Theoretical and Applied Climatology (2019) 137:297–307
https://doi.org/10.1007/s00704-018-2595-1

ORIGINAL PAPER

Precipitation trend and concentration in the Sardinia region

T. Caloiero[1] · **R. Coscarelli**[2] · **R. Gaudio**[3] · **G. P. Leonardo**[3]

Received: 19 January 2018 / Accepted: 5 August 2018 / Published online: 16 August 2018

Abstract

The Mediterranean region is an area potentially vulnerable to climatic changes. In fact, it is characterized by a significant precipitation variability resulting from synoptic dynamics of hazardous events moving and evolving along the Mediterranean basin. In this paper, the results of an investigation on rainfall trend in the Sardinia region are presented. The trend analysis has been performed by means of the Mann–Kendall test and of the Theil–Sen estimator applied on annual, seasonal, and monthly scales. To this aim, a monthly database of precipitation registered at 158 rain gauges, with an average observation of 84 years, was used for the analyses. The results mainly evidenced a rainfall amount reduction in the winter months and an increase during the summer months. The monthly rainfall distribution throughout the year was also investigated by means of the precipitation concentration index (PCI). A negative trend emerged and, more specifically, a tendency towards a more uniform rainfall distribution on the Sardinia region throughout the year.

1 Introduction

As a consequence of the increase of the concentration of anthropogenic greenhouse gases, possibly due to the global economic and population growth, the Intergovernmental Panel on Climate Change (IPCC) warned about the possible escalation of droughts in this century, especially, in some areas such as the Mediterranean basin, owing to an evapotranspiration increase and/or a rainfall decrease (IPCC 2013). In fact, the Mediterranean region, located in a transition zone between North Africa (arid climate) and central Europe (temperate and rainy climate), is affected by the interaction between mid-latitude and tropical processes. For this reason, substantial changes in the Mediterranean climate can also be generated by small modifications in the global circulation, thus making the Mediterranean region potentially exposed to climatic changes (Mehta and Yang 2008; Reale and Lionello 2013).

Several studies focused on the rainfall trend behavior in the Mediterranean basin. According to these, a decrease in winter precipitation has affected a great part of the Mediterranean region in the last decades (Philandras et al. 2011). Because of the winter negative trend, some decreases in annual precipitation in the Mediterranean area have been also detected (del Rio et al. 2011) even though different results have been obtained between the western and eastern side of the Mediterranean basin. Specifically, the west–central Mediterranean area has experienced a decrease in precipitation during the last 50 years (Piervitali et al. 1997; Longobardi and Villani 2010), but trends are not uniform and interdecadal variability is high. A positive trend has been evidenced in the eastern Mediterranean, though not in the rainy season (Maheras et al. 2001; Altin and Barak 2014).

In Italy, numerous investigations carried out using high-quality rainfall databases have detected a reduction in the precipitation amount, even if rarely significant (e.g., Brunetti et al. 2006). Detailed regional analyses have highlighted a varied trend behavior influenced by seasonal factors (or by the time of their observation throughout the year): specifically decreasing precipitation amounts in the winter vs precipitation increase in the summer months have been observed. The regions affected by these trends are principally located in southern Italy: Campania (Diodato 2007; Longobardi and Villani

---

✉ T. Caloiero
tommaso.caloiero@isafom.cnr.it

[1] Institute for Agricultural and Forest Systems in the Mediterranean (CNR-ISAFOM), National Research Council of Italy, Rende, CS, Italy

[2] Research Institute for Geo-Hydrological Protection (CNR-IRPI), National Research Council of Italy, Rende, CS, Italy

[3] Department of Civil Engineering (DINCI), University of Calabria, Rende, CS, Italy

2010), Basilicata (Piccarreta et al. 2004), Sicily (Liuzzo et al. 2016), Calabria (Caloiero et al. 2011a, 2015, 2016), and Sardinia (Montaldo and Sarigu 2017). Such a different seasonal trend behavior and its consequences in water resources management constitute an important topic in climatology.

Oliver (1980) proposed the precipitation concentration index (PCI) as a method to quantify the rainfall distribution throughout the year and to detect possible changes in the climate regime of an area (e.g., Elagib 2011; Ngongondo et al. 2011; Nsubuga et al. 2014; Shi et al. 2014; Xu et al. 2010; Yesilirmak and Atatanir 2016). Although the PCI has been widely applied in the Mediterranean areas (e.g., Apaydin et al. 2006; De Luis et al. 2011; Martins et al. 2012), only few studies, mainly focused on the southern areas, are available in Italy. In a large area of southern Italy, Longobardi et al. (2016) showed a significant shift towards a more uniform pluviometric regime, especially for the hilly areas. In Sicily, a general stable condition has been detected (Cannarozzo et al. 2006), while in Campania (Longobardi and Villani 2010) and in Calabria (Coscarelli and Caloiero 2012), a decrease in the PCI values has been detected, thus showing a tendency towards a more uniform rainfall distribution throughout the year.

Due to the importance of the analysis of the rainfall trend behavior in the Mediterranean basin, and due to the lack of rainfall trend analysis at different timescales in the Sardinia region, the aims of this paper were firstly to detect rainfall trends at annual, seasonal, and monthly scales and then to analyze the effect of climate changes on the rainfall distribution throughout the year by means of the precipitation concentration index (PCI).

2 Study area and data

Sardinia, with an area of about 24,000 km^2, is the second largest island in the Mediterranean Sea (after Sicily and before Cyprus). It is located at 38° 51′ to 41° 15′ N and at 8° 8′ to 9° 50′ E in the center of the western Mediterranean Sea, about 200 km west of mainland Italy. The orography of the region is characterized by two main flat areas in the northwest and in the south of the region and by several mountains and alluvial valleys (Montaldo and Sarigu 2017). The average altitude of the region is 337 m a.s.l. and the tallest relief is 1834 m a.s.l. (Fig. 1). Given its position in the center of the Mediterranean sea, its climate is typically maritime Mediterranean with average yearly

