DOI: 10.31577/ahs-2025-0026.02.0037

ACTA HYDROLOGICA SLOVACA

Volume 26, No. 2, 2025, 366 – 378

Drought study in the Macta watershed (North West of Algeria) using Standardized Precipitation Index (SPI)

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Drought is a persistent challenge in Mediterranean regions, particularly in Algeria, which has endured several intense drought episodes over recent decades. These events have significantly affected both the environment and the country's economy. This study focuses on analyzing drought patterns across space and time within the Macta watershed. First, we identified the most homogeneous observation period (1969–2011) by applying homogeneity tests to data from 42 rainfall stations. This allowed for a consistent assessment of drought evolution using the 12-month Standardized Precipitation Index (SPI-12). The analysis revealed that the most significant drought events occurred between 1980 and 1990 and persisted into the mid-2000s. Dry episodes peaked in 1981, when 31 stations reported severe drought conditions. Other notable years include 1992, 1999, 1996, 1988, 1998, 1983, 1989, and 1993. Overall, droughts in the 1980s were more intense than those in the 1990s. In the 21st century, two major droughts were identified in 2004 and 2007, as evidenced by the spatial distribution of severity levels.

KEY WORDS: drought; SPI; GIS; Macta watershed; Algeria

Introduction

Drought is one of the most complex, harmful, and least understood climatic events, affecting the world with serious consequences on nature and human life (Wilhite, 2020; Dai, 2013; Pavelková et al., 2023). It is a slow-onset natural hazard with effects that accumulate over a considerable period (Zeroual et al., 2017). This insidious natural hazard may result in significant water shortages that affect agricultural systems, ecosystems, and urban water supplies (Spinoni et al., 2014).

Drought is defined as a temporary natural imbalance in water availability and consists of persistent, below-normal precipitation that is difficult to predict. Drought affects more people than any other disaster, making it the costliest natural phenomenon (Keyantash and Dracup, 2002).

As one of the greatest environmental challenges of our time, climate drought is caused by a lack of precipitation that develops into a meteorological, agricultural and hydrological drought over time (Mishra and Singh, 2010; Oliveira et al., 2023). A meteorological drought occurs due to a lack of precipitation, leading to a drop in soil moisture content if it continues. This will affect plant growth and lead to an agricultural drought (Sun et al., 2023). If such drought conditions continue, river runoff will decrease, leading to water shortages in cities and hydrological droughts (Park et al., 2020). Reduced runoff due to drought leads to restrictions on water use, and simultaneously causes significant damage to the aquatic ecosystem and the environment due to reduced water flow into reservoirs and diminished wetlands. Drought is the origin of reduced water and air quality, forest fires, land degradation, and reduced agricultural production (Vicente-Serrano et al., 2020). This situation can lead to water conflicts and people migration to more suitable areas. Therefore, drought monitoring and evaluation are essential to prevent and minimize its impact.

In recent decades, drought events have increased in frequency and intensity in several regions of the planet, especially in North Africa, one of the world's most water-scarce regions (Tanarhte et al., 2024), causing significant losses in agricultural production and affecting various aspects of life, including economic output and demography. This region is likely to suffer the most devastating effects of climatic changes due to its geographical location, low institutional capacity to adapt to rapid environmental changes, low-income population, heavy reliance on climate-sensitive sectors, poor water resource management, and inadequate government mechanisms (IPCC, 2014a; b; Hamad et al., 2018). Climate change in North Africa threatens the region's socio-economic development and population (Schilling et al., 2020). The severity of climate change impacts in North African countries is closely linked to the region's unique geographic and ecological characteristics. The area's biophysical features, socioeconomic challenges, and technological underdevelopment are key

drivers of its heightened vulnerability to climate change (World Bank, 2014). Covering approximately 5 million km², more than 90% of North Africa's land is classified as desert. The region's climate shows stark contrasts between coastal and inland areas. Coastal zones experience a Mediterranean climate, with moderate rainfall ranging from 400 to 600 mm annually, mild, wet winters, and warm, dry summers. In contrast, inland areas are dominated by semi-arid and arid desert climates, marked by extreme temperatures: summer highs reaching up to 50°C, winter lows dropping to -5°C and minimal precipitation: around 200 to 400 mm annually in semi-arid zones and under 100 mm in desert regions (Taibi et al., 2017). North Africa is vulnerable to climate change impacts, particularly the Mediterranean regions, which have been identified as the "hot spot for climate change" (Giorgi and Lionello, 2008). Drought assessment involves various variables, such as temperature, wind, and relative humidity; however, the key factor is the difference between current precipitation levels and normal conditions.

Several drought monitoring techniques have been developed, such as drought indices which are useful tools for monitoring and assessing different drought types (meteorological, agricultural, and hydrological drought). They facilitate communication of climate anomalies to various audiences. Depending on various variables, numerous indices have been developed to identify and quantify drought events, including the Palmer Drought Severity Index (PDSI) (Palmer, 1965, 1968), the Standardized Precipitation Index (SPI) (McKee et al., 1993, 1995), the Standardized Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al. 2010), and the Surface Water Supply Index (SWSI) (Shafer and Dezman, 1982).

Meteorological drought is defined as a temporary period of lower-than-average precipitation, resulting in diminished water resource availability and reduced carrying capacity of the ecosystems. It impacts economic activities, human lives, and the environment (Tabari et al., 2012; Bayissa et al., 2015). Recognized by the World Meteorological Organization (WMO) as the best meteorological drought index, the SPI is also the most widely used and considered one of the most robust and effective indices for analyzing this type of drought, due to its simplicity and effectiveness in analyzing both wet and dry periods based on precipitation (Espinosa et al., 2019). Furthermore, it can also be calculated for a variety of time scales, allowing the analysis of different drought categories (Espinosa et al., 2019). Additionally, the SPI's probabilistic nature makes it ideal for drought risk analysis (Merabti et al., 2018). Considering all of this, the SPI has been extensively applied in different countries. In Europe, countries like Spain and Italy have used the SPI to manage water resources and mitigate drought impacts (Vicente-Serrano et al., 2010; Hayes, 2011; Spinoni et al., 2015; Lorenzo et al., 2024). SPI was used for regional drought evaluation in the United States (McKee et al., 1993; Logan et al., 2010). In South America, Brazil used SPI to analyze droughts in the semi-arid northeastern region (Cunha et al. 2019; Oliveira et al. 2023). SPI was used in Asia by China and India for drought monitoring (Zhang et al., 2012; Ghosh et al., 2019). In south Asia, SPI was used for meteorological drought forecasting for the north-western part of Bangladesh (Awal and Mamun, 2023). In African countries, such as South Africa, the SPI was used to analyze drought frequency and severity (Rouault and Richard, 2005). North African countries (Morocco, Algeria, and Tunisia) also applied it for drought analysis in arid and semi-arid regions (Abbes et al., 2018; Hadri et al., 2021; Berhail and Katipoğlu, 2023; Ben Othman and Abida, 2022). In southeastern Mediterranean countries, the SPI was used to analyze and identify drought events (Tsesmelisetal, 2023). Similarly, In Australia, SPI was used to characterize meteorological drought across South Australia (Rashid and Beecham, 2019).

