.40 mm per 1 min).

For the calculation of R-factor values we used only these erosion efficient rains.

3. Methodology for calculating updated values of the rainfall erosivity factor

When we compared rainfall totals recorded at automatic rain stations with the rainfall totals recorded at manual rain stations, we found significant disagreements. Some automatic rain stations recorded rainfall totals even when no precipitation was observed. From this point of view the first necessary step was to do the selection of real rainfall from all obtained data. We had at disposal a 1-hour data from manual stations for the purpose of comparing the rainfall totals of automatic and manual rain stations. It was necessary to recalculate the 1-minute rainfall data from automatic stations to 1-hour data. We had 1-hour rainfall totals from manual stations for 85 stations only. For this purpose, we had to completely remove those automatic stations which did not have data from manual records. From the original number of 98 automatic stations, after selection, we processed data only from 85 automatic hydrometeorological stations.

In accordance with the method of Wischmeier & Smith (1978) it was necessary to define erosion efficient rains. We calculated the value of the R-factor for each erosive efficient rain that was recorded within individual automatic rain stations during the whole monitored period. The total sum of all calculated R-factor values for erosive rains for a time period of one year expresses annual value of the rain factor for an individual automatic rain station. The mean long-term annual value of the R-factor is a total sum of all its annual values for the monitored period dividing by the number of monitoring years.

This method appears to be the most appropriate for the specific soil-climatic and geomorphological conditions of Slovakia. Malíšek (1990, 1992), Janeček *et al.* (2012), Manderková *et al.* (2012), Antal *et al.* (2015) and Onderka & Pecho (2019) also applied the same method for calculating rain factor values in their studies.

The R-factor for a specific erosive efficient rain is defined by its total kinetic energy and its maximum 30-minute rainfall intensity:

$$\mathbf{R = E_{tot}\, I_{30}/100}$$

where:

R – rainfall erosivity factor [MJ ha^{-1} cm h^{-1}]

E_{tot} – total kinetic energy of rain [J m^{-2}]

I_{30} – maximum 30-minute intensity of rain [cm h^{-1}]

The annual value of the R-factor (for a specific hydrometeorological station) is the sum of R-factors values representing the individual erosive rains in a given year:

$$\mathbf{R_{year} = \sum_{1}^{n} \left(R_1 + R_2 + \ldots + R_n \right)}$$

R_{year} – annual R-factor value [MJ ha^{-1} cm h^{-1}]

n – the number of erosive rains in a given year

Σ – sum of R-factor values of individual erosion rains in a given year

R_1–R_n – R-factor values of individual rains

The long-term mean annual value of R-factor for the monitored period at a specific rain station is the sum of the annual values of the R-factor divided by the number of monitoring years:

$$\mathbf{R_{average} = \frac{\sum_{1}^{N} R_{year}}{N}}$$

$R_{average}$ – mean long-term annual value of R-factor for the monitored period

N – number of monitored years

Σ – sum of annual R-factor values

The total kinetic energy of an erosive rain is the sum of all kinetic energies of individual segments of the rain:

$$\mathbf{E_{tot} = \sum_{i=1}^{n} E_i} \qquad [J.m^{-2}]$$

E_{tot} – total kinetic energy of rain
E_i – kinetic energy of the i^{th} rain segment [$J.m^{-2}$]
n – the number of rain segments

The kinetic energy of the i^{th} rain segment:

$$\mathbf{E = (206 + 87\ Log\ I_S).\ H_S}$$

E_i – kinetic energy of the i^{th} rain segment [$J.m^{-2}$]
I_s – the intensity of the i^{th} segment of the rain [$cm.h^{-1}$]
H_s – total height of the i^{th} rain segment [cm]
I_{30} – maximum 30-minute rain intensity:

