ORIGINAL PAPER

# Rainfall and river flow trends using Mann–Kendall and Sen's slope estimator statistical tests in the Cobres River basin

Richarde Marques da Silva · Celso A. G. Santos · Madalena Moreira ·
João Corte-Real · Valeriano C. L. Silva · Isabella C. Medeiros

**Abstract** The main objective of this study is to obtain a better understanding of the spatial and temporal variability and trends of rainfall and river flow in the Cobres River basin, southern Portugal, using statistical tools. The present study is focused on the analysis of the trends in annual precipitations and river flow at a regional scale over 40 years (1960–2000). Datasets of daily precipitation recorded in eight rainfall stations and three river flow stations were analyzed. The nonparametric Mann–Kendall and Sen's methods were used to determine whether there was a positive or negative trend in rainfall data with their statistical significance. A detailed statistical analysis applied to the river flow and rainfall time series of all gauges indicates that rainfall is highly temporally variable and there is a decrease in the annual rainfall amount for the period studied (1960–2000). Thus, there are signs of significant rainfall reduction in the basin, and in fact, some rain gauges show a small rainfall increase during the recent decades. The annual river flow variation has a cyclic behavior with a period length of approximately 10 years. The results seem integrated to the global and European continental scale findings: Decreasing trends are dominant for almost all indices; most of the calculated slopes are statistically insignificant; the distribution of positive and negative slopes in the area is extremely irregular; and the changes in basin are more significant compared to other studies.

R. M. da Silva
Department of Geosciences, Federal University of Paraíba, João Pessoa, PB 58051-900, Brazil

C. A. G. Santos (✉) · V. C. L. Silva · I. C. Medeiros
Department of Civil and Environmental Engineering, Federal University of Paraíba, João Pessoa, PB 58051-900, Brazil
e-mail: celso@ct.ufpb.br

M. Moreira · J. Corte-Real
Institute of Mediterranean Agrarian and Environmental Sciences (ICAAM), Group Water, Soil and Climate, University of Évora, Núcleo da Mitra, 7002-774 Évora, Portugal

J. Corte-Real
Research Unit Dreams, Department of Aeronautics and Transports, University Lusófona of Humanities and Technologies, Lisbon, Portugal

Ⓐ Springer

# 1 Introduction

Trend changes in climate are the most important topic in climatic research of the last few decades and are still one of the main challenges nowadays. Moreover, large regions in the world are still poorly gauged due to accessibility difficulties, especially in the semiarid regions. Global warming, and therefore changes in annual precipitation, has attracted the attention of the researchers in different regions of the world. One of the most significant consequences of the identified global warming would be an increase or decreasing in the magnitude and frequency of annual precipitation (Croitoru et al. 2013; Santos and Morais 2013). Changes in annual precipitation have been identified in many studies conducted at local, regional or global scales (Gocic and Trajkovic 2013; Hamlaoui-Moulai et al. 2013; Silva et al. 2013).

The knowledge of the climatic behavior especially in semiarid regions is required to optimize the management of water resources. In this study, the climate variability is directly related to water resources that are of a high socioeconomic and environmental significance. To optimize the hydraulic constructions, one needs to know the climatic behavior of the concerned region the role of which is very important in the water resource management in short, medium and long term.

A comprehensive understanding of precipitation and its distribution in time and space is essential for the correct and cost-effective design of many engineering structures. Information on the distribution of rainfall is important in a variety of applications, such as design of rain gauge networks, hydrological forecasting and watershed modeling. Factors that affect rainfall distribution include wind speed and direction, air temperature, humidity, air pressure, elevation, slope, topographic barriers and orientation, continentality and the direction and frequency of jet streams (Celleri et al. 2007). In recent years, various studies have been done for detecting possible climate trends and changes across the world, analyzing changes in temperature, precipitation and runoff (Yunling and Yiping 2005; Zarghami et al. 2011; Tramblay et al. 2012; Yang et al. 2014).

The rainfall regime in Portugal is highly seasonal, being clearly Mediterranean with a rainy season in the autumn and winter (November–March) and an extremely dry summer. The river flows are also very irregular, with severe droughts contrasting with surprisingly high flood discharges. Such patterns are the least pronounced in the northwest and most pronounced in the southeast (Ramos and Reis 2002). More recently, some studies have put into evidence that besides the North Atlantic Oscillation, there are other large-scale climatic modes, namely the Scandinavian pattern and the eastern Atlantic pattern, that also contribute significantly to the Portugal and Spain rainfall regime (e.g., Comas-Bru and McDermott 2014; Kutiel and Trigo 2014). However, the climate variability has not been greatly investigated in southern Portugal. Furthermore, it should be noted that some of these patterns do not impinge the same impact on climate throughout long periods. In particular, the correlation between North Atlantic Oscillation and rainfall in western Portugal is not constant over time (e.g., Trigo et al. 2004; Vicente-Serrano and López-Moreno 2008). The modification of the natural hydrological regime of the Guadiana River in the last four decades has caused problems of water scarcity near the Portuguese–Spanish border. These changes are caused by a combination of the increase in water mobilization and the increase in the volume of water used for agriculture in Spain (Brandão and Rodrigues 2000).

Several works have dealt with changes in various aspects of the rainfall regime over Portugal and Spain, including average annual and monthly precipitation (de Lima et al. 2010, 2013). Moreover, a number of other publications focused in changes of daily extreme precipitation, either with predefined thresholds (e.g., Costa and Soares 2009) or using percentiles (e.g., Gallego et al. 2011).

The effects of climate change on river flow are complex and are presently receiving research scrutiny. In a comprehensive study of global river flow, Milly et al. (2005) project a 10–40 % increase in stream river flow in selected regions of Africa, South America and Eurasia by 2050. Model results from the same study predict a 10–30 % decrease in river flow in selected regions of Africa and the Middle East as a result of global climate change. Therefore, there is a prevailing notion that as climatic warming continues there will be an intensification of the hydrological cycle that can lead to more severe storms, floods and droughts (Rose 2009).

The Portuguese southern rivers have specific discharges 6–7 times lower than those of the northwest. The rivers of the south are mostly intermittent and show great irregularity: The flow in wetter years may be 100–240 times higher than that in the driest years. During the last decades, they suffer severe droughts that last about 6 months and very large flood peaks that are 200–300 times the average annual discharge (Ramos 1994). However, few studies in southern Portugal have analyzed the variability of precipitation and river flow for a period greater than 40 years. Thus, the purpose of this present study is to analyze the space–time rainfall and river flow variability in the Cobres River basin. Given the extreme variability noted in the southern portion of Portugal, this paper examines the space–time variability of rainfall and tendencies of river flow in the Cobres River basin, which drains for Guadiana river, the main water course of southern Portugal.

## 2 Materials and methods

### 2.1 Study area description

This study is carried for Cobres River basin situated in southern Portugal. The basin is semiarid, middle-sized with area of 1194 km² and located in the Alentejo Province of southern Portugal (37°28′N–37°57′N, 8°10′W–7°51′W (Fig. 1), an area suffering from desertification (Bathurst et al. 1996). It is a region of relatively low relief, with the elevation varying from 103 to 308 m above sea level. The climate in this region is characteristically Mediterranean and Continental, with moderate winters and hot and dry summers, high daily temperature range, and a weak and irregular precipitation regime; mean annual precipitation of rain gauge stations in the region varies between 400 and 900 mm, with around 50–80 rainy days per year (Ramos and Reis 2002). The mean annual potential evapotranspiration (PET) is around 1300 mm. Figure 1 also shows the spatial distribution of soil types and stations in the study area.