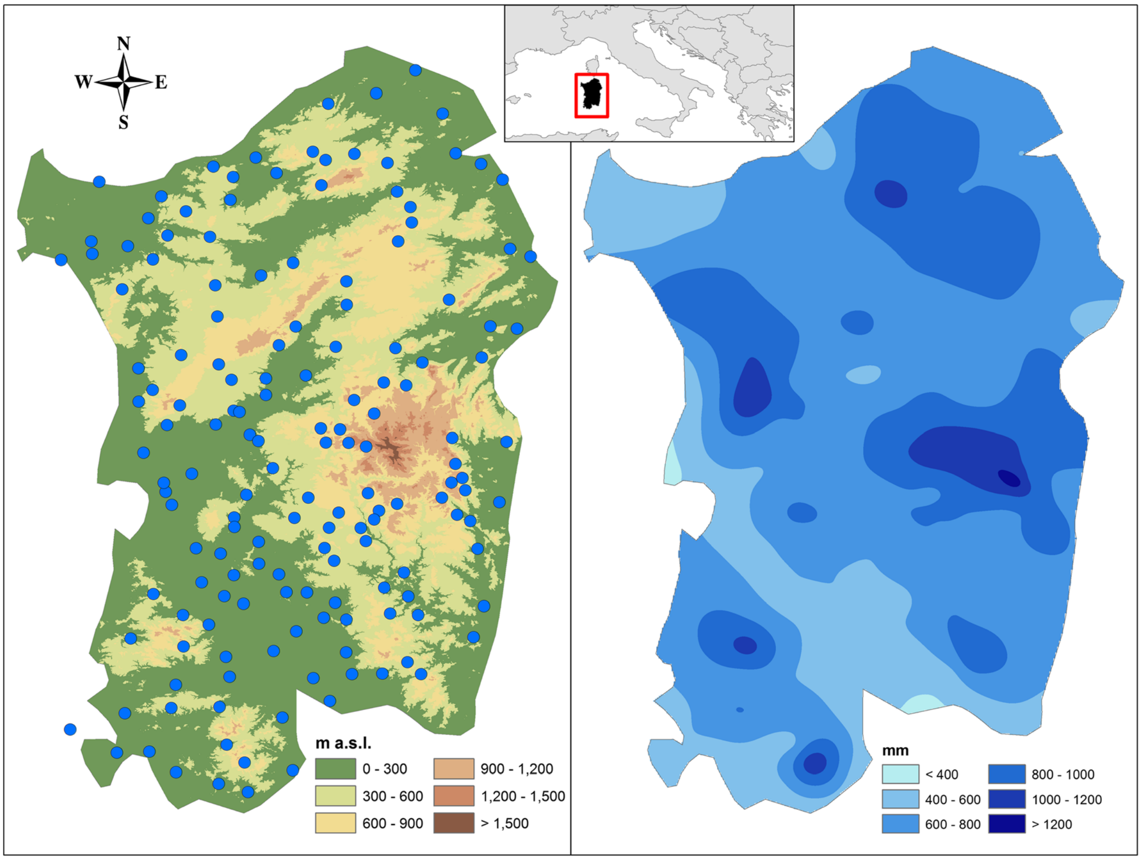


Fig. 1 Location of the selected 158 rain gauge stations on a DEM (left) and spatial distribution of the mean annual precipitation (right)

rainfall of 733.3 mm and mean annual temperature of about 23 °C. The winter season is a rather mild and rainy period (the highest rainfall occurs in autumn and winter) whereas the summer season is very hot and dry (Fig. 2). In particular, autumn and winter can be characterized by very intense but short-duration rainfall events. As regards temperature, in summer, maximum values exceeding 40 °C can be reached while in winter minimum values below 0 °C are recorded only at high altitudes (Montaldo and Sarigu 2017; Soldati and Marchetti 2017).