We did not divide erosive rains into individual rain segments because we work with one-minute rainfall records. We calculated rain kinetic energies using the intensities of the one-minute rain intervals. The total amount of kinetic energy for the entire studied rain is obtained by summing the kinetic energies of these one-minute rain intervals. To find out the maximum 30-minute intensity we proceeded in accordance with the method of Manderková *et al.* (2012). We calculated the sums of intensities achieved in all possible rain intervals starting from 1 min - 31 min interval and continuing with 2 min - 32 min interval, 3 min - 33 min, etc., until the end of the rainfall. Then we selected the interval with greatest maximum 30-minute intensity and this value was used to calculate the values of R-factor employing the equation:

$$\mathbf{R = E_{tot}\ I_{30}}$$

This method was applied also by Manderková *et al.* (2012), Janeček *et al.* (2012), Antal *et al.* (2015), and Onderka & Pecho (2019).

We applied this method for calculating specific values of R-factor for all defined erosive efficient rains during the entire monitored period for all automatic hydrometeorological stations.

In the final phase of this study each rain station will be characterized by the average value of the R-factor for the entire monitored period. This method of calculating the R-factor values is more precise than calculating them from the traditional ombrographic records in graphic form because the inaccuracy arising during the creation of rain segments is eliminated.

4. Generating a digital layer of R-factor

In 2020 we partially started to generate the digital layer of the spatial distribution of updated R-factor values in Slovakia with the aim to create a map of distribution of soils affected by potential water erosion. It was prepared for the Report on state of implementation of the Council directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources in Slovakia (Cibulka *et al.* 2020), which was required for EU agricultural subsidies.

The review on vulnerable areas of surface waters was based on the assessment of the risks of agricultural activities affecting the quality and status of surface water. The geographic digital layer of information on production land blocks (LPIS register) as well as the GIS layer of potential water erosion served as a background material.

The final task of this study was generating a digital layer of the spatial distribution of the R-factor values for the entire territory of Slovakia based on its updated values. We used a vector layers of annual precipitation totals (Faško & Šťastný 2002) as well as climatic regions of Slovakia (Lapin *et al.* 2002) as the map basis for creating of the digital layer of R-factor spatial distribution.

RESULTS AND DISCUSSION

The completion and harmonization of the database of all data on one-minute rainfall totals from automatic hydrometeorological stations located throughout Slovakia was the first step to solve the problem of updating the rain factor values. The initial database of one-minute rainfall totals represented a huge amount of data obtained from all automatic stations (almost 490 million records) during the time period since they were put into operation (approximately 10 years or more).

When processing information from the database we found out that a significant number of automatic stations recorded rainfall totals even when no rainfall was observed. For that reason, SHMI provided data on hourly totals from manual rain hydrometeorological stations. We noted significant differences by comparing the minute rainfall totals measured at automatic stations with the hourly totals measured at manual rain stations. We removed the erroneous records from the database and for this reason some automatic stations were completely removed from the R-factor calculations. The original dataset of 98 automatic stations was reduced to 85 stations (Fig. 1) and the final number of records was reduced to 439 million (Tab. 1).

