

PRECIPITATION AND EROSION IN SOUTHERN PORTUGAL: SEASONAL VARIABILITY AND TRENDS (1950–2008)

Adélia N. Nunes^{1*}, Luciano Lourenço¹, António Vieira², António Bento-Gonçalves²

¹Department of Geography, Center for Studies in Geography and Spatial Planning, University of Coimbra, 3004-530 Coimbra, Portugal

²Department of Geography, Center for Studies in Geography and Spatial Planning, University of Minho, Campus de Azurém, 4800-058 Guimarães, Portugal

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ABSTRACT

Southern Portugal experiences the lowest amounts of annual precipitation and the highest level of susceptibility to soil erosion, drought events and desertification phenomena in mainland Portugal. The first goal of this paper was to analyse spatial variability and trends in annual precipitation and erosion in southern mainland Portugal for the period 1950/1951–2007/2008. The second objective was to evaluate seasonality in relation to precipitation distribution, erosion and concentration over the same period and to evaluate and detect possible changes in the time trend for precipitation erosion. In order to achieve these objectives, the annual and seasonal precipitation figures, corresponding to data from 90 rain gauges, were analysed and the Modified Fournier Index and Precipitation Concentration Index calculated for each station. The results obtained revealed distinct behaviour patterns for yearly precipitation, erosion and concentration trends. Decreases in annual precipitation and erosion figures accompanied by increases in precipitation concentration were found. Nevertheless, no generalised significant trends have been detected for these variables. In seasonal terms, there was a general trend towards an increase in amount, concentration and precipitation erosion in autumn and summer, and a significantly reducing in winter. The increase in precipitation erosion, particularly in the autumn, the most water-erosive season, suggests a rising in potential soil erosion risk in southern Portugal. Copyright © 2014 John Wiley & Sons, Ltd.

KEYWORDS: precipitation trends; precipitation concentration; precipitation erosion; seasonal variability; southern Portugal

INTRODUCTION

Soil erosion caused by precipitation is considering the major land degradation process in the European Mediterranean basin (Kosmas *et al.*, 2002; Grimm *et al.*, 2002; Cerdà *et al.*, 2010), because soils and nutrients can be eroded by the energy of raindrops, surface and subsurface runoff (Lal, 2001). The understanding of precipitation characteristics and variability in connection with precipitation erosion is therefore crucial in assessing soil erosion risk and to adopt a set of sustainable land management strategies to prevent or minimise the soils loss. Precipitation erosion refers to the power of precipitation to cause soil erosion. It is affected by the characteristics of precipitation such as quantity, duration, intensity, drop-size distribution and kinetic energy (Cerdà, 1997; Renard *et al.*, 1997).

This has led to studies on previously established precipitation indices, such as maximum intensity for a certain period, to overall precipitation energy or to analysis of soil detachment rates (Angulo-Martínez & Beguería, 2009). The precipitation erosion factor, R, in the Universal Soil Loss Equation (USLE) or in the Revised USLE, is one of the most commonly used index, in which soil erosion is dependent on the total kinetic energy and the maximum 30-min precipitation intensity (EI_{30}) (Wischmeier, 1959;

Wischmeier & Smith, 1978; Brown & Foster, 1987; Renard *et al.*, 1997). High correlations were found between R factor and soil loss (Diodato, 2004; Hoyos *et al.*, 2005; Onori *et al.*, 2006; Domínguez-Romero *et al.*, 2007).

Although efforts to improve the accuracy of most representative precipitation physical parameters, such as raindrop size or kinetic energy of precipitation, have progressed in recent decades (Cerdà, 1997; Ries *et al.*, 2009; Fernández-Raga *et al.*, 2010), modelling of its behaviour is still complex. Furthermore, the estimation of yearly or long-term erosion risk for a given site requires a continuous precipitation data series and a high time resolution of at least 15 min (Loureiro & Coutinho, 2001; Angulo-Martínez & Beguería, 2009). Nowadays, short duration precipitation intensity data are collected by automated rain gauges that give information about duration and intensity of precipitation; nevertheless, in many areas of the world, good spatial and temporal coverage records are still difficult to obtain (Angulo-Martínez & Beguería, 2012; Diodato *et al.*, 2012).

In order to circumvent this constraint, other indices supported on monthly averages data were suggested. The Modified Fournier Index (MFI), modified by Arnoldus (1980) from the FI, can be considered the result of total annual precipitation (Pt) and monthly Precipitation Concentration Index (PCI) ($MFI = Pt \times PCI$) (Apaydin *et al.*, 2006). On the basis of this relationship, precipitation erosion, obtained by the MFI, is more severe where and when there are high precipitation concentration values (high

*Correspondence to: A. Nunes, Department of Geography, University of Coimbra, Largo da Porta Férea, 3004-530 Coimbra, Portugal.
E-mail: adelia.nunes@ci.uc.pt

PCI) and total annual precipitation (Pt) (de Luis *et al.*, 2010). Thus, precipitation concentration could be considered another important factor, which affects precipitation erosivity (González-Hidalgo, 1996). Oliver (1980) proposed a PCI, which has been used by several researchers in different regions of the world (Apaydin *et al.*, 2006; de Luís *et al.*, 2010; Elagib, 2011).

Several authors detected significant relationships between annual precipitation values and the MFI (Bertoni & Lombardi Neto, 1990; Lombardi Neto & Moldenhauer, 1992; Renard & Freimund, 1994; Oliveira *et al.*, 2011; Taguas *et al.*, 2013) and between annual precipitation and soil erosion (Kosmas *et al.*, 2002; Cerdà *et al.*, 2010; García-Ruiz, 2010; Nunes *et al.*, 2010, 2011; Martínez-Casasnovas *et al.*, 2013; Prats *et al.*, 2013; Ziadat & Taimeh, 2013). In fact, several authors highlight the relationship between annual precipitation and runoff, and soil erosion under different types of land use or burned areas, in the Mediterranean region.

The agreement between the MFI and the USLE R factor (precipitation erosivity factor) is also suggested by many authors (Renard & Freimund, 1994; Loureiro & Coutinho, 2001; Diodato & Bellocchi, 2007), and consequently, they are commonly applied as the aggressiveness factor when regional model to estimate annual or seasonal precipitation erosivity is developed (Gregori *et al.*, 2006). Arnoldus (1977), for instance, achieved significant correlations ($r^2=0.83$) between MFI and the R-factor values in 178 stations (164 US stations and 14 West Africa stations). Using data from 132 stations in the USA, Renard & Freimund (1994) obtained similar results, with a 0.81 coefficient. Several researchers in Brazil also demonstrated that the MFI obtained the best performances in calculating the R factor (Lombardi Neto & Moldenhauer, 1992; Cassol *et al.*, 2008; Oliveira *et al.*, 2011).

