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# APPLICATION OF SPI AND SPEI INDICES FOR THE ANALYSIS AND EVALUATION OF THE DROUGHT PHENOMENON IN THE AIN OUSSERA PLAIN, ALGERIA

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## ABSTRACT

Drought appears to be one of the main natural factors contributing to the degradation of agricultural landscapes and economic frameworks. The occurrence of drought episodes becomes noticeable following a prolonged absence of precipitation; however, it is difficult to determine their onset, extent, and resolution. Therefore, the precise assessment of drought characteristics based on drought intensity, extent, duration, and geographic coverage presents significant complexities. In this scientific article, an effort is made to evaluate the meteorological situation of drought in the Ain Oussera Plain, which is located in Algeria, using two widely recognized drought indices, namely the precipitation index (SPI) and the precipitation evapotranspiration index (SPEI).

The calculation of potential evapotranspiration (PET) required for SPEI evaluation was performed using the Thornthwaite methodology. Water deficiency was detected during the specified period, characterized by a decrease in precipitation levels associated with an increase in potential evapotranspiration rates.

The calculation of the SPI and SPEI over durations of 3, 6, 9, and 12 months was carried out to examine the temporal fluctuations of different drought levels.

The results of the analysis revealed that the years 1983, 1989, 1991, 1995, 2003, 2017, and 2021 were drought periods according to both indices on almost all temporal scales with a notable predominance of normal and moderate drought classifications.

The study mainly reveals that the SPI and SPEI show a significant correlation at the same time scales used in this research. These findings highlight the consistency in detecting periods of severe drought using the SPI and SPEI indices.

**Keywords:** Drought, SPI, SPEI, Semiarid climate, Ain Oussera, Algeria

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## INTRODUCTION

Drought, a disaster of immense proportions, profoundly impacts the ecosystem, economy, and culture. It occurs when precipitation in a specific area falls significantly below average (Kundzewicz and Robson, 2000; Beşel and Kayikci, 2020), manifests as a natural phenomenon in several spatial regions over long periods. Some studies attribute the persistent drought conditions to a notable increase in mildly dry years and a decrease in wet years, emphasizing the severity of droughts. They provide valuable insights into drought characterization, precipitation and climate variability, contributing to a better understanding of drought phenomena in different regions (Boubakeur, 2018; Kouao et al., 2020; Doumounia et al., 2020; Zeggane et al., 2021; Benali Khodja and Ferdjouni, 2024).

In addition, Mediterranean regions experienced alternating wet and dry periods. In a context where climate change is conjugated news at the impact of human activities on the water overuse, it is essential to analyze the dry spells in various time scales for prevention of rationalization of water resources, and investigate whether climate change affects rainfall trends (Remini, 2020; Chadee et al., 2023). To this end, the rainfall series covering the river basin must be analyzed, which should be based on the values of the standardized precipitation index (SPI) calculated for time scales up to almost 70 years (Bouguerra and Benslimane, 2017). Some researches investigate how climate change affects statistical models used to predict extreme rainfall events. They provide insights into the challenges of modeling extreme weather under changing climatic conditions, contributing to the understanding of climate change impacts across different regions and offer valuable insights into regional climate modeling and analysis (Nassa et al., 2021; Pang and Tan, 2023).

Climate change has a profound impact on water resources and their management (Faye, 2016; Bouly et al., 2019; Assemian et al., 2021; Nakou et al., 2023; Kezzar and Souar, 2024), leading to significant challenges in ensuring sustainable water supply, distribution, and strategies (Aroua, 2022; Pandey et al., 2022; Patel and Mehta, 2022; Kouloughli and Telli, 2023; Berrezel et al., 2023). Rising global temperatures intensify evaporation rates, reducing surface water availability in rivers, lakes, and reservoirs (Boutoutaou et al., 2020). Changes in precipitation patterns result in more frequent droughts and extreme rainfall events, causing water scarcity in some regions (Remini, 2020), while increasing flood and flash flood risks in others (Benkhaled et al., 2013; Nezzal et al., 2015; Ayari et al., 2016; Bekhira et al., 2019; Hafnaoui et al., 2022; Hafnaoui et al., 2023; Remini, 2023; Abd Rahman et al., 2023). The depletion of groundwater reserves due to prolonged dry periods further exacerbates water shortages, making efficient water management critical (Qureshi et al., 2024). To address these challenges, water resource management must incorporate climate adaptation strategies such as enhanced reservoir operation (Mezenner et al., 2022; Zegait and Pizzo, 2023; Mehta et al., 2023a; Verma et al., 2023; Shaikh et al., 2024), flood risk protection measures (Benslimane et al., 2020; Aroua, 2020; Baudhanwala et al., 2023; Ben Said et al., 2024), improved irrigation efficiency (Rezzoug et al., 2016), rainwater harvesting, and integrated watershed management (Long et al., 2023). Sustainable policies should focus on climate-resilient infrastructure, real-time hydrological monitoring, and transboundary water cooperation to mitigate the effects of climate change (Trivedi and Suryanarayana, 2023). Without proactive measures, climate variability will continue to disrupt water availability, threatening agriculture, energy production, and overall economic stability.

Nevertheless, drought's interconnected spatial and temporal attributes are often analyzed with insufficient attention (Haslinger and Blöschl, 2017).

The World Meteorological Organization (WMO) established a comprehensive definition of droughts, which involves the existence of persistent and prolonged rainfall deficits (WMO, 1986). Similarly, the Intergovernmental Panel on Climate Change (IPCC) defines droughts as prolonged periods of abnormally dry climatic conditions that result in significant hydrological imbalances. (IPCC, 2021). Due to an insufficiency of precipitation compared to forecasts or expected averages, it represents a pernicious natural hazard that, when prolonged over a season or long periods, proves inadequate to meet the requirements of human activities (Wilhite, 2005).

The use of appropriate methodologies and meteorological drought measures is essential for predicting short- and long-term drought episodes. Several research efforts have been made to assess meteorological droughts in dry and semi-arid areas, such as the work of Zhang et al. (2021) and Tayfur (2021).

Drought is one of the main factors responsible for significant damage to agriculture, the economy, and the environment (Vicente-Serrano et al., 2010). It is a recurrent feature of climate change, but some authors argue that it is exacerbated by climate change. (Sherwood et al., 2014).

An in-depth analysis of drought concepts, indices, forecasts, and predictions is provided. Drought monitoring and risk management tools are examined. Concepts, indicators, monitoring tools, and information on desertification are presented to help identify vulnerability and combat desertification (Santos Pereira et al., 2009). Drought indices play a crucial role in quantifying and comparing the severity, duration, and extent of droughts in regions with different climates and hydrological regimes (James et al., 2014; N'Guessan Bi et al., 2020). The standardized precipitation index (SPI), proposed by McKee et al. (1993) to identify abnormally wet and dry periods, is one of the most widely used meteorological drought indices. Due to its ease of calculation and ability to detect drought at multiple time scales, the SPI has been widely used in previous studies. The four main categories of drought are meteorological, hydrological, agricultural, and socioeconomic (Heim, 2002). In recent decades, many efforts have been made to develop and improve drought indices (Montes-Vega et al., 2023). Regional and global droughts are widely studied using meteorological indices. (Vicente-Serrano et al., 2015; She and Xia, 2018).