Due to its arid and semi-arid climate, Algeria, like other Mediterranean countries, faces significant challenges in managing its water resources. In recent decades, the northern regions of Algeria have been particularly affected by extreme droughts (Elouissi et al., 2017; Ziari and Medjerab, 2024).

This study focuses specifically on drought analyses within the Macta basin in Northwest Algeria, a region highly susceptible to water resource stress and possessing a relatively dense meteorological network compared to the rest of the national territory. This network, comprising over 40active weather stations, provides a valuable opportunity for detailed drought analysis.

To characterize and monitor drought in the Macta basin, the Standardized Precipitation Index (SPI-12 months) was calculated for each station during the study period (1969–2011). This index has an intensity scale for calculation. Positive and negative values are directly correlated with wet and dry years. Negative annual values indicate a drought period compared to the chosen reference period, while positive ones indicate a wet period. Studying drought spatiotemporal variability within the basin is important for analyzing and regionalizing this phenomenon. It relies on Geographical Information Systems (GIS), a well-known and useful tool applied in various studies. The results of this study are expected to contribute to effective regional water resource management strategies in Algeria and provide valuable insights for future research on drought indices and their application in similar arid and semi-arid environments.

Materials and methods

Study area

Located in northwestern Algeria, the Macta watershed covers an area of approximately 14389 km^2. It lies between 1°16′ and 0°58′ west longitude and 34°31′ and 35°21′north latitude (Fig. 1). It is bounded by the Mediterranean Sea to the north, the Oran highlands (Algerian Atlas) to the south, the Chelif watershed to the East, and the Tafna watershed and the coastal Oranais to the West (Chibane et al., 2015). The Macta watershed is formed by the high plain of Sidi Bel Abbes, and the Habra and Mascara plains, and is bounded by two

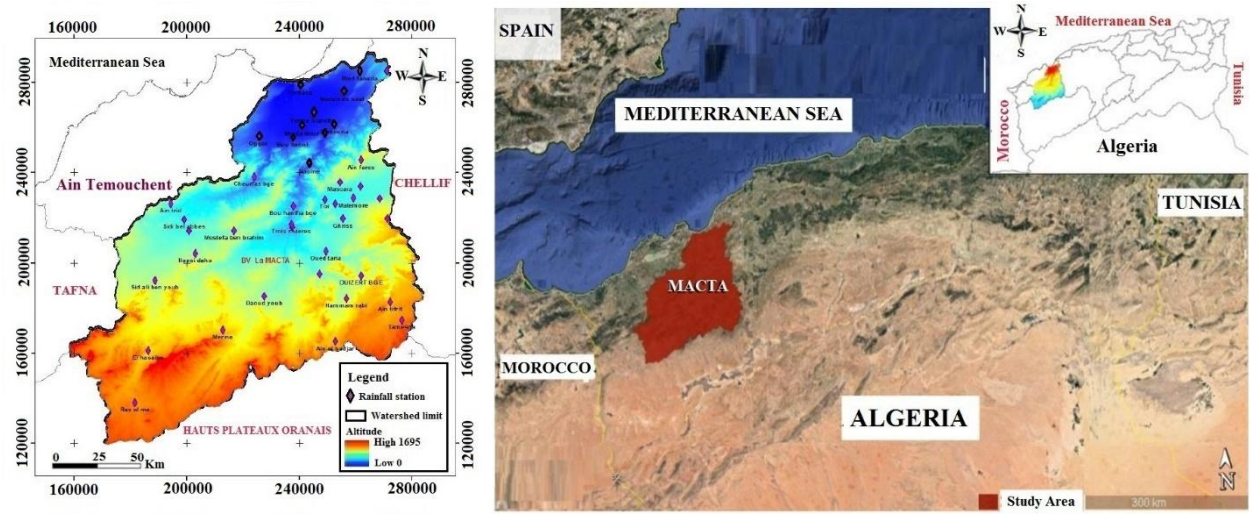


Fig. 1. Geographical situation of the Macta watershed and rainfall stations spatial distribution.

parallel mountain ranges running southwest to northeast. These ranges consist primarily of the Beni-Cheugrane Mountains (altitude ranging from 540 and 900 m) and the Telagh and Saida Mountains (altitude ranging from 600 to 1200 m).

The Macta watershed, the most significant basin in western Algeria, provides the region's main water resources. Its elongated shape results in strong upstream surface flow. It is fed by two main rivers, the Mekerra and the Oued El-Hammam, which converge near the Mediterranean coast to form the Macta River. The Macta Basin is subject to the semiarid climate characterized by a cold winter and hot summer, it undergoes the Mediterranean influence in the North and the continental conditions in the South from where the precipitations are irregular in space and in time (Semari and Korichi, 2023). The average annual temperature in the basin is 17.7°C (2006–2017). This zone contains 6 states: Mascara (39/47 municipalities), Sidi Bel Abbes (43/52 municipalities), Saida (12/16 municipalities), Mostaganem (10/32 municipalities), Tlemcen (1/53 municipalities), and Oran (1/26 municipality) according to the National Agency for Hydraulic Resources "NAHR" (Semari, 2017). The population of the study area reached 1314973 inhabitants in 2015. The potential agricultural area is one of the richest in the region. The main agricultural products are cirrus, market gardening, viticulture, and olive growing. Industry is considered a very important and diverse sector (HBA, 2015).

The climate is continental to semi-arid with two main seasons. From September to May the weather is rainy and cold. During the rest of the year, the weather is dry and hot.

The average annual rainfall in the Macta watershed is estimated at 315 mm, varying between 280 mm in the south and 350 mm in the mountains of Beni-Chaugrane. The wettest years may have rainfall 3 to 4 times higher than the driest years (Khaldi, 2005).