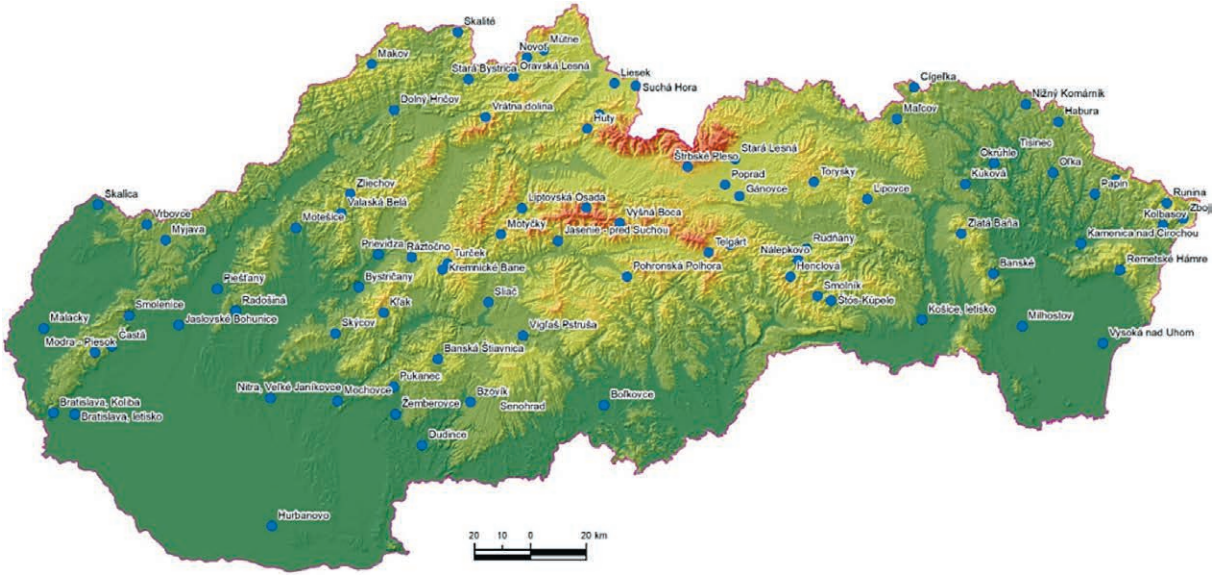

Figure 1 Distribution of 85 rain stations selected for R-factor calculation

We defined erosion efficient rainfall events in accordance with the methodology of Wischmeier & Smith (1978) by selecting the obtained input data of 1-minute annual rainfall totals (not only precipitation in the growing season). Rainfall was classified as erosion efficient when these two requirements were fulfilled: its total amount had to be 12.5 mm or more, and its intensity in at least one time section must be more than 24 mm hour^{-1} (or 6.00 mm in 15 min, or 0.40 mm in 1 min). Individual rains had to be separated from each other by at least a 6-hour time interval.

The occurrence of erosive efficient rains indicates a certain correlation with relief and altitude. We recorded a higher occurrence of erosive efficient rains in mountain and sub-mountainous areas rich in rainfall, and on the contrary, their occurrence was lower in drier areas in the lowlands (Fig. 2). A summary statistics of erosion efficient rainfall distribution is presented in the Tab. 1.

The maximum 30-minute rainfall intensity (I_{30}) was defined in accordance with the method proposed by Manderková *et al.* (2012). We obtained a set of values for individual automatic rain stations. These values entered to the equation for calculating the R-factor. Values of the total kinetic energy of erosive rainfall (E_{tot}) were calculated by counting all the kinetic energies of individual segments of the rainfall measured at a specific rain station. An overview of the average values of the R-factor for individual hydrometeorological stations is presented in Table 1. The values of the R-factor are positively correlated

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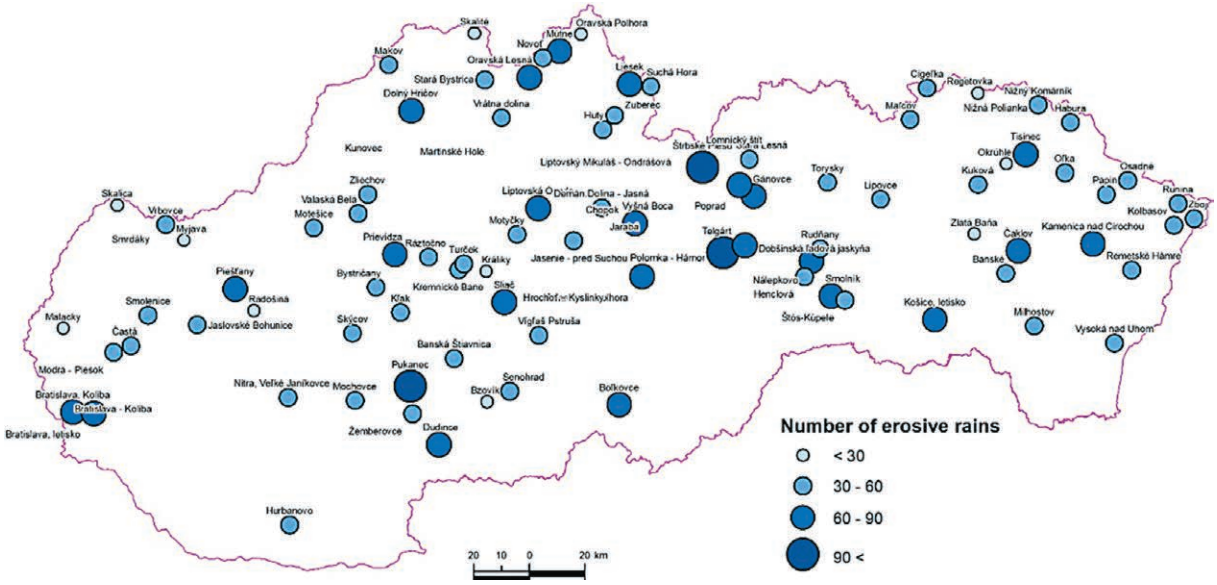

