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Rainfall erosivity in Slovenia: Sensitivity estimation and trend detection

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ABSTRACT

Slovenia is one of the EU countries with the largest values and largest amounts of variability in rainfall erosivity, with maximum annual values exceeding 10,000 MJ mm ha^{-1} h^{-1} yr^{-1}. Five-minute rainfall data was analysed from 10 Slovenian rainfall stations with data-length availability longer than 25 years with a maximum data length of 69 years and a total data-station length equal to 443 years. Trends in the rainfall erosivity *R*-factor were detected for four different sub-samples using monthly, half-year, and annual rainfall erosivity values. The results indicate that rainfall erosivity trends for the selected Slovenian stations are mostly statistically insignificant, with the selected significance level of 0.05. However, a larger share of identified trends are positive than negative. The maximum annual rainfall erosivity values were obtained for one specific mountain station. Furthermore, a sensitivity analysis regarding the rainfall erosivity factor *R* calculation showed that the rainfall threshold parameter (12.7 mm) that is used to remove the small-magnitude rainfall events in order to reduce the computational burden can attribute up to 10% of the average annual *R*-values in cases where this threshold is not used. Other parameters have, on average, a smaller impact on the calculated rainfall erosivity. Furthermore, the application of local kinetic energy equations resulted in, on average, about 20% higher annual rainfall erosivity values compared to the equation that is proposed by the Revised Universal Soil Loss Equation (RUSLE) manual and was not developed specifically for this region.

1. Introduction

As soil erosion is one of modern agriculture's major challenges, rainfall erosivity as one of its parameters plays an important role in estimating and modelling both soil erosion and its overall impacts on society and the environment. The increased interest in rainfall erosivity studies and increased global research is inter alia attested by the number of research papers published; the number of papers indexed in the Web of Science under the topic “rainfall erosivity” grew from less than a few papers a year in 1980's and 1990's to over 50 papers a year in the last few years.

The most widely used soil erosion models around the world (especially at large spatial scales (Panagos et al., 2014, 2016a)) are the Universal Soil Loss Equation (USLE; Wischmeier and Smith, 1978) and the Revised Universal Soil Loss Equation (RUSLE; Renard et al., 1997); the modern definition of rainfall erosivity began with the development of USLE (Nearing et al., 2017). The two models correlate the estimated quantitative value of soil loss per unit area (*A*) as the interaction among rainfall erosivity and runoff (*R*), soil erodibility (*K*), slope length (*L*) and slope steepness (*S*), land cover (*C*), and protective measures (*P*). The rainfall erosivity factor is one of the most frequently studied parameters among a set of RUSLE parameters (e.g. Panagos et al., 2017a, 2017b). Moreover, this parameter is often characterised by high spatial and temporal variability (e.g. Panagos et al., 2016a, 2017b), which makes it interesting to investigate, since it can have significant impact on the soil erosion rates. High-quality and high-frequency precipitation data is needed to accurately estimate the *R*-factor (e.g. Petan et al., 2010). While many authors have tried to determine *R* for various time resolutions with the intention of modelling the rainfall erosivity factor for areas with insufficient rainfall records (Angulo-Martínez and Beguería, 2009; Borrelli et al., 2016; Hernando and Romana, 2016; Renard and Freimund, 1994; Yin et al., 2015), studies spanning across countries and regions often struggle to use the uniform time step of rainfall data and long-time series (Ballabio et al., 2017; Panagos et al., 2015a). However, in the past decade a few studies have also investigated rainfall erosivity at larger spatial scales (e.g. Panagos et al., 2017a, 2017b).