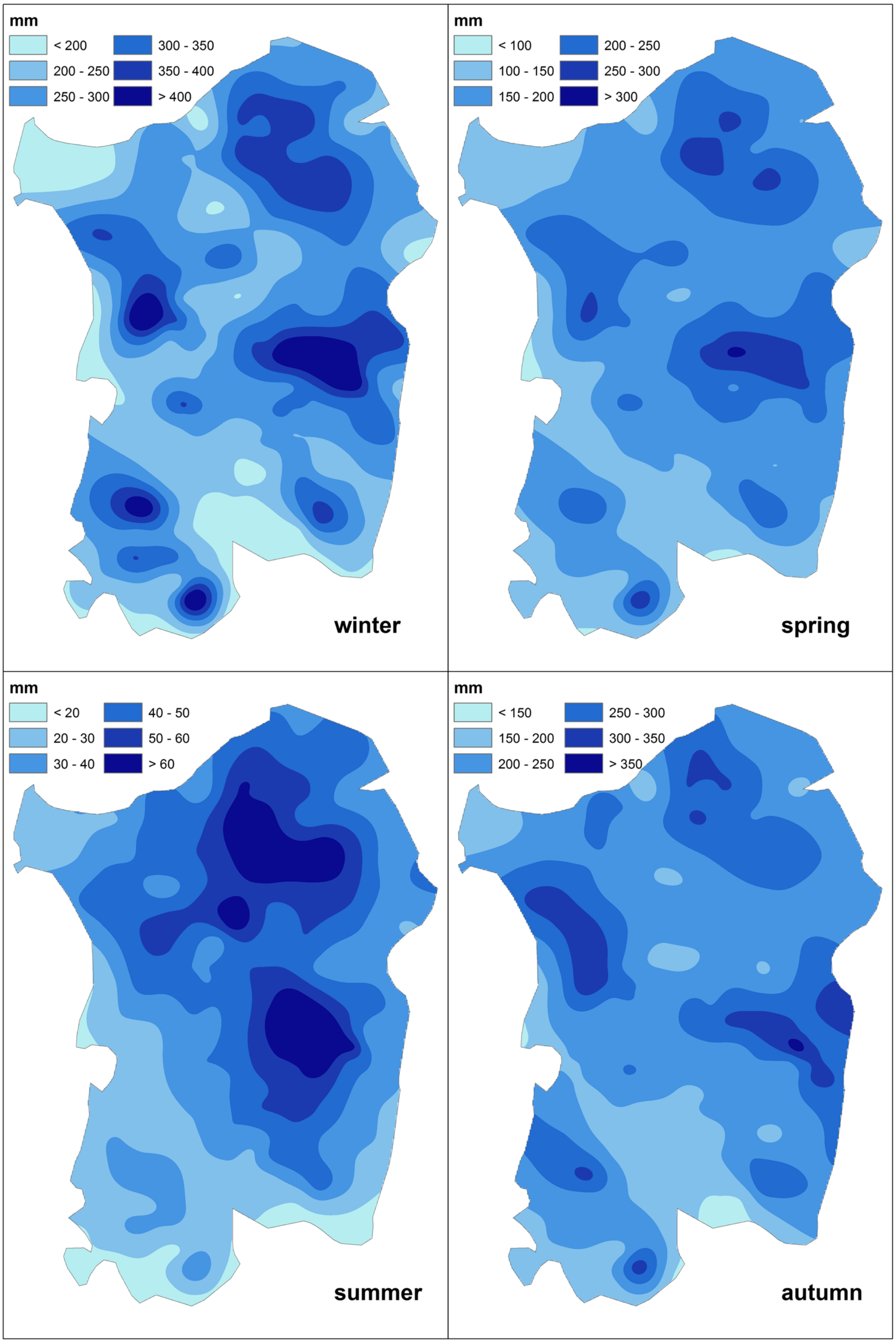


Fig. 2 Spatial distribution of the mean seasonal precipitation

In order to perform a coherent rainfall analysis in the Sardinia region, monthly data have been extracted from the daily online database once managed by the Sardinian Regional Hydrographic Service. Recent studies on Sardinia's climate (e.g., Montaldo and Sarigu 2017) made wide use of this database, which presents high-quality data and complete, or near-complete, records for the period 1922–2011. In fact, until 2011, the Sardinian database consisted of daily rainfall data collected at 262 stations, with a density of 1 station per 92 km^2. In particular, for the present analysis, a number of rainfall series, which presented too low a number of years of observation for statistical purposes, were discarded. Thus, the final selection included 158 stations (Fig. 1) having at least 80 complete years of functioning and data in the last 10 years. The average density of the final database is 1 station per 152 km^2, with an average of 84 years of observations.

3 Methodology

In this paper, in order to evaluate the possible existence of temporal tendencies, the yearly, seasonal, and monthly rainfall series were analyzed for trends with the well-known Mann–Kendall (MK) nonparametric test (Mann 1945; Kendall 1962). In particular, the rainfall series have been examined for a significance level equal to 95%. The statistical significance of the trend has been evaluated using a two-tailed test. Although the MK test is a commonly used nonparametric test for time trend, it is based on an assumption of independence between observations. However, observations in time series are often autocorrelated. In particular, since most series in practice show positive autocorrelation, it is therefore important to check the autocorrelation in a given series and, in some cases, to remove the serial correlation before applying the MK test, or to adjust the test if necessary. In order to remove the serial correlation, before the application of the MK test, in this work the pre-whitening procedure (von Storch 1995) has been applied:

$$Y_t = X_t - r_1 \cdot X_{t-1} \tag{1}$$

where r_1 is the lag-1 serial correlation coefficient of the sample data, which can be expressed as

$$r_1 = \frac{\frac{1}{n-1}\sum_{t=1}^{n-1}[X_t - E(X_t)][X_{t+1} - E(X_t)]}{\frac{1}{n}\sum_{t=1}^{n}[X_t - E(X_t)]^2} \tag{2}$$

where $E(X_t)$ is the mean of the sample data. Von Storch (1995) demonstrated that pre-whitening operation is not necessary for $r_1 \leq 0.1$.

Besides the MK test, in this study, the Theil–Sen estimator (Sen 1968) has been also applied to evaluate the trend slopes, avoiding the influence of the outliers in the trend slope evaluation. In fact, linear regression methods are prone to the influence of extreme values, e.g., very low or very high values at the beginning or at the end of the considered period, while the Theil–Sen estimator is not susceptible to their influence.

Finally, in order to analyze the effect of the seasonal rainfall trend on the annual rainfall distribution, the climate seasonality has been evaluated through the PCI index (Oliver, 1980; De Luis et al. 2011).

The long-term average PCI can be evaluated as follows:

$$\mathrm{PCI} = \frac{1}{N}\sum_{j=1}^{N}\mathrm{PCI}_j \tag{3}$$

where N is the number of years of observations and PCI_j is the PCI calculated in the jth year as

$$\mathrm{PCI}_j = 100\frac{\sum_{i=1}^{12} {P_{ij}}^2}{\left(\sum_{i=1}^{12} P_{ij}\right)^2} \tag{4}$$

with P_{ij} rainfall amount in the ith month of the jth year.

Following the classification proposed by Oliver (1980):

- $\mathrm{PCI} \leq 10$ indicates a uniform precipitation distribution.
- $11 < \mathrm{PCI} \leq 20$ denotes seasonality in the precipitation distribution.
- $\mathrm{PCI} > 20$ corresponds to climates with substantial monthly precipitation variability.

Aiming at studying the temporal effect of the changing precipitation distribution in the year, the PCI time series evaluated through Eq. (3) have been tested for trend detection with the application of the MK nonparametric test.

4 Results and discussion

The results of the trend analysis applied to the annual, seasonal, and monthly precipitation, for a significance level equal to 95%, are presented in Table 1 which shows the percentages of rain gauges with a positive or negative trend. At the annual scale, a clear negative trend has been detected. In fact, about 51% of the rain gauges showed a negative trend, while significant positive trends have not been identified. The negative trend is spatially distributed throughout the entire region and, in particular, in the central and western side (Fig. 3).

Table 1 Results of the MK trend analysis (SL = 95%). Trend of the annual, monthly, and seasonal rainfall and of the PCI expressed as % of rain gauge of the whole data set

Period	% Negative trend	% Positive trend	No trend
January	24.7	0.0	75.3
February	29.7	0.0	70.3
March	23.4	0.0	76.6
April	0.6	12	87.3
May	4.4	0.0	95.6
June	0.0	36.7	63.3
July	0.0	24.1	75.9
August	0.0	17.1	82.9
September	1.3	10.1	88.6
October	13.3	0.0	86.7
November	0.6	7.0	92.4
December	25.3	0.0	74.7
Winter	71.5	0.0	28.5
Spring	12.7	0.6	86.7
Summer	0.0	25.9	74.1
Autumn	8.2	1.9	89.9
Year	51.3	0.0	48.7
PCI	22.8	0.6	76.6