As the climate dynamics is the main cause of precipitation erosivity, we need to use climate analysis methodologies to study erosivity factor. However, long series of precipitation data are required if accurate results about long-term mean value of precipitation erosivity aimed to be achieved. Bertoni & Lombardi Neto (1990) considered that, although it is possible to determine precipitation erosivity using at least 10-year precipitation records, the best condition to predict consistent results is to compute a data set of 20-year precipitation figures. On the other hand, as precipitation erosivity is not uniformly distributed throughout the year, the prediction of soil erosion by water, both spatial and temporal patterns, requires a detailed knowledge of the precipitation regime. In fact, one of the main characteristics affecting the susceptibility of the Mediterranean region to erosion is the intense precipitation following a very long, dry summer and pronounced inter-annual and intra-annual fluctuations in precipitation quantity (Cerdà, 2002; Nunes *et al.*, 2010, 2011).

In Portugal, very few studies have focused on trends in precipitation concentration and erosivity at regional scale, highlighting the work carried out by Loureiro & Coutinho (1995, 2001) in the Algarve region. Thus, this study aims

first to investigate spatial variability and trends in annual precipitation (amount and concentration) and erosivity in southern mainland Portugal during the second half of the 20th century. The second objective is to evaluate seasonality (autumn, winter, spring and summer), what concerns the precipitation distribution and concentration and precipitation erosivity for each season, and to evaluate and detect possible changes in the time trend for precipitation erosivity in an environment very prone to a high water erosion risk and sensitive to desertification processes. Finally, a preliminary analysis of the relationship among distribution and trends in precipitation and related variables, on annual and seasonal scales, and some geographical features are carried out with the aim to identify spatial pattern of distribution and spatial variation of trends.

MATERIAL AND METHODS

The study area corresponds to the southernmost part of mainland Portugal, bordering on the River Tejo in the north (Figure 1). This area includes two distinct administrative regions, the Alentejo and the Algarve, each with different

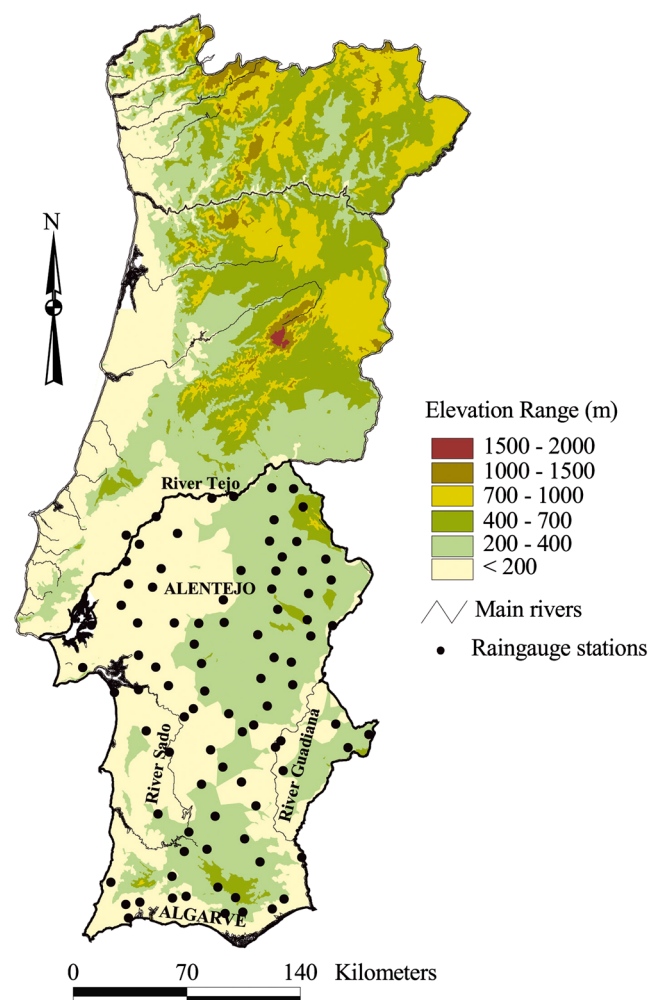


Figure 1. Study area and location of rain gauge stations. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

physiographic characteristics. The Alentejo region is mainly characterised by a smooth topography, that is, the peneplain, where the mean altitude varies between 200–300 m. The highest elevation in the Alentejo region, with an altitude of 1000 m, happens in the São Mamede mountain ridge, which is located in the extreme north-east. The Algarve is the southernmost region of mainland Portugal. The relief is dominated by the two main Algarve mountain ranges, Caldeirão in the east and Monchique in the west.

In southern Portugal, the precipitation regime is characterised by highly irregular pattern in both temporal and spatial terms, namely, the amount and distribution of precipitation. The annual average precipitation in this region ranges from around 1,000 to 400 mm y⁻¹, and most of the precipitation (i.e. about 80%) falls between October and April. During the dry season, about 4 to 6 months having any significant precipitation.

In Portugal, precipitation regime is mainly influenced by two different seasonal atmospheric mechanisms. During the winter, the position and intensity of the Icelandic low chiefly affect the large-scale circulation. In those conditions, Portugal is influenced by westerly winds that transport moist air and generate precipitation events, mainly in the in north-easternmost regions. During the summer, the Azores anticyclone governs the large-scale atmospheric circulation, which is displaced towards its north-westerly position, producing northerly or north-easterly winds that carry warm, dry air into Portugal, of either continental or maritime origins (Trigo & da Camara, 2000). The summer rain that occurred in southern Portugal is mostly generated from convective storms. Consequently, these areas are highly sensitive to drought events, soil erosion, land degradation and intensification of desertification processes (Rosário, 2004; Pereira *et al.*, 2006). According to the Corine Land Resources (Grimm *et al.*, 2002) areas of high actual erosion risk cover almost one-third of Portugal, mainly in the south and east. Additionally, 54% of the territory is classified as having a moderate soil erosion risk. The estimate by the National Action Programme to combat desertification and the desertification information system for the Mediterranean Region project (Rosário, 2004) of the areas sensitive to desertification shows that 36% of Portuguese territory is classified as 'critical', with the southernmost of Portugal emerging as especially fragile.

