



# Spatiotemporal meteorological drought assessment in a humid Mediterranean region: case study of the Oued Sebaou basin (northern central Algeria)

Bilel Zerouali<sup>1</sup> · Mohamed Chettih<sup>1</sup> · Zaki Abda<sup>1</sup> · Mohamed Mesbah<sup>2</sup> · Celso Augusto Guimarães Santos<sup>3</sup> · Reginaldo Moura Brasil Neto<sup>3</sup> · Richarde Marques da Silva<sup>4</sup>

Received: 17 November 2020 / Accepted: 9 March 2021 / Published online: 25 March 2021  
© The Author(s), under exclusive licence to Springer Nature B.V. 2021

## Abstract

In this research, the spatiotemporal meteorological drought pattern was assessed in the Oued Sebaou basin (northern central Algeria) based on data from 23 rain gauges from 1972 to 2010 analyzed at seasonal and annual scales using the standardized precipitation index (SPI). A geographic information system was used to determine the cartographic precipitation concentration index and modified Fourier index (MFI) as well as the drought and rainfall characteristics of the stations. The analysis revealed moderate precipitation concentrations for all stations in the basin, for which longitude explains approximately 60% of the variance. The MFI results show three main aggressiveness distributions: weak, moderate and strong, which are similar to the spatial distribution of rainfall. The results show a prolonged drought that began in the late 1980s. In addition, more than 50% of the stations were affected by moderate and severe dry events during the period from 1986 to 2001. The comparison of the SPI values among the decades indicates that more than 20% of the cases were dominated by wet conditions from 1972 to 1981 and from 2002 to 2010, with near-normal and -normal events exceeding 70%. During the 2002–2010 decade, extreme wet events occurred in 7% of the cases, while in the 1972–1981 decade, only 1.75% of the cases were of this type. These results can provide watershed managers with more information to understand past drought and improve future water resource management.

**Keywords** Precipitation · SPI · PCI · MFI · Drought · Wet · Dry · Sebaou · Algeria

---

✉ Bilel Zerouali  
bilel.zerouali@yahoo.fr; b.zerouali@lagh-univ.dz

<sup>1</sup> Research Laboratory of Water Resources, Soil and Environment, Department of Civil Engineering, Faculty of Civil Engineering and Architecture, Amar Telidji University, P. O. Box 37.G, 03000 Laghouat, Algeria

<sup>2</sup> Earth Sciences Faculty, University of Science and Technology Houari Boumediene, BP 32, 16311 Bab Ezzouar, Algeria

<sup>3</sup> Department of Civil and Environmental Engineering, Federal University of Paraíba, João Pessoa 58051-900, Brazil

<sup>4</sup> Department of Geosciences, Federal University of Paraíba, João Pessoa 58051-900, Brazil

## 1 Introduction

Drought is the scarcity of water over a long period and is one of the impacts of climate change that manifests in several manners: hydrological, meteorological, agriculture and edaphic (related to soil conditions). For example, meteorological or atmospheric droughts ruin a region's agricultural production, reduce food availability, reduce hydropower production, cause grassland or forest fires and, most importantly, cause shortages of drinking water; thus, they may lead to the emergence of epidemics and diseases in the long term.

For meteorological drought assessment, numerous indices have been suggested and proposed, e.g., the standardized streamflow index (SSI) (Shukla and Wood 2008; McKee et al. 1993), Palmer drought severity index (PDSI) (Palmer 1965), standardized precipitation evapotranspiration index (SPEI) (Vicente-Serrano et al. 2010), reconnaissance drought index (RDI) (Tsakiris and Vangelis 2005), streamflow drought index (SDI) (Nalbantis and Tsakiris 2009), regional drought area index (RDAI) (Fleig et al. 2010, 2011), dimensionless precipitation anomaly index (DPAI) (Eris et al. 2020), Percent of Normal Precipitation Index (PNPI) (Willeke et al., 1994), and rainfall anomaly index (RAI) (Van Rooy 1965). Each index has its own strengths and weaknesses.

In the framework of climate change and drought analysis, several studies in recent years have been conducted around the world (e.g., Brasil Neto et al. 2021; Silva et al. 2020; Şen et al. 2020; Jehanzaib et al. 2020; Malik et al. 2020; Junqueira et al. 2020; Cavus and Aksoy 2020; Santos et al. 2019, 2018; Vergni et al. 2016; Murthy et al. 2016). Monitoring agricultural drought using land surface temperatures from Australian retrievals indicates that MTSAT-2 offers earlier drought control than do the greenness indices (Hu et al. 2020). In the Poyang Lake basin, Zhou et al. (2019) proposed an approach for meteorological drought migration monitoring based on topological spatial relations. During the study period, the proposed approach successfully identified a total of 454 drought clusters and 77 drought events. Nikbakht et al. (2013) analyzed hydrological drought in Urmia Lake (Northwest Iran) by PNPI and the Mann–Kendall (MK) test during the 1975–2009 period based on 14 hydrometric stations, and the analysis showed that the worst droughts indicated in the discharge were observed at all stations between 1999 and 2001. Santos et al. (2020) used PERSIANN-CDR-estimated rainfall data for geospatial drought severity analysis at Odisha state in India (1983–2018). The results indicated extreme drought events with increase in the drought severity timescale.

In the Upper Paraíba River basin, Brazil, the spatiotemporal variability in vegetation related to drought dynamics was analyzed using SPI, RAI and Moderate-Resolution Imaging Spectroradiometer (MODIS) products during the 2012–2017 period. Water stress was observed to be related to severe and erratic drought behavior in 2013, 2016 and 2017 (Ferreira da Silva et al. 2020). In the Johor River Basin, in Malaysia, Tan et al. (2019) analyzed spatiotemporal hydrometeorological drought and reported that the standardized precipitation index (SPI) indicated dry conditions occurring in the basin, whereas the SSI showed a strong significant decreasing trend due to drought, reservoir construction and the use of water for agriculture. Cavus and Aksoy (2019) indicated quite different severities simultaneously of droughts that has been experienced the Mediterranean region of Turkey (Seyhan River basin), with increasing drought duration in return periods. The rainfall trends and drought were analyzed over the Oum Er-Rbia River basin, Morocco, during the 1970–2010 period by SPI and MK tests. The results show that a tendency toward drier conditions mostly occurred between the 1980s and 1990s, with a deficit exceeding 50% (Ouatiki et al. 2019). Across KwaZulu-Natal Province, South Africa, Ndlovu and Demlie (2020) assessed

wet conditions and meteorological drought using two drought indices. The PNPI and RAI analyses indicated that the most extreme dry years occurred in 1992 and 2015, and the latter drier year was associated with El Niño conditions in the studied period.

Among the areas most affected by periods of drought are the tropics and subtropics located in the tropics of Cancer and Capricorn. These are in fact the areas with the hottest and driest climates. The most significant droughts in recent years have been located in the Sahel, the Horn of Africa, Mexico, northeastern Brazil and parts of China, India and Russia, as well as in southern Europe. In addition to the arid zones, the most vulnerable countries are found in Africa and West Asia (Cieau 2020). Algeria, which is mostly located in arid and semiarid zones in the Mediterranean basin, is considered one of the regions that can be influenced by periodic and persistent droughts. Since the drought struck the Mediterranean basin, especially Algeria, beginning at the end of 1970, a number of research papers have been written in this context to identify, assess and quantify the established drought in the region (Hallouz et al. 2020; Derdous et al. 2021; Mellak et al. 2020; Bendjema et al. 2019; Habibi et al. 2018; Achite et al. 2017; Khezazna et al. 2017; Meddi et al. 2014, 2010). In the whole of northeast Algeria, Merabti et al. (2018) used the SPI and RDI to analyze the spatiotemporal variability of drought between 1979 and 2014. Severe and moderate droughts were found to have occurred in the southern and more arid subregions, which can be associated with global warming. Using the standardized relative difference of precipitation (SRDP) over 40 years in the Macta basin (Algeria), a notable dry trend was observed in the northern polygon, while a dominant temporal instability was observed at higher elevation polygons (Achite et al. 2017). In the karst area of northwestern Algeria, Bouabdelli et al. (2020) applied bivariate frequency analysis and GR2M model on the representative concentration pathway emission scenario database (RCP4.5 and RCP8.5) for an assessment of hydrological drought risk. All simulations indicated an increase in future hydrological drought risk explained by a decrease in the return periods of droughts. Zerouali et al. (2019), based on cross-wavelet analysis and wavelet coherence, observed a significant and negative impact on the flow decrease, which was explained by drought impacts and by the smuggling and trafficking of gravels and rocks from the Wadi and the commissioning of the Taksebt dam beginning in the year 1998. In this study, spatiotemporal variation in meteorological drought was analyzed and classified using the SPI and geographic information systems (GIS) at monthly, seasonal and annual scales in the Oued Sebaou basin based on 23 rain gauges.

## 2 Study area and databases

The study area is the Oued Sebaou basin of northern Algeria, which is located between 36°30'N and 37°00'N and between 03°30'E and 04°30'E. This area is part of the coastal Algiers watershed, according to the Algerian National Agency of Water Resources (ANRH) (Fig. 1), and it extends over 2500 km<sup>2</sup>. It is bordered by the Mediterranean coastal area (in the north), the Djurdjura mountain chain (in the south), the massif Akfadou and Beni Ghobri (in the east) and the Sidi Ali and Jebel Bounab Bouberak mountains (in the west). The total population of the study area is 1,127,607 inhabitants, and 77.7% of the inhabitants live in rural areas.