Figure 2 Numbers of defined erosion efficient rains (for the monitored period) within individual SHMI automatic precipitation measuring stations

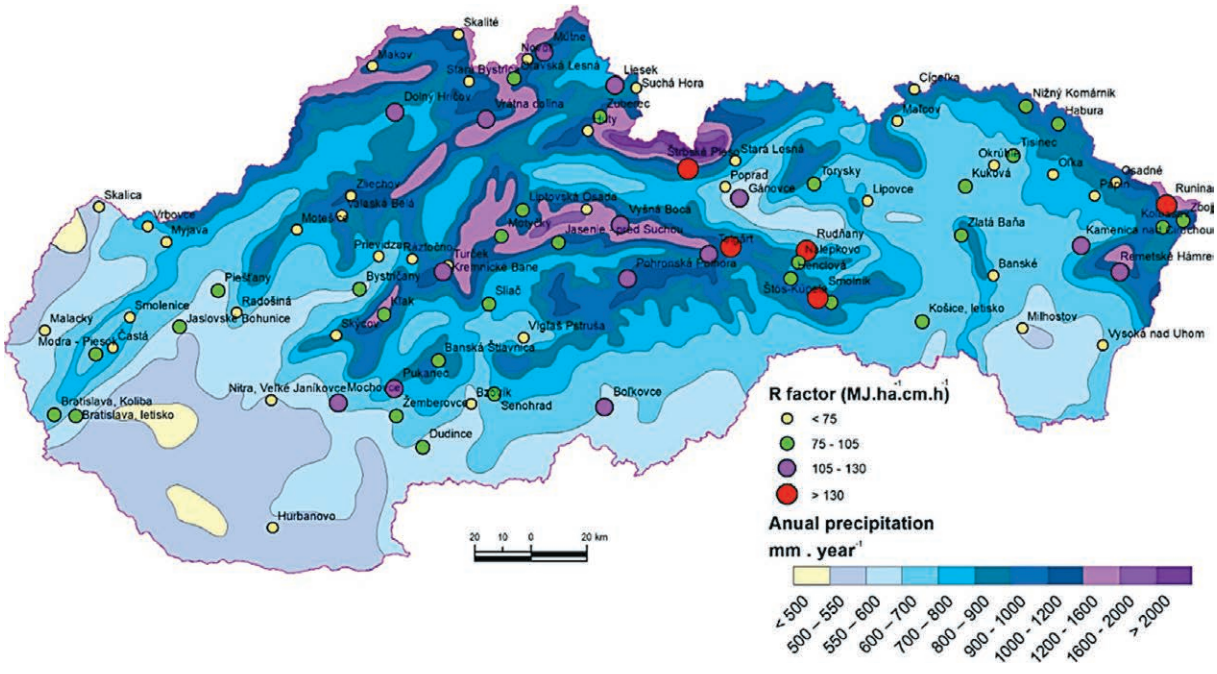

Figure 3 Point values of updated R-factor for SHMI automatic stations on a digital layer of mean annual rainfall totals (Faško & Šťastný 2002)

with the distribution of erosion efficient rainfalls as well as with the volume of average annual precipitation totals (Fig. 3).

