Science of the Total Environment 615 (2018) 564–571

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

A new methodology for estimating rainfall aggressiveness risk based on daily rainfall records for multi-decennial periods

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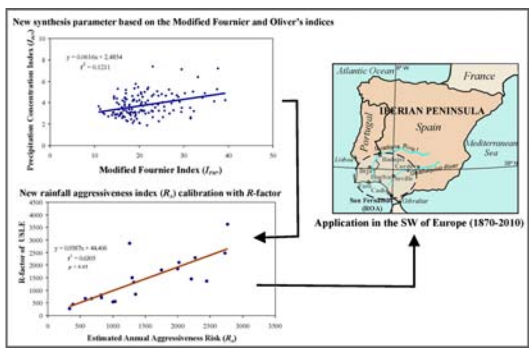
HIGHLIGHTS

- A new methodology is proposed to estimate the rainfall aggressiveness risk.
- This methodology is based on daily rainfall records.
- A new synthesis parameter based on Modified Fournier and Oliver's indices is used.
- It is calibrated with respect to the erosivity *R* factor for a simultaneity period.
- The SW of Iberian Peninsula has been selected to test its regional application.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 16 May 2017
Received in revised form 27 September 2017
Accepted 27 September 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Aggressiveness
Rainfall erosivity
Land use
Environmental risk
Southwest Europe

ABSTRACT

The temporal irregularity of rainfall, characteristic of a Mediterranean climate, corresponds to the irregularity of the environmental effects on soil. We used aggressiveness as an indicator to quantify the potential environmental impact of rainfall. However, quantifying rainfall aggressiveness is conditioned by the lack of sub-hourly frequency records on which intensity models are based. On the other hand, volume models are characterized by a lack of precision in the treatment of heavy rainfall events because they are based on monthly series. Therefore, in this study, we propose a new methodology for estimating rainfall aggressiveness risk. A new synthesis parameter based on reformulation using daily data of the Modified Fournier and Oliver's Precipitation Concentration indices is defined. The weighting of both indices for calculating the aggressiveness risk is established by multiple regression with respect to the local erosion *R* factor estimated in the last decades. We concluded that the proposed methodology overcomes the previously mentioned limitations of the traditional intensity and volume models and provides accurate information; therefore, it is appropriate for determining potential rainfall impact over long time periods. Specifically, we applied this methodology to the daily rainfall time series from the San Fernando Observatory (1870–2010) in southwest Europe. An interannual aggressiveness risk series was generated, which allowed analysis of its evolution and determination of the temporal variability. The results imply that environmental management can use data from long-term historical series as a reference for decision making.

1. Introduction

One of the features of the rainfall regime in a Mediterranean climate is the inter- and intra-annual irregularity (García-Barrón et al., 2013).

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https://doi.org/10.1016/j.scitotenv.2017.09.305
0048-9697/

Inter-decadal climate studies help to explain the causes of terrain alteration over time (Diodato et al., 2008). Rainfall erosivity causes a loss of fertile soil, damage to agriculture and infrastructure and water pollution and is influenced by changes in rainfall patterns (Martín-Fernández and Martínez-Núñez, 2011; Sanchez-Moreno et al., 2014) and by predictable effects of climate change (Diodato et al., 2011). In this study, we consider aggressiveness risk as a potential estimate of the physical effects of rainfall on soil dynamics sensu Fournier (1960). Our view is that aggressiveness risk is an appropriate environmental indicator and directly related to erosion and associated with the incidence of torrents, floods, landslides, displacement, etc. (Gregori et al., 2006). Therefore, knowledge of this variable over long periods is particularly useful for the management of water resources, soil conservation, agricultural planning and the development of environmental policy. Moreover, annual estimates of aggressiveness risk enable the comparison of orders of magnitude among different observation sites at different times. This environmental indicator is based on daily rainfall records and does not include other aspects related to erosion such as slope length, soil types, wind activity, land use, etc.

For the direct calculation of soil erosion, the universal soil loss equation (USLE) has been frequently used (Wischmeier and Smith, 1978). Specifically, the rainfall erosivity, or *R* factor, depends on the energy of every rainfall episode (Panagos et al., 2015). The *R* factor is an accepted instrument for local erosion measurement, successively updated and empirically endorsed by means of field measurements (Renard et al., 1997). Models such as the USLE and RUSLE were originally developed for detailed scale application in the farming sector, so their application on a regional scale presents some limitations (Terranova et al., 2009). Although USLE is one of the most widely used erosivity models worldwide, it has some limitations because the estimations of soil erosion do not fit the empirical measures of sedimentation, and the *R* erosivity factor does not explicitly incorporate direct runoff of water, which affects the accuracy of the model (Kinnell, 2010). Additionally, the spatial distribution tends to overestimate the *R* factor at regional or river basin levels (Hernando and Romana, 2016), and it is not recommended in areas different from those in which it was developed without an analysis of the validity of the equations.