The Taksebt dam is located in this region, which is an important dam that collects water from the Aïssi valley that is effluent from the Sebaou River. It is mainly intended to be a drinking water supply to the cities of Tizi Ouzou and Algiers. Vegetation cover occupies

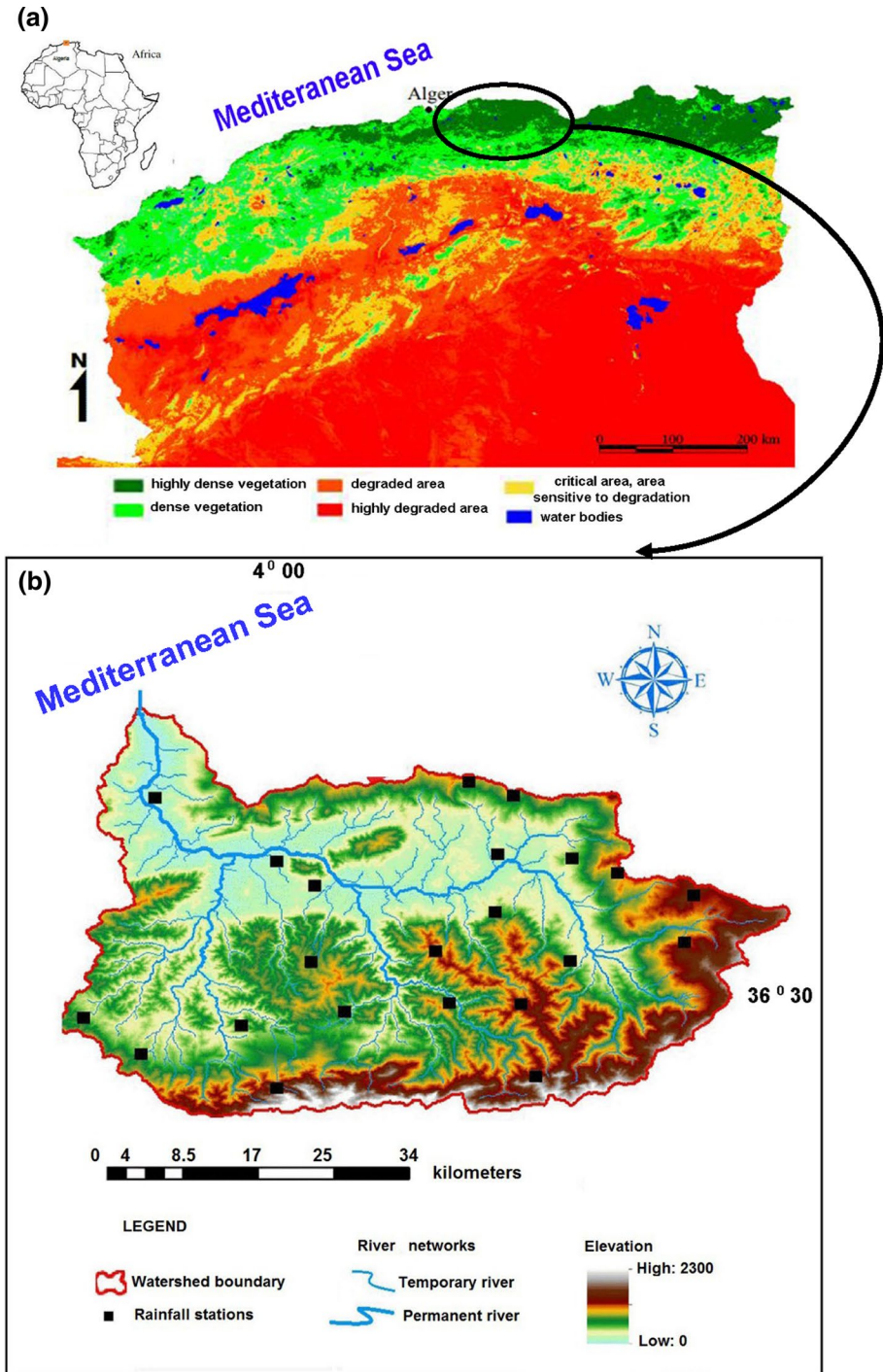


Fig. 1 Land cover map of northern Algeria. (Benslimane et al, 2008), geographic location and digital elevation model of the study basin

the largest percentage of the area, amounting to 71.5% of the total area. In general, the climate is affected by various factors, such as geography, topography, distance from the sea and atmospheric circulation. The climate of the study area is characterized by a dry season that begins at the end of May and ends in September and a wet winter that starts in October and ends at the end of May.

Dry, northwest winds, meeting Iberian mountain chains (Spain) and the Moroccan Atlas Mountains, arrive in northwestern Algeria and then recharge on the Mediterranean to provide heavy rainfall on the northern Tell Atlas Mountains. The rainfall amount declines from north to south, superimposed on an increase in the rainfall amount from west to east with longitude; this trend is distinct in Algeria, which is why the Oued Sebaou basin is one of most-watered areas of northern Algeria.

The rainfall of the study area has had a significant relationship with the North Atlantic Oscillation (NAO) for approximately 1 year, 1–3 years and 3–5 years beginning in the early 1980s, corresponding to the dry period. The Southern Oscillation (SOI), Mediterranean Oscillation (MO) and Western Mediterranean Oscillation (WeMO) indicate local influences on the rainfall, with significant values more or less localized in the time–frequency space. The 5–10-year and greater-than-10-year components are the most effective for representing significant climate index–rainfall relationships (Zerouali et al. 2018). The rainfall series database used in this study includes data collected at 23 stations (Fig. 1) at the monthly scale in the period from 1972 to 2010. These rainfall data were taken from the ANRH.

### 3 Material and methods

#### 3.1 Precipitation concentration index and modified Fourier index

Among the most important aspects of climate studies are monthly precipitation concentrations. An uneven distribution of precipitation reflects periods of excesses and deficits in rainfall, which affect crop growth and cause difficulties in harvests. In addition, precipitation concentrations should be considered when assessing and forecasting soil loss due to water erosion (Michiels et al. 1992). Oliver (1980) introduced the precipitation concentration index (PCI) to study the concentration of rainfall during the hydrologic year by a classification presented in Table 1. The PCI index is given by the following expression:

**Table 1** PCI, MFI and PCI classifications

PCI	Classification	MFI	Classification	SPI	Classification
Than 10	Uniform distribution	0–60	Very weak aggressiveness	2,+	Extremely wet
11–15	Moderate concentration	60–90	Weak aggressiveness	1,5–1,99	Very wet
16–20	Irregular distribution	90–120	Moderate aggressiveness	1,0–1,49	Moderately wet
> 20	Strong irregularity	120–160	Strong aggressiveness	–0,99–0,99	Near normal
–	–	> 160	Very strong aggressiveness	–1,0–1,49	Moderately dry
–	–	–	–	–1,5–1,99	Severely dry
–	–	–	–	–2–Less	Extremely dry

$$PCI = \frac{\sum_{i=1}^{12} P_{mi}^2}{\left(\sum_{i=1}^{12} P_m\right)^2} \times 100 \quad (1)$$

where  $P_m$  is the monthly rainfall in the month  $i$ .

Fournier et al. (1960) first proposed the index of aggressiveness, named modified Fournier index (MFI); afterwards, this index was modified by Arnoldus (1980). Fournier's classification is presented in Table 1, and, according to Fournier et al. (1960) and Arnoldus (1980), the MFI is given by the following equation:

$$MFI = \sum_{i=1}^{12} \frac{P_{mi}^2}{P_a} \quad (2)$$

where  $P_{mi}$  is the monthly rainfall in month  $i$  and  $P_a$  is the annual rainfall amount for a given year. The PCI and MFI were applied to the data from 23 rainfall stations at the monthly scale. For more detail about PCI and MFI methodology and implantation, the lecture is cordially invited to read the paper of Yeşilirmak and Atatanır (2016), De Luis et al. (2010)

### 3.2 Standardized precipitation index

McKee et al. (1993) developed the standardized precipitation index (SPI), an index based on probability theory for monitoring meteorological drought. The following SPI classification proposed in Table 1 defines the classification of dry and wet events according to the index values. According to McKee et al. (1993), the SPI approach first fits the hydrometeorological series to a probability distribution and then the series into a normal distribution  $N(0,1)$ . Thom (1958) found that the gamma distribution fits the hydroclimatological series well. For this reason, the gamma probability density function was used to calculate the distribution of rainfall, which is described in Eq. 3:

$$g(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \quad \text{for } x > 0 \quad (3)$$

where  $\alpha$  and  $\beta$  are the shape and scale parameters, respectively;  $\Gamma(\alpha)$  denotes the gamma function; and  $x$  is the rainfall value. The maximum likelihood method (Eq. 4) was applied for each monitoring rain gauge and each scale observation of each month to calculate the parameters  $\alpha$  and  $\beta$ :

$$\alpha = \frac{1}{4A} \left( 1 + \sqrt{1 + \frac{4A}{3}} \right) \quad \text{and} \quad \beta = \frac{\bar{x}}{\alpha} \quad \text{where } A = \ln(\bar{x}) - \frac{\sum_{i=1}^n \ln(x_i)}{n} \quad (4)$$

where  $n$  and  $\bar{x}$  are the number of observations and their average, respectively. The obtained parameters above were subsequently used to determine the cumulative probability of the observed rainfall episode for the given month- and timescale. The gamma function was not defined for dry months (i.e.,  $x=0$ ), and the time series distribution may thus have comprised zeros (widely observed in arid and semiarid areas), the new cumulative probability was calculated using Eqs. 5 and 6:

$$G(x) = \int_0^x g(x) = \frac{1}{\beta^\alpha \Gamma(\hat{\alpha})} \int_0^x x^{\hat{\alpha}-1} e^{-x/\hat{\beta}} dx \tag{5}$$

$$H(x) = q + (1 + q) G(x) \tag{6}$$

where q indicates that the probability of the rainfall amount is equal to zero. The cumulative probability H(x) is subsequently transformed into a normal distribution of Z random variables. Equations 7, 8 9, and 10 were used to convert the cumulative probability into a normal distribution of the Z variable:

$$Z = SPI = - \left[ t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right] \quad 0 < H(x) \leq 0.5 \tag{7}$$

$$Z = SPI = + \left[ t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right] \quad 0.5 < H(x) \leq 1 \tag{8}$$

where  $c_0=2.515517$ ,  $c_1=0.802853$ ,  $c_2=0.010328$ ,  $d_1=1.432788$ ,  $d_2=0.189269$ ,  $d_3=0.001308$ .

$$t = \sqrt{\ln \left( \frac{1}{H(x)^2} \right)} \quad 0 < H(x) \leq 0.5 \tag{9}$$

$$t = \sqrt{\ln \left( \frac{1}{(1 - H(x))^2} \right)} \quad 0.5 < H(x) \leq 1 \tag{10}$$

According to Shah et al. (2015), the SPI is well spread on dry events with extreme conditions; it is simple and practical and is one of the preferred tools for agricultural field assessments. In this work, the annual and seasonal patterns of droughts were assessed using the SPI-12 and SPI-3 values for each gauge, respectively. For SPI-12, 897 cases were evaluated (39 years × 23 stations), and for the seasonal timescale, the same number of cases was also evaluated for each season (summer, autumn, winter and springer), totaling more than 3,500 cases (39 years × 23 stations × 4 seasons). For more details about the methodology of SPI index calculation and implantation, see Santos et al. (2017) and Okpara et al. (2017).