Data collection

This study utilized precipitation data from 42 meteorological and hydrological stations spanning the period from 1969 to 2011. These stations were selected from an initial network of approximately 80 stations, with exclusions based on factors such as inoperability, missing records, insufficient observation periods, and significant data gaps. The final selection of stations met specific criteria related to data length, quality, and spatial representativeness. Notably, all stations in the dataset had a recording period of over 30 years. Fig. 1 illustrates the spatial distribution of rainfall stations and the relief within the studied area. There is a higher concentration of stations in the central and eastern regions, particularly around Sidi Bel Abbes and Mascara, while coverage is sparse in the western and southern areas, especially in the elevated Oran High Plateaus and the southern border (Fig. 1).

In this work, two approaches are used to analyze drought in the Macta basin:

– This study analyzes drought conditions using the 12-month Standardized Precipitation Index (SPI-12), calculated from rainfall data obtained from the National Agency for Hydraulic Resources "NAHR" and the National Meteorological Office (NMO).
– The spatial distribution of drought within the study area was visualized and mapped using Geographic Information Systems (GIS). The methodological approach adopted in this study is presented in Fig. 2.

Data processing

Observation data analysis requires careful control and verification. Thus, this work primarily aims to collect all available precipitation data and relevant information related to the study area. Some of the selected stations had gaps that were corrected by calculating the mean

arithmetic value over ten years (Table 1).
Generally used when there are no well-correlated stations with the studied series and can be accepted if missing data are not important, the method choice was influenced by the distance between the selected poorly correlated stations. After correcting the basic file, we studied data homogeneity by applying the Wilcoxon test (Wilcoxon, 1945; Conover, 1999), a non-parametric test that uses the ranks series of the observations instead of the values series. The Wilcoxon test is based on the following principle: if the sample X comes from the same population as the sample Y, the union of the sample X and Y is also derived from this same population (Hayes, 2011; Khaldi, 2005). The results obtained from this test indicated that all the stations were homogeneous, confirmed by calculating the statistical characteristics of the rainfall series (The average value, standard deviation, median value and coefficient of variability (CV)) as presented in the Table 2.

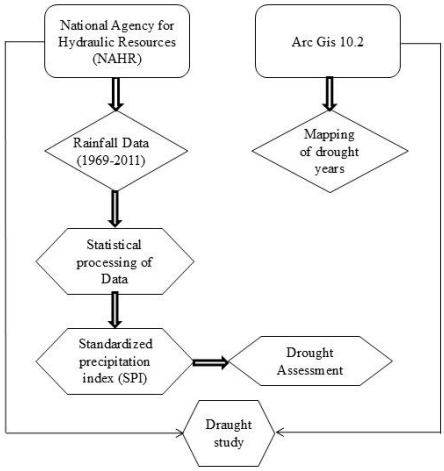


Fig. 2. Methodological flowchart of the approach adopted for the study area.

Table 1. Meteorological Stations with gap-filled precipitation data

Rainfall stations	Year	Month
Ras El Ma, Sid Ali Ben Youb, El Hacaiba, Sarno Bge, Sidi Bel Abbes, Hassi Daho, Mostefa Ben Brahim, Ain Trid, CheurfasBge, Merine	2011	April, May, June, July, August

The Standardized Precipitation Index "SPI" calculation

The Standardized Precipitation Index (SPI) reflects actual precipitation as a standardized baseline concerning the precipitation probability distribution function. Therefore, the index has gained importance in recent years as a potential drought indicator, permitting comparisons across space and time. Based on a long-term precipitation history, the SPI is widely used to characterize meteorological drought on a range of timescales from 1 month to 24 months or longer, depending on the drought type being monitored (Naresh et al., 2009; Spinoni et al., 2014). SPI has several good features, including its simplicity, as it is based only on precipitation and its temporal flexibility at different time scales. These features clearly show the drought impacts on various sectors (McKee et al., 1993; Abbes et al., 2018). The SPI index is expressed mathematically as:

$$SPI = \frac{Xi - Xm}{Si} \quad (1)$$

where
Xi is the cumulative precipitation for year *i*,
Xm and *Si* are the mean and standard deviation, respectively, of the annual precipitation observed for a given series.

The computation of SPI requires long-term data on precipitation to determine the probability distribution function, which is then transformed into a normal distribution with a mean of zero and a standard deviation of one. Thus, the SPI values are expressed in standard deviations. Positive SPI values indicate greater than median precipitation**,** while negative values indicate less than median precipitation (Juliani and Okawa, 2017; Lorenzo et al., 2024). SPI can be compared across regions with markedly different climates. It quantifies observed precipitation as a standardized departure from a selected probability distribution function that models the raw precipitation data. The SPI computation in this paper follows the method proposed by McKee (McKee, 1993; 1995) to evaluate drought events (Table 2).

Table 2. Classification of drought sequences based on SPI (Mckee et al. 1993)

Values of the SPI index	The Sequence of drought
SPI ≥ 2.0	Extremely wet
from 1.5 to 1.99	Very wet
from 1.0 to 1.49	Moderately wet
from -0.99 to 0.99	Near normal
from -1.0 to -1.49	Moderately dry
from -1.5 to -1.99	Very dry
-2 and less	Extremely dry

Results and discussion

Precipitation

In the Macta watershed, average annual precipitation ranges between 200 and 500 mm. The eastern and western parts of the basin, located at altitudes between 750 and 1400 meters, receive higher rainfall amounts, ranging from 380 to 500 mm. In contrast, the northern, central, and southwestern parts of the basin, characterized by more varied elevations, receive the lowest average annual precipitation, between 200 and 300 mm (Fig. 3).

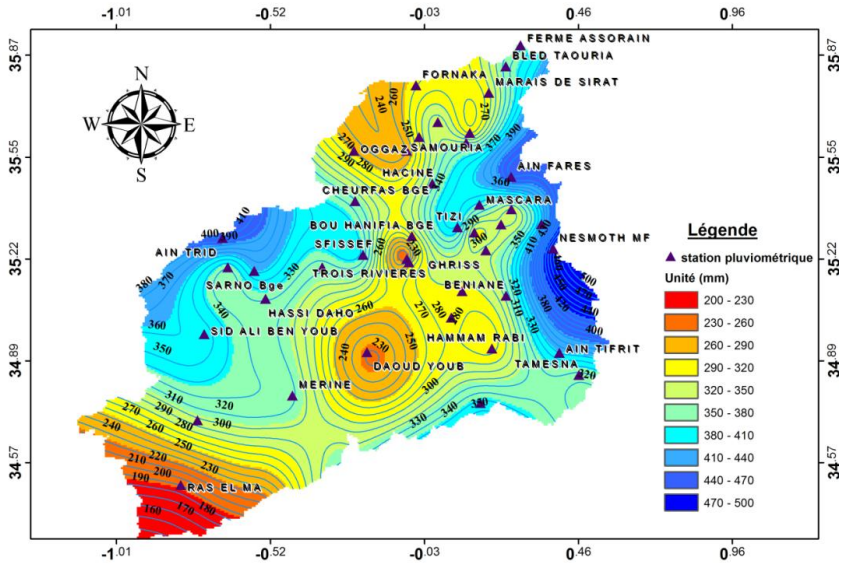


Fig. 3. Spatial Distribution of Average Annual Precipitation in the Macta Watershed (1969–2011).