Table 1
Updated values of the R-factor for SHMI automatic hydrometeorological stations

Number	Name of automatic meteorological station	Number of minutes records	Number of monitored years	Number of erosive rains	Maximum total for one rain (mm)	Mean R-factor value (MJ.ha^{-1}.cm.h^{-1})
1	Bratislava – Koliba	6 298 638	11	61	61.6	91.94
2	Bratislava – letisko	6 105 330	11	61	71.9	87.87
3	Jaslovské Bohunice	5 073 654	9	45	82.2	78.33
4	Piešťany	5 833 348	11	75	64.7	89.06
5	Dolný Hričov	6 167 040	11	82	110.6	106.67
6	Nitra – Veľké Janíkovce	6 270 481	11	49	67.9	49.82
7	Mochovce	6 233 186	7	52	82.8	99.12
8	Hurbanovo	6 288 032	11	59	106.1	67.52
9	Prievidza	6 235 696	11	73	58.8	67.59
10	Dudince	6 233 404	11	78	65.4	93.29
11	Sliač	5 035 985	9	62	72	99.55
12	Liesek	6 235 325	11	86	69.3	107.64
13	Boľkovce	6 261 656	10	67	76.4	109.18
14	Štrbské Pleso	6 189 557	11	122	115.1	135.05
15	Poprad	6 304 157	11	61	57.5	63.14
16	Telgárt	5 007 784	9	93	79	123.03
17	Gánovce	6 287 106	11	84	84.8	123.90
18	Košice – letisko	6 274 765	11	73	70.6	90.62
19	Tisinec	6 259 154	11	72	54.5	84.56
20	Milhostov	6 294 799	11	56	42.6	52.42
21	Kamenica nad Cirochou	6 257 787	11	89	64.3	105.33
2	Stará Lesná	5 250 254	8	31	54.62	56.33
23	Skalica	5 768 538	10	25	52.96	53.44
24	Myjava	4 313 496	8	25	54.4	59.27
25	Vrbovce	5 667 790	11	33	44.9	53.02
26	Malacky	4 266 362	7	15	46.56	33.55
27	Modra – Piesok	4 778 844	10	43	90.55	86.63
28	Smolenice	5 131 803	10	41	40.64	70.58
29	Častá	5 817 079	11	35	57.4	68.83
30	Vyšná Boca	5 525 484	11	64	72.39	106.94
31	Demänovská dolina – Jasná	3 980 287	9	45	69.87	63.97
32	Huty	5 387 935	9	46	63.66	71.45
33	Liptovská Osada	5 205 240	11	64	59.52	85.90
34	Oravská Lesná	5 439 104	11	83	97.79	87.26
35	Novoť	4 138 035	9	38	66.71	46.11
36	Mútne	4 713 801	9	80	91.71	129.29

