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Temporal analysis (1940–2010) of rainfall aggressiveness in the Iberian Peninsula basins

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ABSTRACT

Rainfall aggressiveness causes environmental impacts and it is related to several natural hazards. Therefore, this parameter has been chosen as an environmental indicator. The present study is based on the monthly estimated rainfall using the Precipitation Runoff Integrated Model (SIMPA) for each Spanish hydrographic basin from 1940 to 2010. The main aim is to analyse temporal irregularity of rainfall aggressiveness in large geographic areas and to extract spatio-temporal patterns. For each year the rainfall aggressiveness was calculated using the Modified Fournier Index (I_{FM}) and Oliver's Index of Precipitation Concentration (I_{PC}). The temporal variability of the annual series of these indices was analysed for each zone delimited. The results obtained made it possible to characterize the rainfall aggressiveness in the Iberian Peninsula and to determine its evolution over the past decades. They also reveal that the general pattern of the rainfall aggressiveness is determined by the dual effect of latitude (north–south) and longitude (east–west) as a result of the different maritime influences of the Atlantic and the Mediterranean watersheds. Finally a new variable is proposed, the Annual Aggressiveness Risk R_A, which summarizes the information provided by I_{FM} and I_{PC}.

1. Introduction

Changes in rainfall intensity cause environmental impacts and are related to various natural hazards (Estrela et al., 2012; Machado et al., 2011). Therefore, knowledge of the spatial and temporal variability of precipitation is relevant to characterize the regime of the hydrological basins, its exposure to risks and, if applicable, the adoption of prevention and mitigation measures (Krysanova et al., 2010; Middelkoop et al., 2001). In this paper we focus on estimating the aggressiveness of rainfall as an indicator of potential environmental impact. It is especially important to know the temporal evolution of the rainfall aggressiveness in areas like the Iberian Peninsula, which is characterized by irregular inter-annual and intra-annual precipitation (García-Barrón et al., 2011, 2013).

The Iberian Peninsula is located in the climatic transition zone between the mid-latitudes and the subtropical climates, and it presents complex orographic features that influence the generation of precipitation. Furthermore, its peculiar geographical location between the Mediterranean Sea and the Atlantic Ocean determines a wide range of Mediterranean climates (De Castro et al., 2005) whose different rainfall characteristics reflect a wide range of landscape and environmental varieties. The peninsula's hydrological basins, except the Cantabrian one, show the characteristics associated with the Mediterranean climate: variability of rainfall, wet years mixed with recurrent droughts, high concentrations of rainfall over a few days and low rainfall during the summer (Lionello et al., 2006; Martín-Vide and Olcina, 2001).

We believe that the river basin is an appropriate spatial scale for assessing the natural hazards associated with rainfall, being the natural hydro-climatic area (Gonzalez-Hidalgo et al., 2010). Several authors have also considered the river basin as the territorial unit for the analysis of precipitation and its impact (Angulo-Martínez et al., 2009; Barriendos and Rodrigo, 2006; Caramelo and Manso-Orgaz, 2007; Gonzalez-Hidalgo et al., 2010; Kilsby et al., 2007; López-Moreno et al., 2013; Morán-Tejeda et al., 2012; Valencia et al., 2012). Therefore, understanding the evolution of aggressivity in each basin during the last decades, is crucial in order to undertaking water resource management and planning, including the water supply to populations, the organization of irrigation, the water infrastructure design, the flood and drought management, etc. To do this, it is necessary to develop

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new procedures that provide information about the behaviour of the hydrology of each studied zone over long periods.

Trends and the interannual and intra-annual variability at different time scales have been analysed with different approaches (Acero et al., 2011; Costa et al., 2012; De Luis et al., 2010a; Del Río et al., 2011; García et al., 2007; García-Barrón et al., 2011, 2013; Lorenzo-Lacruz et al., 2012; Martín-Vide, 2004; Sousa et al., 2010). The impact of rain on agriculture and forestry (Nippert et al., 2006; Pérez-Camacho et al., 2012; Sardans and Peñuelas, 2013), on erosion and desertification (Briggs et al., 1992; De Vente et al., 2008; Diodato et al., 2011; Vicente-Serrano, 2006) and on hydrology (Do Ó, 2010; Embid and Gurrea, 2004; Sousa et al., 2013) have also been widely studied from different perspectives.

From this point of view, it is important to analyse environmental indicators and to identify patterns that make it possible to infer consequences for large territorial areas. In this paper, the Spanish territory of the Iberian Peninsula has been divided into zones, largely coincident with the Spanish hydrographic basin; each one is represented by its total annual rainfall values and its intra-annual distribution. We selected rainfall aggressiveness as an environmental indicator parameter that will broaden the knowledge about the spatial variability of precipitation patterns in the zones.

Knowledge of rainfall aggressiveness is linked to several environmental study fields. Its effects are related to torrentiality, erosivity, landslides, floods, silting, etc. (Diodato et al., 2011; Gregori et al., 2006; Sousa et al., 2013). As an environmental indicator, it is based on the calculation of the Modified Fournier Index (I_{FM} from now on) (Arnoldus, 1980; Fournier, 1960), and it is complemented by the Precipitation Concentration Index (I_{PC} hereafter) (Oliver, 1980).