Nearly half of the total area of the basin receives less than 290 mm of rainfall annually. The high-altitude zones, ranging from 750 to 1400 meters and representing about 10% of the total surface area, are characterized by an average annual rainfall exceeding 290 mm.

By applying the isohyetal method, the average rainfall across the entire basin was calculated to be 285 mm. The formula used is as follows:

$$P_{avg} = \frac{\sum A_i p_i}{A} \quad (2)$$

where

P_{avg} average precipitation over the basin [mm],

A total area of the basin [km^2],

A_i area between two isohyets i and *i+1* [km^2],

p_i mean precipitation between two consecutive isohyets *i* and *i+1* [mm].

According to Table 3, the coefficients of variation for the 42 stations are relatively low, ranging from 23% for the Tizi station to 48% for the Beniane station, indicating a moderate level of consistency in rainfall patterns across the study area. The standard deviation values range from 62.9 mm for the Sahouetouizert station to 166.2 mm for the Nesmoth station, indicating differences in the spread of rainfall values. Annual rainfall averages show low variability across the study area, varying from 200.3 mm at the Ras El Ma station to 500 mm at the Nesmoth station.

Temporal variability of SPI

The analysis of the SPI-12 index values for all the precipitation stations studied over the period 1969 to 2011 demonstrates that the decade of the 1970s was marked by the observation of numerous positive values, frequently exceeding a value of 1, at the majority of stations. In contrast, from the 1980s to the mid-2000s, all stations experienced a significant rainfall deficit (SPI values negative and less than 1). This period is characterized by very dry or even extremely dry years (SPI-12< -1.5). This result is similar to that obtained on the Mediterranean basin and North Africa, on the southeastern Mediterranean countries, on Northern Algeria, on Moroco, on the United States and continental United States (Table 4). Thus, the decade from 1981 to 1991 seems to mark the beginning of drought conditions. Towards the end of the observation period, there is an upward trend in rainfall, with index values sometimes exceeding 2 (El Hacaiba, Ras El Ma, Sid Ali Ben Youb and Sidi Bel Abbes).

SPI classification

Table 5 presents a summary of the Standardized Precipitation Index (SPI-12) classification results for the stations studied over the period 1969–2011. The table is designed to clearly illustrate the severity and frequency of drought years. Based on this summary, dry years are mainly occurring during the 1980s and 1990s. Notably, the frequency of extreme wet events exceeds that of extreme dry events.

Spatial distribution of drought

To spatially represent drought, we mapped the spatial distribution of the number of dry years by degree of severity (Fig. 4, Fig. 5, Fig. 6 and Fig. 7). Although the maps display evident spatial variability in both extent and severity of drought, no stable or recurring pattern is observed. Overall, the spatial distribution of drought lacks clear regionalization, indicating that dry years occur irregularly throughout the study area. This irregularity reflects the highly localized and variable nature of rainfall within the region.

Temporal patterns of dry and wet years

We synthesized the temporal variability of dry and wet years from Table 4. The results are shown in Fig. 8a and 8b.

The analysis of these histograms reveals several years characterized by significant drought conditions, where more than half of the stations recorded "dry" conditions. These years include: 1981, 1982, 1983, 1987, 1988, 1989, 1992, 1993, 1994, 1996, 1998, and 1999. Similar results have been found in other regions, including the semi-arid Borana area of southern Ethiopia (Worku, 2024), the Mediterranean (Polychroni and Nastos, 2017), and Europe (Ionita et al., 2021). The year 1981 stands out as the most severe drought year within the study period, affecting 31 out of 42 stations, followed by the years 1992, 1999, 1996, 1988, 1998, 1983, 1989 and 1993. While both decades experienced drought years, the 1980s saw more frequent and widespread drought events. Thus, the 80s were notably drier compared to the 1990s.

Table 3. Statistical characteristics of the studied rainfall stations

Name of stations	Max	Min	Standard deviation	Average	Median	Coeff. of variation
Ras El Ma	456.4	31.2	90.8	200.3	178.2	0.43
Sid Ali benyoub	660.2	79.6	119.3	355.5	367.7	0.34
El hacaiba	530.8	110.8	99.3	307.6	293.3	0.32
Sarno bge	634.2	170.5	106.2	361.1	367.0	0.29
Sidi bel abbes	591.0	159.4	92.8	332.2	328.8	0.28
Hassi daho	522.9	82.9	109.4	324.7	328.3	0.34
Mostefa ben brahim	662.7	107.8	110.2	331.6	316.9	0.33
Ain trid	692.1	127.5	121.8	407.4	392.0	0.29
Cheurfasbge	537.9	153.0	96.3	321.9	311.4	0.29
Merine	512.0	159.6	89.1	322.5	315.5	0.28
Daoud youb	382.6	33.5	79.3	231.9	242.9	0.34
Meftah sidi boubekeur	527.2	111.6	85.5	285.4	281.8	0.29
Ain elhadjar	649.2	74.7	141.2	343.4	305.7	0.41
Hammam rabi	531.9	101.7	103.1	277.6	252.7	0.37
Oued taria	549.6	60.6	102.4	284.1	272.6	0.36
Ain tifrit	598.6	131.2	101.9	359.9	354.2	0.28
Tamesna	907.3	150.8	137.3	327.5	299.8	0.42
Beniane	760.9	66.3	153.4	316.9	310.4	0.48
Maoussa	654.0	154.9	92.2	300.8	298.6	0.31
Froha	514.6	154.4	69.0	288.2	294.1	0.24
Matemore	469.5	175.5	76.5	298.4	280.9	0.26
Tizi	524.6	180.2	80.5	346.6	353.2	0.23
Sidi kada	830.0	198.4	125.9	364.6	351.7	0.35
Ain fares	775.5	171.0	135.7	410.9	379.9	0.33
Nesmoth	1033.1	135.5	166.2	500.0	476.6	0.35
Ghriss	695.1	144.0	108.6	303.5	277.5	0.36
Mascara	654.0	125.8	109.3	337.8	325.8	0.32
Sahouetouizert	369.2	130.0	62.9	252.4	274.1	0.25
Bouhanifiabge	471.0	135.0	81.4	278.3	263.42	0.29
Sfisef	540.2	149.0	105.2	334.2	334.9	0.31
Hacine	500.5	173.2	82.5	318.9	326.7	0.26
Mohammadia	469.9	172.9	76.1	313.1	307.2	0.24
Trois Rivières	460.9	81.6	78.9	230.3	224.5	0.34
Oggaz	487.4	78.0	87.1	260.5	258.8	0.33
Bouhenni	381.6	144.2	63.3	252.0	253.8	0.25
Fornaka	486.3	85.6	87.8	268.5	254.0	0.33
Samouria	511.3	125.1	83.9	278.6	279.7	0.30
Moctadouz	665.5	71.5	127.9	285.6	260.9	0.45
Ferme blanche	611.0	111.8	101.8	305.7	302.2	0.33
Bled taouria	538.8	133.6	97.6	324.1	311.0	0.30
Marais de sirat	457.2	138.3	90.8	287.8	280.4	0.32
Fermeassorain	514.5	129.0	101.9	327.2	323.8	0.31

