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Rainfall erosivity in Europe

Panos Panagos [a,*], Cristiano Ballabio [a], Pasquale Borrelli [a], Katrin Meusburger [b], Andreas Klik [c], Svetla Rousseva [d], Melita Perčec Tadić [e], Silas Michaelides [f], Michaela Hrabalíková [g], Preben Olsen [h], Juha Aalto [i], Mónika Lakatos [j], Anna Rymszewicz [k], Alexandru Dumitrescu [l], Santiago Beguería [m], Christine Alewell [b]

[a] European Commission, Joint Research Centre, Institute for Environment and Sustainability, Via E. Fermi 2749, I-21027 Ispra, VA, Italy
[b] Environmental Geosciences, University of Basel, Switzerland
[c] Institute of Hydraulics and Rural Water Management, University of Natural Resources and Life Sciences, Vienna, Austria
[d] Institute of Soil Science, Agrotechnology and Plant Protection Sofia, Bulgaria
[e] Meteorological and Hydrological Service, Zagreb, Croatia
[f] Department of Meteorology, Nicosia, Cyprus
[g] Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Czech Republic
[h] Department of Agroecology, Aarhus University, Denmark
[i] Finnish Meteorological Institute, Finland
[j] Hungarian Meteorological Service, Budapest, Hungary
[k] UCD Dooge Centre for Water Resources Research, University College Dublin, Ireland
[l] National Meteorological Administration, Bucharest, Romania
[m] Estación Experimental de Aula Dei-Consejo Superior de Investigaciones Científicas (EEAD-CSIC), Zaragoza, Spain

HIGHLIGHTS

- Rainfall erosivity in Europe & Switzerland is estimated to 722 MJ mm ha^{-1} h^{-1} yr^{-1}.
- Rainfall Erosivity Database at European Scale (REDES) includes 1541 stations.
- The highest R-factor is in Mediterranean & Alpine regions and lowest in Scandinavia.
- The erosivity density shows high variability of the R-factor per precipitation unit.
- High resolution (1 km grid cell) dataset of R-factor is available for modelling.

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ABSTRACT

Rainfall is one the main drivers of soil erosion. The erosive force of rainfall is expressed as rainfall erosivity. Rainfall erosivity considers the rainfall amount and intensity, and is most commonly expressed as the R-factor in the USLE model and its revised version, RUSLE. At national and continental levels, the scarce availability of data obliges soil erosion modellers to estimate this factor based on rainfall data with only low temporal resolution (daily, monthly, annual averages). The purpose of this study is to assess rainfall erosivity in Europe in the form of the RUSLE R-factor, based on the best available datasets. Data have been collected from 1541 precipitation stations in all European Union (EU) Member States and Switzerland, with temporal resolutions of 5 to 60 min. The R-factor values calculated from precipitation data of different temporal resolutions were normalised to R-factor values with temporal resolutions of 30 min using linear regression functions. Precipitation time series ranged from a minimum of 5 years to a maximum of 40 years. The average time series per precipitation station is around 17.1 years, the most datasets including the first decade of the 21st century. Gaussian Process Regression (GPR) has been used to interpolate the R-factor station values to a European rainfall erosivity map at 1 km resolution. The covariates used for the R-factor interpolation were climatic data (total precipitation, seasonal precipitation, precipitation of driest/wettest months, average temperature), elevation and latitude/longitude. The mean R-factor for the EU plus Switzerland is 722 MJ mm ha^{-1} h^{-1} yr^{-1}, with the highest values (>1000 MJ mm ha^{-1} h^{-1} yr^{-1}) in the Mediterranean and alpine regions and the lowest (<500 MJ mm ha^{-1} h^{-1} yr^{-1}) in the Nordic countries. The

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* Corresponding author.
E-mail address: panos.panagos@jrc.ec.europa.eu (P. Panagos).

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erosivity density (erosivity normalised to annual precipitation amounts) was also the highest in Mediterranean regions which implies high risk for erosive events and floods.

1. Introduction

Soil erosion by water affects soil quality and productivity by reducing infiltration rates, water-holding capacity, nutrients, organic matter, soil biota and soil depth (Pimentel et al., 1995). Soil erosion also has an impact on ecosystem services such as water quality and quantity, biodiversity, agricultural productivity and recreational activities (Dominati et al., 2010; Dale and Polasky, 2007).

Since soil erosion is difficult to measure at large scales, soil erosion models are crucial estimation tools at regional, national and European levels. The high heterogeneity of soil erosion causal factors, combined with often poor data availability, is an obstacle to the application of complex soil erosion models. The empirical Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997), which predicts the average annual soil loss resulting from raindrop splash and runoff from field slopes, is still most frequently used at large spatial scales (Kinnell, 2010; Panagos et al., 2014a). In RUSLE, soil loss may be estimated by multiplying the rainfall erosivity factor (R-factor) by five other factors: Soil erodibility (K-factor), slope length (L-factor), slope steepness (S-factor), crop type and management (C-factor), and supporting conservation practices (P-factor).

