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ORIGINAL PAPER

Drought assessment and characterization using SPI, EDI and DEPI indices in northern Algeria

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Abstract

The average annual precipitation values in the Cheliff-Zahrez basin range from 80 to 600 mm/an, indicating a semi-arid climate. This work revolves around a new drought exceedance probability index (DEPI), a standardized precipitation index (SPI) and effective drought index (EDI) in different time scales (3, 6, 9, 12 and 24) derived from monthly precipitation series stretching from September 1970 to August 2015. The latter aims to analyze the performance, similarities and differences between the most used drought indices such as SPI and EDI and to compare their results with those obtained using DEPI. The results indicated that the majority of selected stations tend to a decline in annual rainfall, with a dominant break in series between 1970 and 1980. The Mann–Kendall test result showed that the monthly rainfall trend had significantly decreased in the majority of studied stations. Furthermore, the SPI and EDI series showed persistent monthly drought conditions from January 1970 to March 2010 with an extreme drought peak of -3. However, the DEPI index showed monthly drought events (<0.5) of different classes beginning from March 1980 to December 2010. In the study area, the coefficient of determination explained a high variation ($>80\%$) between SPI and EDI at the time scale of 24 months. At the 9- and 12-month scale, the coefficient of determination showed a variance greater than 50% over the entire basin. On the other hand, the coefficients of determination results between SPI and EDI for the time scale of 3 to 6 months are characterized by a gradient from the northeast to southwest or from 10 to 90%. The stations of the Coastline 2 basin have revealed that the relationship between SPI and DEPI as well as EDI and DEPI is not significant, being allowed between 10 and 30% on time scales of 3, 6, 9, 12 and 24 months. The results of this work and information on the severity and persistence of droughts will be essential to enable managers to adopt an integrated and sustainable management of scarce resources and aim at minimizing agricultural production losses in the region.

Keywords Monthly rain · SPI · EDI · DEPI · Drought mapping · Mann–Kendall test

Extended author information available on the last page of the article

1 Introduction

One of the greatest challenges facing human society today is climate change, which will have an impact on social, ecological and economic systems (Semiromi et al. 2014). The impact of this natural phenomenon, which affects many countries around the world, can be more costly for developing nations (Soro et al. 2014). It affects all zones around the world. Drought is a prolonged dry period in the natural climate cycle that can occur anywhere in the world. It is characterized by low rainfall, which leads to water scarcity. Drought can have serious consequences on health, agriculture, the economy, energy and the environment. Drought poses a threat to livestock and crops in almost every region of the world, which threatens people's livelihoods, increases the risks of illness and death and causes mass migrations. Water scarcity affects 40% of the world's population, and due to drought, 700 million people are at risk of being displaced by 2030 (WHO 2021). Drought caused nearly 680,000 deaths, due to the severe African droughts of 1975, 1983 and 1984 (WMO 2014). The African continent has suffered one of the most severe effects of drought in recent decades, experiencing prolonged water shortages. Over the past decade, droughts have occurred with high frequency and severity in most developed and developing countries (Wilhite 2000; WMO 2006).

Algerian northwest has suffered from severe and more frequent droughts events characterized by rainfall deficits (Medjerab and Henia 2005). This part of the country is particularly concerned by the effects of climate change causing an increase in the frequency and intensity of drought conditions. Precipitation variability increases with the increase in longitude and decreases in latitude (Meddi and Meddi 2007). This region has been characterized by a significant precipitations deficit trend since the 1970s for almost all of the considered stations. The study of drought persistence using Markov chains showed that the highest probability of succession of two dry periods is in the west than at the center (Meddi and Meddi 2009). Ghenim and Megnounif (2013) found that after the 1970 period, the precipitation deficit is estimated at nearly 30% and more than 60% for surface runoff. According to Lazri et al. (2015), the probability of severe and extreme drought conditions is increased considerably in northern Algeria. Northern Algeria has experienced a change in the precipitation regime, which resulted in a downward trend of around 28% from the end of the 1970s, and a reduction in the flows that exceed 46% with a break observed in the early 1970s and 1980 (Elmeddahi et al. 2016). Zerouali et al. (2016) highlighted in the northern central region of Algeria through the SPI and the geographic information system (GIS) irregular rainfall with alternating wet periods (during the decades 1972–1981 and 2002–2010) and dry periods (during the decades 1982–1991 and 1992–2001). Ladji et al. (2019) showed that for the period 1967–2015, moderate or severe drought conditions were occurring in the Algerois region. In particular, in the last three decades (1980, 1990 and 2000) the western part of Algeria was the most sensitive to severe/extreme droughts of short duration and high probabilities of exceeding (Mellak and Souag-Gamane 2020). Since 1970, the Cheliff-Zahrez basin has experienced below-average rainfall, mainly in the central and northern regions. This basin is characterized by high spatial variability of rainfall from 1970 to 2010 from one station to another, where the northern and northeast subbasins are much more sensitive to agricultural drought (Habibi et al. 2021). The drought events that began in the late 1980s were distinguished by moderate and severe conditions during the period 1986–2001 (Zerouali et al. 2021). Amiar et al. (2020) also showed that ruptures are detected between the end of the 1970s and the middle of the 1980s at the majority of analyzed stations over the Upper and Middle Cheliff basin area. The World