Table 4. Drought episodes in other regions

Country/region	Study period	Reference
United States	1980–1981	Weisman, 1985
Mediterranean basin, Ireland, United Kingdom	1951–-2016	Caloiero et al., 2018
Eastern Mediterranean	1901–2020	Tsesmelis et al., 2023
Northern Algeria	1968–2021	Diaf et al., 2024
Moroco	1981–2018	Elair et al., 2025
Continental United States	1925–2003	Konstantinos et al., 2006

Table 5. Summary of the class percentages of the SPI for the studied period (1969–2011)

Stations	EW	EW [%]	VW	VW [%]	MW	MW [%]	NN	NN [%]	MD	MD [%]	VD	VD [%]	ED	ED [%]
Ras El Ma	3	6.9	1	2.3	2	4.6	33	76.7	3	6.9	1	2.3	0	0
Sid Ali Ben Youb	2	4.6	1	2.3	2	4.6	32	74.4	4	9.3	1	2.3	1	2.3
El Hacaiba	1	2.3	3	6.9	4	9.3	28	65.1	6	13.9	1	2.3	0	0
Sarno Bge	1	2.3	3	6.9	3	6.9	29	67.4	5	11.63	2	4.6	0	0
Sidi Bel Abbes	1	2.3	2	4.6	4	9.3	28	65.1	6	13.9	2	4.6	0	0
Hassi Daho	0	0.0	3	6.9	5	11.6	25	58.1	8	18.6	1	2.3	1	2.3
Mostefa Ben Brahim	1	2.3	2	4.6	5	11.6	28	65.1	6	13.9	0	0.0	1	2.3
Ain Trid	1	2.3	3	6.9	3	6.9	29	67.4	6	13.9	0	0.0	1	2.3
CheurfasBge	1	2.3	3	6.9	4	9.3	27	62.7	4	9.3	4	9.3	0	0
Merine	2	4.6	1	2.3	6	13.9	28	65.1	4	9.3	2	4.6	0	0
Daoud Youb	0	0.0	1	2.3	6	13.9	28	65.1	4	9.3	3	6.9	1	2.3
Meftah Sidi Boubekeur	1	2.3	4	9.3	0	0.0	30	69.7	6	13.5	1	2.3	1	2.3
Ain El Hadjar	3	6.9	3	6.9	1	2.3	32	74.4	3	6.9	1	2.3	0	0
Hammam Rabi	2	4.6	2	4.6	3	6.9	31	72.0	3	6.9	2	4.6	0	0
Oued Taria	2	4.6	3	6.9	1	2.3	33	76.7	1	2.3	2	4.6	1	2.3
Ain Tifrit	2	4.6	1	2.3	4	9.3	29	67.4	4	9.3	2	4.6	1	2.3
Tamesna	2	4.6	0	0.0	3	6.9	33	76.7	5	11.6	0	0.0	0	0
Beniane	2	4.6	1	2.3	2	4.6	32	74.4	5	11.6	1	2.3	0	0
MaouVDa	1	2.3	1	2.3	3	6.9	31	72.0	6	13.9	1	2.3	0	0
Froha	1	2.3	2	4.6	2	4.6	30	69.7	5	11.6	3	6.9	0	0
Matemore	3	6.9	1	2.3	5	11.6	27	62.7	5	11.6	2	4.6	0	0
Tizi	1	2.3	1	2.3	4	9.3	29	67.4	4	9.3	3	6.9	1	2.3
Sidi Kada	2	4.6	1	2.3	1	2.3	33	76.7	6	13.9	0	0.0	0	0
Ain Fares	2	4.6	3	6.9	1	2.3	31	72.0	5	11.6	1	2.3	0	0
NesmothMf	1	2.3	1	2.3	2	4.6	33	76.7	5	11.6	0	0.0	1	2.3
Ghriss	2	4.6	2	4.6	3	6.9	32	74.4	4	9.3	0	0.0	0	0
Mascara	2	4.6	0	0.0	5	11.6	28	65.1	7	16.2	1	2.3	0	0
Sahouet Ouizert	0	0.0	3	6.9	4	9.3	27	62.7	6	13.9	3	6.9	0	0
Bou HanifiaBge	3	6.9	1	2.3	3	6.9	31	72.0	4	9.3	1	2.3	0	0
Sfisef	0	0.0	4	9.3	3	6.9	29	67.4	5	11.6	2	4.6	0	0
Hacine	1	2.3	2	4.6	3	6.9	29	67.4	6	13.9	2	4.6	0	0
Mohammadia Grha	1	2.3	3	6.9	3	6.9	29	67.4	3	6.9	4	9.3	0	0
Trois Riviéres	2	4.6	0	0.0	3	6.9	29	67.4	8	18.6	1	2.3	0	0
Oggaz	2	4.6	4	9.3	0	0.0	30	69.7	5	11.6	1	2.3	1	2.3
Bou Henni	1	2.3	4	9.3	1	2.3	30	69.7	4	9.3	3	6.9	0	0
Fornaka	1	2.3	3	6.9	3	6.9	27	62.7	7	16.2	1	2.3	1	2.3
Samouria	1	2.3	3	6.9	3	6.9	28	65.1	7	16.2	1	2.3	0	0
Mocta Douz	3	6.9	0	0.0	3	6.9	31	72.0	4	9.3	2	4.6	0	0
Ferme Blanche	2	4.6	1	2.3	3	6.9	32	74.4	3	6.9	2	4.6	0	0
Bled Taouria	1	2.3	2	4.6	4	9.3	29	67.4	3	6.9	4	9.3	0	0
Marais De Sirat	0	0.0	4	9.3	4	9.3	27	62.7	4	9.3	4	9.3	0	0
FermeAssorain	0	0.0	4	9.3	2	4.6	29	67.4	4	9.3	4	9.3	0	0