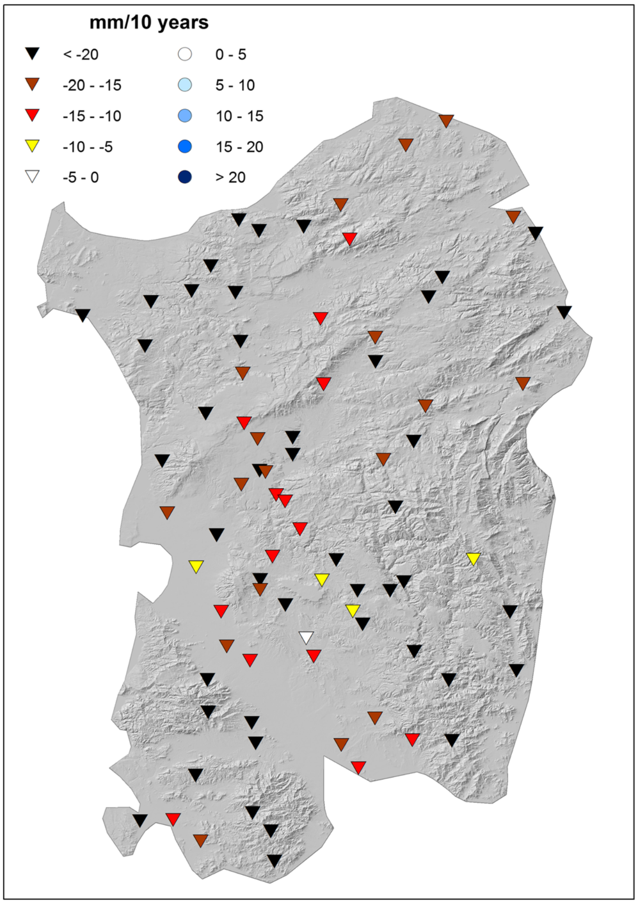
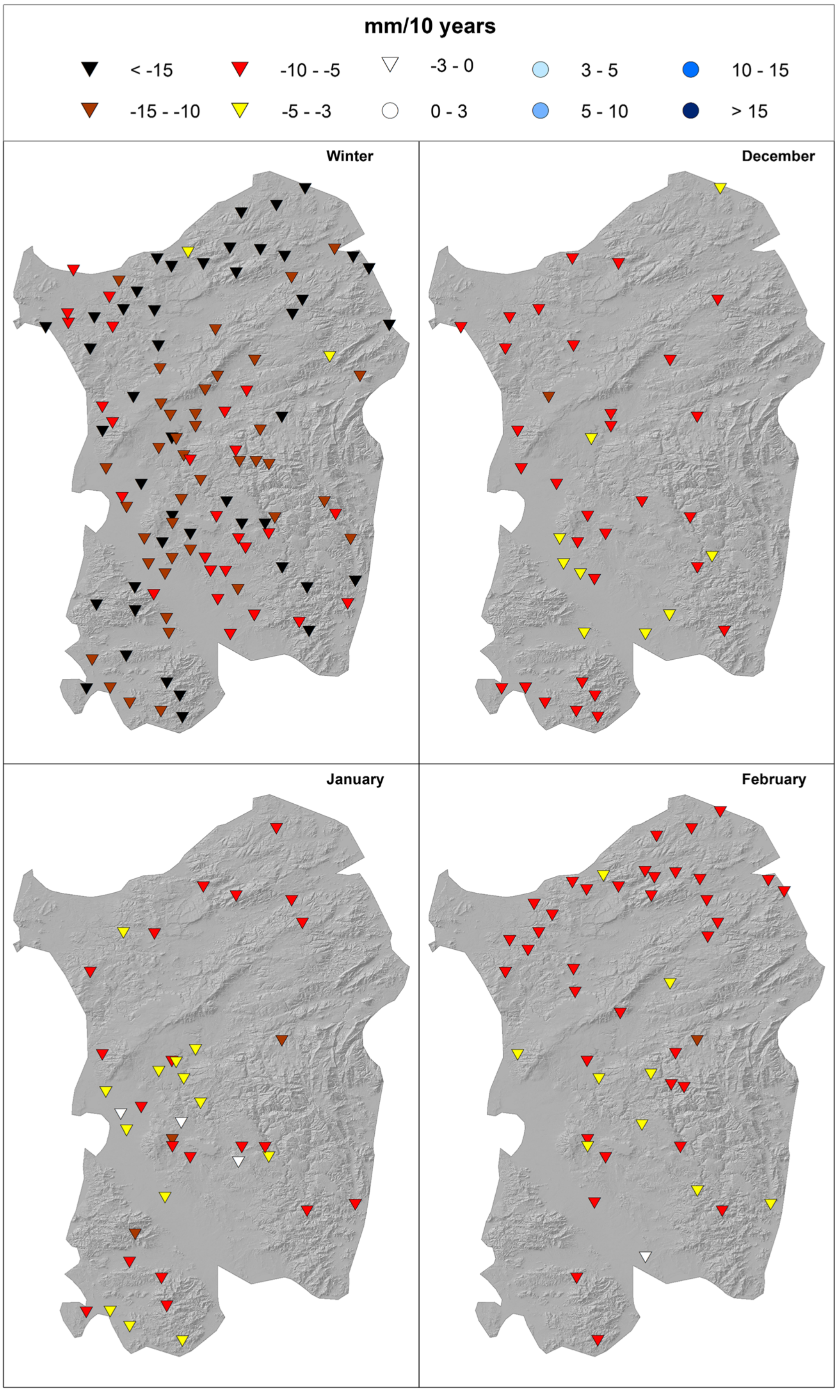


Fig. 3 Spatial distribution of rain gauges showing positive or negative annual rainfall trend

In winter, a marked negative trend has been detected, with more than 70% of the rain gauges showing significant values. This trend behavior in winter is confirmed at the monthly scale, with 25.3, 24.7, and 29.7% of the rain gauges which showed a negative trend in December, January, and February, respectively (Table 1). Regarding the spring months, a negative trend was detected in March (23.4% of the rain gauges) and slightly in May (4.4%), while in April (12.0%), an opposite trend has been evidenced. As a result of this opposite monthly behavior, in spring, 12.7% of the rain gauges showed a negative trend and only 0.6% a positive one (Table 1). As opposed to the winter precipitation, the summer one showed a marked positive trend (25.9% of the rain gauges). In particular, 36.7, 24.1, and 17.1% of the rain gauges showed a positive trend in June, July, and August, respectively (Table 1). Finally, in the autumn months, a prevailing positive trend has been observed in September (10.1%) and in November (7.0%) while an opposite behavior has been detected in October, with 13.3% of the rain gauges showing a negative trend. As a consequence of the monthly trends, in autumn, 8.2% of the rain gauges showed a negative trend while only 1.9% evidenced a positive one (Table 1).

The spatial results of the trend analysis applied to the seasonal and monthly precipitation, for a significance level equal to 95%, are presented in Figs. 5, 6, 7, and 8. In particular, the spatial analysis of the winter trend evidenced a similar behavior as the annual one, with the negative trends spreading across the island but, in particular, in the central and western areas of the region (Fig. 4). Specifically, in December and January, the negative trends involved the western side of the region, while in February, the central area of the region is mostly affected by a precipitation reduction (Fig. 4). In spring, a prevalent negative trend has been detected in the southwestern area although not uniformly distributed (Fig. 5). In particular, on a monthly basis, in March a marked negative trend has been identified especially in the central area of the region, while in April, the trend has been localized in the southeastern side of the region, but with an opposite sign. In May, there are few significant trends which are randomly distributed in the region (Fig. 5). Although less marked than in winter, also in summer, the trend behavior evidenced a difference between the eastern and the western side, particularly at the monthly scale (Fig. 6). In fact, positive trends have been identified in the eastern side of the region, mostly in July and partially in August, while the western side did not show any significant tendency. In June, the positive trend involved the coastal area of the region, with the exception of the southeastern side. As a result, at the seasonal scale, a positive trend, mostly spreading in the northern area of the region and especially on the coast, has been detected in summer (Fig. 6). Finally, in autumn, at the seasonal scale, there are few significant tendencies and it is