### 3.3 Interpolation technique

Inverse distance weighting (IDW) is a deterministic interpolation method that is suitable as a local method of interpolation (Cavus and Aksoy 2019). In this method, the estimated value is determined using the weighted average of the closest points to the reference point. The points that are closer, known values are more influenced than more distant points are. Equation 11 shows how computing the estimated values in this paper:

$$\hat{Z}(X_0) = \frac{\sum_{i=1}^N \left( \frac{Z(X_i)}{D_{X_0}} \right)}{\sum_{i=1}^N \left( \frac{1}{D_{X_0}} \right)} \quad (11)$$

where  $Z(X_i)$  is the value measured at the location,  $D_{X_0}$  is the distance between the value of the known point and the estimated point,  $\hat{Z}(X_0)$  is the estimated value at location  $X_0$ , and  $N$  is the number of measured values.

## 4 Results and discussion

Rainfall in the Oued Sebaou River basin was characterized by high spatiotemporal irregularity during the study period and was influenced most by longitude. Figure 2a, b shows the spatial interpolation of the intra-annual rainfall amounts and variation coefficients, and Fig. 3 provides scatter plots of the intra-annual rainfall amounts according to altitude, latitude and longitude. Although altitude is an important factor that explains more than 34% of the variability in rainfall over the region, longitude is considered the most important variable affecting the geographical distribution of annual precipitation, responsible for at least 62% of the variance in the region. The average intra-annual precipitation of the 23 stations varies between 724 and 1200 mm per year, with variation coefficients greater than 25% for most stations.

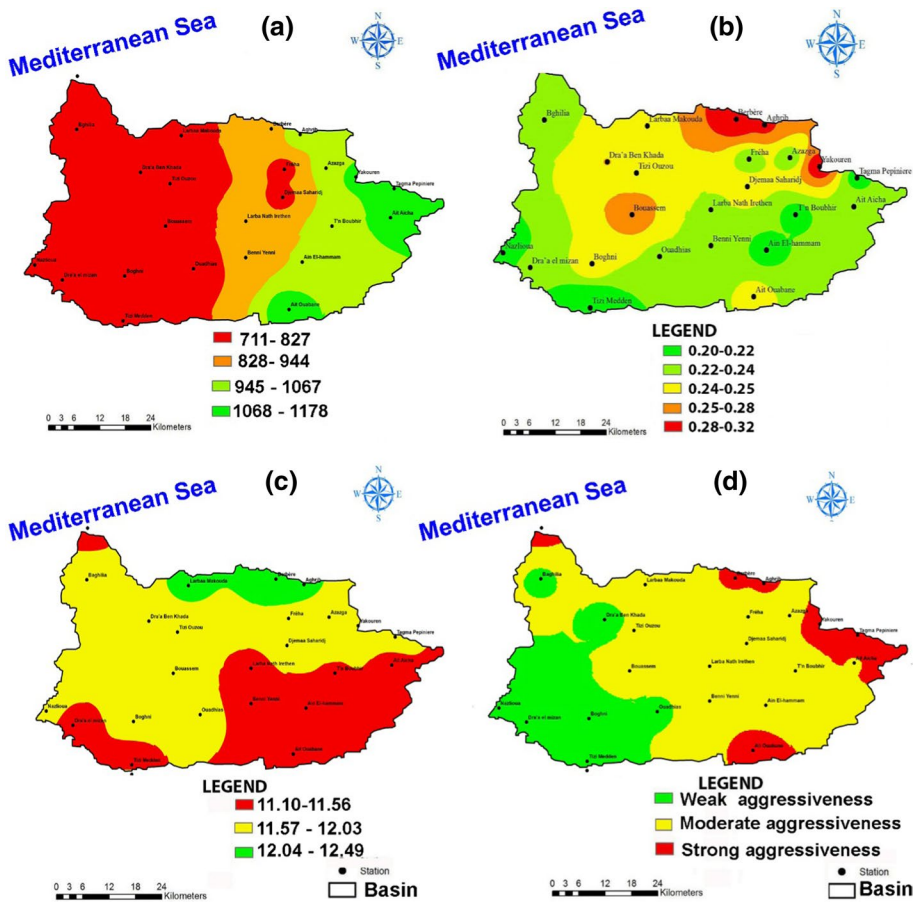
Figure 2c shows the spatial distribution of the PCI values in the region, and it is notable that the PCI results show moderate precipitation concentrations for all stations in the basin, varying from 11.0 to 12.6. The MFI index (Fig. 2d) shows that the aggressiveness of the rainfall is proportionally influenced by the same factors that influence the rainfall variability in the watershed. Additionally, the aggressiveness of rainfall events in recent years contributed to the extent of soil erosion, particularly the erosion of bare soil.

Moreover, the stations were divided in relation to their geographical parameters (altitude, longitude and latitude) and their recorded annual precipitation amounts, as shown in Table 2. Zone 1 is the zone with weak aggressiveness and is concentrated over the lower and western parts of the middle Sebaou River (Fig. 2d). Zone 2 is dominant and presents moderate aggressiveness in the eastern and upper Sebaou River, except for the Ait Ouabane station, which is part of Zone 3 (Fig. 2d). Zone 3 is a region located in the mountainous areas (e.g., Aghrib, Ait Ouabane, Tagma and Yakouren) and shows strong aggressiveness (Fig. 2d).

The SPI-3 and SPI-12 values were computed for each rain gauge between 1972 and 2010 and were adapted for the analysis and monitoring of drought variability in the study area. The Baghlia (Zone 1), T'N Boubhir (Zone 2) and Yakouren (Zone 3) stations were selected as representative stations of each zone, and their SPI values were computed (Fig. 4). The SPI values oscillate between  $-2$  and  $2$ , which highlights wet and dry episodes over the region. Moreover, it can highlight the existence of particularly wet or dry years and note that the dry sequences are relatively longer than the wet sequences are.

Overall, it was found that the 1980s and 1990s were more affected by drought events than other decades were, especially between 1986 and 1998, when the frequencies of moderate and severe dry events were higher in the region. This can be explained by the rainfall deficit, which affected the entire African continent during the same period (Nicholson et al. 2018). Figure 5a shows that more than 60% of the studied years were categorized, in

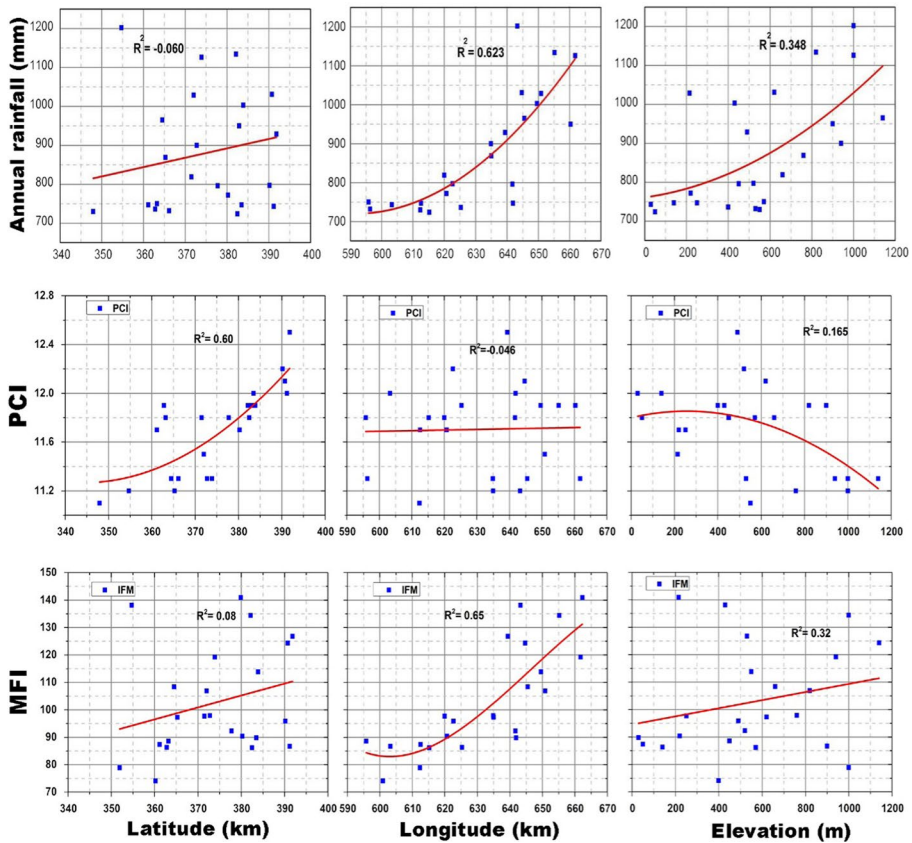




**Fig. 2** Distribution and spatial interpolation of **a** intra-annual rainfall (mm) and **b** variation coefficient, **c** the PCI index and **d** MFI index for monthly precipitation (1972–2010) for 23 rain gauges of Oued Sebaou basin

general, as near normal to normal. Extreme wet and moderately dry events were observed in a pronounced way over 6 years, but the other drought categories did not exceed 10%. The percentages of stations affected by the different categories are documented in Fig. 5b. Rare, moderate dry events affected less than 18% of stations, especially between 1976 and 1978 and between 1983 and 2001. Moderate and severe dry events prevailed throughout 50% of stations in 1987, 1989, 1993, 1996, 1999 and 2001, which can be related to the drought that started in 1980 and affected the African Sahel region (Ozer et al. 2003; Nicholson et al. 2018).