Number	Name of automatic meteorological station	Number of minutes records	Number of monitored years	Number of erosive rains	Maximum total for one rain (mm)	Mean R-factor value (MJ.ha^{-1}.cm.h^{-1})
37	Suchá Hora	5 710 137	11	44	49.24	53.87
38	Zuberec	5 041 823	11	51	55.25	81.86
39	Turček	5 069 143	11	41	46.89	66.58
40	Vrátna dolina	3 954 732	10	58	131.59	105.93
41	Makov	4 872 447	11	43	53.16	49.21
42	Skalité	3 709 758	7	27	56.72	56.64
43	Stará Bystrica	5 878 791	11	46	94	73.61
44	Ráztočno	4 344 940	10	40	49.63	65.72
45	Bystričany	5 547 927	11	56	51.45	88.75
46	Valaská Belá	5 107 576	11	42	52.67	57.22
47	Zliechov	3 344 465	8	31	41.53	52.72
48	Motešice	5 341 785	11	40	40.8	50.28
49	Radošiná	4 721 372	10	26	75.59	63.64
50	Skýcov	5 863 407	11	48	39.72	68.70
51	Pohronská Polhora	5 286 673	11	64	99	128.77
52	Jasenie - pred Suchou	5 480 150	10	60	38.61	79.91
53	Motyčky	4 923 332	11	59	44.67	95.44
54	Vígľaš Pstruša	4 305 364	9	35	56.97	53.48
55	Kremnické Bane	3 575 792	7	43	64.48	113.65
56	Kľak	4 341 717	8	50	110.74	99.82
57	Pukanec	5 721 106	10	92	105.66	124.16
58	Žemberovce	5 240 720	9	43	94.91	90.96
59	Bzovík	4 531 816	9	29	50.18	60.51
60	Senohrad	5 431 611	11	47	46.49	80.27
61	Banská Štiavnica	5 536 247	11	56	59.79	84.65
62	Habura	4 953 573	11	44	61.59	79.40
63	Osadné	3 806 222	8	31	39.34	64.94
64	Papin	5 507 829	11	45	89.44	59.88
65	Runina	4 946 180	10	57	104.61	160.91
66	Kolbasov	5 499 309	11	57	38.65	84.15
67	Zboj	5 192 971	10	40	88.7	76.56
68	Vysoká nad Uhom	4 225 499	7	43	38.69	52.66
69	Remetské Hámre	5 492 887	11	50	146.97	112.06
70	Nižný Komárnik	5 210 830	11	54	62.36	93.84
71	Oľka	4 226 831	10	34	37.2	46.16
72	Maľcov	5 637 924	11	36	53.78	42.77
73	Cígeľka	5 502 567	10	40	52.34	60.12
74	Kuková	3 613 082	8	34	55.7	83.94

Number	Name of automatic meteorological station	Number of minutes records	Number of monitored years	Number of erosive rains	Maximum total for one rain (mm)	Mean R-factor value (MJ.ha^{-1}.cm.h^{-1})
75	Okrúhle	3 930 909	9	30	52.64	52.81
76	Banské	5 542 450	11	35	51.71	40.73
77	Štós-Kúpele	4 567 843	11	57	50.48	97.41
78	Rudňany	4 398 344	10	45	78.2	140.49
79	Dobšinská ľadová jaskyňa	5 552 370	11	77	72.58	148.08
80	Nálepkovo	4 437 889	10	61	127.53	104.69
81	Henclová	3 382 157	7	40	46.7	103.40
82	Smolník	5 212 897	11	84	74.54	144.96
83	Lipovce	4 877 211	10	40	85.23	63.00
84	Torysky	5 225 497	11	45	65.29	90.57
85	Zlatá Baňa	2 559 431	9	30	86.97	75.46
		438 916 469			Average Min. Max. Median St. dev	88.26 33.55 160.91 80.27 27.52

The updated long-term mean annual R-factor values range from 33.55 MJ.ha^{-1}.cm.h^{-1} at Malacky station in southwest Slovakia to 160.91 MJ.ha^{-1}.cm.h^{-1} at Runina station (Snina district) in northeast Slovakia. The average R-factor value is 88.26 MJ.ha^{-1}.cm.h^{-1} and the median value is 80.27 MJ.ha^{-1}.cm.h^{-1} (Tab. 1). The R-factor values fluctuate in a wide range over the entire territory of Slovakia, however in mountainous areas with a significant amount of precipitation in the form of snow the calculated R-factor is exaggerated because the whole amounts of precipitation were taken into account in this study. The mean R-factor value of the area of agricultural land of Slovakia (in accordance with the LPIS register), is much lower (62.10 MJ.ha^{-1}.cm.h^{-1}) and the median value is 64.00 MJ.ha^{-1}. cm.h^{-1}. This is because the highest elevated areas with the highest sums of precipitation and highest proportion of high energy rainfall are occupied by forests.