Determining the onset, severity, and duration of drought remains a challenging task, despite the numerous research efforts dedicated to this endeavor (McKee et al., 1993). Other drought-related factors, such as air temperature, were not included. The standardized precipitation evapotranspiration index (SPEI) is based on precipitation and air temperature data (Vicente-Serrano et al., 2010). The sensitivity of the atmospheric evaporation demand to drought is accounted for by the SPEI, which is influenced by fluctuations and trends in climate variables other than precipitation. In regions where temperature and PET increase, the SPEI may better reflect drought dynamics than the SPI (McEvoy et al., 2012; Vicente-Serrano et al., 2014; Wang et al., 2015). The economies of the Maghreb countries, including Algeria, are facing major problems due to persistent droughts. They are becoming longer and more frequent (Stockton, 1988; Mutin, 2011).

By analyzing rainfall trends in Jalore, Rajasthan, based on indicators such as SPI, RAI, and the percentage deviation of precipitation, an increase in rainfall is observed before and after the monsoon, but a decrease in annual rainfall. (Mehta and Yadav, 2022). Weather data on droughts from 1901 to 2002 showed that droughts were mild, but severe droughts were detrimental due to low annual precipitation rates. This allows for forecasting upcoming drought risks and mitigating their impact. (Mehta and Yadav, 2023). Using statistical and graphical methods, the study of monthly, seasonal, and annual precipitation trends in the Hanumangarh district, northeastern Rajasthan, highlights a variation during the southwest monsoon season, with the ITA method being more effective. (Patel and Mehta in 2023), analysis of climate change in the Hathmati River basin using MCG and MCR tools. A future scenario of precipitation and temperature variations for 2050 has been developed, showing an increase of 8.45% in average precipitation and a rise of 7.05% in temperatures. According to the study, these changes could increase water stress and raise the likelihood of severe events, justifying the implementation of mitigation strategies. (Shaikh et al., 2022)

In India, drought can be predicted using weather variables and the global climate model, with a probability of 75.0% during El Niño years and an accuracy of 60% through statistical downscaling. Policymakers can benefit from this study to organize emergency measures in case of drought. (Mehta et al., 2023b). The analysis of precipitation trends in the Mindhola River basin in Gujarat from 1990 to 2020 identifies fluctuations in rainfall and patterns associated with heat. According to the results, it appears that the Bardoli region is not heavily affected by drought. (Patel and Mehta et al., 2021), in the northeast of Rajasthan, India, the study highlights an increase in annual rainfall during the drought period, emphasizing the importance for policymakers and local administrators to reduce its severity. (Patel et al., 2024) A study of precipitation and drought trends in the Churu district of Rajasthan, India, using monthly data from 1901 to 2022. The aim of the research is to identify drought situations using indicators such as the standardized precipitation index, Z-score, and normal precipitation. (Patel et al., 2024)

Many people in Malegaon have been affected by the drought, which has caused water shortages, and the measures taken to address it are due to changes in crops and land use. The adaptive neuro-fuzzy inference system (ANFIS) model was used by Ramkar et al. (2023) to assess daily flow in the Damanganga basin based on precipitation and soil moisture data from 1983 to 2022. (Kantharia et al. (2024), the results indicate that rock soil moisture allows for more accurate daily flow values.

The study of artificial intelligence models to accurately anticipate precipitation in the Ambica River basin, focusing on climatic factors such as temperature, humidity, and wind speed. The effectiveness of four models is evaluated, including support vector regression and random forest. According to Baudhanwala et al. in 2024, for different periods of water immobilization and the critical lowering rate for a flood height of 80%, it is crucial to determine the ideal dimension of stone coverings. The optimal performance of the stone covering of 6.31 mm and the coastline was demonstrated by its dimension of 6.31 mm. The study showed of the influence of rainfall regimes from other states on the precipitation of Delhi, with the aim of optimizing the reliability of forecasts. The study uses past data to employ machine learning algorithms such as CatBoost, XGBoost, and Random Forest, which yield remarkable results.

Various methodologies have been employed to study environmental flows in the lower Tapi basin. The results indicate a significant correlation between the Tessman and VMF methods, as well as the calculation of the EFR. This helps prevent the deterioration of rivers and supports stakeholders in water distribution. (Umrigar et al., 2023)

Algeria experienced droughts lasting five to six years during the last century, with a 15% rainfall deficit. This persistent aridity has had a negative impact on the water supply and soil nutrition, affecting the country's socioeconomic activities.

Water scarcity issues are more pronounced in steppe regions, where pruning activities dominate, as well as intensive cereal farming and horticulture. The balance between increasing demand and limited availability is already disrupted. (Benalia, 2010)

Many researchers have examined drought in various regions of Algeria, Achite et al (2023) investigated hydrometeorological droughts to determine their distribution and assess the risk of drought.

Bouabdelli et al. (2022) investigated the impact of temperature on the frequency, severity, and temporal extent of agricultural droughts under future scenarios in seven large plains located in the semiarid region of the Mediterranean basin. Copula theory serves as the basis for a multivariate frequency analysis of the meteorological and agricultural characteristics of drought.

Brahim et al. (2024) studied the drought exceedance probability index (DEPI), standardized precipitation index (SPI), and effective drought index (EDI) in the Cheliff-Zahrez basin in Algeria at different temporal scales.

Berhail and Katipoğlu (2023) conducted a comparative study for the evaluation of drought in a semiarid region: the case of the Mekerra River basin (northwest Algeria).

In this article, an effort is made to assess meteorological drought in the Ain Oussera Plain, Algeria, using two widely recognized drought indices, namely, the standardized precipitation index (SPI) and the standardized precipitation evapotranspiration index (SPEI). The SPI and SPEI calculated over periods of 3, 6, 9, and 12 months were used to examine the temporal variability of different drought categories.

The methodology section explains our dataset and the different drought indices used, while the results and discussion section provides a comprehensive comparison of droughts identified by the SPI and SPEI, as previously indicated. Finally, the conclusions and discussion are presented sequentially toward the conclusion of the article.

## DESCRIPTION OF THE STUDY AREA

The Ain Oussera Plain is situated in Djelfa Province, central northern Algeria, between the Tell Atlas and the Saharan Atlas. It is a steppe-like area with longitudinal coordinates of 2°15' and 3°45'E and latitudinal coordinates of 35° and 35°40' N, as shown in Fig. 1.

The region's drinking water needs, among others, depend heavily on the Albian sandstone aquifer. In addition, the Plio-Quaternary alluvium and the Oued Touil aquifer were used for extraction. In the center of the Cretaceous, the Ain Oussera plain features a significant anticlinorium mainly covered with Quaternary sediments. The region experiences hot and dry summers and cold and humid winters due to its semiarid environment. The highest recorded temperature is 24°C, and the average annual precipitation is 226.15 mm (Mebrouk, 2007).

The Ain Oussera plain hosts a number of aquifer formations, including the lower Albie sandstones, which have an average thickness of 150 mm and constitute a substantial and widely distributed unconfined aquifer.

Water quality degradation is most often attributed to organic pollution, which is linked to anthropogenic pollution in this rural area and exacerbated by the absence of a sewage system.