In contrast, 1972, 1973, 1975, 1980, 1984, 1997, 2002, 2008 and 2010 were characterized by moderate, severe and extreme wet events. Figures 6 and 7 explain, in detail, the frequency of dry and wet events at each rainfall station in the Oued Sebaou basin. The findings in this study are consistent with those of other studies carried out at the scale of the Mediterranean basin, which indicates that the existence of dry periods prevailed more during 1986 and 2001. Over Portugal, for example, Barros et al. (1995) observed that 1993 was the driest year based on a 60-year database, as also found by Bordalo et al. (2006). In



**Fig. 3** Relationship between rainfall, PCI, MFI and geographical factors (latitude, longitude and elevation)

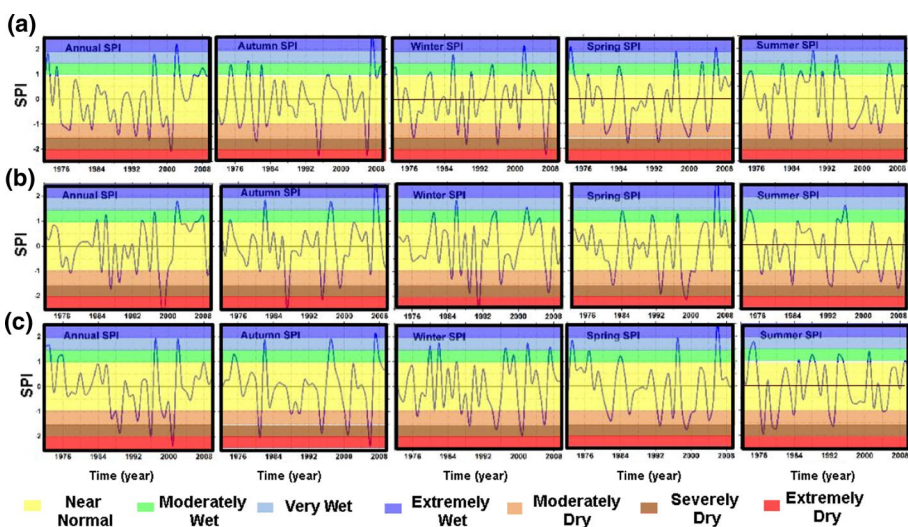
southern Spain, Peñuelas et al. (2001) documented that 1988, 1989 and 1994 were the most dangerous, driest years. In Serbia, Gocic and Trajkovic (2014) showed that one of the driest years throughout history was observed in 2000.

Similarly to the statistical application of Faye et al. (2015), it is assessed a total of 897 events (39 years  $\times$  23 stations) using statistical methods. The results indicate that more than 20% of the cases are marked by wet conditions in the 1970s and 2000s, and near-normal to normal events exceed 70% of all the cases (Fig. 8). Specifically, 1.75% of cases were characterized as extreme wet events during the 1970s, and this percentage increased to 7% for the 2000s. Regarding the patterns of the 1980s and 1990s, it can be noted that drought periods far outweighed wet periods, and the summarization of drought events reached 32% and 21%, respectively, which were specifically composed of severe and moderate dry events. Globally, the analysis based on SPI indicates the alternation of three periods: the first is a wet period (1970s), the second is a long-term drought period, established in the basin during the 1980s and 1990s, and the third is considered a wet period (2000s). Figure 9 characterizes the alternation of the three periods.

Spatiotemporal drought variability was analyzed (Fig. 9) using a GIS by the comparison and assessment of the mean annual and seasonal SPI magnitudes per decade. As discussed above, Fig. 9 clearly emphasizes excess rainfall amounts during the 1970s and 2000s,

**Table 2** PCI, MFI and PCI classifications between the period of 1972 and 2010 for the 23 rainfall stations of the study area

Stations	Longitude (x) (km)	Latitude (y) (km)	PCI	Concentration	IFM	Aggressiveness
Aghrib	620.7	380.25	12.1	Moderate	124.3	Strong
Ain El Hammam	615.2	382.5	11.3	Moderate	108.4	Moderate
Ait Ouabane	641.9	383.5	11.2	Moderate	138.1	Strong
Ait Aicha	649.6	383.9	11.3	Moderate	119.2	Moderate
Azazga	612.55	361.15	11.9	Moderate	113.8	Moderate
Beni Yenni	645.5	364.5	11.2	Moderate	97.3	Moderate
Berbère	596.3	366.1	12.5	Moderate	126.8	Strong
Baghlia	661.78	373.9	12	Moderate	86.7	Weak
Boghni	635	365.25	11.7	Moderate	87.4	Weak
Bouassem	644.7	390.73	11.8	Moderate	97.7	Moderate
DBK	643.25	354.7	11.8	Moderate	86.2	Weak
DEM	603.25	391.15	11.3	Moderate	74.1	Weak
Djemaa Saharidj	639.35	391.8	11.8	Moderate	92.3	Moderate
Freha	620	371.5	12	Moderate	89.8	Weak
LNI	641.7	377.75	11.3	Moderate	97.9	Moderate
Larbaa Makouda	634.9	372.75	12.2	Moderate	95.9	Moderate
Nezlioua	622.65	390.15	11.8	Moderate	88.6	Weak
Ouadhias	595.8	363.2	11.9	Moderate	86.3	Weak
Tagma	625.3	362.8	11.9	Moderate	140.9	Strong
Tizi Medden	612.35	347.92	11.1	Moderate	78.9	Weak
Tizi Ouzou	660.3	382.9	11.7	Moderate	90.4	Moderate
T’N’Boubhir	650.9	372	11.5	Moderate	106.9	Moderate
Yakouren	655.2	382.15	11.9	Moderate	134.4	Strong



**Fig. 4** Annual and seasonal distribution of SPI for Baghlia, T’N Boubhir and Yakouren between 1972 and 2010

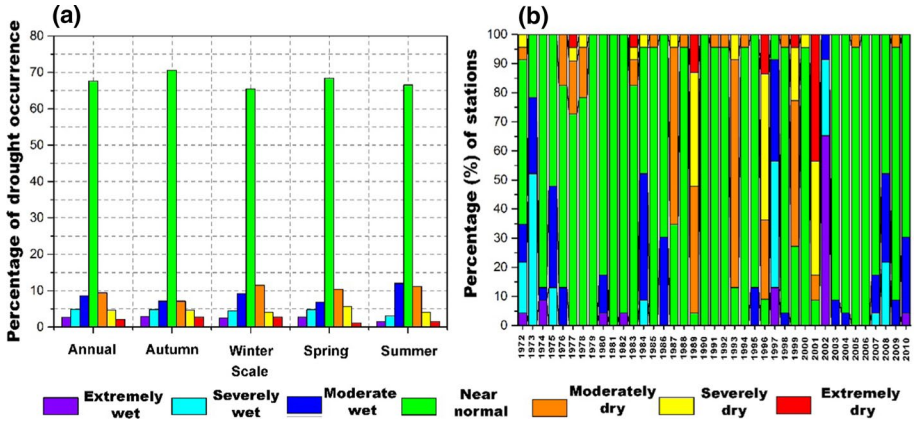


Fig. 5 Classification of drought **a** average percentage of occurrence of drought and **b** percentage of stations affected by the different categories of drought according to the SPI index during the period of 1972–2010