### 2.2 Space–time tendencies for rainfall and river flow

The nonparametric Mann–Kendall criterion, originally due to Mann (1945) and rephrased by Kendall (1975), was chosen to test randomness against trend because this procedure has the advantage of not assuming any special form for the data distribution function, while having a power nearly as high as their parametric competitors; for these reasons, it is
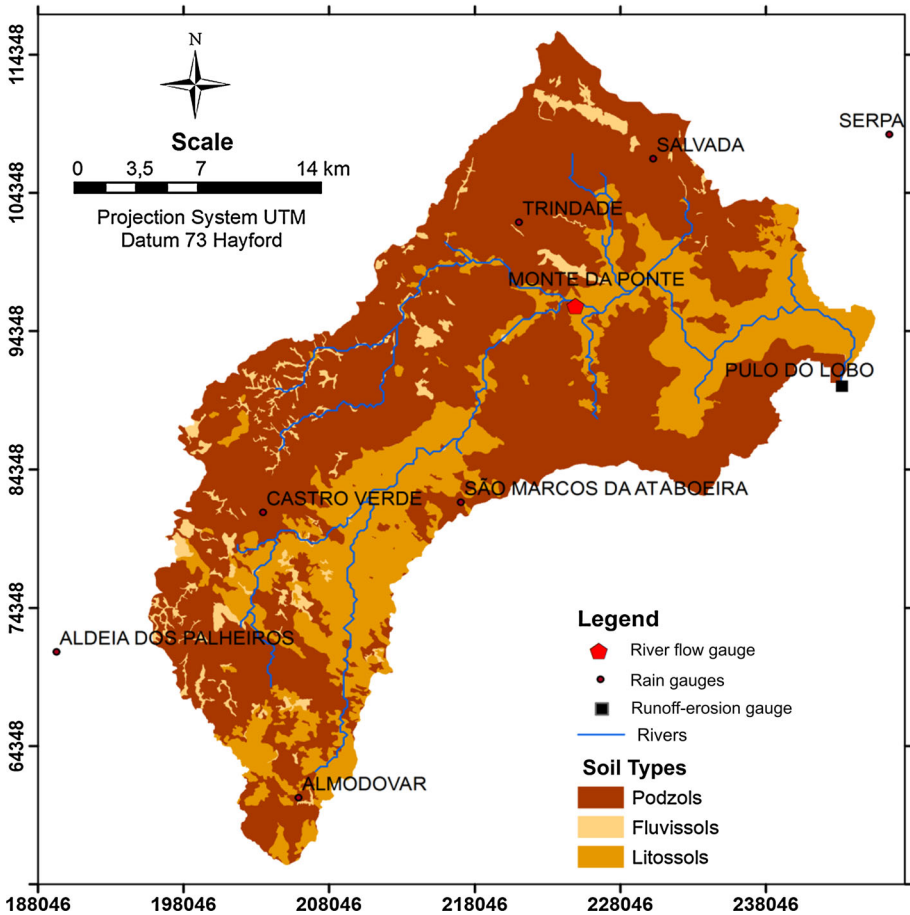
**Fig. 1** Spatial distribution of soil types and stations in the study area

highly recommended by the World Meteorological Organization (Mourato et al. 2010; Nalley et al. 2013).

Detection of trend is a complex subject because of characteristics of data, and the main idea of trend analysis is to detect whether values of data are increasing, decreasing or trendless over time (Kisi and Ay 2014). In this study, nonparametric tests have been applied for trend detection (Gocic and Trajkovic 2013). Parametric trend tests are more powerful than nonparametric ones, but they require data to be independent and normally distributed. On the other hand, nonparametric tests require only that the data are independent and can tolerate outliers in the data. In this study, daily data from eight rainfall and three river flow gauges for the period 1960–2000 (Table 1), obtained from the *Sistema Nacional de Informação de Recursos Hídricos*, available in http://www.snirh.pt, were used to study the seasonality and trends on an annual basis. The spatiotemporal trends of rainfall and river flow in the basin were analyzed by the normalized rainfall, Mann–Kendall (Mann 1945; Kendall 1975) and the Sen's slope tests. Their efficiency and power were already demonstrated for similar applications (Hamlaoui-Moulai et al. 2013; Silva et al. 2013).

**Table 1** Geographic characteristics of the rain gauges used in the study

| Stations | Type | Period of data | Latitude (E) | Longitude (N) | Elevation (m.a.s.l.) |
|---|---|---|---|---|---|
| Almodovar | Rainfall | 1960–2000 | 60,592 | 205,953 | 286 |
| Castro Verde | Rainfall | 1960–2000 | 81,240 | 203,510 | 217 |
| Salvada | Rainfall | 1960–2000 | 106,797 | 230,322 | 185 |
| Serpa | Rainfall | 1960–2000 | 108,565 | 246,521 | 209 |
| São Marcos da Ataboeira | Rainfall | 1960–2000 | 81,966 | 217,104 | 182 |
| Trindade | Rainfall | 1960–2000 | 102,222 | 221,085 | 172 |
| Aldeia dos Palheiros | Rainfall | 1960–2000 | 71,143 | 189,316 | 210 |
| Aljustrel | Rainfall | 1960–2000 | 100,108 | 197,000 | 193 |
| Entradas | River flow | 1972–1990 | 88,664 | 209,927 | 167 |
| Monte da Ponte | River flow | 1960–1988 | 96,669 | 224,106 | 123 |
| Pulo do Lobo | River flow | 1947–1989 | 93,073 | 244,025 | 113 |

### 2.3 Mann–Kendall test

The Mann–Kendall statistical test has been frequently used to quantify the significance of trends in hydrometeorological time series (Subash et al. 2011; Yue et al. 2002; Tabari and Marofi 2011; Duhan and Pandey 2013; Silva et al. 2013). The Mann–Kendall (Mann 1945; Kendall 1975) is calculated as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(x_j - x_i) \tag{1}$$

where $n$ is the number of data points, $x_i$ and $x_j$ are the data values in the time series $i$ and $j$ ($j > i$), respectively, and $\text{sgn}(x_j - x_i)$ is the sign function as:

$$\text{sgn}(x_j - x_i) = \begin{cases} +1 & \text{if } x_j - x_i > 0 \\ 0 & \text{if } x_j - x_i = 0 \\ -1 & \text{if } x_j - x_i < 0 \end{cases} \tag{2}$$

The variance is computed as:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{P} t_i(t_i - 1)(2t_i + 5)}{18} \tag{3}$$

where $n$ is the number of data points, $P$ is the number of tied groups, the summary sign ($\sum$) indicates the summation over all tied groups, and $t_i$ is the number of data values in the $P$th group. If there are not the tied groups, this summary process can be ignored (Kisi and Ay 2014). A tied group is a set of sample data having the same value. In cases where the sample size $n > 30$, the standard normal test statistic $Z_S$ is computed using Eq. (4):

$$Z_S = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}}, & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}}, & \text{if } S < 0 \end{cases} \tag{4}$$

Positive values of $Z_S$ indicate increasing trends while negative $Z_S$ values show decreasing trends. Testing trends is done at the specific $\alpha$ significance level. When $|Z_S| > Z_{1-\alpha/2}$, the null hypothesis is rejected and a significant trend exists in the time series. $Z_{1-\alpha/2}$ is obtained from the standard normal distribution table. In this study, significance levels $\alpha = 0.01$ and $\alpha = 0.05$ were used. At the 5 % significance level, the null hypothesis of no trend is rejected if $|Z_S| > 1.96$ and rejected if $|Z_S| > 2.576$ at the 1 % significance level.

## 2.4 Normalized rainfall

The normalized departure of any meteorological variable can be defined by (Junker et al. 2007):

$$N_p = (X - \mu)/\sigma \tag{5}$$

where $N_p$ is normalized variable, $X$ is the value of the variable, $\mu$ is the mean monthly data of station and $\sigma$ is the standard deviation for each station.