Meteorological Organization (WMO) adopted the standardized precipitation index (SPI) in 2009 as the global standard to measure meteorological droughts (Kafle et al. 2023). The SPI index is powerful, flexible to use and less complex to calculate. Rainfall data are actually the only required parameter. In addition, the SPI index is considered effective in analyzing wet periods and cycles, as in analyzing dry periods and cycles (WMO 2012). This index is widely used to characterize drought conditions (Yildirim et al. 2022a). It is based on a probabilistic normalization procedure, which converts a Gamma-type probability distribution function (PDF) into normal (Gaussian) standard series with zero mean and unit standard deviation (Şen and Almazroui 2021). SPI and GIS have allowed scientists to follow the spatiotemporal evolution of drought and to improve decision-making for water resources management, agriculture and other activities that may be affected by the drought phenomenon (Derdous et al. 2021). Achite et al. (2022) showed that the SPI index is able to identify historical drought events from 1982 to 2007. This index showed multi-year drought conditions in the 1990s (extremely dry), and Markov chain analysis indicated that the southern and southwestern parts of the Cheliff-Zahrez basin are the most prone to drought (Habibi et al. 2018). Recently, many researchers around the world have used SPI (Khezazna et al. 2017; Bouabdelli 2020; Achite et al. 2021; Menna et al. 2022; Singh et al. 2022; Abro et al. 2022).

Furthermore, Byun and Wilhite (1999) proposed the effective drought index (EDI) to characterize and monitor drought conditions. This drought index provides more information on the duration and severity of the rainfall deficit, the beginning and the end of the drought period. Several researchers have recently applied the EDI index across the world, for example Swain et al. (2017), Djellouli et al. (2019), Kamruzzaman et al. (2019a), Ekhtiari and Dinpashoh (2019), Malik et al. (2021), Park et al. (2022), Yildirim and Rahman (2022a, b), Shiravand and Bayat (2023). We also note that the performances of (SPI) and (EDI) in predicting droughts have been compared by several authors. For example, Morid et al. (2007) conducted a study on seven different drought indices in Tehran. They concluded that SPI and EDI were effective in detecting the onset of drought and could be recommended for drought monitoring. Dogan et al. (2012) examined six drought indices (PN, rain decile-based drought index (RDDI), ZSI, CZI, SPI and EDI) for drought detection in the semi-arid watersheds of Konya, Turkey, and concluded that the EDI index was better for long-term monitoring. Wambua et al. (2014) found that optimal EDI forecast models were superior to SPI values with correlation coefficient values ranging from 0.82 to 0.51 in predicting a 6-month drought period. Jain et al. (2015) examined six meteorological drought indices in the Ken River basin, India, and showed that EDI is a more suitable drought index. The correlation between EDI values and SPI is better for all time scales, whereas the best was found for the 9 months (Djellouli et al. 2016). Zarei et al. (2017) showed similar behavior using several indices including CZI and SPI, and EDI and Z-scores. They also found that the EDI index is more sensitive than other indices to detect the onset of a drought. Adisa et al. (2021) showed that the EDI and SPI drought indices are replaceable in some districts of South Africa for drought monitoring and forecasting. The EDI and SPI values for 1, 3, 6, 9 and 12 months revealed that the indices were highly correlated for a similar period while the 9-month scale has the highest correlation using EDI (Srinivas et al. 2022). Yildirim and Rahman (2022a, b) confirmed the similarity between extreme drought categories obtained using EDI and SPI in southeastern Australia. Mi et al. (2023) showed that the EDI index could more accurately reproduce the intensity of historical drought events, be more robust in hydrological drought monitoring and be less affected by differences in geographic and climatic conditions. EDI and SPI can be used together to identify the onset of a short-term hydrological drought, which may be suitable for an early

warning system (Yildirim et al. 2022b). Several researchers have confirmed the strong correlation between the SPI index and the EDI (e.g., Mahmoudi et al. 2019; Mondol et al. 2021a, b; Lemma et al. 2022). The different drought indices make it possible to characterize and analyze different types of drought. Typically, short accumulation times are used to estimate meteorological drought (e.g., 1.3 months), and average accumulation times are used for agricultural drought analysis (e.g., 3.6 months) and long accumulation times for hydrological drought (e.g., 6, 12 months).