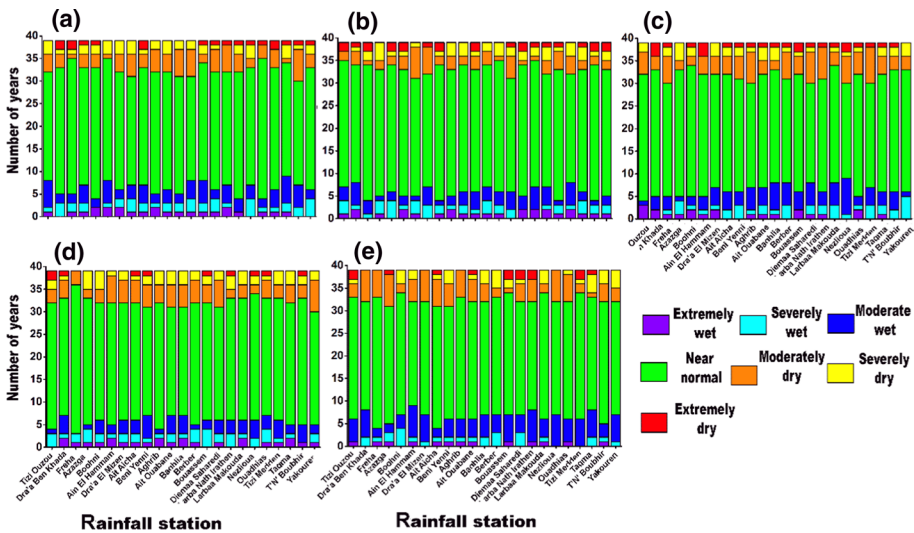
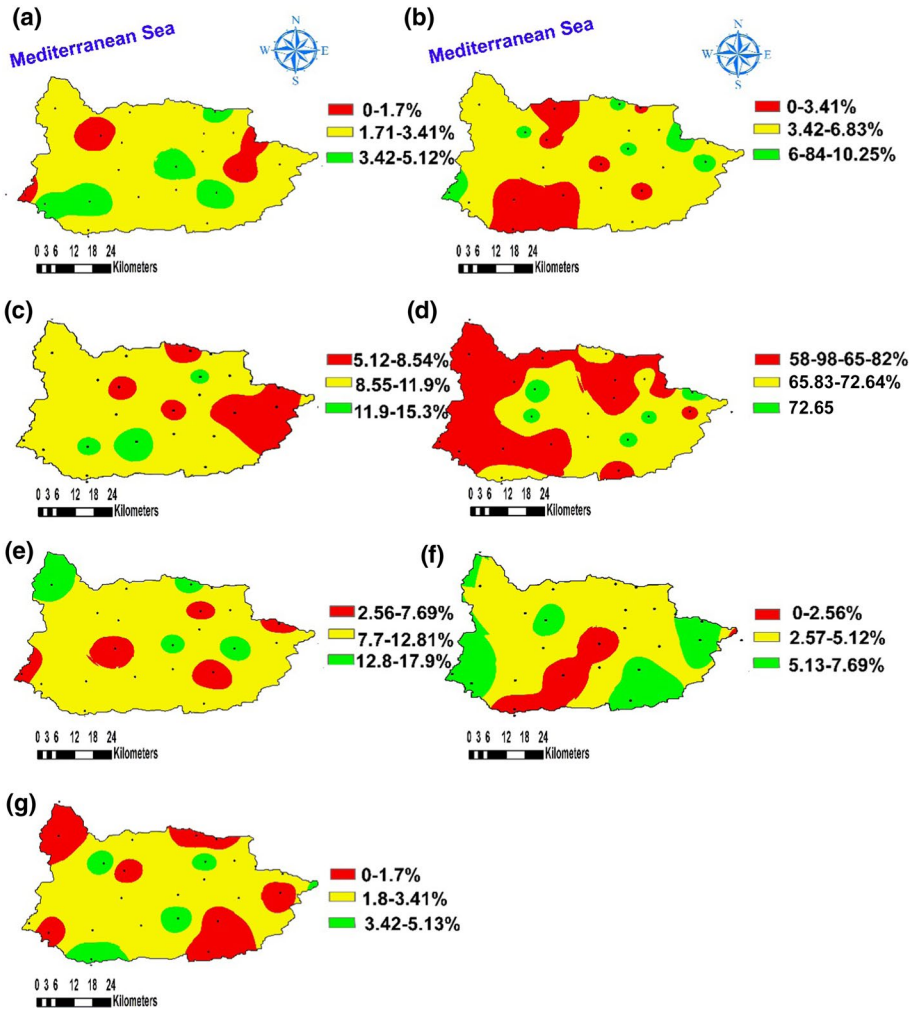


Fig. 6 Drought classification (duration or number of years) at **a** annual, **b** autumn, **c** winter, **d** spring, **e** summer for each station in the study region during the period of 1972–2010

which were prominent in all cities, except at the stations of Berber, Baghlia and Ait Ouabane, where extreme dry events were detected. At the scale of the Mediterranean basin, Khomsi et al. (2015) pointed to a nonsignificant upward trend in heavy rainfall events in some Moroccan regions, and Donat et al. (2014) observed a positive trend toward wetter conditions, especially in the western parts of Algeria, Tunisia, Libya, Morocco and Mauritania.

The maps representing two successive decades, the 1980s and 1990s, clearly reveal the deficit of rainfall, which was found particularly in the southern part of the basin, where the SPI values varied between -0.2 and -0.7. The results presented in this paper at the basin



**Fig. 7** Spatial distribution of percentage of occurrence of each drought category: **a** extremely wet, **b** very wet, **c** moderately wet, **d** near normal, **e** moderately dry, **f** severely dry, **g** extremely dry during the period of 1972–2010

scale agree with the observations reported by researchers in northern Algeria and in the Mediterranean region (Gader et al. 2020; Bouabdelli et al. 2020; Achour et al. 2020; Hal-loulou et al. 2020; Zerouali et al. 2020; Mrad et al. 2020; Caloiero et al. 2019; Spinoni et al. 2018; Jemai et al. 2018; Taibi et al. 2017; Nouaceur and Murărescu 2016; Meddi et al. 2014; Hamlaoui-Moulai et al. 2013). In a south Mediterranean transboundary catchment (Medjerda), drought was assessed by Gader et al. (2020) using multivariate and geostatistical approaches during the period 1973–2012. A significant drought was detected in the 41 stations studied with moderate drought was observed during the decades 1980 and 1990.

Ghenim and Megnounif (2013) revealed a climatic wet period in northwestern Algeria between the 1940s and the mid-1970s and a dry period beginning in the 1980s and continuing to the end of the 1990s. In Serbia, Gocic and Trajkovic (2014) documented severe

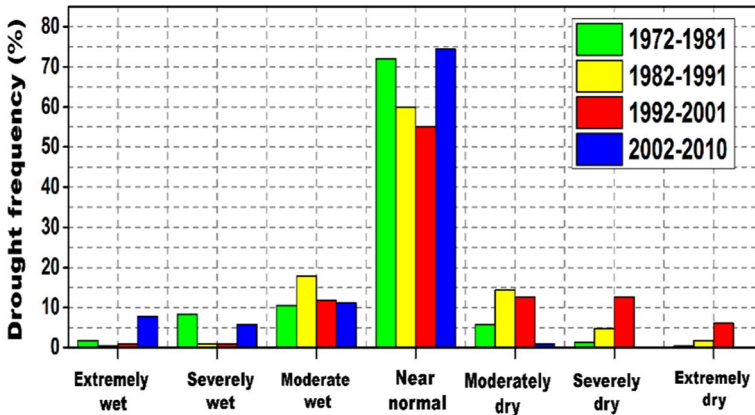


Fig. 8 Frequencies (number of stations multiplied by years in %) of SPI classes during the period of 1972–2010

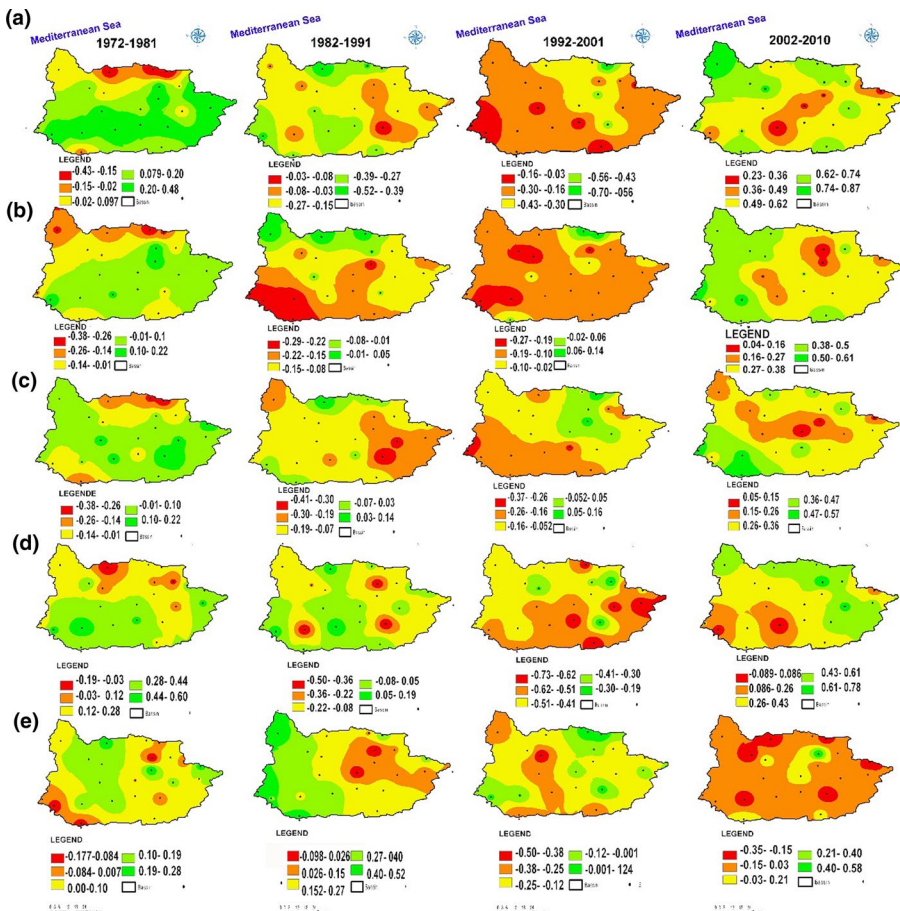


Fig. 9 Mapping of average values of SPI index by decade at **a** annual, **b** autumn, **c** winter, **d** spring and **e** summer