EW: Extremely Wet – MW: Moderately Wet – VW: Very Wet
ED: Extremely Dry – MD: Moderately Dry – VD: Very Dry
NN: Near Normal

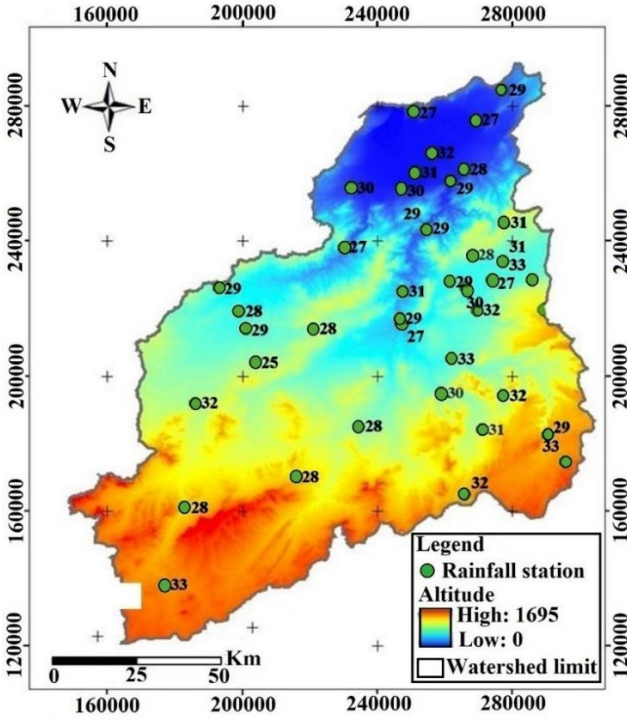


Fig. 4. Spatial Distribution of the number of years in the Near Normal category at rainfall stations during 1969–2011

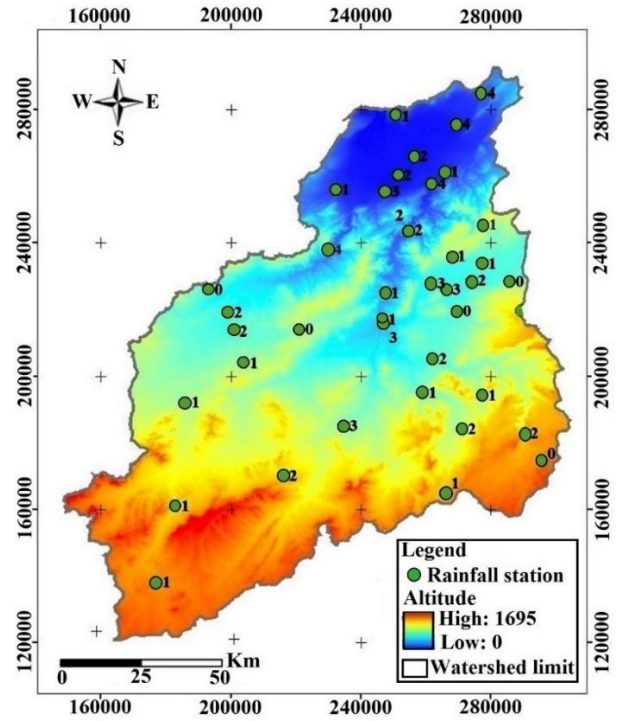


Fig. 6. Spatial Distribution of the number of years in the Very dry category at rainfall stations during 1969–2011.

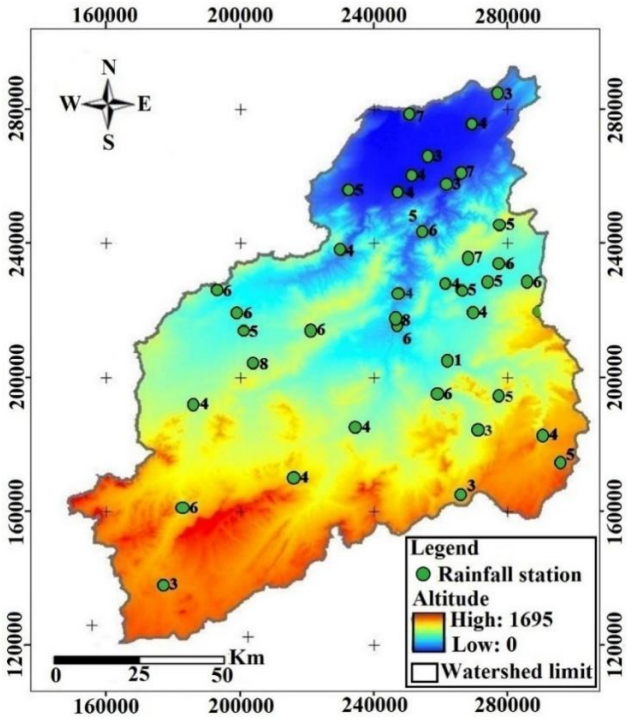


Fig. 5. Spatial Distribution of the number of Moderately dry years at rainfall stations during 1969–2011.

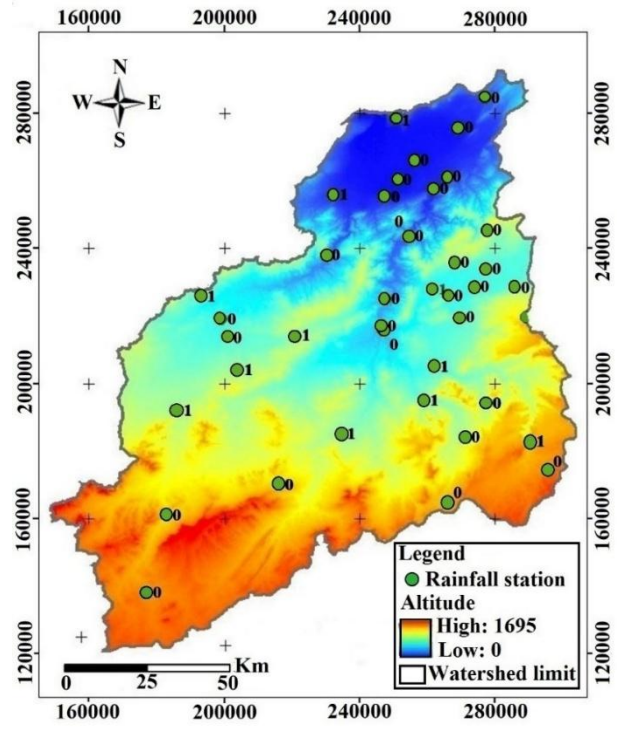


Fig. 7. Spatial Distribution of the number of years in the Extremely dry category at rainfall stations during 1969–2011.