The values of the R-factor calculated in this work are in some cases several times higher than the values published in the earlier works of Malíšek (1990, 1992). His calculated annual averages R-factor values range from 5.46 to 37.87 MJ.ha^{-1}.cm.h^{-1} with a mean value of 20.7 MJ.ha^{-1}.cm.h^{-1}.

Janeček *et al.* (2012) published in their work that in mountainous areas of Czech Republic, where the proportion of agricultural land is very low, the R-factor values range from 60 to 120 MJ.ha^{-1}. cm.h^{-1}. The average annual value of the rain factor on the area of agricultural land, is in the range of 30–45 MJ.ha^{-1}.cm.h^{-1} what fits well with our results because in Slovakia agricultural land is situated also in more elevated areas as grassland is abundant is many mountainous areas of Slovakia so R-factor in agricultural land is expected to be higher in Slovakia than in Czech Republic.

Onderka & Pecho (2019) published similar values of the rain factor for 95 rain gauge stations located on the territory of Slovakia. The median value of the R-factor within the entire territory of the Slovak Republic is 71.13 MJ.ha^{-1}.cm.h^{-1} (min – 34.8 MJ.ha^{-1}.cm.h^{-1}, max – 138.3 MJ.ha^{-1}.cm.h^{-1}). Their calculated values are significantly correlated with our R-factor values for individual automatic SHMI stations. The spatial distribution of R-factor is presented in their work.

According to the study R-factor distribution in European Union and Switzerland done by the European Soil Data Center (ESDAC) the R factor values in Slovakia range from 33 to 111 MJ.ha^{-1}.cm.h^{-1} (Panagos *et al.* 2015). From the Global Rainfall Erosivity Database (GloREDa) (Panagos *et al.* 2017), the R-factor values for the territory of the Slovakia reach 40 to 90 MJ.ha^{-1}.cm.h^{-1}.

Finally, we generated a digital layer of R-factor distribution over the entire territory of Slovakia (Fig. 4). We converted it into a map where each automatic rain station is represented by one value. In the areas between these stations, we supplemented the missing values by points with R-factor values similar to the nearest meteorological station to increase the grid density. These supplement points were added as centroids of a regular square grid of 10 km. The final digital layer of R-factor spatial distribution in the entire territory of Slovakia was generated from the obtained point data using the spline geoprocessing tool with barriers.

When we defined individual polygons having similar values of the R-factor we considered as a barrier to their area distribution of the following digital layers:

- average annual rainfall totals (Faško & Šťastný 2002),
- climatic regions (Lapin *et al.* 2002)
- natural heterogeneity of the SR relief (DTM, grid 5 meters).