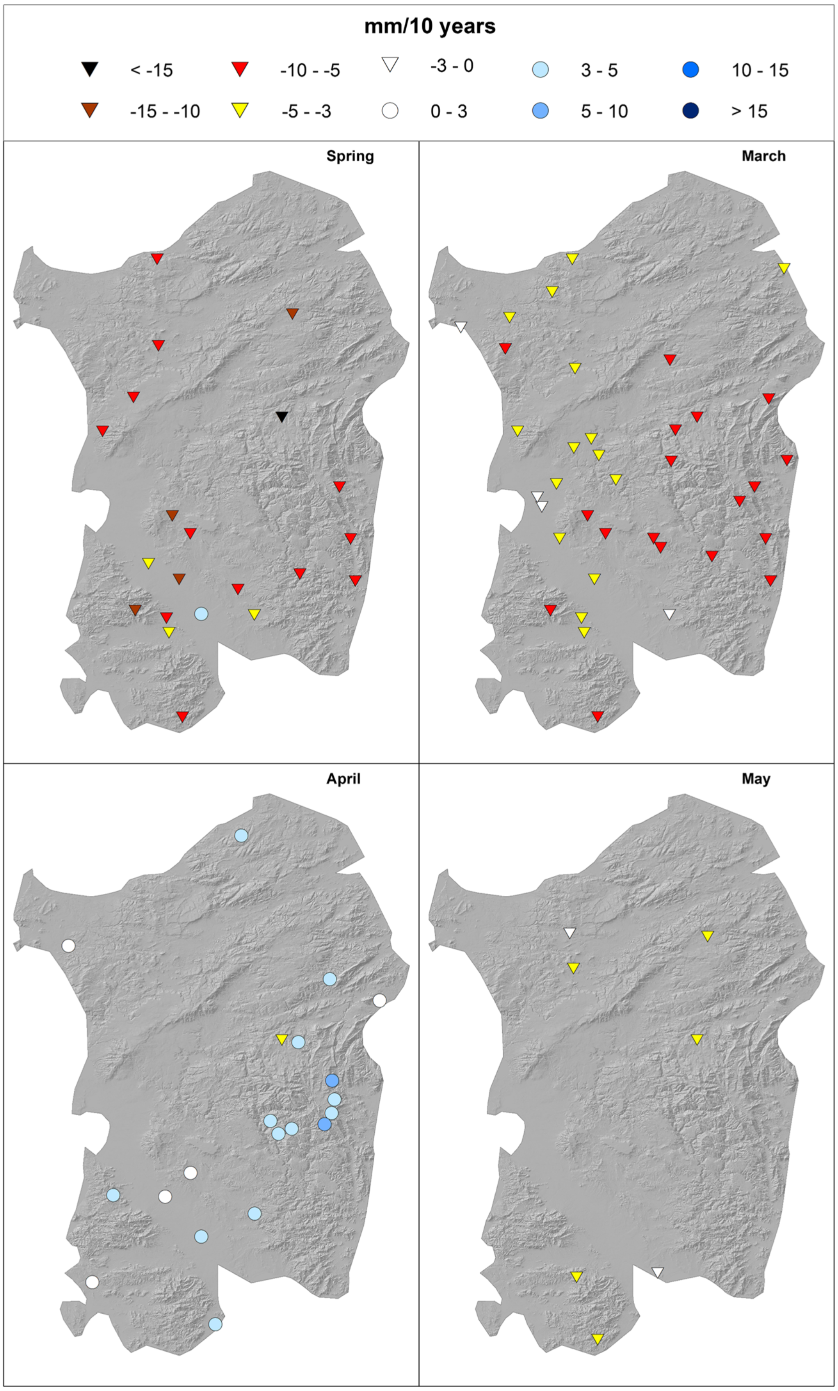
Fig. 4 Spatial distribution of rain gauges showing positive or negative rainfall trend (winter)



not possible to identify a marked spatial pattern (Fig. 7). Conversely, at the monthly scale, negative trends in the central area of the region (October) and positive trends in the eastern side (September) have been detected (Fig. 7).

These results, which evidenced a reduction in the winter months and an increase during the summer months, confirmed the ones obtained in other Italian regions (Brunetti et al. 2012; Caloiero et al. 2015; Diodato 2007; Longobardi and Villani 2010; Piccarreta et al. 2013). The different rainfall behaviors could be linked to the time variability of the circulation types. In fact, Maheras et al. (2004) analyzed the daily circulation types at 500 hPa for the period 1958–2000 and found a general positive trend of anticyclonic circulation, normally associated with a lower-than-average probability of rainfall, and a

Fig. 5 Spatial distribution of rain gauges showing positive or negative rainfall trend (spring)



negative trend of cyclonic types. Moreover, Guijarro et al. (2006), by analyzing the time variability of cyclonic geostrophic circulation in the Mediterranean basin, in the time span 1957–2002, by means of the ERA-40 data set of the European Centre for Medium-Range Weather Forecasts (ECWMF), detected a varied monthly distribution in the cyclone frequencies. In particular, they revealed negative frequency trends in the Western Mediterranean, mainly in winter, and significant positive trends in summer in the Eastern Mediterranean, in accordance with the analogous trends detected by the same authors in the circulation yields.