According to Guerrero-Salazar and Yevjevitch (1975), the theory of runs is based on the choice of a critical threshold, y_c (Fig. 1). Negative sequences in the precipitation time series are related to drought and the difference between y_c and x_t is called a deficit.

The drought exceedance probability index (DEPI) shows a great ability to reflect the actual duration of meteorological drought in all cases, to monitor and control long-term droughts, especially in semi-arid climates (Limones et al. 2022). According to Topçu (2021), research on drought using index (DEPI) in Turkey for the period 2000–2021 showed that the highest correlation between DEPI and SPI-12 was 0.75 while the lowest correlation was between DEPI and SPI-24 with a value of 0.62.

The study of the management and characterization of drought conditions in the largest semi-arid basin in northern Algeria contains 17 dams and numerous irrigated areas. The study of drought is directly linked to the filling of dam reservoirs and the optimal management of water resources for irrigation purposes. This work aims to analyze the performance, similarities and differences between the most commonly used drought indices such as SPI and EDI applied in drought-prone areas and compare them with the results of the newer drought index DEPI. These indices were compared to obtain the most efficient operational index between the SPI, EDI and DEPI forecasts to better represent drought episodes in the study area. The results of this study can provide valuable information for decision-making regarding drought phase management and water resource management in semi-arid and arid regions.

2 Study area description

The study basin is located in the northwest of Algeria (Fig. 2). It covers 56,227 Km^2 (0° 18′–3° 30′ E and 33° 53′–36° 34′ N). The Cheliff upstream Boughzoul, Zahrez, the Upper and Middle Cheliff, the Lower Cheliff, the Mina Plain, and the coastline area 1 are the

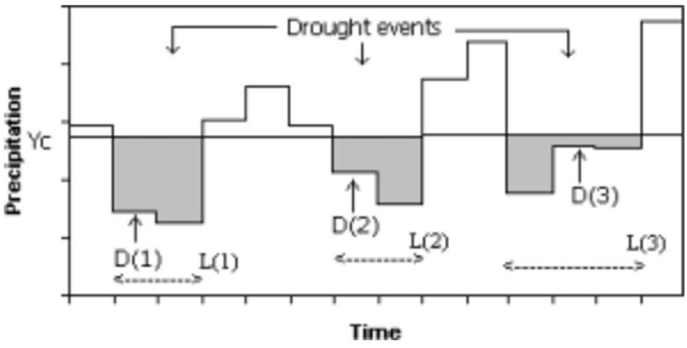


Fig. 1 Characteristics of local drought events with the theory of runs

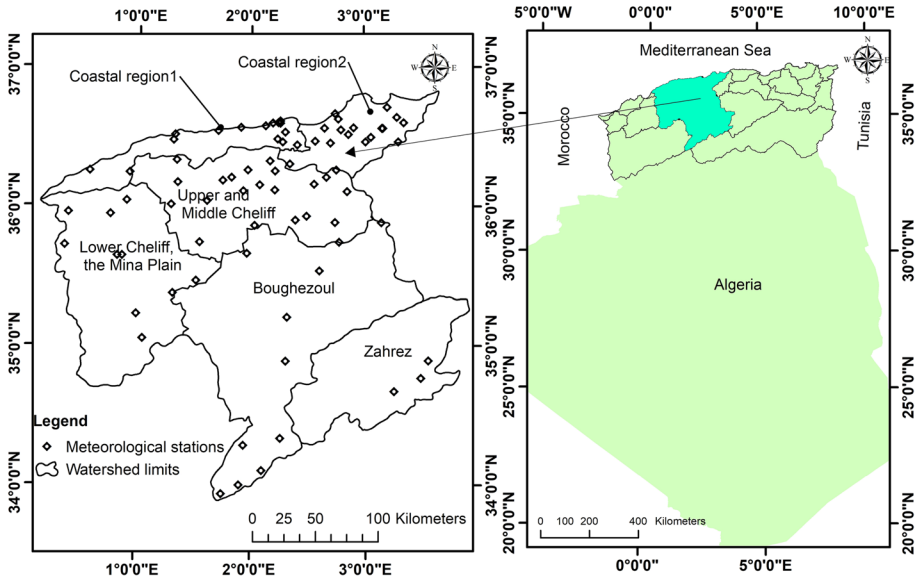


Fig. 2 Location of the Cheliff-Zahrez basin and Algerois basin in Algeria (right) and subregions (left)