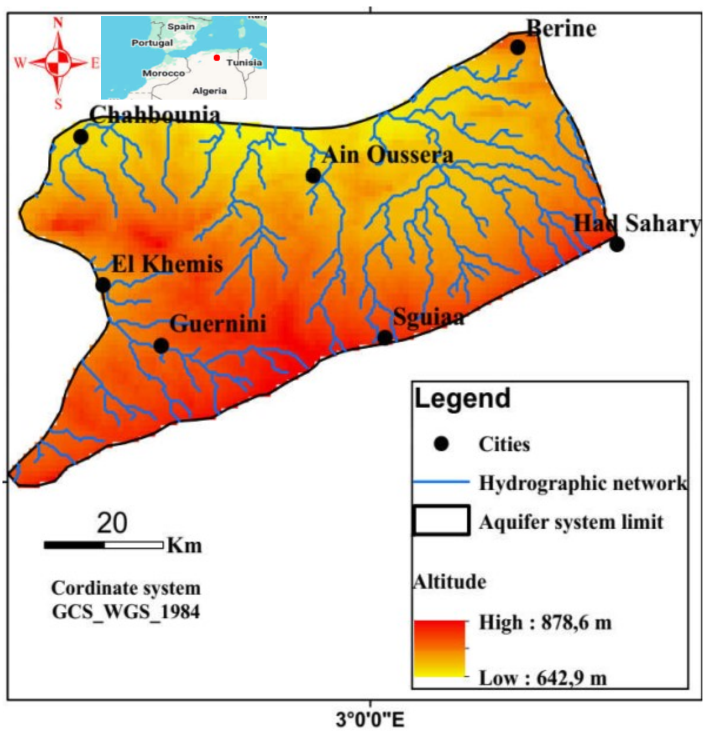



**Figure 1: Geographical location of the study area**

## METHODOLOGY

### Data collection

The analysis in this study was carried out using temperature and precipitation data from the National Aeronautics and Space Administration (NASA), power project's data access viewer (NASA,2023), covering the period from 1981 to 2022. In this study, the SPI and SPEI at time scales of 3, 6, 9 and 12 months were calculated using the "SPEI" package in the statistical software R

### Standardized Precipitation and Evapotranspiration Index (SPEI)

Vicente-Serrano et al. (2010) introduced the standardized precipitation evapotranspiration index (SPEI). The precipitation sensitivity index (SPI) is determined in the same way as the SPI, except that the PSI incorporates the disparity between precipitation and potential evapotranspiration (PET) (Equations 1 - 4). Potential evapotranspiration was estimated using the Thornthwaite method (1948).

The Thornthwaite method, which is referred to as Vicente-Serrano et al (2010), was used to calculate PET.

$$PET = 16K\left(\frac{10T}{I}\right)^{m} \tag{1}$$

Vicente-Serrano et al. (2010) used the mean monthly temperature to calculate the heat index (I), which is calculated as the sum of the twelve-monthly heat index values. T stands for monthly-mean temperature (°C).

$$i = \left(\frac{T}{5}\right)^{1.514} \tag{2}$$

where K is a correction coefficient that depends on the latitude and month, and m is a deduced coefficient that depends on I:

$$m = 6.75\times10^{-7} I^3 - 7.71\times10^{-5} I^2 + 1.79\times10^{-2} I + 0.492 \tag{3}$$

$$K = \left(\frac{N}{12}\right)\left(\frac{NDM}{30}\right) \tag{4}$$

where the total number of days in the specified month is represented by NDM. The maximum number of hours of sunshine (N), as calculated by Vicente-Serrano et al. (2010)

$$N = \left(\frac{24}{\pi}\right) w_S \tag{5}$$

where ($\omega s$) is the sun's hourly angle of rise, provided as:

$$w_S = \arccos\left(-\tan\varphi\tan\delta\right) \quad (6)$$

where δ is the solar declination in radians, calculated from: and φ is the latitude in radians.

$$\delta = 0.4093\sin\left(\frac{2\pi J}{365} - 1.405\right) \quad (7)$$

where J is the average Julian day for that month.

The following formula was used to determine the climate-water balance:

$$D_i = P_i - PET_i \quad (8)$$

The values of $Di$ were aggregated on several time scales, where $Di$ represents the $ith$ month moisture deficit (mm), $Pi$ represents the $ith$ month precipitation (mm), and $PETi$ represents the $ith$ month potential evapotranspiration (mm).

$$D_n^k = \sum_{i=0}^{k=1}\left(P_{n-1} - PET_{n-1}\right), n \geq k \quad (9)$$

In the context of SPEI, a three-parameter probability distribution is used, and the D series is standardized using a log-logistic distribution f(x), where k is the monthly timescale and n is the number of calculations (Vicente-Serrano et al., 2010)

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x-y}{\alpha}\right)^{\beta-1}\left[1+\left(\frac{x-y}{\alpha}\right)^{\beta}\right]^{-2} \quad (10)$$

where the scale, shape, and origin parameters are denoted by α, β, and γ, respectively.Consequently, the cumulative distribution function for a certain time scale was ascertained as follows:

$$f(x) = \left[1+\left(\frac{\alpha}{x-y}\right)^{\beta}\right]^{-1} \quad (11)$$

SPEI was computed in this way:

$$SPEI = W - \frac{C_0 + C_1W + C_2W^2}{1 + d_1w + d_2w^2 + d_3w^3} \quad (12)$$

$w = \sqrt{-2\ln(P)}$, for P ≤ 0.5 and $= \sqrt{-2\ln(1 - P)}$ , for P > 0.5, $C1$ = 0.8028, $C2$ = 0.0203, $d_1$=1.4327, $d_2$ = 0.1892, $d_3$ = 0.0013.

The minimum SPEI value indicates the drought's peak intensity, the sum of consecutive months with negative SPEIs indicates the length of the drought, and the sum of all negative SPEI values indicates the severity of the drought (Mouatadid et al.,2018)

**Standardized Precipitation Index (SPI)**

McKee et al. (1993) in order to delineate and monitor drought episodes over different time spans (1, 3, 6, 12, and 24 months) formulated the standardized precipitation index (SPI). The World Meteorological Organization (WMO) (Potop et al., 2012) proposed the recommendation of the SPI index as the main drought indicator. Depending solely on precipitation data, the SPI index has the ability to examine both dry and wet conditions (Morid et al., 2006). The manifestation of negative and positive values consequently indicates arid and moisture-laden intervals (Damberg, and AghaKouchak, 2014). The SPI tends toward more negative or positive values with the escalation of severe drought or humidity levels (Wang et al., 2015). A prerequisite for calculating the SPI is the possession of a minimum of 20 to 30 years of monthly precipitation records, with an optimal range extending over 50 to 60 years or more (Guttman,1994). Monthly precipitation data covering the period from 1971 to 2011 (41 years) were used to calculate the monthly SPI indices for the Ningxia region. The calculation of the SPI involves calibrating a gamma distribution against a sequence of precipitation values (Mansouri, 2013). Detailed explanations of the calculation methodology can be found in various literary works such as those written by as Almedeij (2014)

Positive SPI values indicate precipitation above the median, while negative values indicate precipitation below the median. Since the indices are normalized, wet and dry climates can be represented in the same way. In addition, it is possible to monitor wet periods and their frequency of recurrence using this SPI (Table. 1) (McKee et al., 1993).