## 2.5 Sen's slope estimator

Sen (1968) developed a nonparametric procedure for estimating the slope of trend in a sample of $n$ pairs of data. The Sen's method uses a linear model to estimate the slope of the trend, and the variance of the residuals should be constant in time calculated as:

$$Q_i = \frac{X_j - X_k}{j - K} \; for \; i = 1, \ldots, n \tag{6}$$

where $X_j$ and $X_k$ are the data values at times $j$ and $k$ ($j > k$), respectively. If there is only one datum in each time period, then $N = n(n - 1)/2$, where $n$ is the number of time periods. If there are multiple observations in one or more time periods, then $N < n(n - 1)/2$. The $n$ values of $Q_i$ are ranked from smallest to largest, and the median of slope or Sen's slope estimator is computed as:

$$Q_{med} = \begin{cases} Q_{[(n+1)/2]}, & \text{if n is odd} \\ \dfrac{Q_{[n/2]} + Q_{[(n+2)/2]}}{2}, & \text{if n is even} \end{cases} \tag{7}$$

The $Q_{med}$ sign reflects data trend, while its value indicates the steepness of the trend. To determine whether the median slope is statistically different than zero, one should obtain the confidence interval of $Q_{med}$ at specific probability. The confidence interval about the time slope (Gilbert 1987) can be computed as follows:

$$C_\alpha = Z_{1-\alpha/2}\sqrt{Var(S)} \tag{8}$$

where $Var(S)$ is defined in Eq. (3) and $Z_{1-\alpha/2}$ is obtained from the standard normal distribution table. In this study, the confidence interval was computed at two significance levels ($\alpha = 0.01$ and $\alpha = 0.05$). Then, $M_1 = (n - C_\alpha)/2$ and $M_2 = (n + C_\alpha)/2$ are computed. The lower and upper limits of the confidence interval, $Q_{min}$ and $Q_{max}$, are the $M_1$th largest and the ($M_2 + 1$)th largest of the $n$-ordered slope estimates (Gilbert 1987). The slope $Q_{med}$ is statistically different than zero if the two limits ($Q_{min}$ and $Q_{max}$) have similar sign. Sen's slope estimator has been widely used in hydrometeorological time series (El Nesr et al. 2010; Gocic and Trajkovic 2013).

These methods offer many advantages that have made them useful in analyzing atmospheric chemistry and climatological data. Missing values are allowed, and the data need not conform to any particular distribution.

## 3 Results and discussion

### 3.1 Rainfall trends

In this section, the results of the trend analysis using Mann–Kendall and Sen's tests are presented. The rainfall data from eight rainfall stations are used, which had good quality datasets with reliable data and adequate record length. Figure 2 shows annual normalized rainfall for Cobres River basin between 1960 and 2000. It can be observed that only the annual normalized precipitation depth of 4 years (1963, 1969, 1989 and 1997) were above one; thus, those years are considered rainy for the region. The years 1973, 1980, 1981, 1982, 1994 and 1998 showed normalized precipitation depths below −1 and so can be classified as very dry years for the basin. The space–time rainfall variability obtained for Serpa, São Marcos da Ataboeira, Trindade and Aljustrel rain gauges was relatively high (i.e. relative standard deviations [(standard deviation/mean) × 100 %] were typically < 33 %). The results show modest temporal trends, but strong and coherent spatial trends in the rainfall data from Cobres River basin. In sum, the findings agree with work in other semiarid regions (Lazaro et al. 2001; Batisani and Yarnal 2010; Ramos and Durán 2014), which highlight intra- and interannual variability of rainfall. Although annual rainfall variations of about 100 mm would be considered low in some climate regions, such variations could mean the difference between a good harvest and complete crop failure in semiarid environments.

Figure 3 presents rainfall anomaly and mean annual rainfall for Cobres River basin between 1960 and 2000. The average annual rainfall within the study area is 549 mm, in which the highest value was 900 mm in 1989 and the lowest one was 338 mm in 1998. Observing the decades, separately, it appears that the smallest average rainfall depths occurred in 1960, 1963, 1989, 1996 and 1997, i.e., 750–900 mm. The large annual variability of precipitation observed in this study has been shown to be affected by a few large-scale patterns of atmospheric circulation variability particularly between 1960 and 2000 (e.g., Espírito Santo et al. 2013; Kutiel and Trigo 2014). These studies have pointed out the strong influence of the North Atlantic oscillation (NAO) upon the variability of
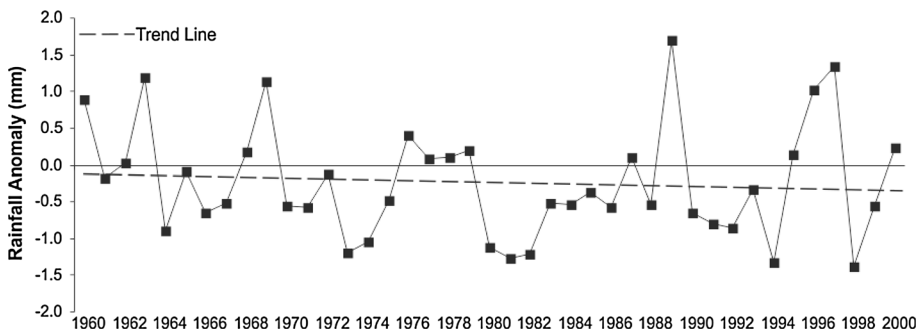


**Fig. 2** Annual normalized rainfall for Cobres River basin between 1960 and 2000
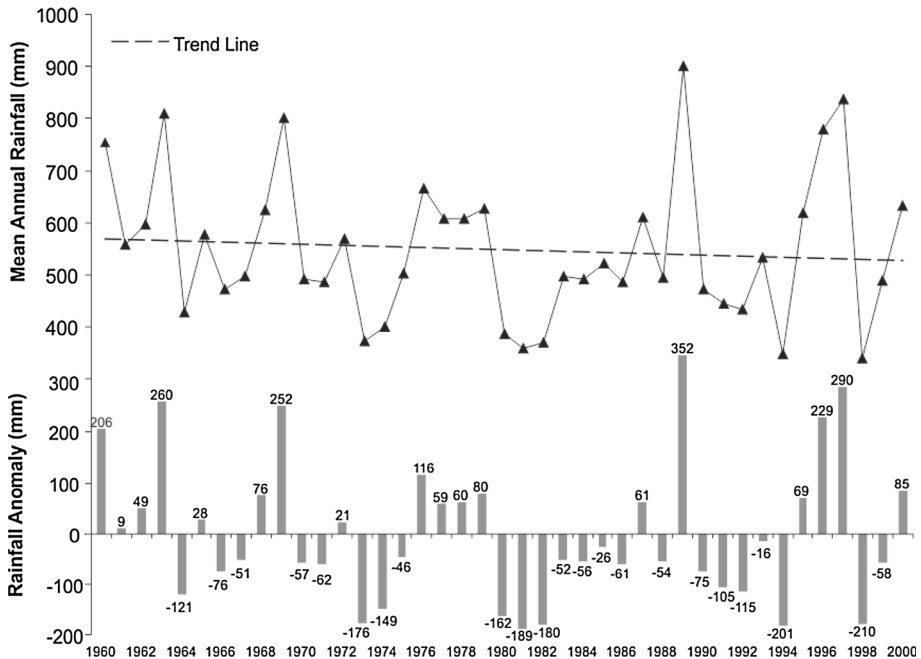
**Fig. 3** Rainfall anomaly and mean annual rainfall for Cobres River basin between 1960 and 2000

precipitation in Portugal, especially as regards the winter rainfall, which dominates the precipitation regime of Portugal (e.g., Hurrell and van Loon 1997; Trigo and daCamara 2000; Trigo et al.2002, 2004; Fragoso and Gomes 2008). The present results show that rainfall has been not decreasing in the Cobres River basin, even showing high variability on annual bases. These results suggest that climate change is not affecting the decrease of rainfall, but only in variability spatiotemporal of rainfall in the basin.