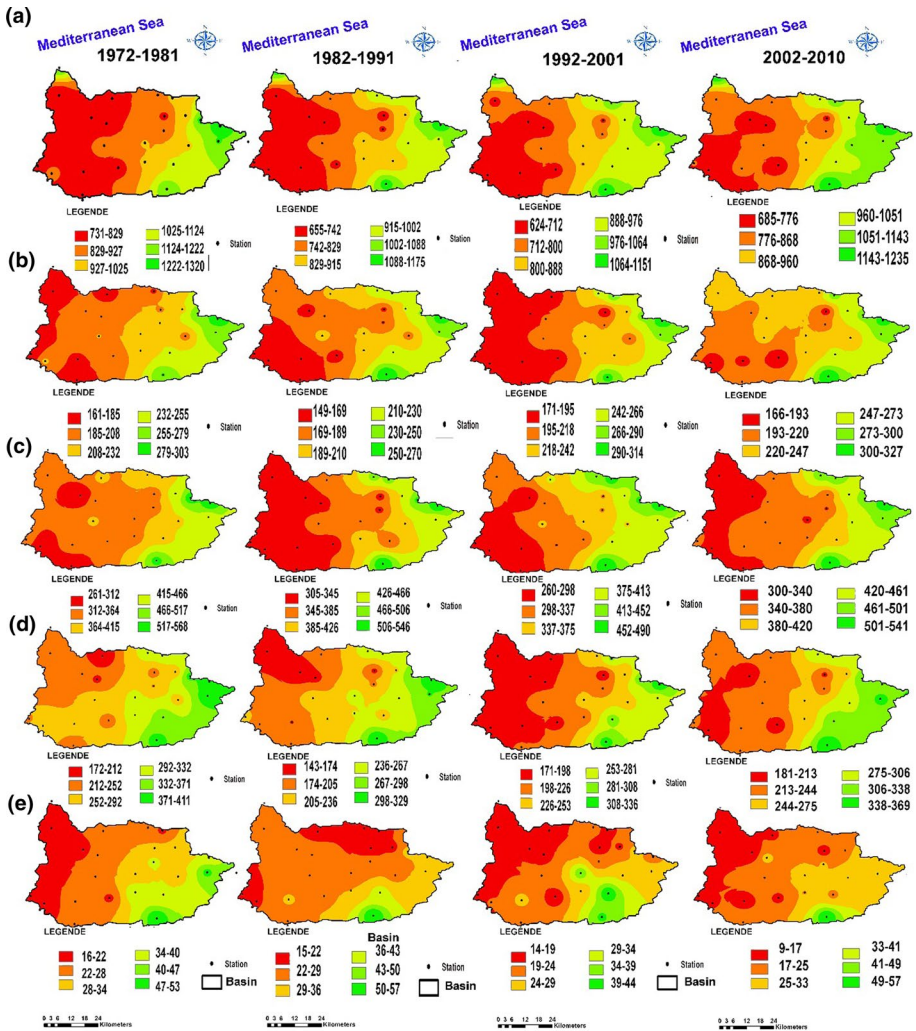
droughts during the period of 1987–1994, with the worst dry year observed in 2000. Over Morocco, Esper et al. (2007) pointed out dry conditions in the 1980s, and Xoplaki et al. (2004) observed a particularly dry period from 1981–1995. In Central Italy, Di Lena et al. (2014) revealed a downward trend between 1970 and 1995, followed by an increasing trend during the subsequent decade. Vicente-Serrano et al. (2006) observed in the Iberian Peninsula that the most severe and intense drought episodes occurred between 1940 and 1960 and from 1980 to 2000. Silva et al. (2015) analyzed the trends in annual precipitations and river flow at a regional scale over 40 years (1960–2000) for Cobres River basin, southern Portugal, using statistical tools to obtain a better understanding of the spatial and temporal variability and trends of rainfall and river flow. In Algeria, a wet period occurred between 1999 and 2009, and similar results were observed in all seasons except in autumn (Khezazna et al. 2017).

In addition, the analyses of the annual and seasonal rainfall amounts show great variability in the rainfall averages between decades (Fig. 10). At the Ait Aicha station, for example, the precipitation tends toward dry conditions for the first three decades: 1225 mm (1970s), 994 mm (1980s) and 959 mm (1990s). However, in the 2000s, an increase in the average rainfall was observed compared to the 1980s and 1990s, but the value was still below the 1970s average. This reversibility of the trend can be integrated into the decrease in drought in the Sahel, a cyclical periodicity, the fluctuation of rainfall phenomena or even external impacts linked to large-scale teleconnection patterns, such as the NAO, which is responsible for variability in precipitation in northern Algeria and the Mediterranean basin (Zerouali et al. 2018; Zeroual et al. 2017; Vergni et al. 2016; Leila-Hamlaoui et al. 2013; Ferrari et al. 2013).

Several research studies have shown that the NAO is a principal cause of the appearance of drought in northern Algeria (Zeroual et al. 2017; Taibi et al. 2017). Using wavelet techniques, Zerouali et al. (2018) showed that the relationship between the NAO and precipitation in northern central Algeria is significant for 1-year and 3–5-year timescales, especially during the period with a dry tendency beginning in 1980. Mathbout et al. (2019) analyzed the spatiotemporal variability in daily precipitation and the relationship of the variability with large-scale circulation phenomena. The decrease in precipitation over the western Mediterranean could be linked to the positive trend of the NAO during the 1975–1995 period. In the Mediterranean region, Montaldo and Sarigu (2017) analyzed the potential links between the NAO and the reduction in precipitation and river flows. The results indicate that a decrease in winter precipitation induces a decrease in river flow, and the NAO was found to be an influencing factor on the appearance of negative trends in winter precipitation. Corona et al. (2019) analyzed the effect of the interannual variability driven by the NAO in the seasonality of precipitation on water resources. The results showed that the decrease in annual runoff was more pronounced than that in annual precipitation, and winter precipitation was significantly negatively correlated with the NAO.

## 5 Conclusion

This study evaluated the spatiotemporal pattern of meteorological drought in northern central Algeria using SPI and GIS tools. In general, the precipitation over the study area can be described as irregular and nonuniform in spatiotemporal terms, especially considering the intra-annual distribution from 1972 to 2010. The results revealed moderate precipitation concentrations at all stations in the basin, and longitude was found to be one of the



**Fig. 10** Spatial interpolation and mapping of rainfall averages variations: **a** annuals **b** autumn, **c** winter, **d** spring and **e** summer between the decades 1972–1981, 1982–1991, 1992–2001 and 2002–2010

most influential factors for this effect, responsible for approximately 60% of the variance in precipitation. The results based on the MFI show three main distributions of aggressiveness over the region: (a) weak, in the case of the lower Sebaou River, (b) moderate, in the case of the middle Sebaou River and (c) strong, in the case of the upper Sebaou River.

In terms of drought, the existence of dry periods that were more pronounced between the 1980s and 1990s is highlighted, which reached rainfall deficits of 30%, and wet periods that occurred frequently in the 1970s and 2000s. On the seasonal scale, the pattern was similar to the results found on the annual scale, except for in spring, which showed a clear downward trend in the 1980s. At the regional level, results presented in this paper corroborate those of other researchers that reported an increase in average precipitation across the Mediterranean basin over the 2000s. The results presented in this paper can be used for



understanding past climate and drought variability over the study area and can be useful for decision-making and for the planning and management of water resources.

**Acknowledgments** The authors gratefully thank the Directorate General for Scientific Research and Technological Development of Algeria and the Brazilian Agency for the Improvement of Higher Education (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior—CAPES) for supporting this research. The authors thank all the engineers of the National Agency of Water Resources (ANRH), who provided us with necessary data. This and all my works are dedicated to the memory of my beloved wonderful mom and darling sister. Will they forever remain in my soul.

**Author contributions** BZ, MC, ZA and MM conceived the framework of this research, processed data, designed the experiments, plots and maps preparation, validated the processing results and wrote the manuscript for this study. CAGS, RMBN, RMdS gave feedback on the written manuscript, helped to analyze, edited the manuscript for proper English language, grammar, punctuation, spelling, and technical improvements were added in all sections of the manuscript. All authors read and approved the final manuscript.

**Data availability** The data that support the findings of this study are owned by National Agency of Water Resources (ANRH) of Algeria. To access and obtain the data, please contact the Agency at [anrh@anrh.dz](mailto:anrh@anrh.dz) (<http://www.anrh.dz>).

#### Declarations

**Conflicts of interest** The authors declare that there are no conflicts of interest regarding the publication of this paper.

## References

- Achite M, Buttafuoco G, Toubal KA et al (2017) Precipitation spatial variability and dry areas temporal stability for different elevation classes in the Macta basin (Algeria). *Environ Earth Sci* 76:458. <https://doi.org/10.1007/s12665-017-6794-3>
- Achour K, Meddi M, Zeroual A et al (2020) Spatio-temporal analysis and forecasting of drought in the plains of northwestern Algeria using the standardized precipitation index. *J Earth Syst Sci* 129:42. <https://doi.org/10.1007/s12040-019-1306-3>
- Arnoldus, HMJ (1980). An approximation of the rainfall factor in the Universal Soil Loss Equation. An approximation of the rainfall factor in the Universal Soil Loss Equation., 127–132.
- Barros MC, Mendo MJM, Negrão FC (1995) Surface water quality in Portugal during a drought period. *Sci Total Environ* 171:69–76. [https://doi.org/10.1016/0048-9697\(95\)04671-7](https://doi.org/10.1016/0048-9697(95)04671-7)
- Bendjema L, Baba-Hamed K, Bouanani A (2019) Characterization of the climatic drought indices application to the Mellah catchment. *North-East Algeria Water Land Dev* 43(1):28–40. <https://doi.org/10.2478/jwld-2019-0060>
- Benslimane M, Hamimedi A, El Zerey W, Khaldi A, Medebal K (2008) Analyse et suivi du phénomène de désertification en Algérie du Nord. *Vertigo, la revue en sciences de l'environnement* 8(3):1–9
- Bordalo AA, Teixeira R, Wiebe WJA (2006) Water Quality Index applied to an international shared river basin: the case of the dourou river. *Environ Manag* 38:910–920. <https://doi.org/10.1007/s00267-004-0037-6>
- Bouabdelli S, Meddi M, Zeroual A, Alkama R (2020) Hydrological drought risk recurrence under climate change in the karst area of Northwestern Algeria. *J Water Clim Change*. <https://doi.org/10.2166/wcc.2020.207>
- Brasil Neto RM, Santos CAG, Silva, J.F.C.B.d.C. et al (2021) Evaluation of the TRMM product for monitoring drought over Paraíba State, northeastern Brazil: a trend analysis. *Sci Rep* 11:1097. <https://doi.org/10.1038/s41598-020-80026-5>
- Caloiero T, Aristodemo F, Ferraro DA (2019) Trend analysis of significant wave height and energy period in southern Italy. *Theor Appl Climatol*. <https://doi.org/10.1007/s00704-019-02879-9>
- Cavus Y, Aksoy H (2019) Spatial drought characterization for Seyhan River basin in the mediterranean region of Turkey. *Water* 11(7):1331. <https://doi.org/10.3390/w11071331>
- Cavus Y, Aksoy H (2020) Critical drought severity/intensity-duration frequency curves based on precipitation deficit. *J Hydrol* 584:124312. <https://doi.org/10.1016/j.jhydrol.2019.124312>