**Table 1: Probability of occurrence of climatic categories according to McKee et al., (1993)**

| SPI | Category | Number of times out of 100 | Frequency |
|---|---|---|---|
| From 0 to 0.99 | Slight drought | 33 | 1 time every 3 years |
| From -1,00 to -1,49 | Moderate drought | 10 | 2 time every 10 years |
| From -1,5 to -1,99 | Severe drought | 5 | 3 time every 20 years |
| < -2 | Extreme drought | 2 | 4 time every 50 years |

## RESULTS AND DISCUSSION

### Statistical analysis

A statistical analysis of the mean annual precipitation and temperature, as presented in Table 2, revealed that the precipitation fluctuated between 0 and 147.66 mm/year, with a coefficient of variation of 0.28. Similarly, the mean annual temperature varies from 4.78 to 30.12°C, with a coefficient of variation of 0.03. The coefficient of variation (CV) can be used as an indicator of the level of dispersion of random variables. A CV value below 10% generally indicates low variability, while a CV value between 10% and 100%

suggests moderate variability. Conversely, a CV value above 100% indicates high variability (Nielsen et al., 1983). It should be noted that temperature shows minimal variation, while precipitation shows a moderate degree of variability.

**Table 2: Average values and statistics for precipitation and temperature**

| Parameter | Min | Max | Mean | Std dev | CV | Skew | Kurt | Median |
|---|---|---|---|---|---|---|---|---|
| P (mm) | 0 | 147,66 | 24,93 | 7,2 | 0,28 | 0 .003 | 2,89 | 25,26 |
| T °C | -7,64 | 42,33 | 16,41 | 0,61 | 0,03 | 0,7 | 4,42 | 16,42 |

**Annual Water Deficit**

Potential evapotranspiration (PET) plays a crucial role in research on agricultural water management and climate change. Although several studies have already examined the impact of climatic factors on potential variations in evapotranspiration, the quantitative impacts of various driving factors (Thompson et al., 2014; Wang et al., 2017; Duhan et al., 2021).

The climatic water balance was used to determine the annual water deficit, which is illustrated in Fig. 2. The Thornthwaite method was used to calculate potential evapotranspiration (PET). The annual potential evapotranspiration exceeded the annual precipitation. Therefore, a water deficit was present throughout the observed period. Additionally, Figure 5 illustrates the fluctuations in annual precipitation and annual PET from 1981 to 2022.

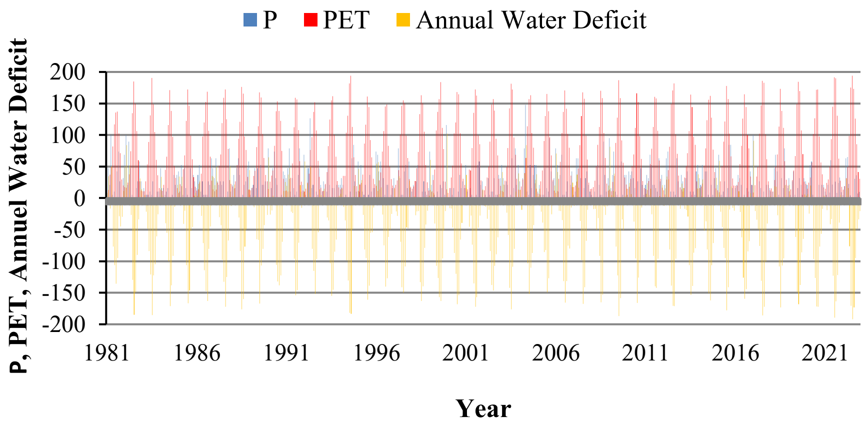
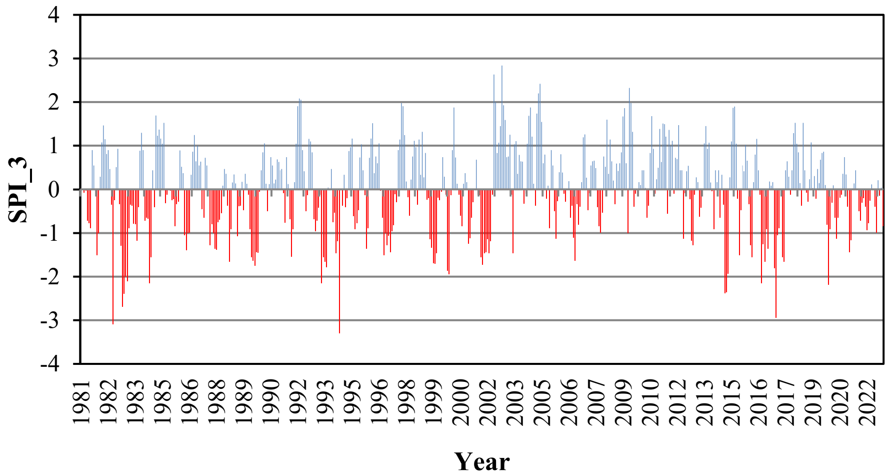



**Figure 2: Annual changes in precipitation, PET, and annual water deficit (1981-2022)**

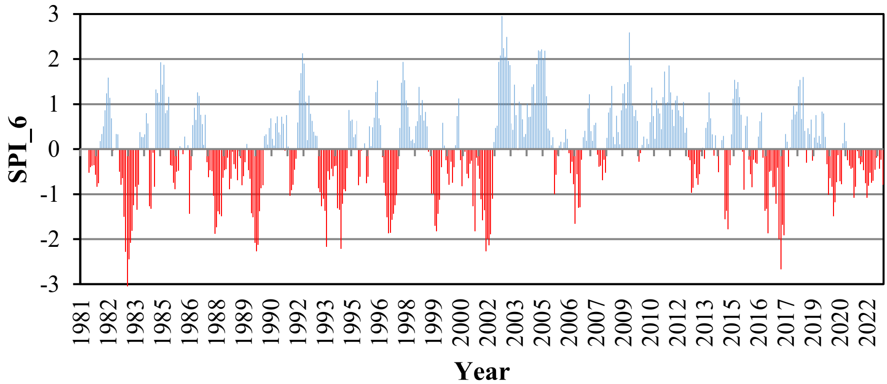
**Monthly changes in the SPI**

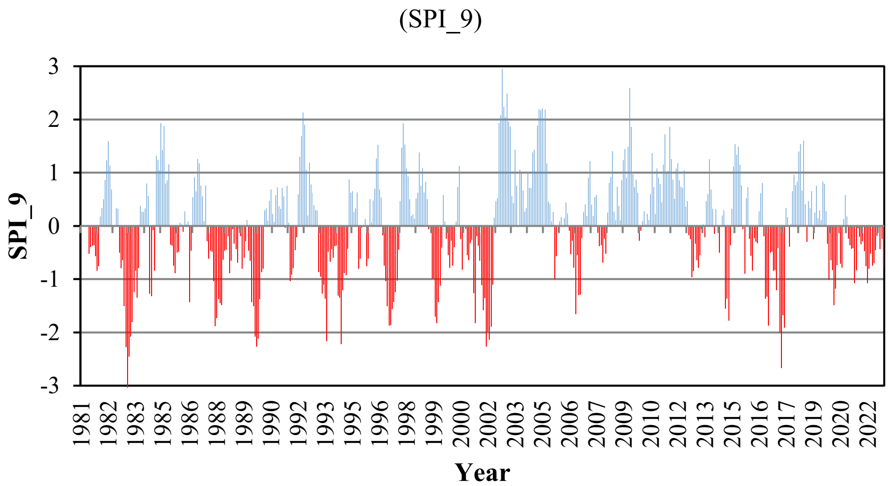
The SPI for the Ain Oussera Plain from 1981 to 2022 is illustrated in Fig. 3, with separate representations for time scales of 3, 6, 9, and 12 months.