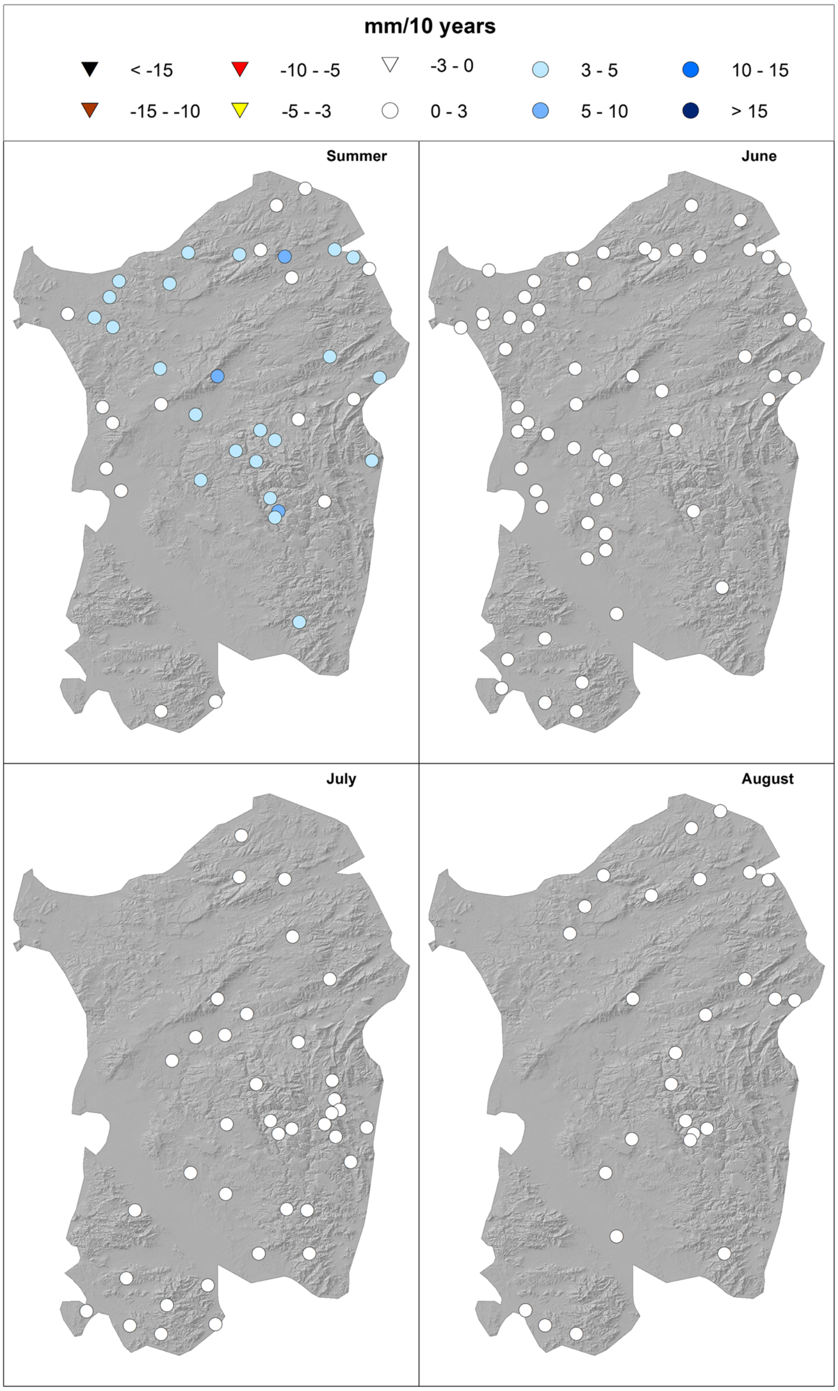
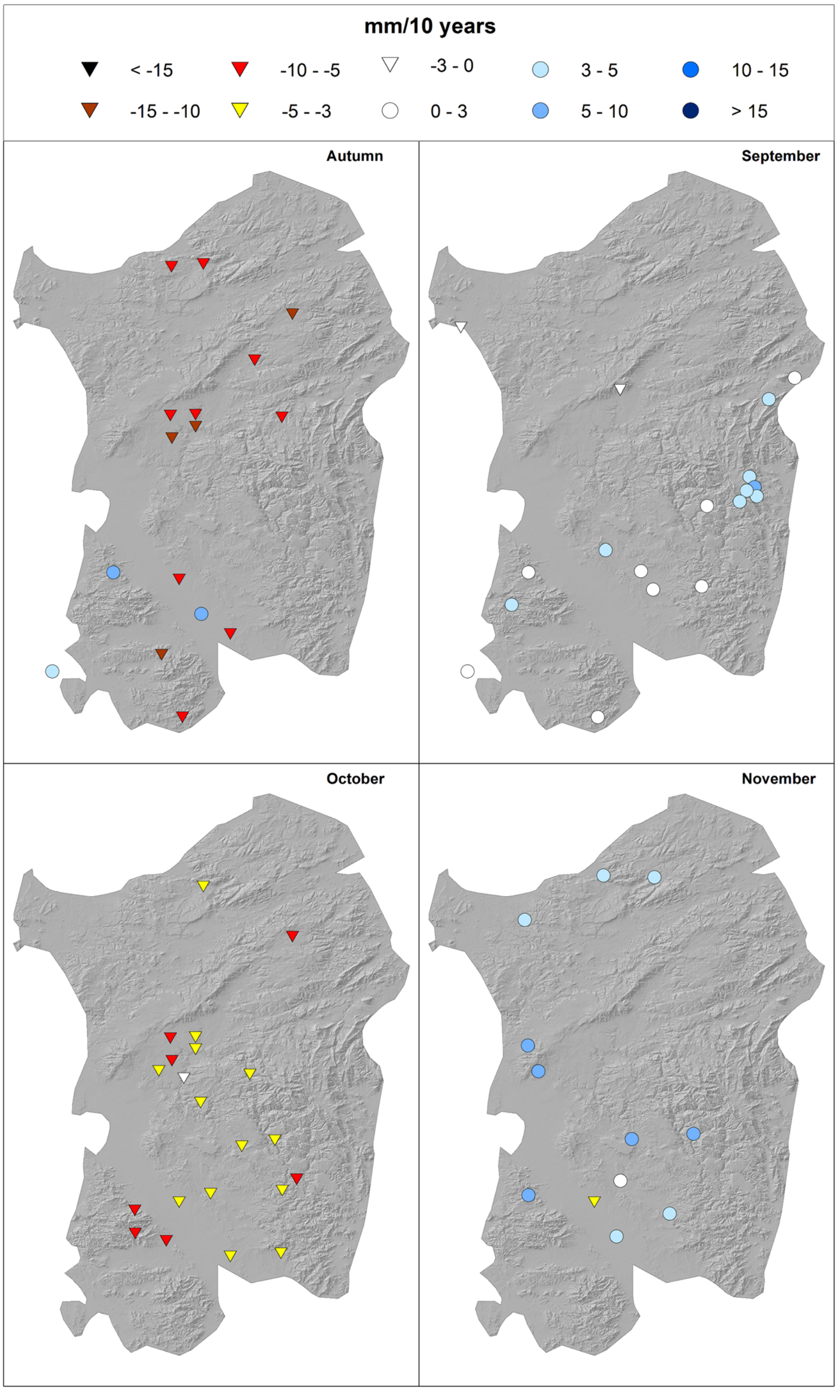


Fig. 6 Spatial distribution of rain gauges showing positive or negative rainfall trend (summer)

The different trends between the western and the eastern sides of Sardinia confirm the findings of Montaldo and Sarigu (2017) who, in the winter period, detected in the west coast a negative trend magnitude almost twice as the ones on the east coast. These differences can be due to the orography of Sardinia, which strongly influences its rainfall pattern. In fact, as pointed out by Delitala et al. (2000), the climate of the island is linked with large-scale circulation structures westward to the North Atlantic. The interaction between these patterns and the orography can lead to a precipitation gradient between the two sides of the region, as also evidenced in several studies on other southern Italian regions with a similar orography, trending south–north, which constitutes an important barrier to the mean airflow approaching from the west

Fig. 7 Spatial distribution of rain gauges showing positive or negative rainfall trend (autumn)



(Caloiero et al. 2011b; Ferrari et al. 2013). As a consequence, an increase in the differences in precipitation between the east coast and the west one, characterized by drier climate conditions, can be expected in Sardinia.