Spatial distribution of weather stations with increasing, decreasing and no trends for the annual data series during the period 1960–2000 is presented in Fig. 4. The tests of Sen and Mann–Kendall were also applied to the data series of annual rainfalls of the eight selected stations. One rain gauge did not show any significant trend (São Marcos da Ataboeira). Only two rain gauges, Salvada in the northeastern zone and Almodovar in the southeastern zone of the studied domain, present a significant increasing trend at 5 % significance level (Fig. 4). These stations are located at isolated points within the basin. Thus, this result does not indicate any specific regional behavior. The test revealed that the other series present important positive or negative variations, indicating the alternating presence of very rainy and very dry periods. The intersection point between both curves (forward and backward) within the confidence interval indicates approximately the change point that corresponds to the break date.

Figure 5 shows annual time series and trend statistics of annual total rainfall during 1960–2000. The results show that an abrupt change (decrease of rainfall) within the time series is mainly observed from the end of the 1980s up to the beginning of the 2000s. For five rain gauges, the beginning of the trend was detected between 1980 and 1995 so that two stations lead to a very significant decreasing trend between periods studied; the other ones appear to be stationary. The analysis shows that Castro Verde and Aljustrel were rain gauges with higher $Q_{med}$ ranged between $-3.686$ and $-6.452$, respectively.
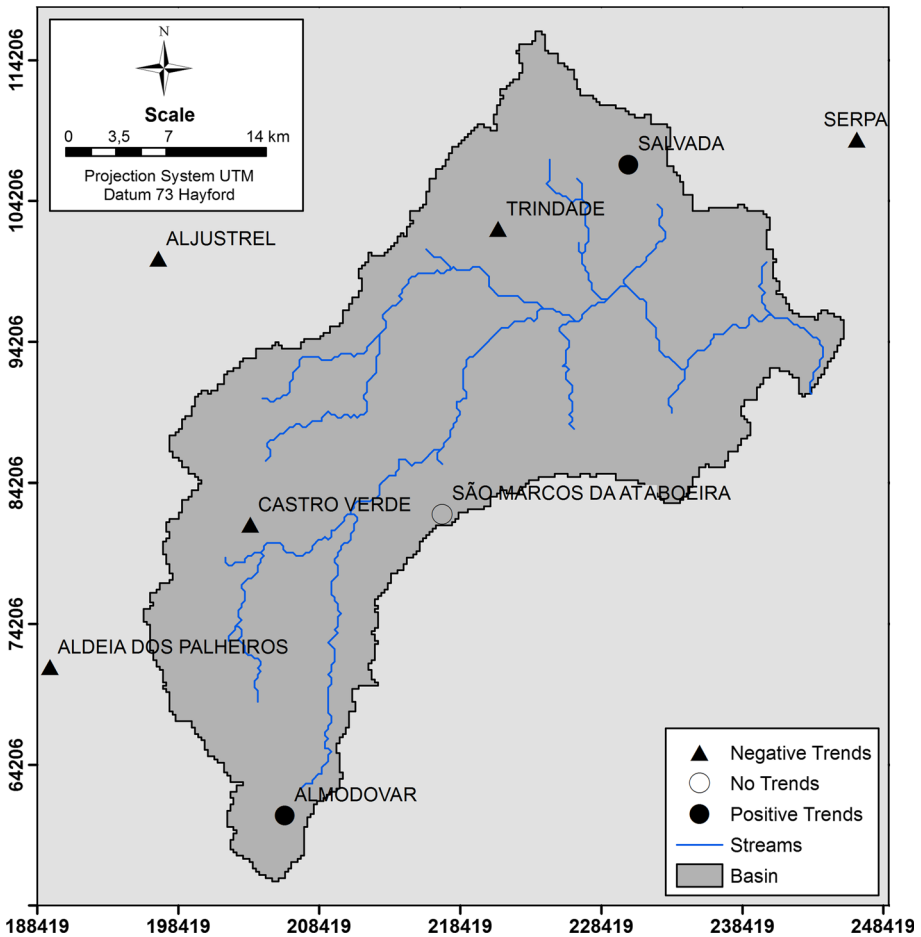
**Fig. 4** Trends in annual total rainfall during 1960–2000 detected by the Mann–Kendall test

Table 2 shows the results of Sen's slope estimator ($Q_{med}$) and Mann–Kendall ($Z_s$) of the eight stations, with statistically significant (1, 5 and 10 % levels) increasing or decreasing trends according to the Mann–Kendall test in annual and seasonal precipitation series. According to these results by Sen's slope estimator, the significant decreasing trend in annual precipitation series was detected at the Castro Verde, Serpa, Trindade, Aldeia dos Palheiros and Aljustrel rain gauges, while other stations had positive or no trends. For Mann–Kendall test, the significant increasing trend in annual precipitation series was detected at the Almodovar and Salvada, and no trend at the São Marcos da Ataboeira, while other stations had negative trends.

Figure 6a, b shows the spatial analysis of precipitation series on annual and seasonal basis for entire time period 1960–1980 (Fig. 6a) and after the change point 1980–2000 (Fig. 6b). Indeed, the results can deduce the existence of a rainfall deficit in the central and northwestern zones from the beginning of the 1960s and is accentuated during the 1960s and 1980s by its extension to the whole region (Fig. 6a). It is clear that over the considered region, there has been a slight decrease in rainfall, particularly after 1980s. After 1980s, the
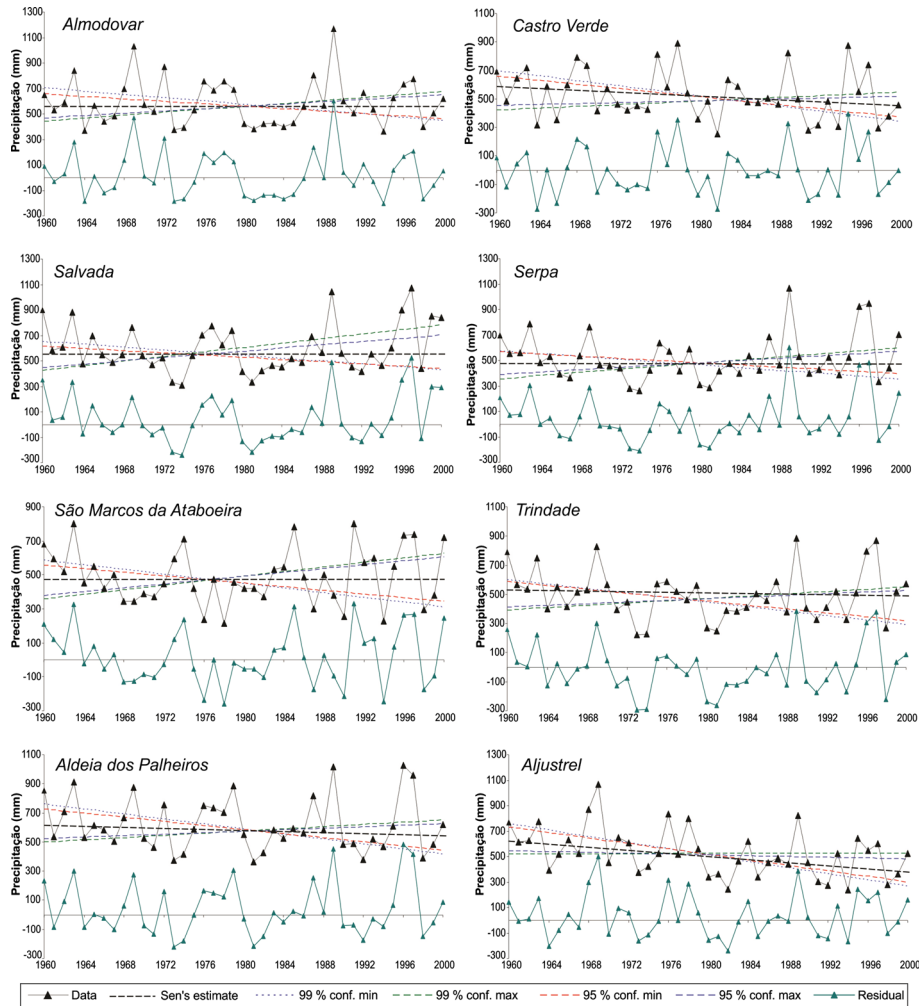
**Fig. 5** Annual time series and trend statistics of annual total rainfall during 1960–2000

