IS RAINFALL EROSIVITY INCREASING IN THE MEDITERRANEAN IBERIAN PENINSULA?

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ABSTRACT

The risk of erosion and desertification is one of the main environmental concerns in the Mediterranean Iberian Peninsula. Changes in precipitation are expected in Mediterranean areas because of climate change, but predictions are not certain. For this reason, dense precipitation databases are required to explore observed changes in the amount, concentration and variability of precipitation, to gain a clearer understanding of the dynamics involved in the main climatological agent of erosion. For this study, we took the recently developed MOPREDAMES dataset, which includes 1113 complete and homogeneous monthly rainfall series from the Mediterranean fringe of the Iberian Peninsula (IP) covering the period 1951–2000. These were used to calculate and analyse trends in Total Annual Precipitation ($P_t$), the Precipitation Concentration Index (PCI) and Modified Fourier Index (MFI). Our results show that, although there were decreases in annual rainfall, increases in the concentration of precipitation also predominated in the Mediterranean Iberian Peninsula during the period 1951–2000. However, spatial variability of these trends is high, and changes in rainfall erosivity exhibit a complex spatial pattern. Thus, decreases in rainfall erosivity are detected under semiarid conditions (Central Ebro basin and South East IP), while increases mainly occur in dry and sub-humid areas. We present a detailed spatial description of the results and discuss their implication for the risk of erosion and desertification in different regions of the study area. Copyright © 2009 John Wiley & Sons, Ltd.

KEY WORDS: rainfall erosivity; precipitation trends; Precipitation Concentration Index; Modified Fourier Index; Mediterranean Spain

INTRODUCTION

Soil erosion and desertification are one of the main environmental problems in Mediterranean climate areas, and Mediterranean regions of Spain, in particular, have been described as the most threatened area in Europe (Vallejo et al., 2005).

Most of the soil erosion in the Mediterranean areas is due to rainfall (splash and wash), but soil erosion by water is a complex phenomenon in which there is no exact relationship between soil erosion and the total amount of rainfall. Neither is there one with the intensity of rainfall and its distribution in time (Kirkby and Neale, 1987).

Because of global warming, a higher risk of desertification has been predicted, due to increased aridity around the Mediterranean basin (Trenberth et al., 2007), but there is also great uncertainty about the future development of soil erosion by water, because the reliability of model outputs for precipitation are less accurate than those for temperature (Christensen et al., 2007).

As far as possible, regional analysis of potential erosion should take into account the variability of rainfall in space and time, and this should be achieved by using dense spatial information. At present, there are many datasets on a global or continental scale (Klein-Tank et al., 2002; Wijngaard et al., 2003), but these are not useful at sub-regional level because of the low density of observations. This situation is especially critical in areas with high variability in rainfall, such as those in the Mediterranean climate.

Different indices of rainfall aggressivity (erosivity) have been proposed for analysing soil erosion, and the most appropriate ones seem to be those relating to soil erosion with kinetic energy of rainfall, such as the well-known EI$_{30}$ (Wischmeier, 1959). However, there is scarce availability of high quality datasets on a regional scale, because EI$_{30}$ requires rainfall data at intervals of one minute (Loureiro and Coutinho, 2001). To avoid this problem, other indices based on monthly data averages have been proposed, such as Fourier Index (FI) and its modification by Arnoldus (1980) (MFI). Agreement between FI or MFI with the USLE R factor (rainfall aggressivity factor) has been described on many occasions (Renard and Freimund, 1994; Gabriels, 2001; Loureiro and Coutinho, 2001; Diodato and Belloch,
and, as consequence, they are commonly used as the input aggressivity factor in the development of regional models (Gregori et al., 2006). Basically, the Modified Fournier Index (MFI) may be expressed as the product of Total Annual Precipitation \( P_t \) and monthly precipitation concentration (PCI) (MFI = \( P_t \times \text{PCI} \)) (Apaydin et al., 2006). According to this relation, rainfall erosivity (MFI) is more intense where there are high values of precipitation concentration (high PCI) and Total Annual Precipitation \( P_t \).