In Europe the highest values of the *R*-factor are characteristic of the Mediterranean and alpine regions (Panagos et al., 2017a). Studies have classified Slovenia and its western areas as one of the most rainfall erosive areas in Europe and even worldwide (Borrelli et al., 2016; Panagos et al., 2015b). Previous studies saw the average values for *R*-factor estimated at above 2000 MJ mm $ha^{-1}h^{-1}yr^{-1}$ in the north of

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Slovenia (Mikoš et al., 2006). The average value of rainfall erosivity was estimated at 3393 MJ mm $\text{ha}^{-1}\text{h}^{-1}\text{yr}^{-1}$ by Petan (2010), with values over 10,000 MJ mm $\text{ha}^{-1}\text{h}^{-1}\text{yr}^{-1}$ in the Julian Alps, and the average value of *R*-factor dropping below 2000 MJ mm $\text{ha}^{-1}\text{h}^{-1}\text{yr}^{-1}$ in the northeast of the country (Bezak et al., 2015). This means that local lower rainfall erosivity values (below 2000 MJ mm $\text{ha}^{-1}\text{h}^{-1}\text{yr}^{-1}$) that are characteristic for the Slovenia northeast lead to lower average rainfall erosivity despite some local extremes. Soil loss in Slovenia is also an important environmental issue, as Slovenia is one of the EU countries with the highest local rainfall erosivity values (Panagos et al., 2017a). While the high values of the *R*-factor are correlated with areas of predominately frequent convective precipitation, Panagos et al. (2015b) concluded that the value of the *R*-factor is correlated with geographical latitude, precipitation seasonality, and altitude. Moreover, the high local *R*-values that were detected in Slovenia are also relatively high on a global scale, where values above 7000 MJ mm $\text{ha}^{-1}\text{h}^{-1}\text{yr}^{-1}$ are characteristic of mostly tropical areas (Panagos et al., 2017b). On the other hand, for temperate climates the mean *R*-value is about 3700 MJ mm $\text{ha}^{-1}\text{h}^{-1}\text{yr}^{-1}$ (Panagos et al., 2017b), which is relatively similar to the mean *R* annual value in Slovenia, which is predominantly covered by a temperate climate (Ogrin, 1996; Petan, 2010).

Studies investigating trends in rainfall erosivity are rare because high-frequency data, which are needed to estimate the *R*-factor, are only available for the past 10 or 20 years. Some exceptions can be found around the world (e.g. Verstraeten et al., 2006). One of the few such studies was carried out by Mueller and Pfister (2011), who showed that a statistically significant increasing trend has been present for the last 35 years in a number of high-intensity rainfall events for the Emscher-Lippe catchment in Germany. Thus, various sources of information can be used to estimate future rainfall erosivity factor values. For example, estimations of future rainfall erosivity were made using climate change scenarios for several regions (Nearing et al., 2004; Panagos et al., 2017a; Plangoen and Babel, 2014; Zhang et al., 2006). Among these studies, a projected increase in future rainfall erosivity is common to a varying degree. In the study encompassing European countries (Panagos et al., 2017a) Slovenia was one of the three countries with a projected decrease in its rainfall erosivity factor, namely by 22.7% by 2050 (Panagos et al., 2017a).

Since Slovenia has 10 stations with more than 25 years of high frequency data (5-min time step), this information can be used to evaluate consistency of projected future rainfall erosivity factor values with actual trends in the measured data. The aims of the study are as follows: (i) to evaluate the presence of trends in the rainfall erosivity *R*-factor in Slovenia using a relatively long time series (10 stations between 25 and 69 years of data), and (ii) to perform a sensitivity analysis regarding parameters that are used to define erosive events and calculate *R*-factor according to the RUSLE methodology (Renard et al., 1997).

2. Data and methods

2.1. Data

High temporal resolution rainfall data from 10 pluviographic gauging stations located throughout Slovenia was analysed (Table 1) to achieve the aims of this study. The gauging stations were chosen among an existing network in Slovenia (ARSO, 2017), based on their geographic location (Fig. 1), their altitude, and a sufficient data length (a minimum of 25 years of data was selected). These 10 stations are the only ones that met the data length requirement. The time step of the selected data was 5 min. Data through the end of the year 2016 was used in the analyses (Table 1). Analysed stations are located in three different climate types: mountain, temperate continental, and sub-Mediterranean (Table 1; Ogrin, 1996).