**Table 2** Results of the statistical tests for seasonal and annual rainfall over the period 1960–2000

| Rain gauges | $Z_s$ | $Q_{med}$ | $Q_{min99}$ | $Q_{max99}$ | $Q_{min95}$ | $Q_{max95}$ |
|---|---|---|---|---|---|---|
| Almodovar | 0.03 | 0.19 | −6.36 | 5.86 | −4.79 | 4.52 |
| Castro Verde | −1.27 | −3.69 | −8.87 | 3.15 | −7.16 | 1.59 |
| Salvada | 0.03 | 0.09 | −5.52 | 8.87 | −4.37 | 6.34 |
| Serpa | −0.26 | −0.58 | −5.49 | 6.07 | −4.27 | 4.495 |
| São Marcos da Ataboeira | 0.00 | 0.01 | −6.88 | 6.73 | −5.33 | 5.665 |
| Trindade | −0.81 | −1.16 | −7.73 | 3.91 | −6.73 | 2.85 |
| Aldeia dos Palheiros | −0.95 | −2.16 | −8.56 | 3.80 | −7.04 | 2.55 |
| Aljustrel | −2.53 | −6.45 | −12.27 | 0.11 | −10.76 | −1.59 |

**(a)**                                                    **(b)**
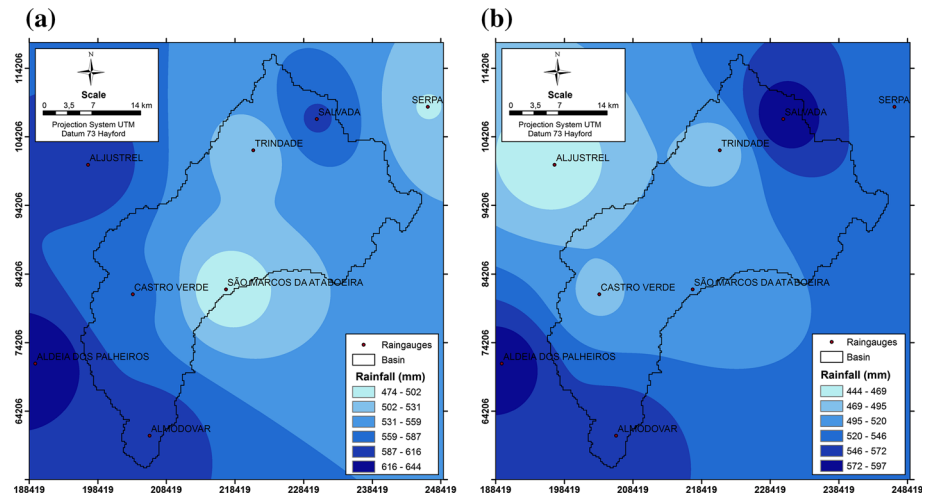


**Fig. 6** Spatial distribution of precipitation during **a** 1960–1980, and **b** from 1980 to 2000

results show the existence of a rainfall deficit in the central and northeastern zones (Fig. 6b). Trends can be detected using Sen's and Mann–Kendall's tests. However, these tests cannot detect more than one break date. This represents the drawback of these tests while investigating rainfall time series which could have multiple increasing and decreasing trends and/or breaks, especially for long series. In addition, a limitation is due to the difficulty in interpreting the results at a regional scale, mainly when the number of used stations is not very large.

As expected, spatially, the trends for the 40 years of the study period are even clearer than the temporal variation. The interpolated linear slopes for the annual rainfall from 1980 to 2000 indicated lowest values of rainfall in the basin when compared with prior period (1960–1980). Figure 7a, b presents the spatial distribution of Mann–Kendall test for period between 1960 and 2000 (Fig. 7a), and results of Sen's slope test for period between 1960 and 2000 (Fig. 7b).

As shown, the significant decreasing trends in annual rainfall in the basin were detected from the period, with decreasing for the annual data series for rain gauges located in the central and northwestern parts of Cobres River basin. The results show a negative slope almost all over the entire study area. Only small regions in the north, central and south showed near-zero or positive slopes in booth statistic tests. The slopes decreased from west to east in basin, inferred that annual precipitation trends were decreased from western to eastern in basin. The rainfall had the significant decreasing trends in the northern part of basin. Since the precipitation patterns are critical for the economic activities in the study area, it would be important to perform spatial patterns for entire time period and after the change point. The decrease in slope after the change point is larger (which decreased up to −40 mm).

### 3.2 River flow trends

For better understanding of the river flow regime, the descriptive statistics of the annual river discharge time series at the selected stations were computed (Table 3). The analyses indicated that Pulo do Lobo and Monte da Ponte stations with the average annual river discharge
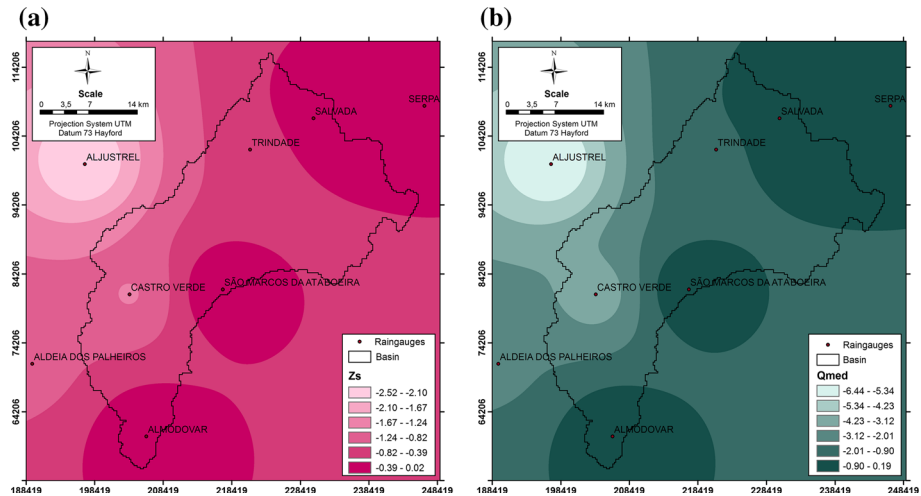
**(a)**                                                    **(b)**



**Fig. 7** Spatial distribution of **a** Mann–Kendall test for period between 1960 and 2000, and **b** results of Sen's slope test for period between 1960 and 2000

**Table 3** Descriptive statistics of the annual river discharge series at the study stations

| Stations | Mean (m$^3$) | SD | DM | Max | Min | CV (%) | $Z_S$ | $Q_{med}$ |
|---|---|---|---|---|---|---|---|---|
| Entradas | 31.86 | 23.33 | 17.84 | 88.11 | 0.05 | 73.23 | 1.37 | 1.27 |
| Monte da Ponte | 294.42 | 174.78 | 148.10 | 600.42 | 0.66 | 59.37 | −0.09 | −0.47 |
| Pulo do Lobo | 2709.36 | 2053.94 | 1777.19 | 8127.29 | 26.42 | 75.81 | −1.07 | −22.13 |

*SD* standard deviation, *DM* mean deviation, *CV* coefficient of variation

of 2709.36 and 294.42 m$^3$ had the highest annual water yields. In contrast, Entradas station had the lowest annual water yields. Moreover, the monthly river discharge time series of Pulo do Lobo and Entradas stations with coefficient of variations (CV) of 76.81 and 73.23 %, respectively, showed the highest temporal variability. The lowest CV of 59.37 % was found at Monte da Ponte station. The results of CV showed high annual variability of the river discharge at the stations over the study period, mainly in the Pulo do Lobo station with standard deviation and mean deviation equal 2053.94 and 1777.19 m$^3$, respectively.