- Cieau (2020). La sécheresse : d'où vient-elle et comment agir ? la sécheresse dans le monde <<https://www.cieau.com/connaitre-leau/secheresse-comment-agir/>> (Feb. 15.2020)
- Corona R, Montaldo N, Albertson JD (2018) On the role of NAO-driven interannual variability in rainfall seasonality on water resources and hydrologic design in a typical mediterranean basin. *J Hydro-meteorol* 19(3):485–498. <https://doi.org/10.1175/JHM-D-17-0078.1>
- Derdouane O, Bouamrane A, Mrad D (2021) Spatiotemporal analysis of meteorological drought in a Mediterranean dry land: case of the Cheliff basin–Algeria. *Model Earth Syst Environ* 7:135–143. <https://doi.org/10.1007/s40808-020-00951-2>
- Di Lena B, Vergni L, Antenucci F, Todisco F, Mannocchi F (2014) Analysis of drought in the region of Abruzzo (Central Italy) by the standardized precipitation index. *Theor Appl Climatol* 115:41–52. <https://doi.org/10.1007/s00704-013-0876-2>
- De Lima M, Isabel P, Santo FE, Ramos AM, Trigo RM (2015) Trends and correlations in annual extreme precipitation indices for mainland Portugal, 1941–2007. *Theor Appl Climatol* 119:55–75. <https://doi.org/10.1007/s00704-013-1079-6>
- De Luis M, González-Hidalgo JC, Longares LA (2010) Is rainfall erosivity increasing in the mediterranean Iberian Peninsula? *Land Degrad Dev* 21(2):139–144. <https://doi.org/10.1002/ldr.918>
- Donat MG, Peterson TC, Brunet M, King AD, Almazroui M et al (2014) Changes in extreme temperature and precipitation in the Arab region: long-term trends and variability related to Enso and NAO. *Int J Climatol* 34(3):581–592. <https://doi.org/10.1002/joc.3707>
- Eris E, Cavus Y, Aksoy H et al (2020) Spatiotemporal analysis of meteorological drought over Kucuk Menderes River Basin in the Aegean Region of Turkey. *Theor Appl Climatol* 142:1515–1530. <https://doi.org/10.1007/s00704-020-03384-0>
- Esper Jan, Frank David, Büntgen Ulf, Verstege Anne, Luterbacher Jürg, Xoplaki Elena (2007) Long-Term Drought Severity Variations in Morocco. *Res Lett Geophys*. <https://doi.org/10.1029/2007GL030844>
- Faye C, Sow AA, Ndong JB (2015). Étude des sècheresses pluviométriques et hydrologiques en Afrique tropicale: caractérisation et cartographie de la sècheresse par indices dans le haut bassin du fleuve Sénégal. *Physio-Géo*:17–35
- 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. <https://doi.org/10.1007/s00704-013-0856-6>
- Ferreira da Silva GJ, de Oliveira NM, Santos CAG et al (2020) Spatiotemporal variability of vegetation due to drought dynamics (2012–2017): a case study of the upper Paraíba River basin, Brazil. *Nat Hazards* 102:939–964. <https://doi.org/10.1007/s11069-020-03940-x>
- Fleig AK, Tallaksen LM, Hisdal H, Hannah DM (2011) Regional hydrological drought in north-western Europe: linking a new regional drought Area Index with weather types. *Hydrol Process* 25(7):1163–1179. <https://doi.org/10.1002/hyp.7644>
- Fleig AK, Tallaksen LM, Hisdal H, Stahl K, Hannah DM (2010) Inter-comparison of weather and circulation type classifications for hydrological drought development. *Phys Chem Earth* 35(9–12):507–515. <https://doi.org/10.1016/j.pce.2009.11.005>
- Fournier F et al (1960) Climat et érosion : la relation entre l'érosion du sol par l'eau et les précipitations atmosphériques. Presses universitaires de France, Paris
- Gader et al (2020) Drought assessment in a south Mediterranean transboundary catchment. *Hydrol Sci J* 65(8):1300–1315. <https://doi.org/10.1080/02626667.2020.1747621>
- Galván L, Olías M, Cerón JC, Cánovas CR, Pérez-López R, Nieto JM (2013) Assessment of the dissolved pollutant flux of the Odiel River (Sw Spain) during a Wet Period. *Sci Total Environ* 463:572–580. <https://doi.org/10.1016/j.scitotenv.2013.06.067>
- Ghenim AN, Megnounif A (2013) Ampleur de la Sécheresse Dans le Bassin d'alimentation du Barrage Meffrouche (Nord-Ouest de l'Algérie). *Physio-Géo* 7:35–49
- Gocic M, Trajkovic S (2014) spatiotemporal characteristics of drought in Serbia. *J Hydrol* 510:110–123. <https://doi.org/10.1016/j.jhydrol.2013.12.030>
- Habibi B, Meddi M, Torfs PJ, Remaoun M, Van Lanen HA (2018) Characterisation and prediction of meteorological drought using stochastic models in the semi-arid Chélif-Zahrez basin (Algeria). *J Hydrol Reg Stud* 16:15–31. <https://doi.org/10.1016/j.ejrh.2018.02.005>
- Hallouz F, Meddi M, Mahé G et al (2020) Analysis of meteorological drought sequences at various timescales in semi-arid climate: case of the Cheliff watershed (northwest of Algeria). *Arab J Geosci* 13:280. <https://doi.org/10.1007/s12517-020-5256-5>
- Hamlouli-Moulai L, Mesbah M, Souag-Gamane D et al (2013) Detecting hydro-climatic change using spatiotemporal analysis of rainfall time series in Western Algeria. *Nat Hazards* 65:1293–1311. <https://doi.org/10.1007/s11069-012-0411-2>

- Hu T, Renzullo LJ, van Dijk AI, He J, Tian S, Xu Z, Liu Q (2020) Monitoring agricultural drought in Australia using MTSAT-2 land surface temperature retrievals. *Remote Sens Environ* 236:111419. <https://doi.org/10.1016/j.rse.2019.111419>
- Jehanzaib M, Sattar MN, Lee J et al (2020) Investigating effect of climate change on drought propagation from meteorological to hydrological drought using multi-model ensemble projections. *Stoch Environ Res Risk Assess* 34:7–21. <https://doi.org/10.1007/s00477-019-01760-5>
- Jemai H, Ellouze M, Abida H, Laignel B (2018) Spatial and temporal variability of rainfall: case of Bizerte-Ichkeul Basin (Northern Tunisia). *Arab J Geosci* 11(8):177. <https://doi.org/10.1007/s12517-018-3482-x>
- Junqueira R, Viola MR, de Mello CR et al (2020) Drought severity indexes for the Tocantins River Basin, Brazil. *Theor Appl Climatol* 141:465–481. <https://doi.org/10.1007/s00704-020-03229-w>
- Khezazna A, Amarchi H, Derdous O, Bousakhria F (2017) Drought monitoring in the Seybouse basin (Algeria) over the last decades. *Water Land Dev* 33(1):79–88. <https://doi.org/10.1515/jwld-2017-0022>
- Khomsî K, Mahe G, Trambly Y, Sinan M, Snoussi M (2015) Trends in rainfall and temperature extremes in Morocco. *Nat Hazards Earth Syst Sci* 3(2):1079–1090. <https://doi.org/10.5194/nhess-5>
- Malik A, Kumar A, Kisi O et al (2020) Analysis of dry and wet climate characteristics at Uttarakhand (India) using effective drought index. *Nat Hazards*. <https://doi.org/10.1007/s11069-020-04370-5>
- Mathbout S, Lopez-Bustins JA, Royé D, Martin-Vide J, Benhamrouche A (2020) Spatiotemporal variability of daily precipitation concentration and its relationship to teleconnection patterns over the Mediterranean during 1975–2015. *Int J Climatol* 40(3):1435–1455. <https://doi.org/10.1002/joc.6278>
- McKee, Thomas B, Nolan J Doesken, and John Kleist. (1993) The Relationship of Drought Frequency and Duration to Time Scales. In *Proceedings of the 8th Conference on Applied Climatology*, 17, 179–183: American Meteorological Society Boston, MA, USA,
- Meddi MM, Assani AA, Meddi H (2010) Temporal variability of annual rainfall in the Macta and Tafna Catchments. *Northwestern Algeria Water Resour Manage* 24:3817–3833. <https://doi.org/10.1007/s11269-010-9635-7>
- Meddi H, Meddi M, Assani AA (2014) Study of drought in seven Algerian Plains. *Arab J Sci Eng* 39:339–359. <https://doi.org/10.1007/s13369-013-0827-3>
- Mellak S, Souag-Gamane D (2020) Spatio-temporal analysis of maximum drought severity using Copulas in Northern Algeria. *J Water Clim Change*. <https://doi.org/10.2166/wcc.2020.070>
- Merabti A, Martins DS, Meddi M et al (2018) Spatial and time variability of drought based on SPI and RDI with various time scales. *Water Resour Manage* 32:1087–1100. <https://doi.org/10.1007/s11269-017-1856-6>
- Michiels P, Gabriels D, Hartmann R (1992) Using the seasonal and temporal precipitation concentration index for characterizing the monthly rainfall distribution in Spain. *CATENA* 19(1):43–58. [https://doi.org/10.1016/0341-8162\(92\)90016-5](https://doi.org/10.1016/0341-8162(92)90016-5)
- 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. <https://doi.org/10.1016/j.jhydrol.2017.08.018>
- Mrad D, Dairi S, Boukhari S, Djebbar Y (2020) Applied multivariate analysis on annual rainfall in the northeast of Algeria. *J Water Clim Change* 11(4):1165–1176
- Murthy CS, Singh J, Kumar P et al (2016) Meteorological drought analysis over India using analytical framework on CPC rainfall time series. *Nat Hazards* 81:573–587. <https://doi.org/10.1007/s11069-015-2097-8>
- Nalbantis I, Tsakiris G (2009) Assessment of hydrological drought revisited. *Water Resour Manage* 23:881–897. <https://doi.org/10.1007/s11269-008-9305-1>
- Ndlovu MS, Demlie M (2020) Assessment of meteorological drought and wet conditions using two drought indices across KwaZulu-Natal Province. *South Africa Atmosphere* 11(6):623. <https://doi.org/10.3390/atmos11060623>
- Nicholson SE, Funk C, Fink AH (2018) Rainfall over the African continent from the 19th through the 21st century. *Glob Planet Change* 165:114–127. <https://doi.org/10.1016/j.gloplacha.2017.12.014>
- Nikbakht J, Tabari H, Talaei PH (2013) Streamflow drought severity analysis by percent of normal index (PNI) in northwest Iran. *Theor Appl Climatol* 112:565–573. <https://doi.org/10.1007/s00704-012-0750-7>
- Nouaceur Z, Murărescu O (2016) Rainfall variability and trend analysis of annual rainfall in North Africa. *Int J Earth Atmos Sci* 2016:7230450. <https://doi.org/10.1155/2016/7230450>
- Okpara JN, Afiesimama EA, Anuforum AC et al (2017) The applicability of Standardized Precipitation Index: drought characterization for early warning system and weather index insurance in West Africa. *Nat Hazards* 89:555–583. <https://doi.org/10.1007/s11069-017-2980-6>
- Oliver JE (1980) Monthly precipitation distribution: a comparative index. *Prof Geograph* 32(3):300–309