five subregions of the Cheliff-Zahrez basin. The coastline area 2 is part of the Algerois basin. This region is limited by the Mediterranean Sea to the north, in the west by the Oran basin, Chott-Chergui and the high desert plains in the south and the area of Isser and Chott-Hodna in the east. The Tellian Atlas in the north and the Saharian Atlas in the south border the Cheliff-Zahrez basin. This basin is characterized by a semi-arid climate with chilly rainy winters and scorching dry summers. Average annual precipitation decreases from north to south and from east to west. An average annual rainfall between 500 and 700 mm characterizes the two coastal basins (region 1 and region 2). In the Upper and Middle Cheliff catchment (Fig. 2), the average annual rainfall is more than 500 mm. In the plains of Upper and Middle Cheliff, precipitation is lower, varying on average between 300 and 500 mm/year. The average rainfall in the Lower Cheliff and Mina basin varied between 400 and 350 mm/year. The southern plain (Boughezoul–Zahrez region) is extremely dry with an average annual rainfall between 260 and 170 mm (Habibi et al. 2018). This region is characterized by a high agricultural potential in the center and north and an agro-pastoral farming system in the south.

3 Data and methods

The study of the climate and its evolution requires a large number of observations. This information is essential to understand the temporal and geographic variability of precipitation and drought evolution. Monthly precipitation data from 77 meteorological stations during the period 1970–2015 were used in this study. The used databases were obtained from electronic data provided by the National Agency for Hydraulic Resources (ANRH).

The analyzed duration of the selected stations was 45 years, starting with the hydrological year 1970–1971. The hydrological year begins on September 1 and ends on August 31. The selected data are relatively evenly distributed (Fig. 2). There are more stations in the

wetter north than in the drier south. Before using these data, we first removed aberrant monthly measurements including abnormally high values due, in general, to an entry error in the database. The majority of selected weather stations have complete, uninterrupted recording. We filled the monthly gaps of five stations using the technique developed by Laborde (1998) to obtain an acceptable spatial distribution.

3.1 Mann–Kendall trend test

The Mann–Kendall (S) trend test statistic 'S' as specified by Mann (1945) and Kendall (1975) is defined as follows (Khan et al. 2017).

$$S = \sum_{i=1}^{n-1} Q_{ij} \sum_{j=i+1}^{n} \text{Signe}\left(x_i - x_j\right) \tag{1}$$

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

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

If the size of the sample is > 10, the variance is: $\mu(s) = 0$

$$\sigma^2(s) = n(n-1)(2n+5) - \frac{\sum_{j=1}^{m} t_i\left(t_i - 1\right)\left(2t_i + 5\right)}{18} \tag{3}$$

where t_i is the number of ties of extent i and m is the number of tied groups.

$\boldsymbol{Z_S}$ is computed as:

$$Z_s = \begin{cases} \frac{S-1}{\sigma^2(s)} & \text{if} \quad S > 0 \\ 0 & \text{if} \quad S = 0 \\ \frac{S+1}{\sigma^2(s)} & \text{if} \quad S < 0 \end{cases} \tag{4}$$

where $\sigma^2(s) =$ the variance of the dataset and $n =$ the number of data points.

Positive values explain an increasing trend and negative values explain decreasing trends at the 5% level of significance. The null hypothesis is rejected if $|Z| > 1.96$ (Sneyers 1990).