In the specific case of the study of rainfall aggressiveness effects, two complementary approaches are taken: intensity models are based on sub-hourly rainfall records, and volume models are based on monthly rainfall records. This model refers to the different partial accumulations of rainfall. That is, it does not take into account the number, the duration and the rainfall amount of each episode, so that it's based exclusively on the total monthly rainfall. Nevertheless for the direct calculation of the rainfall erosivity in large areas, it is desirable to make use of high frequency rainfall records collected by nearby weather stations during a period longer than twenty years (Angulo-Martínez et al., 2009). However, except for modern automatic weather stations, traditional observatories have no high-frequency series with sub-hourly records. On the other hand, volume models are based on monthly rainfall records that are extensively available in most countries. In this case, the regular use of the aggressiveness index in environmental studies (Fournier, 1960), subsequently modified by Arnoldus (1980) as the Modified Fournier Index (I_{FM}) and complemented with the Precipitation Concentration Index (I_{PC}) developed by Oliver (1980), is remarkable.

Both estimations for calculating the intensity of rainfall aggressiveness present limitations. The drawback of the intensity models is the lack of adequate time series records, and that of the volume models is the imprecision in the treatment of heavy rain episodes because they are based on finer timescale resolutions. The amount of precipitation is not the only relevant parameter; its temporal distribution is also relevant, as studies on Mediterranean river basins in the NE Iberian Peninsula (Sánchez-Canales et al., 2015) and in the SW Iberian Peninsula (Sousa et al., 2009) have made evident. Various studies have compared the results obtained using intensity models (the *R* factor of USLE) to those obtained using volume models. In the Iberian Peninsula, the Institute for the Conservation of Nature (ICONA, 1988) under the Spanish Ministry of Agriculture proposed an empirical relationship that locally associates the *R* factor with the I_{FM} index. Additionally, a high correlation between the *R* factor and the monthly and/or annual precipitation parameters, including the Fournier Index, has been obtained in various geographic areas, such as in the Mediterranean area (Diodato and Bellocchi, 2007; Taguas et al., 2013), East Asia (Lee and Heo, 2011; Yue et al., 2014) and the tropical zone (Sanchez-Moreno et al., 2014). In the USA, Renard and Freid (1994) proposed regression equations that calculate the *R* factor from I_{FM}. Additionally, Loureiro and Couthino (2001) estimated the *R* factor based on the monthly rainfall aggressiveness in southern Portugal, and Da Silva (2004) estimated the same in Brazil.

In this study, we propose to estimate the aggressiveness risk by means of a single annual parameter that improves the limitations of models based only on monthly records (volume models) and those based on sub-hourly records (intensity models). We used a method based on the daily scaled reformulation of the traditional indices of aggressiveness, I_{FM} and I_{PC}, that provides more accurate results. The method also allows numerous investigations because there are many weather stations that have large time series of daily data. This Estimated Annual Aggressiveness Risk (R_A) is calibrated locally by means of regression equations with respect to the erosivity *R* factor for a period of simultaneity. Backwards extrapolation of the resulting function generates the corresponding time series of the aggressiveness risk. Recently, García-Barrón et al. (2015) have synthesized in this parameter the aggressiveness risk using I_{FM} and I_{PC} to study trends in river basins of the Iberian Peninsula. In this article, we propose two main objectives:

a) To define and calculate a single annual parameter based on daily records that synthetically estimates the rainfall aggressiveness risk.
b) To apply this methodology to a study area with a Mediterranean climate to analyse the temporal behaviour and deduce patterns in the evolution of the rainfall aggressiveness risk.

2. Study area and data

We chose the South-Atlantic region of the Iberian Peninsula for the methodological application, which is based on a long period and can help to draw conclusions about the potential risks of rainfall on the land. Spain is one of the countries' most severely affected by soil erosion in the European Mediterranean region due to extreme spatial and temporal variations in its physical environment, with frequent periods of drought and torrential rainfall (Solé, 2006). The importance of erosion in the Mediterranean is related to the long history of human activity in a region characterized by low annual precipitation, the occurrence of intense rainstorms and long-lasting droughts, high evapotranspiration, the presence of steep slopes and the occurrence of recent tectonic activity, together with the recurrent use of fire, overgrazing and farming (García-Ruiz et al., 2013).

The southwestern Iberian Peninsula falls within the domain of the Mediterranean climate, although it is influenced by an oceanic effect because of its proximity to the Atlantic Ocean. The average annual rainfall is approximately 600 mm (average values are substantially higher in the mountain range separating the watersheds of the Guadiana and Guadalquivir rivers). Rainfall is subject to marked inter-annual irregularity, with great oscillations in annual totals that include multi-year periods of drought (Aguilar, 2007). In general, the profile of the intra-annual precipitation shows an asymmetric unimodal curve, ascending in autumn and descending smoothly from winter to summer, when it reaches its minimum.

The Royal Observatory of the Spanish Navy (ROA) located in San Fernando (province of Cadiz, at the southern tip of the Iberian Peninsula) includes the oldest active weather station in Spain; rainfall records have been recorded since 1805 and accessible daily data since 1870. Because of these long-term and high-quality records, different studies