Yearly and seasonal precipitation data using a network consisted of 90 udometric stations between the hydrological years 1950/1951 and 2007/2008 were analysed (Figure 1), located between 39°62' and 37°15'N and 7°00' and 9°12' W Greenwich. The altimetric gradient oscillates between 1 and 552 m asl.

The dataset was collected from the National Institute of Water database (INAG—Instituto da Água/SNIRH—Sistema Nacional de Informação de Recursos Hídricos, <http://snirh.inag.pt>). Three criteria were used in the selection of time series from udometric stations: (i) available data from 1950/1951 to 2007/2008 on a monthly basis; (ii) a limited number of gaps on the pluviometric records, with less than 5% of the

total observations; and (iii) the data met the requirements of normality and homogeneity.

The following procedure was adopted when some data were missing from the time series: a linear correlation was established for the time series with the aim to choose the nearest udometric station with the time series wherein precipitation characteristics most closely resembled those of the station with the missing data. Then, a spatial regression was used to estimate the missing values (Peterson & Easterling, 1994) or correct anomalous precipitation values. Afterwards, using non-parametric tests, the Shapiro–Wilk test and the Kolmogorov–Smirnov (Lima *et al.*, 2010), the data were statistically tested for normality. In order to check the time series homogeneity, the Standard Normal Homogeneity Test was selected (Alexandersson & Moberg, 1997; Lima *et al.*, 2010).

The mean annual Precipitation (R), MFI (Fournier, 1960; Arnoldus, 1980) and the mean inter-annual PCI (Oliver, 1980) were estimated for each station during the second half of the 20th century. The MFI (1) and PCI (2) were calculated for each station using the next equations:

$$\text{MFI} = \frac{\sum_{i=1}^{12} p_i^2}{\sum_{i=1}^{12} P_i} \quad (1)$$

$$\text{PCI} = \frac{\sum_{i=1}^{12} p_i^2}{\left(\sum_{i=1}^{12} P_i\right)} \cdot 100 \quad (2)$$

Where: p correspond to the monthly precipitation at month i and P_i to the annual precipitation.

In the MFI results, the precipitation erosivity climate was classified as follows: values below 60 (markedly low); values between 60 and 90 (low); values from 90 to 120 (moderate); values from 120 to 160 (high); values over 160 (very high) (CEC, 1992). In the PCI results, values below 10 imply uniform precipitation distribution, values from 11 to 20 indicate seasonality in precipitation distribution, and values above 20 correspond to climates with significant monthly variability.

Seasonal indices were also derived from the original precipitation data. The seasons in this study are defined as: autumn—October, November and December; winter—January, February and March; spring—April, May and June; and summer—July, August and September.

The annual and seasonal R, MFI and PCI time series were used to determine tendencies and to identify changes over the period 1950–2008. In order to analyse the direction of the relationship between the independent and the dependent variables (positive or negative) and the degree of significance of the trend (not significant, statistically significant at p -value < 0.05 and p -value < 0.01), a non-parametric test—the Spearman's rank correlation coefficient (R_s)—was used (Brunet *et al.*, 2007; de Luis *et al.*, 2009). This non-parametric test is considered robust against outliers and when data are not normally distributed. The statistical analysis was performed by using the SPSS (IBM SPSS software) (19.0 for Windows).

Relationships among large-scale geographic variables (latitude, longitude and elevation) and distribution and trend in annual and seasonal precipitation (amount, erosivity and concentration) were performed in order to check for specific spatial pattern in precipitation distribution and change tendencies.

RESULTS

Annual Precipitation, Precipitation Erosivity and Concentration: Spatial Variability and Trends

The average annual precipitation values for the study area varied from 433 to 968 mm y^{-1} , with a standard deviation higher than 200 mm (Table I). The maximum values occurred in the highest altitudes, namely, the mountainous areas of the Alentejo (the São Mamede mountain ridge) and the Algarve (Monchique and Caldeirão). Conversely, the lowest average quantities were found in the southeastern Alentejo, particularly on the left bank of the Guadiana River (Figure 2, left).

The average values for the MFI present an identical spatial precipitation pattern as seen in the Figure 2. The analyses of the spatial relationship between annual precipitation

and erosivity values show a high positive linear correlation ($R=0.946$; $p < 0.001$) and suggest that in southern Portugal, the geographical distribution of yearly precipitation erosivity is strongly influenced by the annual precipitation depth. Consequently, the MFI demonstrates high spatial variability, revealing higher values in mountainous areas of the Algarve and Alentejo and lower values in the eastern part of the Alentejo where the land surface elevation is about 200 m. According to the CEC (1992) classification, 17% of the stations were categorised as having low annual precipitation erosivity values, 64% as moderate, 16% as strong and 3% as very strong. No region was classified as having very low erosivity values.

In the analysis of the PCI classification, the entire study area has seasonal variation type, according to the Michiels & Gabriels classification (1996). Nevertheless, the highest values can be found in the south and southeastern part of the study area, whereas the lowest values are observed in the northern Alentejo region (Figure 2, right). On an annual scale, the PCI reveals a different behaviour from those observed for the annual amount of precipitation. In fact, the correlation found between these two variables was $R_s = -0.017$, and they are not statistically significant ($p > 0.001$).

On the basis of an analysis of Figure 3 (left), annual precipitation decreased in around 90% of the udometric stations of the study area, although this tendency is not statistically significant for the majority of the cases. The reduction in annual precipitation is statistically significant ($p < 0.05$) for 22% of the stations. Decreases in yearly precipitation are found in extensive areas of the Alentejo region, whereas the increases are mainly located in the Algarve and in the south-east Alentejo. Figure 3 (centre) illustrates the spatial trend in precipitation erosivity over the period 1950/1951–2007/2008, showing that precipitation

Table I. Mean, maximum, minimum and standard deviation of rainfall, PCI and MFI estimated for hydrological years 1950/1951 to 2007/2008

	Rainfall (mm)	PCI	MFI
Mean annual	624.5	17.3	107.7
Maximum	968.0	20.4	180.6
Minimum	432.8	15.9	80.9
Standard deviation	201.4	3.6	42.3

PCI, Precipitation Concentration Index; MFI, Modified Fournier Index.