(SPI_3)




(SPI_6)





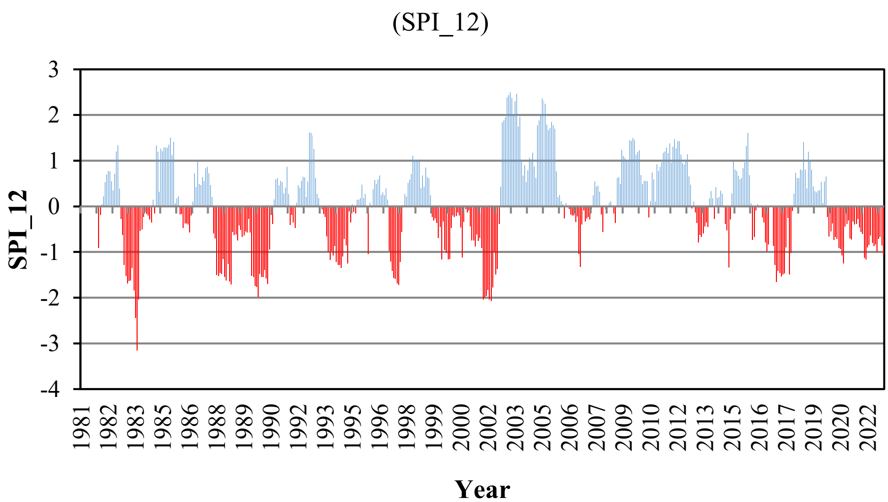




**Figure 3: Temporal evolution of the SPI on 3-, 6-, 9- and 12-month time scales from 1981 to 2022 on the Ain Oussera Plain.**

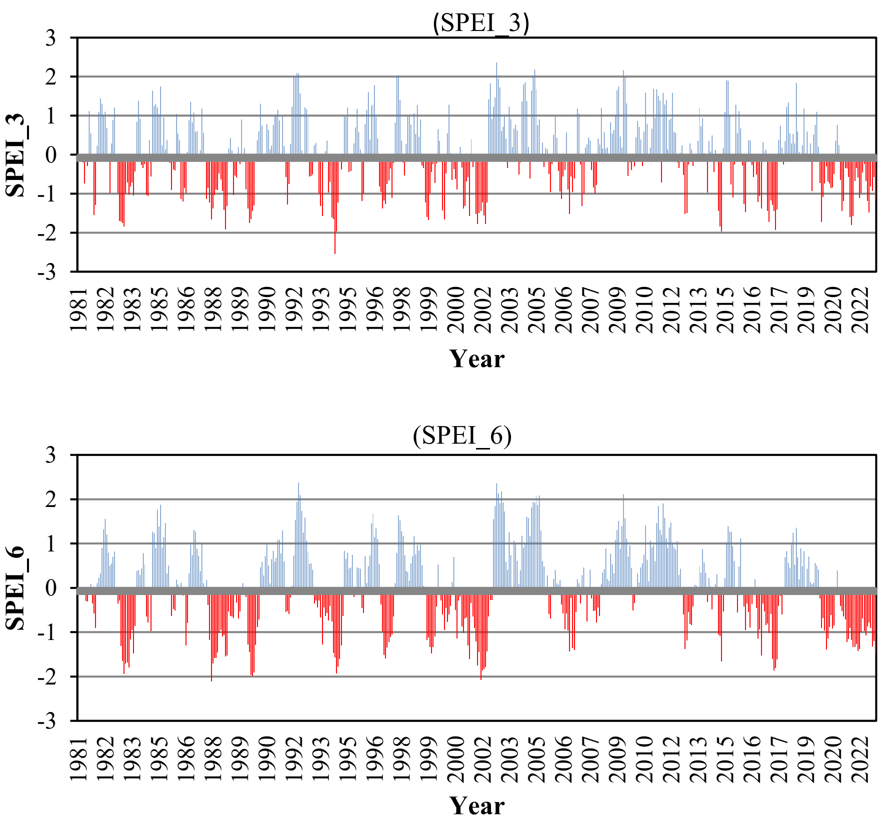
Fig. 3 illustrates the temporal fluctuations in the standardized precipitation index (SPI) for different time scales (3, 6, 9, and 12 months) derived from a 30-year precipitation dataset (1981 to 2022). The monthly variability in the SPI showed noticeable trends at different time scales, indicating a significant modification of aridity and humidity levels for each month in the study area. The sharp increase in drought severity during certain months after 2014 was particularly remarkable.

The years 1981, 1982, 1983, 19985, 1994, 1995, 1996, 2014, 2017, 2018, and 2020 were marked by extreme drought, with an SPI below -2.0 over a 3-month period. According to the 6-month SPI, extreme drought with intensities below -2.0 was observed in 1982, 1983, 1984, 1991, 1994, 1995, 2002, 2003, and. Extreme drought was observed in 1983, 2002, and 2017 based on the 9-month SPI. In 1984 and 2002, extreme drought was observed based on the 12-month SPI.

The longest drought episodes occurred between 1982 and 1985, with a magnitude of -3 in 1982 on a 3-month scale. On a 6-month time scale, the longest drought period was observed from 1981 to 2002, with a severity of -2.13 in 2002, indicating a period of severe drought during that time.

**Monthly changes in the SPEI**

The SPEI for the Ain Oussera Plain from 1981 to 2022 is shown in Fig. 4, with separate representations for time scales of 3, 6, 9 and 12 months.