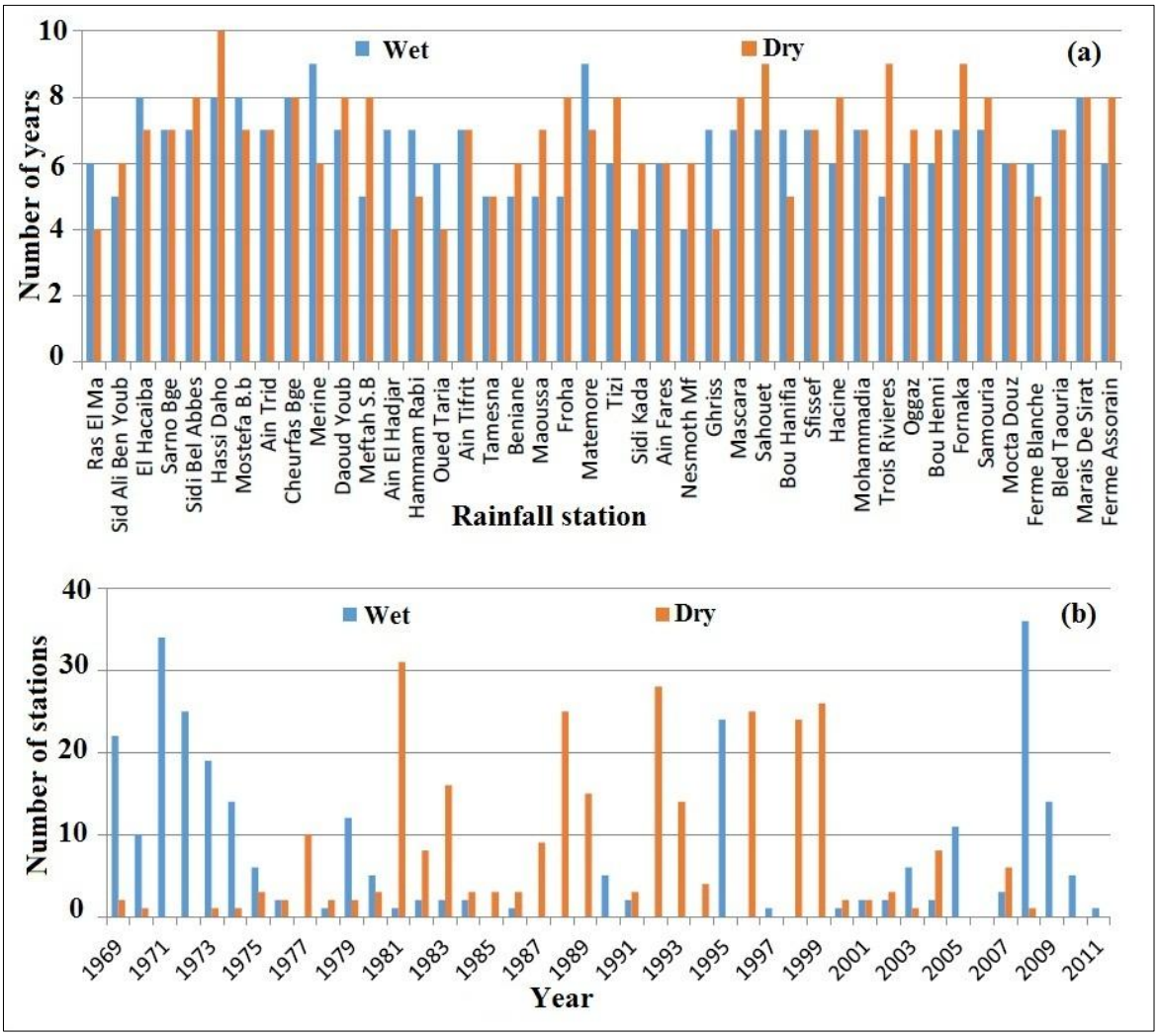


Fig. 8. a) Number of dry and wet years recorded at each station, b) Distribution of the number of stations affected by drought.

Analysis of the spatial distribution of drought severity reveals that certain stations consistently experienced drier conditions. In the 21st century, two main drought events were detected specifically in 2004 and 2007. This result closely aligns with findings from studies conducted in Khuzestan province, Southwest Iran (Adib et al., 2024), and across other semi-arid regions of Iran (Hamarash et al., 2022). The following stations experienced the driest conditions, with an average of nine dry years: Sahouet, Ouizert and Trois Rivere stations (eastern region), Hassi Daho (western region) and Fornaka (northern region). In contrast, Merine and Matemore stations recorded more wet years, indicating spatial variability in rainfall patterns. Comparable results have been reported in Greece by Kourtis et al. (2023).

The Standardized Precipitation Index (SPI-12) analysis further supports the findings from the histograms, highlighting distinct temporal trends: the 1970s were characterized by a surplus of rainfall followed by a prolonged deficit period spanning from 1980 to 2004, corroborating the observation that the 1980s and early 1990s were particularly dry. The period from 2005 to 2011 indicates a return to more normal rainfall conditions.

Drought years mapping

In order to visualize the spatial distribution of climatic drought within the study area, the spatial distribution of Standardized Precipitation Index (SPI-12) was mapped for the driest years: 1981, 1988, 1992, 1996, 1998, and 1999 (Fig. 9, Fig. 10, Fig. 11, Fig. 12, Fig. 13 and Fig. 14). Analysis of the SPI-12 maps reveals significant spatial variation in drought extent across the study area, both east-west and north-south. Notably, in 1981, the entire study area was affected by drought of varying severity, ranging from very dry to extremely dry (SPI-12 < -2) across all regions. The 1992, 1996, and 1999 maps reveal a northward and east-central shift in drought occurrence, with SPI values in the east-central regions reaching as low as -1.00 and occasionally exceeding -2.00. These typically well-watered regions support rainfed vegetable and cereal crops. Conversely, the 1988 and 1998 maps highlight significant drought in the central and southwestern areas.