In this paper, we analyse the variability in space and time of the MFI, the Precipitation Concentration Index (PCI) and total precipitation \( P_t \) trends by using a dense precipitation database recently developed for the Mediterranean fringe of Iberian Peninsula (i.e., the runoff contribution area to the Mediterranean Sea).

The objectives of this paper are to analyse the relationship between trends of \( P_t \), MFI and PCI to describe the evolution of rainfall aggressivity during 1951–2000 in environments subject to a high erosion risk, and to look for spatial distribution patterns.

**MATERIAL AND METHODS**

We used the monthly precipitation database (MOPREDAMES) recently presented by González-Hidalgo et al. (2009) and De Luis et al. (2009). MOPREDAMES was produced after analysing the archives of National Meteorological Agency of Spain, where large amounts of monthly precipitation data are stored. After being exhaustively processed for quality control and homogenisation, 1113 monthly precipitation stations were reconstructed, covering the period 1951–2000, with an overall density of 1 observatory per 150–200 km\(^2\) (Figure 1).

This database is, at present, probably the most dense and the highest quality monthly precipitation database available for the western Mediterranean area and comprises five hydrological divisions which are drained into the Mediterranean Sea: Eastern Pyrenees, Ebro, Júcar, Segura and Eastern Andalusia.

The Modified Precipitation Index (MPI) (Fournier, 1960; Arnoldus, 1980) and Precipitation Concentration Index (PCI) (Oliver, 1980) were calculated on an annual basis for each station, according to the following equations:

\[
\text{MFI} = \sum_{i=1}^{12} \frac{p_i^2}{P_t} \quad \text{PCI} = \frac{\sum_{i=1}^{12} p_i^2}{\left(\sum_{i=1}^{12} p_i\right)^2}
\]

with \( p_i \) being the monthly precipitation at month \( i \), and \( P_t \) the annual precipitation.

The annual time series of MFI, PCI and \( P_t \) were used to test for trends and to detect changes during the second half of the 20th century. The intensity of observed changes was estimated by using linear regression techniques (Suppiah and Hennessy, 1998; De Luis et al., 2000; González-Hidalgo et al., 2001).

The spatial distribution of results (rate of change measured as the slope of linear models) is shown by spatial interpolation (Inverse Distance Weighted Methods) of observed trends at each of the 1113 stations (Ninyerola et al., 2007). Finally, we studied surfaces affected by different trends by using raster maps and area statistics obtained for each variable, using ArcGis 9.1 software.

**RESULTS**

The mean annual precipitation for the whole study area is 562 mm; however, values higher than 2000 mm y\(^{-1}\) (the Pyrenees and most SW mountain areas) and lower than 200 mm y\(^{-1}\) (extreme South East) have been observed (Figure 2). The trend analysis of Total Annual Precipitation shows an overall decrease in annual precipitation (Figure 3). The exception is the extreme SE, where a very complex spatial pattern emerges, and includes patches of both positive and negative trends. Thus, on an annual scale, precipitation diminished over 90-1 per cent of the territory, with a decrease in the value of the global mean annual precipitation of \(-12.4\) per cent during the period 1951–2000.

Precipitation concentration (PCI) exhibits a different pattern from those observed for Total Annual Precipitation. Higher values are observed in the south and south-eastern part of the study area, while lower values are found in the Central Pyrenees (Figure 4). The trend analysis also shows a different pattern, and a general increase in precipitation concentration (PCI) is observed (Figure 5). Thus, precipi-
Rainfall concentration has increased over 80.5 per cent of the territory, with a mean increase of 8.8 per cent during the period 1951–2000.

Rainfall aggressivity (MFI) is relatively high in most parts of study area, with higher values observed in the Pyrenees, inner coastal of the Valencia region and Southern Andalusia (Figure 6). However, because of opposite results from annual precipitation and precipitation concentration, complex patterns are observed when analysing trends in rainfall aggressivity (MFI) (Figure 7). Thus, we found increases in rainfall aggressivity mainly in the Central Pyrenees and extensive areas of the regions of Valencia and Andalusia, while decreases are mainly located in the Central Ebro basin.
DISCUSSION

Erosion and desertification are key elements to understanding the implications of climate change in Mediterranean climate environments. In this regard, not only changes in total precipitation, but also in its distribution and concentration, are the key to understanding and quantifying these processes on a regional scale.