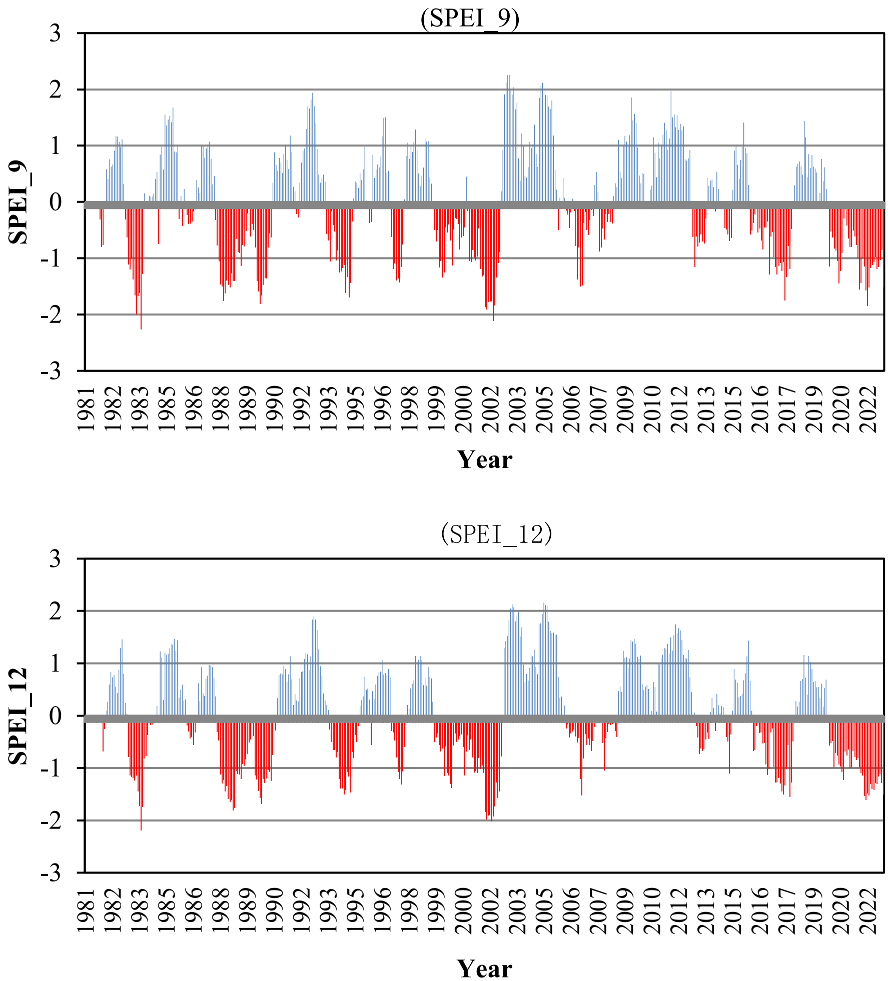



**Figure 4: Temporal evolution of SPEI values on 3, 6, 9 and 12 month time scales from 1981 to 2022 on the Ain Oussera Plain.**

The temporal variability of the monthly standardized precipitation-evapotranspiration index (SPEI) at different time scales (3, 6, 9, and 12 months) was calculated using precipitation and temperature data covering a 25-year period (1981 to 2022). This information is visually presented in Figure 4. Across almost all temporal scales, the SPEI for the period 2002-2003 had values below -2.0, indicating the occurrence of extreme drought during this period. Data analysis of the 3-month SPEI period revealed that the year 1994 experienced severe drought, characterized by an intensity of -2.55. Similarly, the 6-month SPEI reveals extreme droughts in 1988 and 2002, with intensities of -2.11 and -2.07, respectively. Furthermore, the 9-month SPEI index shows that extreme droughts occurred in 1983 and 2002, with intensities of -2.25 and -2.1, respectively.

Additionally, the 12-month SPEI index highlights an extreme drought in 1983, with an intensity of -2.18. Therefore, the year 1983 is considered a period of drought in almost all calculated series.

Table 2 represents the correlation coefficients (R) between the SPI and SPEI at time scales of 3, 6, 9, and 12 months. We find that the correlation between the two indices is stronger at longer scales (9 and 12 months) than at shorter scales (3 and 6 months).

According to the results of the SPI analysis based on the data from the Ain Oussera station, the distribution of drought classes is presented in Fig. 5. An examination of all periods at the Ain Oussera station revealed that normal drought classes prevailed, as indicated by the percentages derived from the SPI. A notable observation is the decrease in extreme periods, accompanied by an increase in the frequency of severe drought periods, while the percentages of moderate drought periods generally increase. Furthermore, as the period lengthened, there was a trend toward an increase in severe and extreme drought periods.

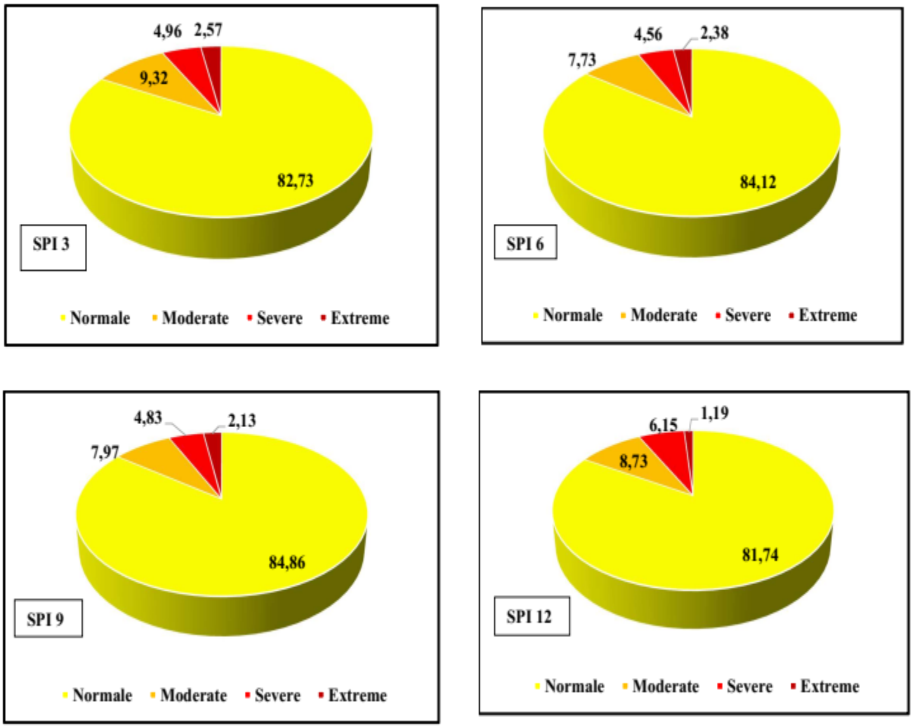



**Figure 5: Occurrence percentages of drought classes (SPI) at the Ain Oussera station**

**Correlation Analysis of the SPI and SPEI**

Correlation analysis is a technique used to determine the direction and strength of the association between two variables. Since drought indices are derived through standardization, Pearson correlation analysis was used to study these associations in the present study. The Pearson correlation matrix for the drought indices is presented in Table 3. The strength of the linear relationship between two variables: The closer the coefficient is to +1 or -1, the stronger the association between the two variables. Conversely, the closer the coefficient is to 0, the less covariance the variables share, and therefore, the weaker the association. (Pearson, 1897)

**Table 3: Pearson correlation coefficients for the SPI and SPEI at different time scales.**

| | SPEI3 | SPI3 | SPEI6 | SPI6 | SPEI9 | SPI9 | SPEI12 | SPI12 |
|---|---|---|---|---|---|---|---|---|
| SPEI3 | 1 | | | | | | | |
| SPI3 | 0,899 | 1 | | | | | | |
| SPEI6 | 0,775 | 0,629 | 1 | | | | | |
| SPI6 | 0,755 | 0,689 | 0,938 | 1 | | | | |
| SPEI9 | 0,688 | 0,527 | 0,881 | 0,773 | 1 | | | |
| SPI9 | 0,690 | 0,577 | 0,853 | 0,823 | 0,951 | 1 | | |
| SPEI12 | 0,586 | 0,431 | 0,791 | 0,666 | 0,912 | 0,819 | 1 | |
| SPI12 | 0,596 | 0,488 | 0,790 | 0,727 | 0,894 | 0,875 | 0,956 | 1 |

During the analysis of the correlation matrix, the most significant association was identified between indices that share the same time scale. Specifically, the highest correlation coefficient (0.956) was observed between SPI_12 and SPEI_12, while the lowest correlation coefficient (0.431) was found between SPI_3 and SPEI_12.

**Comparison of SPI_12 and SPEI_12**

There is a strong association between the SPI and SPEI. Table 3 shows a robust correlation between the SPI_12 and SPEI_12. Both indices had a correlation coefficient of 0.956 and demonstrated a similar manifestation of drought incidence.These indices were evaluated for the period from 1981 to 2022, as shown in Fig. 6. Both drought indices indicate the occurrence of a drought episode in the years 1983 and 2002, where the SPI was progressively greater than the SPEI in the periods from 1981 to 1988 and from 2001 to 2011, respectively.