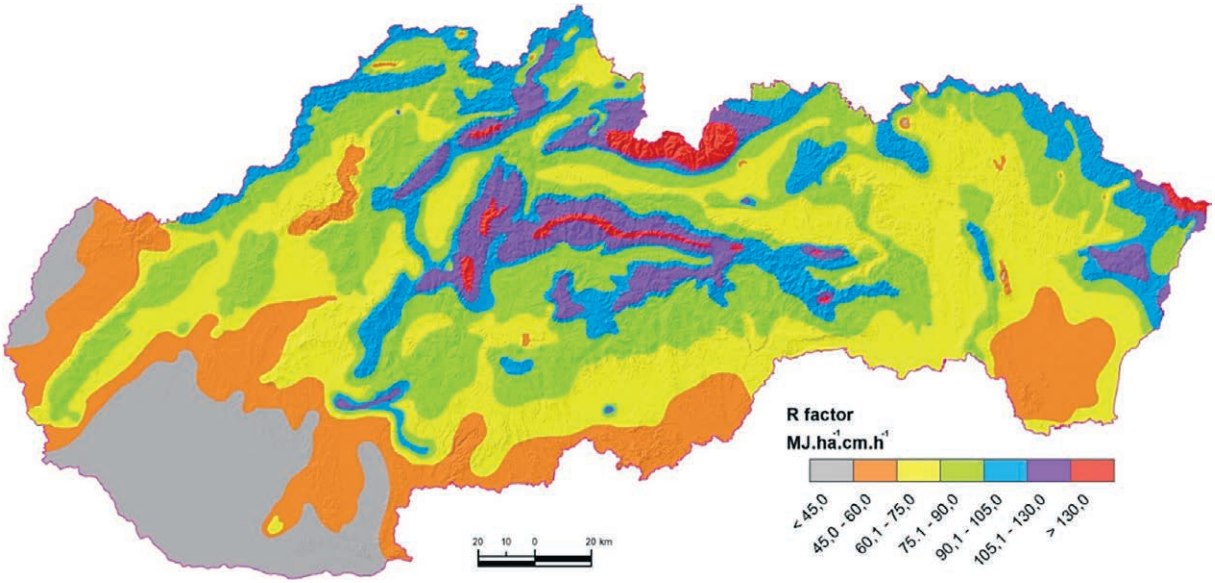

Figure 4 Digital layer of R-factor spatial distribution in Slovakia, on the resulting digital layer, we have distinguished 7 categories <45.0; 45 – 60; 60 – 75; 75 – 90; 90 – 105; 105 – 130; >130 MJ.ha^{-1}.cm.h^{-1}.

Comparison of obtained results to the R-factor values presented in earlier studies in Slovakia and at regional and global level

Janeček *et al.* (2012), Manderková *et al.* (2012), Antal *et al.* (2015), Onderka & Pecho (2019) and many other authors used a similar method for calculating the R-factor values. We compared our results with the R-factor values at the regional and global level (Janeček *et al.* 2012, Onderka & Pecho 2019, Panagos *et al.* 2015, 2017).

Our results are in some cases several times higher than the values published by Malíšek (1990, 1992). These values are close to the values calculated for Slovakia by Onderka & Pecho (2019), and for Czech Republic by Janeček *et al.* (2012) as well as at for the European Union and World by (Panagos *et al.* 2015, 2017).

Janeček *et al.* (2012) published the updated R-factor values as well as its spatial distribution in the entire territory of Czech Republic. These values are more than 2 times higher than the values were used in Czech Republic in the past. Onderka & Pecho (2019) also published similar rain factor values for 95 meteorological stations in Slovakia (including the map with point values).

We have selected data from the European digital layer as well as from the global digital layer (Panagos *et al.* 2015, 2017) for the territory of Slovakia with aim of verification and comparison of the currently

calculated R-factor values (Styk, Pálka 2022). These digital layers are freely available on the ESDAC (European Soil Data Centre) website. For the European Union (including Switzerland) this data is available with a grid resolution of 500 m. The global R-factor layer for the whole world is on a scale of about 1 km.

CONCLUSIONS

The digital layer of the R-factor spatial distribution is a key input for the USLE erosion prediction model, which is still commonly used as a key tool for most soil conservation activities. Therefore, significant attention was paid to determine R-factor values in Slovakia. Nevertheless, this parameter still needs attention because of some methodological shortcomings of earlier studies and also because of medium-term and long-term dynamics of rainfall requiring periodic auditing of R-factor values. This study made a key contribution to updating the R-factor values.

The updated R-factor values were calculated from rainfall data provided by Slovak Hydrometeorological Institute. The calculated long-term mean annual values of the R-factor range from 33.55 MJ.ha^{-1}.cm.h^{-1} (Malacky, southwest Slovakia to 160.91 MJ.ha^{-1}.cm.h^{-1} (Runina, Snina district, northeast Slovakia with an average value of 88.26 MJ.ha^{-1}.cm.h^{-1} and a median of 80.27 MJ.ha^{-1}.cm.h^{-1}. The highest values occur mostly in mountains and represent forested areas. For agricultural land the average value is 62.10 MJ.ha^{-1}.cm.h^{-1} and the median is 64.00 MJ.ha^{-1}. cm.h^{1}.

We generated a digital layer expressing the R-factor distribution in Slovakia from the calculated R-factor values of the rain factor using the spline geoprocessing tool with barriers (average annual rainfall totals, climatic regions).

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