Because of the different rainfall trends in the summer and winter periods, in order to analyze the precipitation distribution throughout the year, the PCI has been evaluated and spatially distributed (Fig. 8a). As a result, different PCI values have been detected in the two sides of the region, thus confirming the important influence of the orography. In fact, while the western and central areas of the region evidenced seasonality in the precipitation distribution, the eastern side of

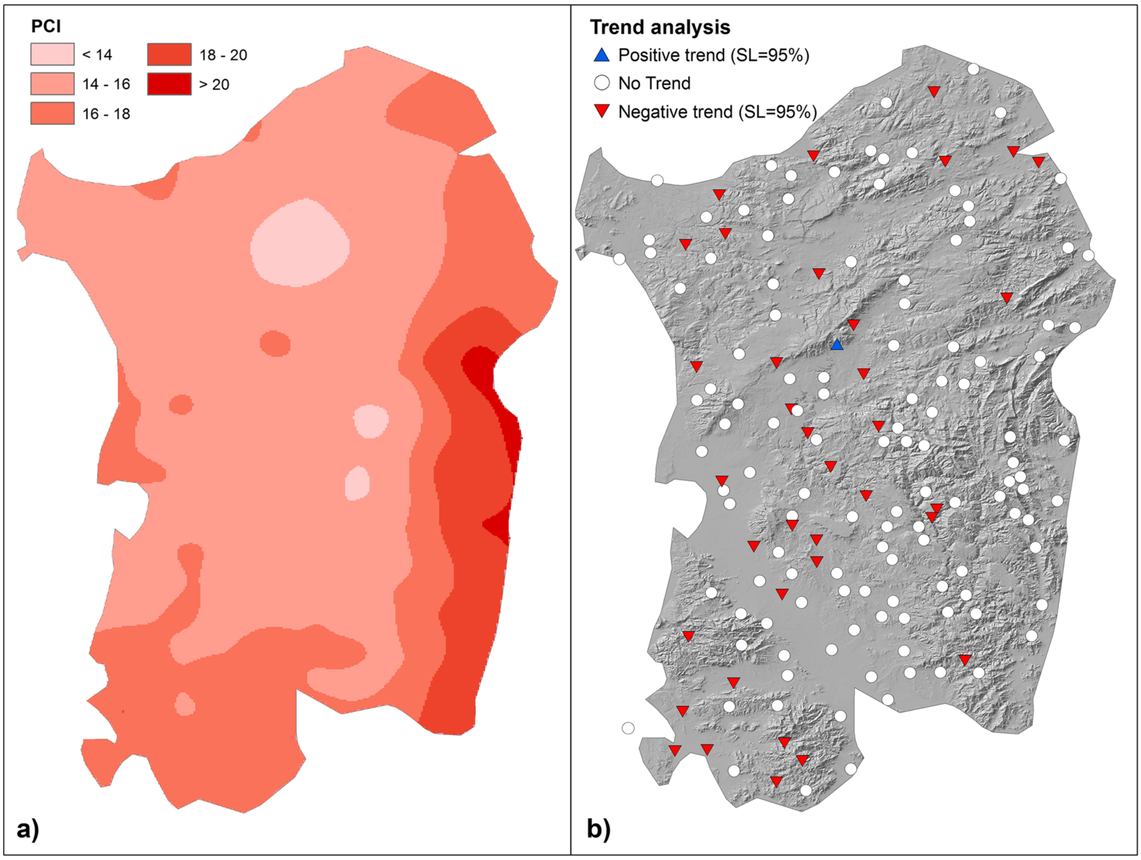


Fig. 8 Spatial distributions of the PCI (**a**) and of rain gauges showing positive or negative PCI trends (**b**)

the region showed PCI values which correspond to climates with substantial monthly precipitation variability (Fig. 8a). The results of the trend analysis, for a significance level equal to 95%, applied to the annual PCI values are presented in Table 1 and Fig. 8b. Generally, a clear negative trend has been detected, with about one fourth of the rain gauge presenting this trend behavior and only 0.6% of the rain gauges evidencing a positive trend (Table 1). The negative trend is mainly located in the central and western sides of the region, while no significant trends have been identified in the eastern side (Fig. 8b). This is a very important result; in fact, as evidenced in other studies (e.g., Coscarelli and Caloiero 2012; Longobardi et al. 2016), some areas of the Mediterranean basin, such as the western side of the Sardinia region, showed a tendency towards a more uniform rainfall distribution throughout the year.

5 Conclusions

In this paper, an investigation of the precipitation variability in the Sardinia region has been performed by means of a monthly rainfall dataset. A statistical analysis was carried out through the Mann–Kendall nonparametric test to detect possible trends at monthly, seasonal, and annual scales. Moreover, the monthly rainfall distribution throughout the year was investigated by means of the PCI. Results showed a link between the rainfall trend and the orography of the region, which influences its rainfall pattern. In fact, while in the western side of Sardinia, where the lowest precipitation is usually registered, a negative rainfall trend has been detected especially in winter, in the eastern side, which is characterized by higher precipitation values than the western side, lower negative trend values have been evaluated. As a consequence of these rainfall behaviors, a tendency towards a more uniform distribution of the monthly precipitation during the year has been evidenced in the western side of the Sardinia region. The analysis of these results could be paramount in water resources management of the Sardinia region. In fact, the decreasing trend of the rainfall, if confirmed, could cause an increase in the occurrence frequency of drought events.