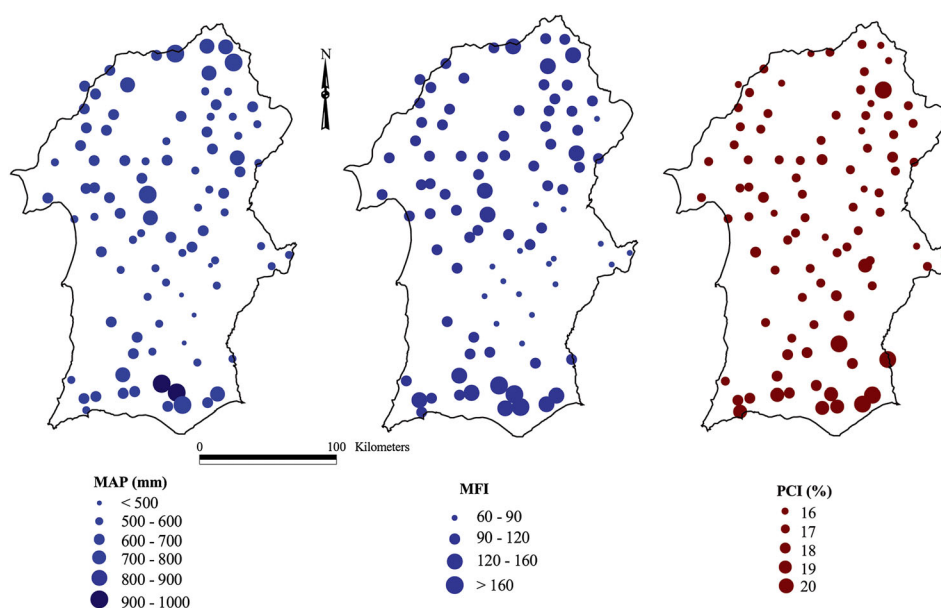


Figure 2. Spatial distribution of mean annual precipitation (MAP), Modified Fournier Index (MFI) and Precipitation Concentration Index (PCI) (between the hydrological years 1950/1951 and 2007/2008). This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

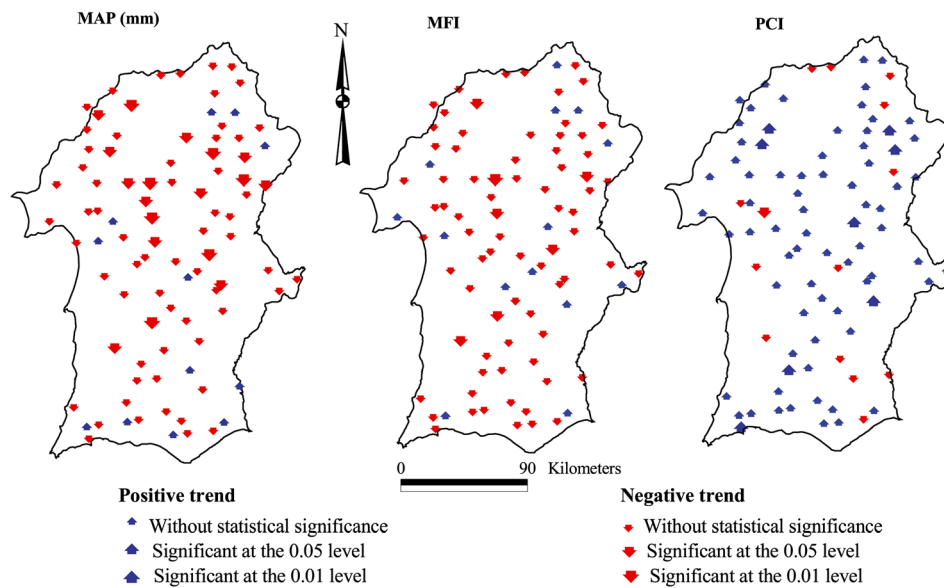


Figure 3. Trends on mean annual precipitation (MAP), Modified Fournier Index (MFI) and Precipitation Concentration Index (PCI) (between the hydrological years 1950/1951 and 2007/2008). This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

erosivity decreased in more than 80% of cases, following the negative trend registered by annual precipitation.

Concerning to the intra-annual distribution of precipitation in the 90 udometric stations studied (Figure 3, right), expressed as the PCI, a tendency towards the greatest irregularities in distribution throughout the year were detected in 85% of cases, although this positive trend is only statistically significant in 10% of the stations. This allowed the identification of some patterns not previously known. In fact, although the annual trend in precipitation amount is predominantly negative, the vast majority of udometric stations denote a more marked seasonality in the precipitation during the period 1950–2008.

Seasonal Precipitation, Precipitation Erosivity and Concentration: Spatial Variability and Trends

Table II shows the seasonal concentration of precipitation, MFI and PCI (mean \pm standard deviation). Around $43.1 \pm 44.3\%$ of the annual precipitation occurred in autumn (October, November and December), $32.2 \pm 27.4\%$ in winter (January, February and March), $18.9 \pm 219.4\%$ in spring (April, May and June) and $5.8 \pm 8.8\%$ in summer (July, August and

Table II. Seasonal distribution of rainfall, Modified Fournier Index and Precipitation Concentration Index (mean \pm standard deviation) estimated for the 1950/1951–2007/2008 period

	Autumn	Winter	Spring	Summer
Rainfall (%)	43.1	32.2	18.9	5.8
Standard deviation (%)	44.4	27.4	19.4	8.8
MFI (%)	49.7	35.7	12.1	2.5
Standard deviation	45.6	35.1	14.6	4.6
PCI (%)	48.2	35.5	13.3	3.1
Standard deviation	40.4	34.3	18.9	6.5

PCI, Precipitation Concentration Index; MFI, Modified Fournier Index.

September). This distribution reveals the strong seasonal contrasts in precipitation, typical of Mediterranean environments.




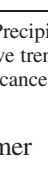
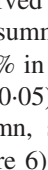

With regard to seasonal trends, opposite behaviour patterns were observed in the precipitation time trend: most time series shows positive trends for autumn (72.0% of the stations) and summer (88.8%), with an overall tendency towards lower precipitation in winter (100%) (Table III and Figure 4). For the spring season, an opposite tendency was registered in the precipitation time series: around half of the stations show a negative trend, whereas the other half denote a positive tendency. The decrease trend occurred mainly in the northmost region of Alentejo, whereas the increase tendency coincides with the western of Alentejo and the Algarve region.

The seasonal analysis revealed that winter is the season that experienced the most significant changes in precipitation, given that a negative trend was found for all the stations, and this diminution is statistically significant ($p < 0.05$) in 87% of cases. In the other seasons of the year, a small number of stations showed statistically significant trends when the Spearman's rho coefficient was used, namely 19% in summer and 3.3% in autumn.