Both indices are based on monthly rainfall records. Some environmental impacts depend on the rainfall intensity of each event but, except for the modern automatic weather stations, traditional stations do not have high frequency rainfall records (in min). Moreover, torrential rain events in the Mediterranean area are often highly concentrated.

For example, for the direct calculation of rainfall erosivity at a regional scale (Angulo-Martínez et al., 2009) it is convenient to use a set of closely spaced (<15 km) weather stations, each of which holds high frequency records for at least twenty years. In Spain, the rain gauge network is recent, scarce and unevenly distributed; therefore, it is not possible to directly analyse the evolution of impacts using a network of high frequency local records across large regions over the course of a long period of time. Thus, to obtain information about the potential risks of rainfall in the area that have sufficient spatial and temporal validity, it is necessary to use alternative methods based on monthly data, as proposed in this work.

The usefulness and value of this new methodological approach, based on monthly rainfall data, is that it allows reconstructing the evolution of the rainfall aggressiveness in the large river basins of the Iberian Peninsula during the period 1940–2010. Subsequently, this approach can be used as a basis for linking the rainfall aggressiveness with hydrological processes that can have a great impact, such as the evolution of soil erosion, and the silting of reservoirs. The high rainfall variability entails a significant irregularity of the environmental effects associated with precipitation. Different studies of rainfall aggressiveness have been made from rainfall records. Gregori et al. (2006) highlighted the enormous versatility of the Modified Fournier Index (I_{FM}) to describe the characteristics of the rainfall regime and its relationship to some instability phenomena (quick flows, erosivity, shallow landslides, etc.). Michiels et al. (1992) used the I_{PC} to describe the variability of rainfall in the Iberian Peninsula and considered that it was suitable to evaluate erosivity. De Luis et al. (2010b) executed both the I_{FM} and the I_{PC} to study the possible increase in erosivity in the Spanish Mediterranean area from a wide range of selected weather stations. I_{PC} has also been employed with monthly data from scattered weather stations across the Iberian Peninsula to analyse the temporal trend in rainfall and to describe spatial patterns (De Luis et al., 2011). In general, these papers focus on the analysis of annual or seasonal trends. In addition, there are many precedents for the use of these indices of aggressiveness (the I_{FM} and the I_{PC}) and the analysis of their relationship with other parameters in the Mediterranean area (Apaydin et al., 2006; Diodato and Bellocchi, 2007) and in different climatic areas and different continents (Da Silva, 2004; Diodato et al., 2013; Elagib, 2011; Febles et al., 2009; Gabriels, 2006; Lee and Heo, 2011; Munka et al., 2007; Rey et al., 2012; Sauerborn et al., 1999; Vrieling et al., 2010). However, we believe that the analysis of the multi-annual irregularity of the indices proposed in this paper and applied to large basins provides an innovative approach that could broaden the study perspective.

For all these reasons, we intended to determine the specific temporal behaviour of rainfall aggressiveness in each zone and to establish the relationships between the different climatic areas in order to extract general patterns, if possible. Thereby, the overall objective of the study was to determine the evolution of rainfall aggressiveness during the period 1940–2010 in the defined Spanish zones. More specifically, by using the time series generated for both the I_{FM} and the I_{PC} the intentions were:

- To characterize the temporal irregularity of aggressiveness in each zone delimited by the comparative analysis of trends, interannual variability and disparity.
- To check whether the results reveal similarities and differences between the zones that allow for the establishment of a spatial pattern for each watershed (Mediterranean/Atlantic) or for the whole Iberian Peninsula.

The indicators of the rainfall intensity that we developed in this study allow a comparative analysis of the evolution of the rainfall aggressiveness in different basins for an extended period (1940–2010). As a result of this comparative analysis it is possible that a general pattern of evolution in the Iberian Peninsula, which may be supplemented by variations according to the geographic location, appears. The knowledge of these patterns of variation could have interesting implications for water planning (management of water resources, conservation of rivers, flow regulation, assessment of river ecosystems, etc.) and, generally, for the development of environmental policies, besides serving as a basis for further studies of climate change scenarios.

2. Study area and data

The study area is the Spanish territory of the Iberian Peninsula, which is divided into large basins which are largely coincident with the boundaries of the Spanish hydrographic basins. We chose to aggregate small adjoining basins. The Water Information Service (Sistemas de Información del Agua, SIA in Spanish) of the Ministry of Agriculture, Food and Environment of Spain is responsible for the quality of water resources and environmental status management, and it is also in charge of the water risk prevention in the Spanish hydrographic basin.

In collaboration with some university departments, this service has developed the Sistema Integrado de Modelización Precipitación-Aportación (Precipitation Runoff Integrated Model) known as SIMPA (Estrela and Quintas, 1996). For climate information, SIMPA estimates the rainfall for each Spanish hydrographic basin, month by month throughout the simulation period, from