References

Altin TB, Barak B (2014) Changes and trends in total yearly precipitation of the Antalya District, Turkey. Procedia Soc Behav Sci 120:586–599

Apaydin H, Erpul G, Bayramin I, Gabriels D (2006) Evaluation of indices for characterizing the distribution and concentration of precipitation: a case for the region of Southeastern Anatolia Project, Turkey. J Hydrol 328:726–732

Brunetti M, Caloiero T, Coscarelli R, Gullà G, Nanni T, Simolo C (2012) Precipitation variability and change in the Calabria region (Italy) from a high resolution daily dataset. Int J Climatol 32:55–73

Brunetti M, Maugeri M, Monti F, Nanni T (2006) Temperature and precipitation variability in Italy in the last two centuries from homogenised instrumental time series. Int J Climatol 26:345–381

Caloiero T, Buttafuoco G, Coscarelli R, Ferrari E (2015) Spatial and temporal characterization of climate at regional scale using homogeneous monthly precipitation and air temperature data: an application in Calabria (southern Italy). Hydrol Res 46:629–646

Caloiero T, Callegari G, Cantasano N, Coletta V, Pellicone G, Veltri A (2016) Bioclimatic analysis in a region of southern Italy (Calabria). Plant Biosys 150:1282–1295

Caloiero T, Coscarelli R, Ferrari E, Mancini M (2011a) Trend detection of annual and seasonal rainfall in Calabria (southern Italy). Int J Climatol 31:44–56

Caloiero T, Coscarelli R, Ferrari E, Mancini M (2011b) Precipitation change in southern Italy linked to global scale oscillation indexes. Nat Hazards Earth Syst Sci 11:1–12

Cannarozzo M, Noto L, Viola F (2006) Spatial distribution of rainfall trends in Sicily (1921 2000). Phys Chem Earth 31:1201–1211

Coscarelli R, Caloiero T (2012) Analysis of daily and monthly rainfall concentration in southern Italy (Calabria region). J Hydrol 416–417: 145–156

De Luis M, Gonzalez-Hidalgo JC, Brunetti M, Longares LA (2011) Precipitation concentration changes in Spain 1946–2005. Nat Hazards Earth Syst Sci 11:1259–1265

Del Rio S, Herrero L, Fraile R, Penas AP (2011) Spatial distribution of recent rainfall trends in Spain (1961–2006). Int J Climatol 31:656–667

Delitala AMS, Cesari D, Chessa PA, Neil-Ward M (2000) Precipitation over Sardinia (Italy) during the 1946-1993 rainy seasons and associated large-scale climate variations. Int J Climatol 22:519–541

Diodato N (2007) Climatic fluctuations in southern Italy since 17th century: reconstruction with precipitation records at Benevento. Clim Chang 80:411–431

Elagib NA (2011) Changing rainfall, seasonality and erosivity in the hyper-arid zone of Sudan. Land Degrad Dev 22:505–512

Ferrari E, Caloiero T, Coscarelli R (2013) Influence of the North Atlantic oscillation on winter rainfall in Calabria (southern Italy). Theor Appl Climatol 114:479–494

Guijarro JA, Jansà A, Campins J (2006) Time variability of cyclonic geostrophic circulation in the Mediterranean. Adv Geosci 7:45–49

IPCC (2013) Summary for policymakers. Fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

Kendall MG (1962) Rank correlation methods. Hafner Publishing Company, New York

Liuzzo L, Bono E, Sammartano V, Freni G (2016) Analysis of spatial and temporal rainfall trends in Sicily during the 1921–2012 period. Theor Appl Climatol 126:113–129

Longobardi A, Buttafuoco G, Caloiero T, Coscarelli R (2016) Spatial and temporal distribution of precipitation in a Mediterranean area (southern Italy). Environ Earth Sci 75:189

Longobardi A, Villani P (2010) Trend analysis of annual and seasonal rainfall time series in the Mediterranean area. Int J Climatol 30: 1538–1546

Maheras P, Flocas HA, Patricas I, Anagnostopoulou C (2001) A 40 year objective climatology of surface cyclones in the Mediterranean region: spatial and temporal distribution. Int J Climatol 21:109–130

Maheras P, Tolika K, Anagnostopoulou C, Vafiadis M, Patrikas I, Flocas H (2004) On the relationships between circulation types and changes in rainfall variability in Greece. Int J Climatol 24:1695–1712

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

Martins DS, Raziei T, Paulo AA, Pereira LS (2012) Spatial and temporal variability of precipitation drought in Portugal. Nat Hazards Earth Syst Sci 12:1493–1501

Mehta AV, Yang S (2008) Precipitation climatology over Mediterranean Basin from ten years of TRMM measurements. Adv Geosci 17:87–91

Montaldo N, Sarigu A (2017) Potential links between the North Atlantic Oscillation and decreasing precipitation and runoff on a Mediterranean area. J Hydrol 553:419–437

Ngongondo C, Xu CY, Gottshalk L, Alemaw B (2011) Evaluation of spatial and temporal characteristics of rainfall in Malawi: a case of data scares region. Theor Appl Climatol 106:79–93

Nsubuga FNW, Olwoch JM, deW Rautenbach CJ, Botai OJ (2014) Analysis of mid-twentieth century rainfall trends and variability over southwestern Uganda. Theor Appl Climatol 115:53–71

Oliver JE (1980) Monthly precipitation distribution: a comparative index. Prof Geogr 32:300–309

Philandras CM, Nastos PT, Kapsomenakis J, Douvis KC, Tselioudis G, Zerefos CS (2011) Long term precipitation trends and variability within the Mediterranean region. Nat Hazards Earth Syst Sci 11: 3235–3250

Piccarreta M, Capolongo D, Boenzi F (2004) Trend analysis of precipitation and drought in Basilicata from 1923 to 2000 within a southern Italy context. Int J Climatol 24:907–922

Piccarreta M, Pasini A, Capolongo D, Lazzari M (2013) Changes in daily precipitation extremes in the Mediterranean from 1951 to 2010: the Basilicata region, southern Italy. Int J Climatol 33: 3229–3248

Piervitali E, Colacino M, Conte M (1997) Signals of climatic change in the central-western Mediterranean basin. Theor Appl Climatol 58: 211–219

Reale M, Lionello P (2013) Synoptic climatology of winter intense precipitation events along the Mediterranean coasts. Nat Hazards Earth Syst Sci 13:1707–1722

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

Shi P, Qiao X, Chen X, Zhou M, Qu S, Ma X, Zhang Z (2014) Spatial distribution and temporal trends in daily and monthly precipitation concentration indices in the upper reaches of the Huai River, China. Stoch Env Res Risk A 28:201–212

Soldati M, Marchetti M (2017) Landscapes and landforms of Italy. Springer-Verlag, Berlin

von Storch H (1995) Misuses of statistical analysis in climate research. In: von Storch H, Navarra A (eds) Analysis of climate variability: applications of statistical techniques. Springer, New York

Xu L, Zhou H, Liang C, Du L, Li H (2010) Spatial and temporal variability of annual and seasonal precipitation over the desert region of China during 1951-2005. Hydrol Process 24:2947–2959

Yesilirmak E, Atatanir L (2016) Spatiotemporal variability of precipitation concentration in western Turkey. Nat Hazards 81:687–704