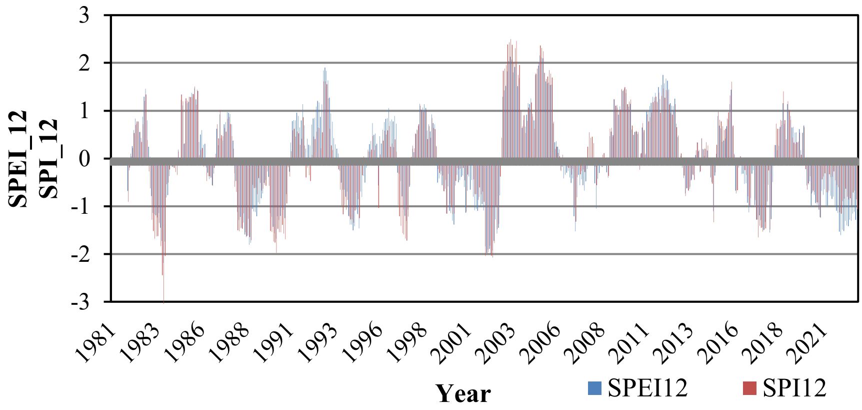



**Figure 6: Comparison between the SPI and SPEI**

The drying trend in the Ain Oussera Plain from 2003 to 2017 is indicated by the SPEI and SPI series with different time scales. However, on a time scale of 12, this drying trend is much more obvious as it shows a dry character almost every month of every year. On time scales of 1, 3, 6 and 12 months, the study area was mainly characterized by conditions ranging from normal to moderate humidity.

### Seasonal variation in drought

The proportional distributions of the seasonal values of the SPI_12 and SPEI_12 are shown in Tables 4 and 5.

**Table 4: Percentage of seasonal values of SPI_12**

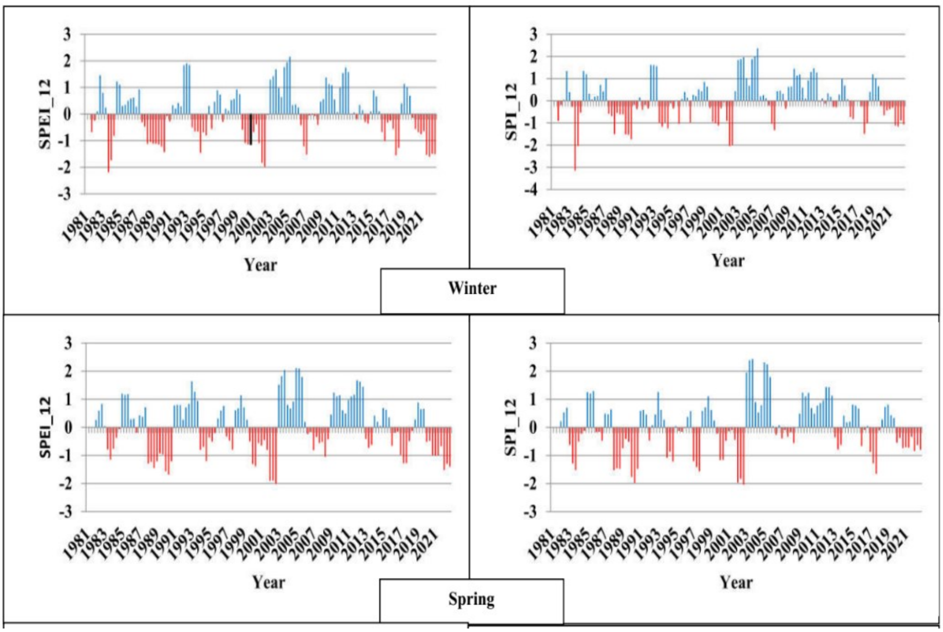
| Type of drought | Winter | Spring | Summer | Autumn |
|---|---|---|---|---|
| Normal | 83,33 | 84,13 | 82,54 | 85,71 |
| Moderate | 9,52 | 8,73 | 7,94 | 9,52 |
| Severe | 4,76 | 6,35 | 9,52 | 3,97 |
| Extreme | 2,38 | 0,79 | 0,79 | 0,79 |

**Table 5: Percentage of seasonal values for SPEI_12**

| Type of drought | Winter | Spring | Summer | Autumn |
|---|---|---|---|---|
| Normal | 80,16 | 82,54 | 78,57 | 77,78 |
| Moderate | 12,70 | 12,70 | 17,46 | 17,46 |
| Severe | 6,35 | 3,97 | 3,97 | 4,76 |
| Extreme | 0,79 | 0,79 | 0,00 | 0,00 |

In this study, the four seasons were classified as winter (December to February), spring (December to February), spring (March to May), summer (June to August), and autumn (September to November). Fig. 6 shows a visual representation of the seasonal variability ofin the SPI_12 and SPEI_12 indices in the Ain Oussera Plain. Observations revealed a constant decrease in the values of both indices during all seasons over a 12-month period, indicating an increased probability of drought.

The analysis of tables 4 and 5, along with fig. 7, reveals that the incidence of normal climatic periods, defined by the absence of drought, is significantly high; conversely, cases of moderate drought are relatively infrequent. Excluding the years 1983, 1984, and 2002, the probability of experiencing extreme drought episodes remains minimal.



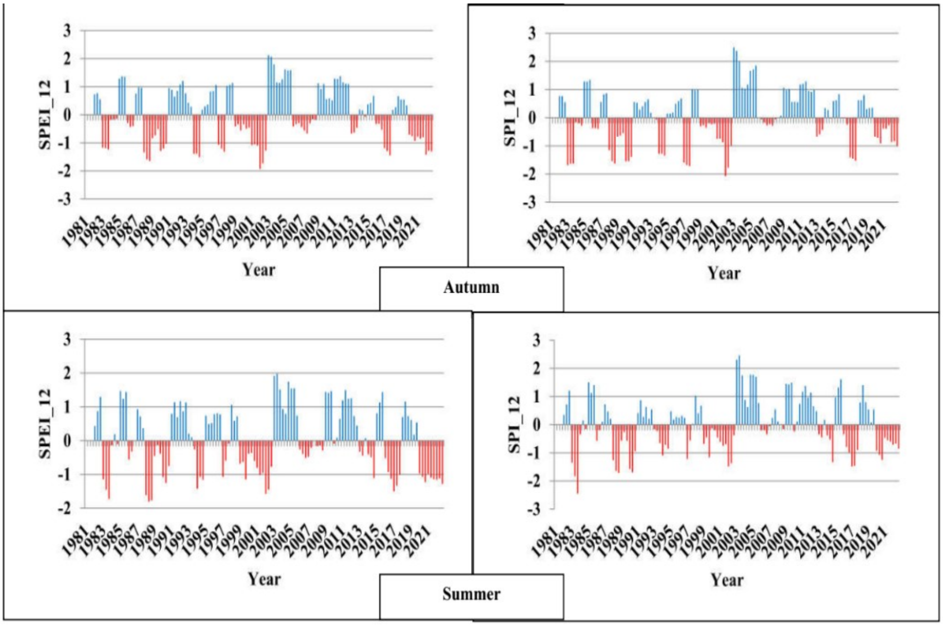



**Figure 7. Seasonal variation in the SPI_12 and SPEI_12 in the Ain Oussera Plain**

Fig. 8 shows the average number of dry months per year from 1981 to 2022. For each year, the different SPEI time scales were considered.