Throughout the period analysed, autumn was the most water-erosive season, during which $49.7 \pm 45.6\%$ of the precipitation erosivity was concentrated, followed by winter, with an average of $35.7 \pm 35.1\%$, spring ($12.1 \pm 14.6\%$) and summer ($2.5 \pm 4.6\%$) (Table II). Analysing trends in precipitation erosivity, increases were found in autumn (100% of cases) spring (88.9%) and summer (91.1%), whereas a general decrease was recorded in winter (100%) (Table III and Figure 5).

Precipitation Concentration Index presents similar behaviour to seasonal precipitation amounts. Thus, the highest concentration occurred in autumn ($48.2 \pm 40.4\%$), followed by winter ($35.5 \pm 34.3\%$), spring ($13.3 \pm 18.9\%$) and

Table III. Trends in seasonal precipitation, Modified Fournier Index and Precipitation Concentration Index estimated between the hydrological years 1950/1951 and 2007/2008

Trends Precipitation	Autumn		Winter		Spring		Summer	
	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%
	3	3.3			1	1.1	8	8.9
	62	68.9			41	45.6	63	70.0
	25	27.8	12	13.3	48	53.3	10	11.1
			9	10.0				
			69	76.7				
	1	1.1					5	5.5
	8	8.9			2	2.2	11	12.2
	81	90.0			78	86.7	66	73.3
			3	3.3	10	11.1	8	8.9
			9	10.0				
			78	86.7				
	10	11.1			1	1.1	6	6.7
	37	41.1			6	6.7	12	13.3
	43	47.8			83	92.2	68	75.5
			2	2.2			4	4.4
			4	4.4				
			84	93.4				

PCI, Precipitation Concentration Index; MFI, Modified Fournier Index.

Positive trend:  No statistical significance,  Correlation significant at 0.05 level and  Correlation significant at 0.01 level; Negative trend:  No statistical significance,  Correlation significant at 0.05 level and  Correlation significant at 0.01 level.

summer ($3.1 \pm 6.5\%$) (Table II). An increase can be observed in precipitation concentration in autumn, spring and summer (in 100% of cases in autumn and spring and 95.6% in summer). These trends are statistically significant ($p < 0.05$) in 41.1%, 7.8% and 20.0% of the stations in autumn, spring and summer, respectively (Table III and Figure 6). During winter, an overall decline in PCI can be identified, which correlates with the decrease in average precipitation for this season.

Spatial Variability and Trends on Annual and Seasonal Precipitation, Concentration and Precipitation Erosivity: Correlations with Geographical Variables

In order to interpret the influence of certain geographic variables, such as altitude, latitude and longitude (which can represent the distance to the Portuguese west coast), on the precipitation parameters differentiated features can be observed (Table IV): elevation greatly affects the spatial patterns of mean annual precipitation ($r: 0.385$) and precipitation erosivity ($r: 0.338$), and the latitudinal gradients show a significant negative correlation with the intra-annual distribution of precipitation ($r: -0.704$), expressed by the PCI.

The results obtained also demonstrate that latitude and elevation were the main factors to explain the spatio-temporal changes in annual average of precipitation, showing a significant negative relationship ($r: -0.387$ and $r: -0.278$, respectively) (Table V). These results suggest that reduction in annual precipitation was more significant in the northmost areas and in the higher altitude stations of southern Portugal. Precipitation erosivity only shows a negative correlation with the elevation.

Analysing the relationship among long-term trends in the precipitation at seasonal level and the three geographical features, strong negative correlations were obtained between the latitude and the precipitation trend in winter ($r: -0.435$), spring ($r: -0.517$) and summer ($r: -0.718$). A negative relationship between elevation and precipitation trend in all the seasons was also detected. These correlations are significant at $p < 0.05$ level.

Concerning to the seasonal trends in precipitation erosivity, a negative inter-correlation between elevation and winter precipitation was found ($r: -0.317$), as well as between latitude and spring ($r: -0.344$) and summer ($r: -0.672$) trend precipitation erosivity. The relationship between longitude and seasonal trends in precipitation erosivity is only significant for summer time ($r: 0.212$).

With regard to seasonal trends in precipitation concentration, the latitude factor showed opposite behaviours: correlates positively with the precipitation concentration trend in autumn ($r: 0.252$) and negatively with precipitation concentration in spring ($r: -0.259$) and, mainly, in summer ($r: -0.638$). A positive inter-correlation between longitude and summer precipitation trend was also observed ($r: 0.216$).

DISCUSSION

Trend analysis for southern Portugal highlights certain opposite behaviour patterns for yearly precipitation, erosivity and precipitation concentration. Over the analysed period (1950–2008), decreases in annual precipitation and precipitation erosivity accompanied by increases in precipitation concentration predominated in southern Portugal, although