The magnitude of the values of Pulo do Lobo station is due to great area of drainage, having a large volume of river flow discharge and propitious to rainfall and river flow variability in the basin, because as rainfall is one of the key drivers of river flow, the decreasing flows may be largely due to decreased rainfall totals. According to Abghari et al. (2013), the observed increasing trend of air temperature in region might be another reason for the decreasing trends in river flow during low-flow periods, although temporal variations of discharge have been found to be much more strongly related to precipitation changes than to temperature changes (Espírito Santo et al. 2013). The increase of temperature affects the time of evaporation in the study area and advances the timing of evaporation causing increase in summer flows and subsequent decrease in spring and early winter flows. However, there are not so many stations that have centennial-long reliable daily records, particularly in Southern Europe (Kutiel and Trigo 2014), that can be used to study the spatiotemporal variability of

precipitation and river flow. In many cases, when long records are available, they may suffer from inhomogeneity due to various reasons such as: (a) change in station location, (b) change of measuring devices and (c) change in the environmental conditions around the station due urbanization (Pingale et al. 2014). In other cases, they may be missing data for a certain period which may alter some of the analyses (WMO 2007).

Kahya and Kalayci (2004) found that the presence of trends in Turkish river flow patterns may be attributed to the observed decreases in rainfall and, to some extent, to increases in temperature. In addition to the climatic parameters, the perception of river flow change is driven by humans impacting the timing of flows through flow regulation and by the various diversions and net consumption (i.e., more irrigation water consumptions by the farmers) that can alter the recorded flow patterns over time (Hu et al. 2011). However, the temporal behavior of the rainfall (inter- and intra-annual) is usually more variable than those of other meteorological parameters (such as temperature or pressure), and therefore, longer records are required to present accurately the rainfall regime in a certain location. Furthermore, it is much more difficult to detect any long-term changes in the rainfall regime as compared, for example, to changes in the air temperature regime (Kutiel and Trigo 2014).

The Mann–Kendall test and Sen's slope estimator were applied to the time series for the three river flow gauges. Among the stations, neither of them had significant serial correlation. The time series with significant serial correlation at the significance level of 0.05 are subjected to prewhitening procedure before applying the trend tests. The results of the trend tests on the annual river discharge series are (a) Entradas = 1.37, (b) Monte da Ponte = $-0.09$ and (c) Pulo do Lobo = $-1.07$. Trends are considered statistically significant at the 0.05 level when identified by the two statistical methods, viz. Mann–Kendall and Sen. As the results indicate, all of the annual discharge series were characterized with a negative trend, except for Entradas station, suggesting a possible future water resource scarcity.

Annual river discharge variation at Entradas, Monte da Ponte and Pulo do Lobo stations during the last 40 years is plotted in Figs. 8, 9, 10, which show the decreasing tendency of
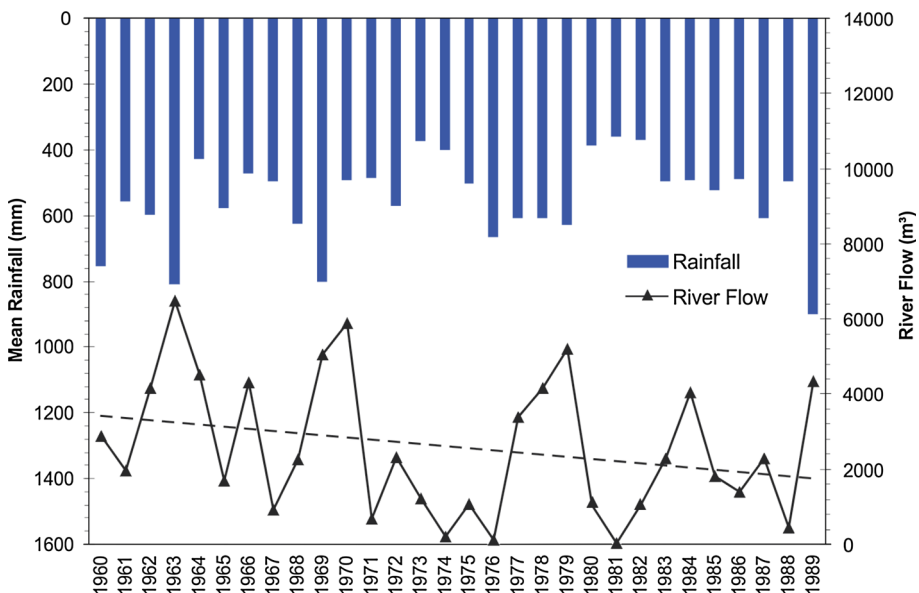


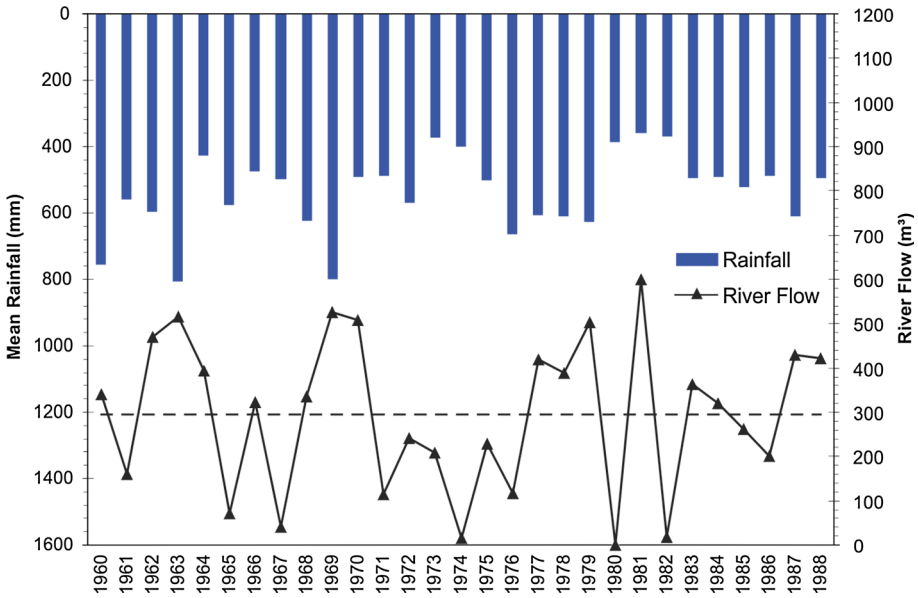Fig. 8 Annual average river flow for Pulo do Lobo between 1960 and 1989