- Ouatiki H, Boudhar A, Ouhinou A, Arioua A, Hssaisoune M, Bouamri H, Benabdelouahab T (2019) Trend analysis of rainfall and drought over the Oum Er-Rbia River Basin in Morocco during 1970–2010. *Arab J Geosci* 12(4):128. <https://doi.org/10.1007/s12517-019-4300-9>
- Ozer P, Ercpicum M, Demaree G, Vandiepenbeeck M (2003) The Sahelian drought may have ended during the 1990s. *Hydrol Sci J* 48(3):489–492. <https://doi.org/10.1623/hysj.48.3.489.45285>
- Palmer, W. C. (1965). *Meteorological drought* (Vol. 30). US Department of Commerce, Weather Bureau.
- Peñuelas J, Lloret F, Montoya R (2001) Severe drought effects on mediterranean woody Flora in Spain. *Forest Science* 47:214–218
- Santos CAG, Brasil Neto RM, Nascimento TVM, Silva RM, Mishra M, Frade TG (2020) Geospatial drought severity analysis based on PERSIANN-CDR-estimated rainfall data for Odisha state in India (1983–2018). *Sci Total Environ* 750:141258. <https://doi.org/10.1016/j.scitotenv.2020.141258>
- Santos CAG, Brasil Neto RM, Passos JSA, Silva RM (2017) Drought assessment using a TRMM-derived standardized precipitation index for the upper São Francisco River basin. *Brazil Environ Monit Assess* 189:250. <https://doi.org/10.1007/s10661-017-5948-9>
- Santos CAG, Brasil Neto RM, Silva RM, Passos JSA (2018) Integrated spatiotemporal trends using TRMM 3B42 data for the upper São Francisco River basin. *Brazil Environ Monit Assess* 190:175. <https://doi.org/10.1007/s10661-018-6536-3>
- Santos CAG, Brasil Neto RM, Silva RM, Santos DC (2019) Innovative approach for geospatial drought severity classification: a case study of Paraíba state, Brazil. *Stoch Environ Res Risk Assess* 33:545–562. <https://doi.org/10.1007/s00477-018-1619-9>
- Şen Z, Şişman E, Dabanlı I (2020) Wet and dry spell feature charts for practical uses. *Nat Hazards* 104:1975–1986. <https://doi.org/10.1007/s11069-020-04257-5>
- Shah R, Bharadiya N, Manekar V (2015) Drought index computation using standardized precipitation index (Spi) method for Surat District, Gujarat. *Aquat Procedia* 4:1243–1249. <https://doi.org/10.1016/j.aqpro.2015.02.162>
- Shukla S, Wood AW (2008) Use of a standardized runoff index for characterizing hydrologic drought. *Res Lett Geophys*. <https://doi.org/10.1029/2007GL032487>
- Silva RM, Santos CAG, Moreira M, Corte-Real J, Silva VCL, Medeiros IC (2015) Rainfall and river flow trends using Mann-Kendall and Sen's slope estimator statistical tests in the Cobres River basin. *Nat Hazards* 77:1205–1221. <https://doi.org/10.1007/s11069-015-1644-7>
- Silva RM, Silva JFCBC, Santos CAG, Brasil Neto RM (2020) Spatial distribution and estimation of rainfall trends and erosivity in the Epitácio Pessoa reservoir catchment, Paraíba - Brazil. *Nat Hazards* 102:829–849. <https://doi.org/10.1007/s11069-020-03926-9>
- Spinoni J, Vogt JV, Naumann G, Barbosa P, Dosio A (2018) Will drought events become more frequent and severe in Europe? *Int J Climatol* 38(4):1718–1736. <https://doi.org/10.1002/joc.5291>
- Taïbi S, Meddi M, Mahé G et al (2017) Relationships between atmospheric circulation indices and rainfall in Northern Algeria and comparison of observed and RCM-generated rainfall. *Theor Appl Climatol* 127:241–257. <https://doi.org/10.1007/s00704-015-1626-4>
- Tan ML, Chua VP, Li C et al (2019) Spatiotemporal analysis of hydro-meteorological drought in the Johor River Basin. *Malaysia Theor Appl Climatol* 135:825–837. <https://doi.org/10.1007/s00704-018-2409-5>
- Thom HC (1958) A note on the gamma distribution. *Mon Weather Rev* 86:117–122
- Tsakiris G, Vangelis HJEW (2005) Establishing a drought index incorporating evapotranspiration. *Eur water* 9(10):3–11
- Van Rooy MP (1965) A rainfall anomaly index independent of time and space. *Notos* 14:43–48
- Vergni L, Di Lena B, Chiaudani A (2016) Statistical characterisation of winter precipitation in the Abruzzo region (Italy) in relation to the North Atlantic Oscillation (NAO). *Atmos Res* 178:279–290. <https://doi.org/10.1016/j.atmosres.2016.03.028>
- Vicente-Serrano SM (2006) Differences in spatial patterns of drought on different time scales: an analysis of the Iberian Peninsula. *Water Resour Manage* 20:37–60. <https://doi.org/10.1007/s11269-006-2974-8>
- Vicente-Serrano SM, Beguería S, López-Moreno JI (2010) A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. *J Clim* 23(7):1696–1718. <https://doi.org/10.1175/2009JCLI2909.1>
- Willeke, G., Hosking, J.R.M., Wallis, J.R., Guttman, N.B. (1994). *The national drought atlas*. Institute for Water Resources Report 94-NDs-4, Army Corps of Eng., Washington, D.C.
- Xoplaki E, González-Rouco JF, Luterbacher J et al (2004) Wet season Mediterranean precipitation variability: influence of large-scale dynamics and trends. *Clim Dyn* 23:63–78. <https://doi.org/10.1007/s00382-004-0422-0>
- Yeşilirmak E, Atatanır L (2016) Spatiotemporal variability of precipitation concentration in western Turkey. *Nat Hazards* 81:687–704. <https://doi.org/10.1007/s11069-015-2102-2>

- Zeroual A, Assani AA, Meddi M (2017) Combined analysis of temperature and rainfall variability as they relate to climate indices in northern Algeria over the 1972–2013 period. *Hydrol Res* 48(2):584–595. <https://doi.org/10.2166/nh.2016.244>
- Zerouali B, Chettih M, Abda Z et al (2020) The use of hybrid methods for change points and trends detection in rainfall series of northern Algeria. *Acta Geophys* 68:1443–1460. <https://doi.org/10.1007/s11600-020-00466-5>
- Zerouali B, Mesbah M, Chettih M et al (2018) Contribution of cross time-frequency analysis in assessment of possible relationships between large-scale climatic fluctuations and rainfall of northern central Algeria. *Arab J Geosci* 11:392. <https://doi.org/10.1007/s12517-018-3728-7>
- Zerouali B, Mesbah M, Chettih M, Djemai M, Abda Z (2019) Hydrogeological system of Sebaou River Watershed (Northern Central Algeria): an assessment of rainfall-Runoff Relationship. *Adv Sustain Environ Hydrol Hydrogeol Hydrochem Water Resour*. [https://doi.org/10.1007/978-3-030-01572-5\\_7](https://doi.org/10.1007/978-3-030-01572-5_7)
- Zhou H, Liu Y, Liu Y (2019) An approach to tracking meteorological drought migration. *Water Resour Res* 55(4):3266–3284. <https://doi.org/10.1029/2018WR023311>

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.