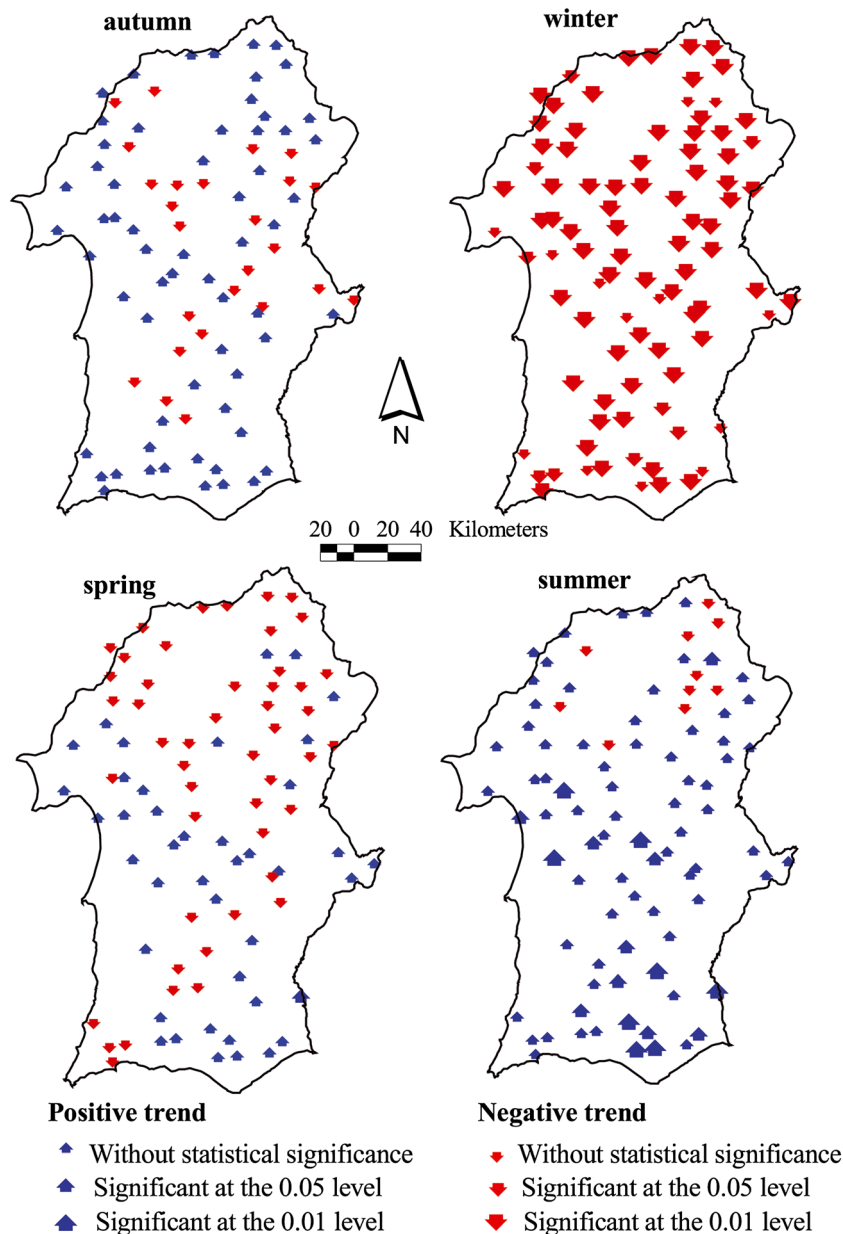


Figure 4. Trends in seasonal precipitation amount (1950/1951–2007/2008). This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

no generalised, significant trends for these variables have been detected. The results obtained agree with those obtained by Labajo & Piorno (2001), when the study of spatio-temporal variability in precipitation in Castilla and León during the period 1945–1996 was performed, in which they identified a declining trend in annual precipitation, although not statistically significant. De Luis *et al.* (2009, 2010) also found decreases in yearly precipitation, in the majority of Mediterranean Iberian Peninsula, when analysing the annual trends during the period 1951–2000. The same authors when analysed the MFI reported a generalised decrease trend in Mediterranean basins of the Iberian Peninsula. For southern Portugal, a negative long time trend was also observed in the vast majority of the stations.

Concerning to the PCI, a trend towards greater irregularity in intra-annual precipitation distribution was founded in

almost of the southern Portuguese territory. This tendency is also in agreement with the results obtained by de Luis *et al.* (2010) for the Mediterranean margin of the Spanish Iberian Peninsula.

The results obtained for seasonal trends revealed a much more homogenous pattern: a general increase in precipitation, erosivity and concentration was detected in autumn and summer, whereas an overall decrease in the same variables was registered in winter. These opposite seasonal trends suggest a redistribution of precipitation within the wet season (from October to March), associated with significant and spatially coherent trends identified on a monthly scale, particularly in October (mainly positive) and March (mainly negative), leading to a concentration of precipitation at the beginning of the season, which has become shorter. Previous researches highlighted a fall in precipitation in March in the

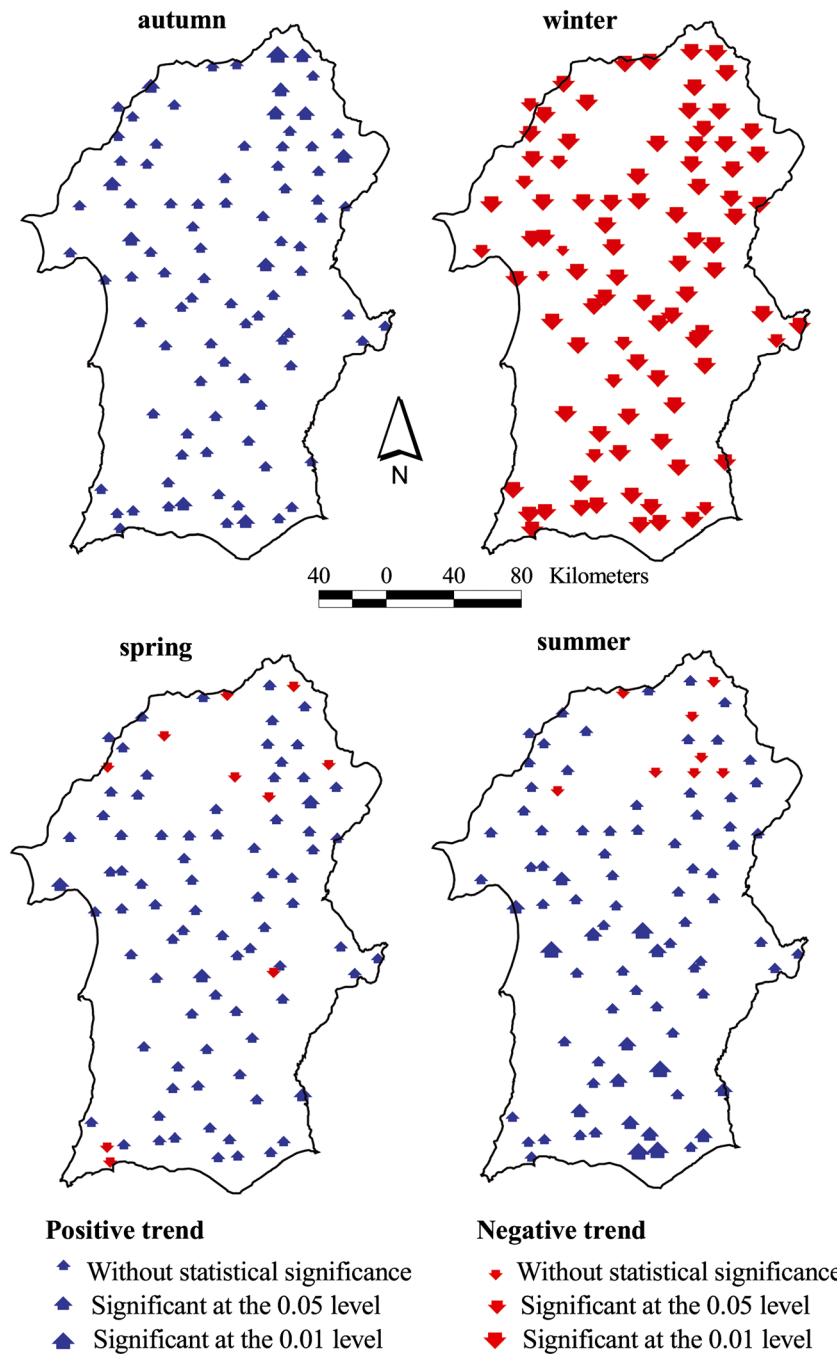


Figure 5. Trends in seasonal precipitation erosivity (1950/1951–2007/2008). This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

Iberian Peninsula, particularly in western areas (Paredes *et al.*, 2006; Trigo & da Camara, 2000; del Río *et al.*, 2010; González-Hidalgo *et al.*, 2010).