2.2. Rainfall erosivity R-factor

Rainfall erosivity, as one of the driving forces of soil erosion, encompasses particle detachment, the breaking up of agglomerates, and the transport of eroded particles by runoff (Wischmeier and Smith, 1978). As such, rainfall erosivity is determined by the various characteristics of a rainfall event, such as rainfall intensity and duration, the kinetic energy of raindrops, their size (diameter), and velocity (e.g. Petan et al., 2010). The rainfall erosivity factor *R*, as proposed by the (R)USLE methodology, is defined by the following equation (Renard et al., 1997):

$$R = \frac{\sum_n E \bullet I_{30}}{N} \tag{1}$$

where *R* represents the rainfall erosivity (in MJ mm $\text{ha}^{-1}\text{h}^{-1}$), *E* is the kinetic energy of a specific rainfall event (MJ ha^{-1}), and I_{30} is the maximum 30-min intensity (mmh^{-1}) of erosive event *n*, which occurred within a time span of *N* years. The kinetic energy *E* of a rainfall event can, however, be determined according to several different authors and equations (Brown and Foster, 1987; Ciaccioni et al., 2016; Petkovšek and Mikoš, 2004; Renard et al., 1997; van Dijk et al., 2002; Wischmeier and Smith, 1958). For Slovenia Petan (2010) developed equations for several stations located in three of Slovenia's climate types using the 1-min rainfall data that was measured using an optical disdrometer for specific locations in Slovenia (Petan, 2010):

i. mountain climate (station Bovec)

$$e_B = 0.336 \bullet [1 - 0.60 \bullet \exp(-0.047 \bullet I)] \tag{2}$$

sub-Mediterranean climate (station Kozjane)

$$e_B = 0.318 \bullet [1 - 0.56 \bullet \exp(-0.056 \bullet I)] \tag{3}$$

temperate continental climate (station Ljubljana)

$$e_B = 0.310 \bullet [1 - 0.60 \bullet \exp(-0.074 \bullet I)] \tag{4}$$

where e_B is specific kinetic energy (MJ ha^{-1} mm^{-1}) and *I* is rainfall intensity (mm h^{-1}). Often the equation proposed by Brown and Foster (1987) is also used (e.g. Panagos et al., 2015b):

$$e_B = 0.29 \bullet [1 - 0.72 \bullet \exp(-0.05 \bullet I)] \tag{5}$$

or the equation suggested by van Dijk et al. (2002), which was formulated based on a review of the literature:

$$e_B = 0.283 \bullet [1 - 0.52 \bullet \exp(-0.042 \bullet I)] \tag{6}$$

The relationship between *E* and e_B can be defined by (e.g. Renard et al., 1997):

$$E = e_B \bullet I \bullet \Delta t \tag{7}$$

where Δt is the time interval (h). In this study rainfall erosivity was calculated using Brown and Foster (1987), van Dijk et al. (2002) and local equations, developed for specific Slovenian gauging stations (Eqs. 2–4; Petan, 2010). Eq. (5) was used for the trend analysis. Meanwhile, all the equations listed above (Eqs. 2–6) were used for the sensitivity analysis. However, the Brown and Foster (1987) equation was used in order to evaluate the sensitivity of parameters that are used to calculate the rainfall erosivity. This equation is most frequently used (e.g. Panagos et al., 2016b) and it is also included in the Rainfall Intensity Summarisation Tool (RIST) software, which can be used to calculate rainfall erosivity (USDA, 2014). An erosive rainfall event, according to Renard et al. (1997), is an event with at least 12.7 mm of rain, or 6.35 mm of rain within 15 min. Events are split into two separate events if there is less than 1.27 mm of rain within 6 h. For stations listed in Table 1 the rainfall erosivity factor *R* was calculated using the above described procedure for the entire data period shown in Table 1.