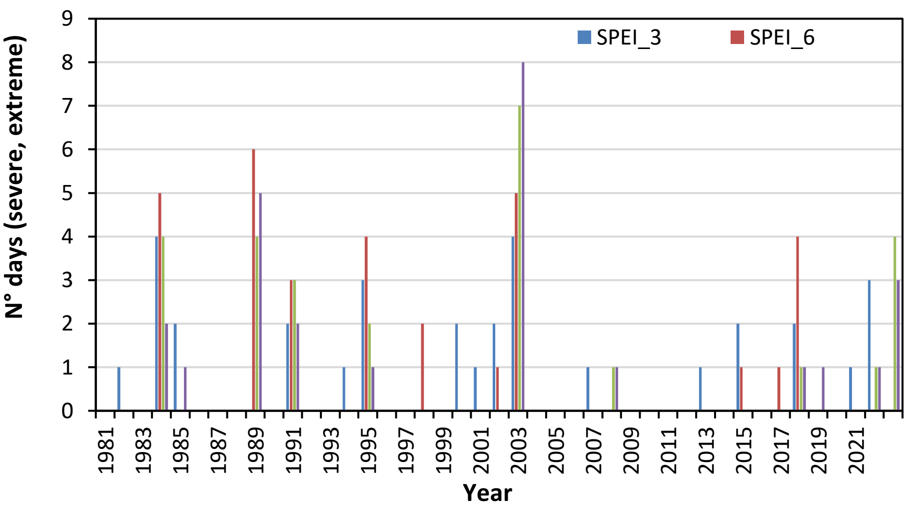



**Figure 8. Number of dry months (severe and extreme) on time scales of 3, 6, 9 and 12 months from 1981 to 2022 on the Ain Oussera Plain.**

Fig. 8 shows that during 1981, the frequency of dry months (SPEI ≤ - 1.99) was limited to less than one month before 1983. Thereafter, there was a notable increase in the frequency of dry months, notably in 1983, 1989, 1991, 1991, 1995, 1995, 2003, 2003, 2017 and 2021. This trend toward more dry months continued between 1989 and 2003 for the SPEI_6 and SPEI_12. In addition, the maximum number of dry months increased to 8 months for SPEI_12, 7 months for SPEI_3, 6 months for SPEI_6 and 4 months for SPEI_9.

## DISCUSSION

This research undertook an examination of meteorological drought from 1981 to 2022, where the analysis focused on average precipitation, average minimum and maximum temperatures, and observed minimum and maximum temperatures. The potential evapotranspiration (PET) used in the calculation of the SPEI was calculated using the Thornthwaite method. A water deficit was observed throughout the selected period due to a decrease in precipitation and an increase in potential evapotranspiration. The main result of this study is that the SPI and SPEI show a strong correlation on the same time scales as those adopted in this study. After examining the temporal distributions related to 3-, 6-, 9-, and 12-month periods of SPI and SPEI values derived from monthly average precipitation records between 1981 and 2022 at the Ain Oussera station, it became evident that the duration of drought periods increased with increasing duration (Fig. 3 and 4). According to the results of the SPI examination based on data from the Ain Oussera station, the frequencies of different drought categories can be observed in Fig. 5. Subsequently, upon examining all the timeframes at the Ain Oussera station, it is evident that the categories of normal drought and moderate drought are prominent.

Under the same climatic conditions, Choutri and Hussien (2024) assessed meteorological drought in Algeria using the standardized precipitation index (SPI) and the standardized precipitation evapotranspiration index (SPEI). The results obtained show a negative trend, a transition from a near-normal situation to a moderately dry situation, and a strong correlation between the two indices. Another study conducted on analyzing drought indices in northeastern Algeria by Merabti et al. (2023), compared their behavior across a long-term dataset. The results showed a decrease in frequency and severity in the northern sub-region and an increase in frequency and severity in the southern region. The new MedPDSI index compares well with other indices and better explains the spatial variability of extreme droughts.

In their research, Dechemi et al. (1994) simulated the average monthly hydrological flows in a semi-arid region (Beni-Bahdel dam,Algeria) using principal component analysis (PCA) as a methodological approach to improve water resource management. The analysis retained the first seven principal components, which accounted for 89% of the variance; the residual values that emerged indicated the loss of information attributed to the exclusion of the other principal components, which were then examined using Markov chains. The resulting simulation produced synthetic time series that were used for water resource management, yielding favorable results that underscored the methodological reliability of the analysis.

Another study on the phenomenon of drought in the coastal territories of Algeria was conducted by Bougara et al. (2020), using eight weather stations (Ghazaouat, Oran, Arzew, Algiers, Chlef, Skikda, Skikda, Annaba, and El Kala) that cover 48 years of annual and monthly precipitation records (ranging from 1954 to 2001). The methodologies used include estimates derived from the Jackknife model and the Bootstrap technique. The application of these simulations allowed for a clear delineation of the chronological data related to precipitation along a temporal axis, thus enabling the differentiation of two distinct periods: the wet phase, which lasts from 1954 to 1986, and the dry phase, which corresponds to the last decade (1990-2000). According to these two analytical approaches, a significant rainfall deficit is primarily observed in the western regions (notably in Oran, Ghazaouat, and Arzew), while the central and western regions recorded a rainfall deficit exceeding 50%, and in the eastern regions, it was noted at 30% during the interval (1987-2001).

Other researchers studied floods and precipitation deficits in the Wadi Mina watershed, using the methodology of principal component analysis (PCA), which facilitates the optimization of annual precipitation datasets and the reconstruction of hydrological sequences over a 30-year research period (ranging from 1970/71 to 1999/00). The results of the analysis of the average rainfall associated with the main component highlight a phase of surplus extending from 1970/71 to 1980/81, followed by a phase of deficit starting from 1981/82.

The study conducted by the authors concerns the northwestern region of Algeria (Mokadmi, 2012). The approach used is the PLUVIA numerical model, which facilitates the creation of a cartographic representation of the spatial distribution of precipitation on a monthly basis. This methodology has allowed for the generation of precipitation distribution maps for the months of January, March, and November, taking into account the topographical characteristics. The merit of this methodology lies in its ability to illustrate the impact of topographical variables on the spatial distribution of precipitation at both regional and local scales. The results indicate that monthly precipitation shows an increasing trend from south to north and from west to east. Coastal areas and adjacent peaks receive the highest precipitation, while inland regions experience a decrease in precipitation due to the dissipation of moisture-laden cloud masses as they move inland.

## CONCLUSION

The assessment of drought using an appropriate drought index is essential for effective water resource management. In this study, the drought scenario was evaluated using two internationally recognized drought indices, namely, the SPI and SPEI, at different time scales. An assessment of the effectiveness of these two indices at different time scales was conducted to determine the most suitable drought index for the Ain Oussera Plain. Based on the results of this analysis, it can be inferred that water scarcity constantly increased throughout the study period due to a reduction in precipitation levels and an increase in PET in the plain.

The use of the two drought indices revealed a substantial increase in dry months, especially during the years 1983, 1989, 1991, 1995, 2003, 2017, and 2021, with normal and moderate drought categories showing significant prevalence.

The study mainly reveals that the SPI and SPEI show a significant correlation at the same time scales used in this research. These findings highlight the consistency in detecting periods of severe drought using the SPI and SPEI indices.

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