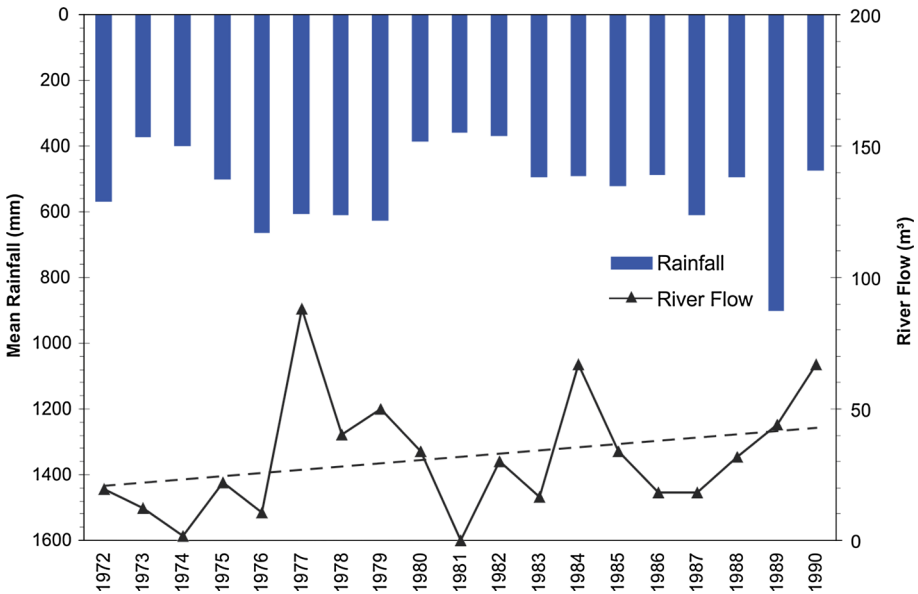**Fig. 9** Annual average river flow for Monte da Ponte between 1960 and 1988



**Fig. 10** Annual average river flow for Entradas between 1972 and 1990

annual river discharge at the Monte da Ponte ($Z_S = -0.09$) and Pulo do Lobo ($Z_S = -1.07$) stations, and increasing tendency of annual river discharge at the Entradas station ($Z_S = 1.37$). As shown, annual mean river flow at Monte da Ponte station declined by

18.9 % from 420 m$^3$ in 1958 to 341 m$^3$ in 1990. At Pulo do Lobo station, annual flow declined by 46.6 % from 8127 m$^3$ in 1946 to 4344 m$^3$ in 2000. Elevations of basin and relief around are by far the most important geological control upon rainfall, and, consequently, of river flow within the region.

The standard deviation values for annual river flow varied between 60 and 80 % within the study area and were greater than twice the standard deviation value of rainfall. The important implication for water resource management in the Cobres River basin is that a relatively great amount of variation with respect to river flow results from a much larger relative variation with respect to rainfall. As the results indicate, all of the annual discharge series were characterized with a negative trend, except at Entradas station, suggesting again a possible future water resource scarcity in the downstream of the basin.

The results of these trend analyses clearly indicate that although there have been persistent oscillations from normal rainfall and river flow within the basin, there has been no consistently negative long-term temporal trends. The results of similar Mann–Kendall tests also indicate that there is a statistically significant trend with respect to successive 40-year sets of rainfall variance and time within the study area. There has been ample variation on the mean values in the river flow. In short, these results indicate that annual mean river flow in the Cobres River basin have become more variable in recent decades. Both rainfall and river flow vary greatly from year to year within the basin and it is not uncommon for rainfall to be well above average 1 year followed by a well below average rainfall and river flow year.

## 4 Conclusions

A regional approach was used for this study for the purpose of better discriminating spatial and temporal trends. This paper presents trends computed for the 40-year period of annual river discharge and monthly rainfall obtained from 11 stations (eight rain gauges and three river flow stations) in the southern Portugal. Two nonparametric trend tests, viz. Sen and Mann–Kendall, were used for the trend analysis. Statistically significant downward trends in annual river discharge were found at Monte da Ponte and Pulo do Lobo stations. Cobres River basin is a large basin located in southeastern Portugal with specific characteristics.

These results can be used for the design of rain gauge networks, hydrological forecasting and for other applications in the Cobres River basin. The average annual rainfall within this study area is 548.56 mm, and the average river flow is 1011 m$^3$. The results showed that the rainfall/river flow varied widely temporally and spatially. Rainfall is highly temporally variable, and there is a decrease in the annual rainfall amount for the period studied.

In general, the results of using Mann–Kendall and Sen's slope estimator statistical tests pointed out the agreement of performance which exists in the detection of the trend for the meteorological variables. The use of these methods allowed us to evidence regions with coherent precipitation variability and to show that the investigated area is under the influence of rainfall: A central zone that is always affected by the rainfall deficit. The nonparametric statistical tests applied to series of annual rainfall reveal a decreasing trend in most of the investigated stations. This is in good agreement with the results obtained in many trend analysis studies.

# References

Abghari H, Tabari H, Talaee PH (2013) River flow trends in the west of Iran during the past 40 years: impact of precipitation variability. Glob Planet Change 101:52–60. doi:10.1016/j.gloplacha.2012.12.003

Bathurst JC, Kilsby C, White S (1996) Modelling the impacts of climate and land-use change on basin hydrology and soil erosion in Mediterranean Europe. In: Brandt CJ, Thornes JB (eds) Mediterranean desertification and land use. Wiley, Chichester, p 355–387

Batisani N, Yarnal B (2010) Rainfall variability and trends in semi-arid Botswana: implications for climate change adaptation policy. Appl Geogr 30:483–489. doi:10.1016/j.apgeog.2009.10.007

Brandão C, Rodrigues R (2000) Hydrological simulation of the international catchments of Guadiana River. Phys Chem Earth (B) 25(3):329–339. doi:10.1016/S1464-1909(00)00023-X

Celleri R, Willems P, Buytaert W, Feyen J (2007) Space–time rainfall variability in the Paute Basin, Ecuadorian Andes. Hydrol Processes 21:3316–3327. doi:10.1002/hyp.6575

Comas-Bru L, McDermott F (2014) Impacts of the EA and SCA patterns on the European twentieth century NAO–winter climate relationship. Q J R Meteorol Soc 140(679):354–363. doi:10.1002/qj.2158

Costa AC, Soares A (2009) Trends in extreme precipitation indices derived from a daily rainfall database for the South of Portugal. Int J Climatol 9:1956–1975. doi:10.1002/joc.1834

Croitoru A-E, Chiotoroiu B-C, Todorova VI, Torică V (2013) Changes in precipitation extremes on the Black Sea Western Coast. Glob Planet Change 102:10–19. doi:10.1016/j.gloplacha.2013.01.004

de Lima MIP, Carvalho SCP, de Lima JLMP (2010) Investigating annual and monthly trends in precipitation structure: an overview across Portugal. Nat Hazards Earth Syst Sci 10:2429–2440. doi:10.5194/nhess-10-2429-2010

de Lima MIP, Santo FE, Ramos AM, de Lima JLMP (2013) Recent changes in daily precipitation and surface air temperature extremes in mainland Portugal, in the period 1941–2007. Atmos Res 27:195–209. doi:10.1016/j.atmosres.2012.10.001

Duhan D, Pandey A (2013) Statistical analysis of long term spatial and temporal trends of precipitation during 1901–2002 at Madhya Pradesh, India. Atmos Res 122:136–149. doi:10.1016/j.atmosres.2012.10.010

El Nesr MN, Abu-Zreig MM, Alazba AA (2010) Temperature trends and distribution in the Arabian Peninsula. Am J Environ Sci 6:191–203. doi:10.3844/ajessp.2010.191.203

Fragoso M, Gomes TP (2008) Classification of daily abundant rainfall patterns and associated large-scale atmospheric circulation types in Southern Portugal. Int J Climatol 28:537–544. doi:10.1002/joc.1564

Gallego MC, Trigo RM, Vaquero JM, Brunet M, García JA, Sigró J, Valente MA (2011) Trends in frequency indices of daily precipitation over the Iberian Peninsula during the last century. J Geophys Res 116:D02109. doi:10.1029/2010JD014255