The decrease in rainfall trends around the Mediterranean basin has been related to global warming and changes in pressure gradients between the islands of the Azores and Iceland associated with the North Atlantic Oscillation (Houghton et al., 2001). However, in the aforementioned study, the average spatial density of observations was low, and therefore, spatial variability and transient areas might not be correctly identified. Furthermore, the most recent global revision covering the Mediterranean basin highlighted large spatial variations and did not detect any clear spatial pattern of precipitation trends during the period 1951–2000 (Norrant and Douguedroit, 2006). Our results, based on a high-density data-set (1113 time series) and covering the five hydrological divisions of the eastern IP, describe high variability in precipitation regimes and trends, and constitute a new tool for detailed spatial analysis. Furthermore, they allow us to identify some general patterns not previously described. Thus, annual trends are characterised globally by a general decrease in precipitation, but an increase in precipitation concentration during the period 1951–2000.

Indices based on monthly data average such as the Fourier Index and its modification by Arnoldus (1980) (MFI) are often used to quantify the nature of rainfall variability and its effects on the distribution of soil erosion. As has been recently described by Apaydin et al. (2006), MFI can be expressed as the product of Total Annual Precipitation and the Precipitation Concentration Index described by Oliver (1980). Consequently, opposite trends observed in total rainfall and precipitation concentration draw a complex pattern for the trends of rainfall aggressivity in the Mediterranean IP.

The importance of precipitation seasonality has been highlighted previously. Langbein and Schumm (1958) suggested that the available energy for erosion and transport increases positively with the amount of annual rainfall up to about 300 mm, at which perennial and annual vegetation cover increases surface protection and limits soil erosion. On the other hand, Kirkby and Neale (1987) proposed a seasonal erosion model in which peak maximum precipitation, plant cover and soil erosion are out of phase. Thus, the vegetation dynamic emerges as a key factor in quantifying and interpreting the risk of erosion and desertification.

It is widely accepted that precipitation concentration and seasonality play a leading role in vegetation dynamics. Moreover, rainfall seasonality is directly related to disturbances like forest fires, which have a critical effect on erosion. Thus, on one hand, the frequency and extent of forest fires in Mediterranean areas are directly related to summer water stress (Moreno, 1998; Prosper-Laget et al., 1998; Rambal and Hoff, 1998). On the other hand, winter,
and mainly spring, rainfall is linked to fine fuel growth, this fact being critical in determining the occurrence (Bessie and Johnson, 1995) and spread (Viegas and Viegas, 1994) of forest fires. Last, but not least, the regeneration capacity of ecosystems and restoration activities after summer fires are highly dependent on seasonal rainfall, particularly in autumn (Bautista et al., 1996; Vallejo, 1996; De Luis et al., 2001).

In short, the observed decrease in total precipitation should not be interpreted as a decrease in the risk of erosion, because the process of soil erosion is closely linked to the vegetation dynamic and to the probability of disturbances, such as forest fires, occurring, and these are mainly linked to rainfall seasonality and concentration.

CONCLUSIONS

Trend analysis of a dense monthly precipitation database in the Mediterranean fringe of Spain (western Mediterranean basin) indicates opposite behaviour between annual precipitation (P) and seasonal precipitation concentration (PCI). Thus, during the period 1951–2000, decreases in annual rainfall, but increases in precipitation concentration, predominated in the Mediterranean Iberian Peninsula. As a consequence, and due to the opposing influence of precipitation components, trends in rainfall aggressivity (MFI) exhibit a complex spatial pattern.

Is spite of this general behaviour, there is high spatial variability among these trends, and we attach detailed spatial maps of these precipitation components. Our results may contribute to a better understanding of the local dynamic of the main climatological agents of erosion in Mediterranean areas, and may also be valid for identifying areas subject to different erosion and desertification risks in Mediterranean ecosystems in Spain when creating suitable mitigation strategies in the assessment of global warming.

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