Among the factors used within RUSLE and its earlier version, the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), rainfall erosivity is of high importance as precipitation is the driving force of erosion and has a direct impact on the detachment of soil particles, the breakdown of aggregates and the transport of eroded particles via runoff. Rainfall erosivity is the kinetic energy of raindrop's impact and the rate of associated runoff (Wischmeier and Smith, 1978). The R-factor is a multi-annual average index that measures rainfall's kinetic energy and intensity to describe the effect of rainfall on sheet and rill erosion. However, the erosive forces of runoff due to snowmelt, snow movement, rain on frozen soil, or irrigation are not included in this factor. Besides (R)USLE, the rainfall erosivity can be used as input in other models such as USPED, SEMMED and SEDEM. Further, this dataset could also be interesting for natural hazard predictions such as landslide and flood risk assessment that are mainly triggered by high intensity events.

A precise assessment of rainfall erosivity requires recordings of precipitation at short time intervals (1–60 min) for a period of at least several years. The rainfall erosivity is calculated by multiplying the kinetic energy by the maximum rainfall intensity during a period of 30-minutes for each rainstorm. The R-factor accumulates the rainfall erosivity of individual rainstorm events and averages this value over multiple years.

Field experiments using plot-sized rainfall simulators provide precise results of rainfall erosivity (Marques et al., 2007). However, since field experiments are expensive and often not easily transferable to large scales, researchers develop models for estimating rainfall erosivity. Two approaches are used to model rainfall erosivity: a) calculate the R-factor based on high-temporal-resolution precipitation data, and b) develop functions that correlate the R-factor with more readily available (daily, monthly, annual) rainfall data (Bonilla and Vidal, 2011). Only a few studies in Europe have determined the R-factor directly from high-temporal-resolution data (the first approach), including those carried out in Slovenia (Mikos et al., 2006), the Ebro catchment in Spain (Angulo-Martinez et al., 2009), Switzerland (Meusburger et al., 2012), and one of the federal states of Germany, North Rhine Westphalia (Fiener et al., 2013). At the continental scale, a recent study has accounted for the rainfall erosivity in Africa based on time series of 3-hours precipitation data (Vrieling et al., 2014).

In most soil erosion studies, the calculation of rainfall erosivity is limited due to the lack of long-term time series rainfall data with high temporal resolution (<60 min). Following the second approach (called the empirical approach), equations have been developed to predict R-factor based on rainfall data with lower temporal resolution (Loureiro and Coutinho, 2001; Marker et al., 2007; Diodato and Bellocchi, 2007; Panagos et al., 2012a). In those cases, expert knowledge of local conditions and seasonal characteristics plays an important role in estimating rainfall erosivity. Authors have suggested that rainfall erosivity equations should be used with caution in different applications, as the empirical relationships are location dependent and, in most cases, cannot be applied to larger areas (Oliveira et al., 2013). Moreover, those empirical equations cannot capture the high rainfall intensities which have significant influence on the average rainfall erosivity. R-factor equations developed for a specific region cannot be applied to the whole of Europe.

The main objective of this study is to estimate rainfall erosivity based on high-temporal-resolution precipitation data in Europe. It aims to:

a) present the spatial and temporal extent of high-resolution precipitation data available in Europe,
b) compute rainfall erosivity for 1541 precipitation stations in Europe, and propose a pan-European database of stations with R-factor data,
c) produce a European R-factor map based on a regression approach,
d) identify spatial patterns and map the relationship of the R-factor to precipitation (erosivity density), and
e) identify the possible use of the final R-factor dataset in situations beyond soil erosion monitoring.

2. Data collection

The geographical extent of this study includes the 28 Member States of the European Union (EU) plus Switzerland. High-resolution precipitation data were also available for the Swiss territory, which permitted us to avoid the “white lake” effect in the European rainfall erosivity map.

Given the growing concerns about climate change, climatic data is particularly important for the scientific community and society in general, as decisions of individuals, business and governments are dependent on available meteorological data (Freebairn and Zillman, 2002). More than 15 years ago, Peterson et al. (1998) recognised that data infrastructures hosting climatic data are becoming more important and that their contributions are becoming more valuable to policy making.

The present data collection exercise is based on an initiative to develop a network of high-temporal-resolution precipitation stations, which could also be useful for other research purposes such as climate change studies. Generally, climatic data of high temporal resolution are not easily accessible in Europe, or are only available for a fee.

The data collection exercise began in March 2013 and was concluded in May 2014. Previous attempts to collect soil erosion data from Member States used a top-down approach, and the response from countries was rather limited. In a recent top-down data collection exercise, only 8 Member States from a network of 38 countries provided estimates on soil loss (Panagos et al., 2014a). For the present rainfall erosivity data collection exercise, a participatory approach has been followed in order to collect data from all Member States.