These changes are to a northward shift in the Atlantic storm track and to a negative trend in westerly and north-westerly cyclones, coupled with a strengthening of the North Atlantic Oscillation (NAO) (Paredes *et al.*, 2006). All of these aspects are also coincident with a negative cyclone frequency trend throughout the last four decades detected for March, with a low located in the area extending from the Azores archipelago in the mid-Atlantic Ocean to the west of Iberia (Paredes *et al.*, 2006). Sánchez-Lorenzo

et al. (2007) also detected a positive trend in anticyclonic activity and sunshine duration throughout Spain in March, which corroborates the decrease in precipitation.

It is accepted that precipitation variability results from various geographical variables such as latitude, longitude and topography. However, a small number of studies have studied the correlation between precipitation variation trends and the geographical variables, and most of them analysing the relationship between precipitation variation trends and altitude (Yang *et al.*, 2011). In southern Portugal, altitude is the most important variable that governs the spatial variations of mean annual precipitation and precipitation

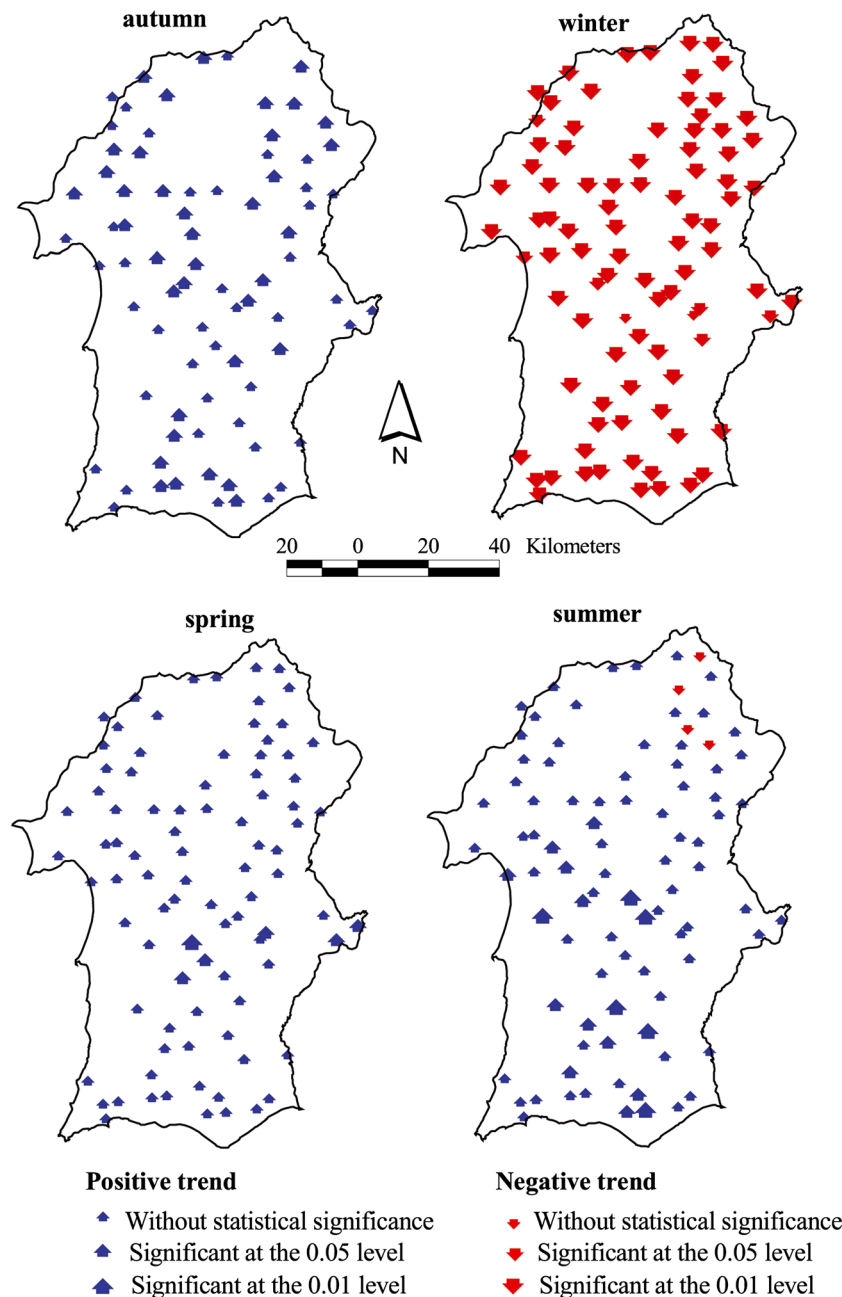


Figure 6. Trends in seasonal precipitation concentration (1950/1951–2007/2008). This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

erosivity. Although the founded correlations were statistically significant, altitude only explains 15% of the variance of mean annual precipitation. Conversely, the intra-annual distribution of precipitation is more powerfully influenced by the latitude. Latitude and altitude influence the spatial variability of annual and seasonal precipitation tendency, although latitude appears as major determinant. Thus, the udometric stations with stronger decreasing trends in precipitation are largely located in the northmost region of Southern Portugal and in the most elevated areas, which coincides with the mountains of Alentejo and Algarve regions.

These changes in precipitation (amount and inner-annual distribution) can origin important economic and environmental effects that could be greater than the climatic variation

itself. Variations in precipitation lead to degradation of the landscape: water content and soil humidity deficiency starts earlier in the hydrological year limiting ecosystem productivity (Qadir *et al.*, 2013); soil erosion becomes more severe after an extended, dry summer (Nunes *et al.*, 2010); forest fires are more frequent (Martin *et al.*, 2012); and in some areas, desertification processes can spread quickly (Salvati *et al.*, 2013).