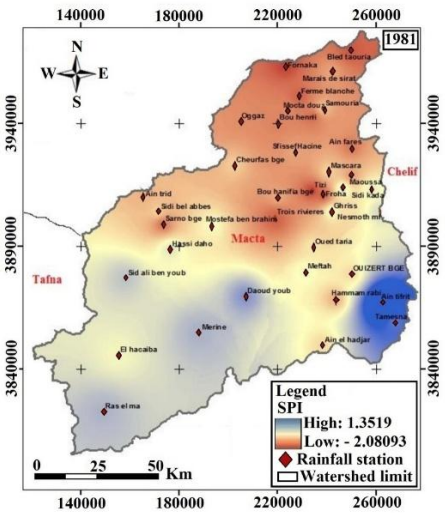


Fig. 9. Standard Precipitation Index (SPI) map for 1981.

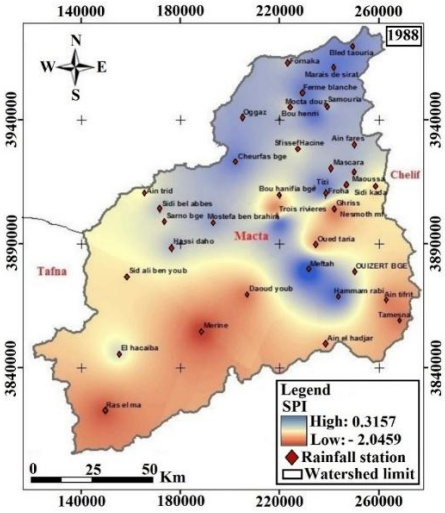


Fig. 10. Standard Precipitation Index (SPI) map for 1988.

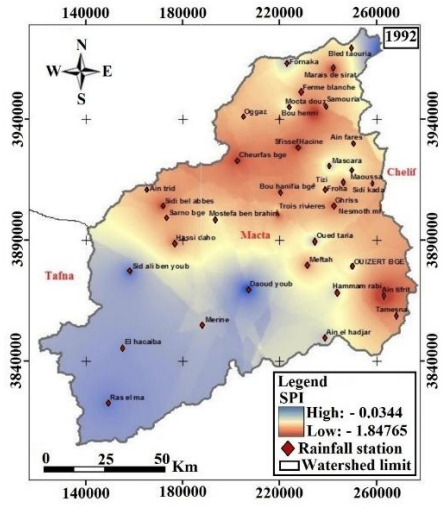


Fig. 11. Standard Precipitation Index (SPI) map for 1992.

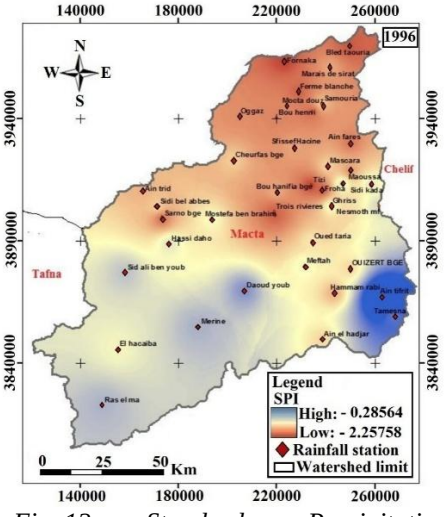


Fig. 12. Standard Precipitation Index (SPI) map for 1996.

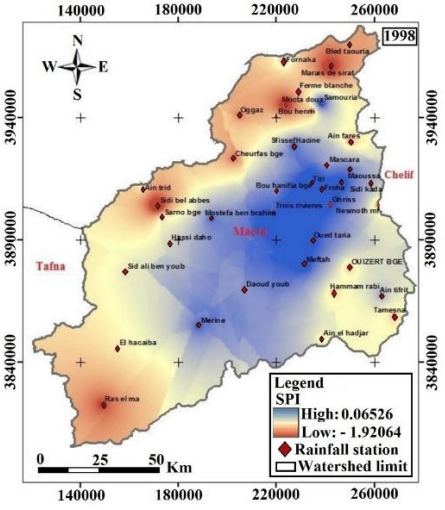


Fig. 13. Standard Precipitation Index (SPI) map for 1998.

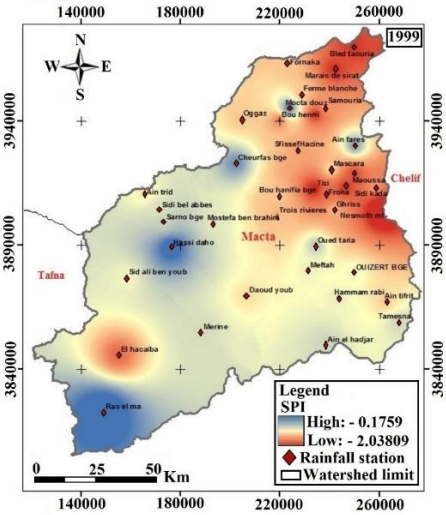


Fig. 14. Standard Precipitation Index (SPI) map for 1999.

Conclusion

Drought is a global natural phenomenon that adversely affects several areas and sectors, such as agriculture, health, environment and even natural reserves and resources. In this study, several statistical methods were employed to assess whether drought trends are region-wide or localized across the study area. The annual rainfall totals for the period between 1969 and 2011 show a low inter-annual variability, with averages ranging from 200.3 mm to 500 mm and coefficients of variation from 0.23 to 0.48.

Over this 43-year period, analysis using the 12-month Standardized Precipitation Index (SPI-12) highlights a significant drought trend. The most intense and widespread drought events occurred during the 1980s and 1990s, with particularly severe years including 1981, 1983, 1988, 1989, 1992, 1993, 1996, 1998, and 1999. Among these, the 1981 drought was the most extensive, affecting over 80% of the study area. While the 1980s were marked by more extreme drought conditions, two notable events were also detected in the early 21st century, in 2004 and 2007.

Using Geographic Information Systems (GIS), drought severity was mapped to identify the most affected zones within the Macta basin. The spatial analysis revealed no clear regionalization of drought occurrence, indicating that dry years are randomly distributed across the study area, reflecting the highly variable and localized nature of rainfall.

The findings indicate a clear increasing trend in drought severity over recent decades. Drought has become a dominant feature of northwestern Algeria and a characteristic of the semi-arid Mediterranean climate. This intensifying aridity has led to a persistent water deficit, disrupting the balance between water availability and demand. The impact on water resource management has been more pronounced than on agriculture or vegetation. These results underscore the importance of robust drought monitoring and assessment systems as essential tools for mitigation and sustainable resource planning.

Further research is recommended to incorporate more recent climatic data and additional variables, using advanced analytical and remote sensing approaches to improve understanding of drought dynamics in northern Algeria.

Acknowledgements

The authors would like to thank the numerous people who helped in the preparation of this paper especially Prof. Mahi Habib, Center of Space Techniques (CTS)-Algeria.

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