Gilbert RO (1987) Statistical Methods for Environmental Pollution Monitoring. Wiley, New York

Gocic M, Trajkovic S (2013) Analysis of changes in meteorological variables using Mann–Kendall and Sen's slope estimator statistical tests in Serbia. Glob Planet Change 100:172–182. doi:10.1016/j.gloplacha.2012.10.014

Hamlaoui-Moulai L, Mesbah M, Souag-Gamane D, Medjerab A (2013) Detecting hydro-climatic change using spatiotemporal analysis of rainfall time series in Western Algeria. Nat Hazards 65(3):1293–1311. doi:10.1007/s11069-012-0411-2

Hu Y, Maskey S, Uhlenbrook S, Zhao H (2011) Runoff trends and climate linkages in the source region of the Yellow River, China. Hydrol Processes 25(22):3399–3411. doi:10.1002/hyp.8069

Hurrell JW, van Loon H (1997) Decadal variations associated with the North Atlantic Oscillation. Clim Change 36(3–4):301–326. doi:10.1023/A:1005314315270

Junker NW, Grumm RH, Hart R, Bosart LF, Bell KM, Pereira FJ (2007) Use of normalized anomaly fields to anticipate extreme rainfall in the mountains of Northern California. Weather Forecast 23(3):336–356. doi:10.1175/2007WAF2007013.1

Kahya E, Kalayci S (2004) Trend analysis of stream flow in Turkey. J Hydrol 289(2):128–144. doi:10.1016/j.jhydrol.2003.11.006

Kendall MG (1975) Rank correlation methods. Griffin, London

Kisi O, Ay M (2014) Comparison of Mann–Kendall and innovative trend method for water quality parameters of the Kizilirmak River, Turkey. J Hydrol 513(26):362–375. doi:10.1016/j.jhydrol.2014.03.005

Kutiel H, Trigo RM (2014) The rainfall regime in Lisbon in the last 150 years. Theoret Appl Climatol. doi:10.1007/s00704-013-1066-y

Lazaro R, Rodrigo FS, Gutierrez L, Domingo F, Puigdefabregas J (2001) Analysis of a 30 year rainfall record (1967–1997) in semi-arid SE Spain for implications on vegetation. J Arid Environ 48:373–395. doi:10.1006/jare.2000.0755

Mann HB (1945) Nonparametric tests against trend. Econometrica 13:245–259

Milly PCD, Dunne KA, Vecchia AV (2005) Global pattern of trends in stream flow and water availability in a changing climate. Nature 438:347–350. doi:10.10138/nature04312

Mourato S, Moreira M, Corte-Real J (2010) Interannual variability of precipitation distribution patterns in Southern Portugal. Int J Climatol 30:1784–1794. doi:10.1002/joc.2021

Nalley D, Adamowski J, Khalil B, Ozga-Zielinski B (2013) Trend detection in surface air temperature in Ontario and Quebec, Canada during 1967–2006 using the discrete wavelet transform. Atmos Res 132–133:375–398. doi:10.1016/j.atmosres.2013.06.011

Pingale SM, Khare D, Jat MK, Adamowski J (2014) Spatial and temporal trends of mean and extreme rainfall and temperature for the 33 urban centers of the arid and semi-arid state of Rajasthan, India. Atmos Res 138(1):73–90. doi:10.1016/j.atmosres.2013.10.024

Ramos, C. (1994) Condições geomorfológicas e climáticas das cheias da Ribeira de Tera e do Rio Maior (Bacia Hidrográfica do Tejo), Ph.D. Dissertation, Departamento de Geografia, Lisboa, F.L. Universidade de Lisboa, 520

Ramos MC, Durán B (2014) Assessment of rainfall erosivity and its spatial and temporal variabilities: case study of the Penedès area (NE Spain). Catena 123:135–147. doi:10.1016/j.catena.2014.07.015

Ramos C, Reis E (2002) Floods in Southern Portugal: their physical and human causes, impacts and human response. Mitig Adapt Strateg Glob Change 7(3):267–284. doi:10.1023/A:1024475529524

Rose S (2009) Rainfall–runoff trends in the south-eastern USA: 1938–2005. Hydrol Processes 23(8):1105–1118. doi:10.1002/hyp.7177

Santo FE, Ramos AM, de Lima MIP, Trigo RM (2013) Seasonal changes in daily precipitation extremes in mainland Portugal from 1941 to 2007. Regional Environ Change. doi:10.1007/s10113-013-0515-6

Santos CAG, Morais BS (2013) Identification of precipitation zones within São Francisco River basin (Brazil) by global wavelet power spectra. Hydrol Sci J 58(4):789–796. doi:10.1080/02626667.2013.778412

Sen PK (1968) Estimates of the regression coefficient based on Kendall's tau. J Am Stat As 63:1379–1389. doi:10.1080/01621459.1968.10480934

Silva RM, Santos CAG, Macedo MLA, Silva L, Freire PKMM (2013) Space–time variability of rainfall and hydrological trends in the Alto São Francisco River basin. IAHS-AISH Publ 359:48–54

Subash N, Singh SS, Priya N (2011) Variability of rainfall and effective onset and length of the monsoon season over a sub-humid climatic environment. Atmos Res 99:479–487. doi:10.1016/j.atmosres.2010.11.020

Tabari H, Marofi S (2011) Changes of pan evaporation in the west of Iran. Water Resour Manage 25:97–111. doi:10.1007/s11269-010-9689-6

Tramblay Y, Badi W, Driouech F, El Adlouni S, Neppel L, Servat E (2012) Climate change impacts on extreme precipitation in Morocco. Glob Planet Change 82(2):104–114. doi:10.1016/j.gloplacha.2011.12.002

Trigo RM, DaCamara CC (2000) Circulation weather types and their influence on the precipitation regime in Portugal. Int J Climatol 20:1559–1581. doi:10.1002/1097-0088(20001115)20:13<1559::AID-JOC555>3.0.CO;2-5

Trigo RM, Osborn TJ, Corte-Real JM (2002) The North Atlantic Oscillation influence on Europe: climate impacts and associated physical mechanisms. Clim Res 20:9–17. doi:10.3354/cr020009

Trigo RM, Pozo-Vazquez D, Osborn TJ, Castro-Diez Y, Gámis-Fortis S, Esteban-Parra MJ (2004) North Atlantic Oscillation influence on precipitation, river flow and water resources in the Iberian peninsula. Int J Climatol 24:925–944. doi:10.1002/joc.1048

Vicente-Serrano SM, López-Moreno JI (2008) The nonstationary influence of the North Atlantic Oscillation on European precipitation. J Geophys Res Atmos 113:D20120. doi:10.1029/2008JD010382

WMO (2007) The role of climatological normal in a changing climate. WCDMP-No. 61, WMO-TD No. 1377, Geneva

Yang K, Wu H, Qin J, Lin C, Tang W, Chen Y (2014) Recent climate changes over the Tibetan Plateau and their impacts on energy and water cycle: a review. Glob Planet Change 112(1):79–91. doi:10.1016/j.gloplacha.2013.12.001

Yue S, Pilon P, Phinney B, Cavadias G (2002) The influence of autocorrelation on the ability to detect trend in hydrological series. Hydrol Processes 16:1807–1829. doi:10.1002/hyp.1095

Yunling H, Yiping Z (2005) Climate change from 1960 to 2000 in the Lancang River Valley China. Mt Res Dev 25(4):341–348. doi:10.1659/0276-4741(2005)025[0341:CCFTIT]2.0.CO;2

Zarghami M, Abdi A, Babaeian I, Hassanzadeh Y, Kanani R (2011) Impacts of climate change on runoffs in East Azerbaijan Iran. Glob Planet Change 78(3–4):137–146. doi:10.1016/j.gloplacha.2011.06.003