These changes in precipitation patterns may be of particularly concern in Mediterranean areas where the dry season is very marked, most of the ground vegetation disappears and the soils remain bare during this period. The peak of runoff and sediment exported from soils generally happens at the end of the summer and beginning of autumn as a

Table IV. Correlations among spatial distribution and trends in annual precipitation (R), Modified Fournier Index and Precipitation Concentration Index and some geographical variables

	Spatial distribution			Trends		
	R	MFI	PCI	R	MFI	PCI
Altitude	0.385**	0.338**	-0.096	-0.278**	-0.249*	0.055
Latitude	0.110	-0.150	-0.704**	-0.387**	-0.206	0.188
Longitude	0.142	0.137	-0.004	0.059	0.016	-0.027

PCI, Precipitation Concentration Index; MFI, Modified Fournier Index.

***p*-value < 0.01. **p*-value < 0.05.

Table V. Correlations among spatial distribution and trends in seasonal precipitation (R), Modified Fournier Index and Precipitation Concentration Index and some geographical variables

		Autumn	Winter	Spring	Summer
R	Altitude	-0.210*	-0.257*	-0.208*	-0.247*
	Latitude	-0.133	-0.435**	-0.517**	-0.718**
	Longitude	0.092	0.089	0.071	0.238*
MFI	Altitude	-0.044	-0.317**	-0.054	-0.132
	Latitude	0.097	-0.088	-0.344**	-0.672**
	Longitude	0.003	0.063	-0.081	0.212*
PCI	Altitude	0.157	-0.205	0.149	-0.094
	Latitude	0.252*	-0.052	-0.259*	-0.638**
	Longitude	0.027	-0.041	-0.166	0.216*

PCI, Precipitation Concentration Index; MFI, Modified Fournier Index.

***p*-value < 0.01. **p*-value < 0.05.

consequence of the greater erodibility of the topsoil layer following a hot, dry season and because of the presence of sparse plant coverage (Nunes *et al.*, 2010, 2011). Dry soils are much more susceptible to erosion by water than moist soils, because the water infiltration compresses the air and breaks soil aggregates (Cerdà, 2000). This has negative impacts on soil porosity and infiltration. Thus, the soil particles can be transported easily by surface runoff (Sauerborn *et al.*, 1999). Very dry soils also increase soil water repellency and sudden runoff discharges and then high erosion rates (Bodí *et al.*, 2013).

During the dry season and at the beginning of the wet season (autumn), storms occur with high erosive consequences. In fact, several studies on soil erosion suggested that amount of precipitation and precipitation intensity are the main factors controlling sediment yield. Some authors stress the key role of precipitation intensity and energy (Prats *et al.*, 2013; Ziadat & Taimeh, 2013). Precipitation intensity related with raindrop sizes and the kinetic energy, highly influence soil erosion processes, and in the Mediterranean region, precipitation intensity can be very high during extremes precipitation events, and larger raindrops are only found during extreme precipitation events (Cerdà, 1997).

Although the high erosion rates occurring in Mediterranean Europe are attributed to the extreme irregularity and intensity of annual precipitation, land use/cover is also a key factor controlling soil erosion processes (Cerdà *et al.*, 2010; García-Ruiz, 2010; Nunes *et al.*, 2010).

Currently in the Alentejo Region, agricultural production is still based on the production of cereals and grazing cereal

(Roxo & Casimiro, 2004). The cultivation of cereals, which involves deep ploughing, heavy and frequent soil mobilisation generally in late summer and early autumn, disturbing the upper layer, breaks up the soil aggregate structure and decreases the quantity of barriers to overland flow (such as plant and litter cover), leading to a more efficient sediment transport (Nunes *et al.*, 2010).

Moreover, as extensive areas are cultivated with rainfed cereals, the adverse weather conditions of some years during the crops growing season leave the soil bare for a longer period, condition that favour runoff and soil erosion. According to Roxo & Casimiro (2004), overgrazing situations are common in Alentejo. It is generally accepted that overgrazing affects negatively soil surface, reduces ground cover and accelerates erosion by runoff. In both activities, the soils become more exposed to erosion because the reduced vegetation cover means less protection from raindrop impact during precipitation events. The inadequate soil conservation practices associated to an intense and heavy episodic precipitation event occurred in 5 November 1997 generate flash floods and substantial properties damage because of sediment transport in the Alentejo Region (Rebelo & Ganho, 1998). Eleven deaths were recorded as a consequence of this event.

Even though the southern region of Portugal had the lowest total for burnt areas over the last three decades, some large forest fires occurred in the mountainous areas of Alentejo and Algarve, where the highest precipitation erosivity is recorded. The occurrence of forest fires disrupts the bio-geophysical balance of a hillslope and triggering

several erosive processes, leading to serious damages in the land degradation and also in the human infrastructures. As soil becomes less stable because of lack of vegetation, exceptionally high precipitation events can create a greater potential for severe flooding and intense erosive processes. Rebelo & Ganho (1998) studied the hydro-geomorphic effects of a violent storm occurred in 26 October 1997 in the Monchique mountain, which caused serious damage in the Monchique village (at least 11 families were dislodged, and several public infrastructures were also affected). The authors related the hydro-geomorphic consequences with the high amount and intensity of precipitation but also with a forest fire that occurred 2 years ago and destroyed the vegetal cover leaving large areas exposed to heavy precipitation.

The depletion of vegetation and other ground cover due to wildfire reduces the rates of precipitation intercepting and stored by the canopy, and changes in physical and hydrologic properties of soils increase runoff rates and the availability of loose sediment, that is, increase erosion (Cerdà & Lasanta, 2005; Ferreira *et al.*, 2008; Shakesby, 2011). These severe erosion processes not only reinforce the sediment transport into rivers but also increase the pollutants that reach the water supply systems and affecting the fresh water quality.

CONCLUSION

Although decrease in annual precipitation amounts and erosivity and an increase in the precipitation concentration are the global tendency in the area studied, during the period analysed, few stations show significant time trends when using the Spearman's rank correlation coefficient. The decrease in annual precipitation amount and erosivity is partly counterbalanced by an increase in its concentration. Thus, the recorded decrease in precipitation should not be interpreted as a decline in the potential risk of soil erosion and desertification. Significant negative trends could be confirmed during winter season for most of the stations, whereas for autumn and summer, although increases in precipitation and precipitation erosivity prevailing, only few stations showed statistically significant trends.

The estimation of MFI at annual and, particularly, at seasonal time scales was found to be very important in determining the potential of precipitation to cause erosion, once they provide information about its long-term variability. Thus, the slight increase in precipitation erosivity during the autumn, the period when water erosion processes are at its maximum, combined with inadequate land use management and the deterioration or destruction of the plant cover can significantly increase the soil erosion risk, as well as the risk of desertification that threatens substantial areas of southern Portugal.

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