3.2 Standardized precipitation index (SPI)

The SPI index (McKee et al. 1993, 1995) is a powerful, flexible and simple index to calculate. It indicates that a drought event occurs when its value is less than or equal to -1.0 and the event ends when its value becomes positive (WMO 2012). SPI is a widely used indicator to describe meteorological drought on various time scales (Climate Data Guide 2018). Recently, researchers have used the standardized precipitation index (SPI) to characterize drought (e.g., Wang et al. 2022; Parida et al. 2022; Achite et al. 2023). It is expressed mathematically as follows (McKee et al. 1993, 1995):

$$g(x) = \frac{1}{\beta^{\alpha}\tau(\alpha)} X^{\alpha-1} e^{\frac{-x}{\beta}} \quad \text{for} \quad x > 0 \tag{5}$$

where $\alpha > 0$ is the shape parameter, $\beta > 0$ is a scale parameter and $x > 0$ is the amount of precipitation and defines the log normal distribution. Maximum likelihood solutions are used to optimally estimate the distribution parameters of gamma, α and β for each station and for each time scale:

$$\Gamma_{(\alpha)} = \int_0^{\infty} y^{\alpha-1} e^{-y} \mathrm{d}y \tag{6}$$

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right), \beta = \frac{\bar{x}}{\alpha}; \quad \text{Where} \quad A = \ln\left(\bar{x}\right) - \frac{\sum \ln(x)}{n} \tag{7}$$

And, n = number of precipitation observations. This allows the distribution of precipitation at stations to be effectively represented by a mathematical cumulative probability function given by:

$$G(x) = \int_0^x g(x)\mathrm{d}x = \frac{1}{\beta^{\alpha}\tau(\alpha)} \int_0^x x^{\alpha-1} e^{-x/\beta} \mathrm{d}x \tag{8}$$

As the gamma function is not defined for $x = 0$ and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(x) = q + (1 - q)G(x) \tag{9}$$

Here, q is the probability of a zero. The cumulative probability $H(x)$ is then transformed to the standard normal distribution to give the SPI.

$$\mathrm{SPI} = \frac{X_i - X_m}{\sigma} \tag{10}$$

where X_i is the cumulative rainfall for the month i and X_m and σ, are, respectively, the mean and the standard deviation of the monthly rainfall observed for a given series. A drought classification is performed according to the SPI values (Table 1) (McKee et al. 1993, 1995).

Table 1 SPI drought classifications according to SPI values (Mckee et al. 1993, 1995)

SPI class	Degree of drought	Probability
SPI > 2.00	Extreme humidity	2.30
1.50 < SPI < 1.99	High humidity	4.40
1.00 < SPI < 1.49	Moderate humidity	9.20
−0.99 < SPI < 0.99	Normal year	68.20
−1.49 < SPI < −1.00	Moderate drought	9.20
−1.99 < SPI < −1.5	Severe drought	4.40
SPI < −2.00	Extreme drought	2.30

3.3 Effective drought index (EDI)

Byun and Wilhite (1999) proposed the effective drought index (EDI) to monitor drought situations. The EDI provides more information on the duration and severity of the rainfall deficit, the beginning and the end of the drought period.

The original form of the EDI is calculated with a daily time step from daily rainfall data. It was then adapted to a monthly scale, defining a moving time scale of 12 correlative months and compared to other drought indices (Smakhtin and Hughes (2007); Dogan et al. 2012; Jain et al. 2015). The original EDI algorithm was modified and extended to be tested using monthly data and to improve its performance by Kim et al. (2009), Smakhtin and Hughes (2007).

EDI is a good tool for operational monitoring of meteorological and agricultural drought conditions at daily and monthly time scales (Morid et al. 2007; Jain et al. 2015; WMO 2016; Wable et al. 2019; Mondol et al. 2021a; Anshuka et al. 2021; Chen et al. 2022; Pinto et al. 2022). According to Smakhtin and Hughes (2007), deciles, EDI or SPI can show at different time scales areas that are simultaneously drier or wetter. We find researchers who have used a recent index at different scales (Wambua et al. 2014; Djellouli et al. 2016; Khan et al. 2018; Quesada-Montano et al. 2018; Mishra et al. 2019a, b; Herdita et al. 2020, 2023; Mi et al. 2023).

The effective precipitation (EP) which represents the daily depletion of water resources forming the basis of the EDI concept. Thus, the first step in calculating EDI is to calculate EP. If Pi corresponds to the precipitation "$m-1$" month before the current month and N to the duration of the previous period, the effective precipitation for the current month (EPI) is then given:

$$\mathrm{EP}_j = \sum_{N=1}^{D} \left(\left(\sum_{m=1}^{N} \mathrm{P}_m \right) \Big/ N \right) \tag{11}$$

For example, if $N=3$, then $\mathrm{EP}=\mathrm{P1}+(\mathrm{P1}+\mathrm{P2})/2+(\mathrm{P1}+\mathrm{P2}+\mathrm{P3})/3$, where P1, P2 and P3 are precipitation values during the current month, previous month and 2 months before, respectively. The mean and standard deviations of the EP values for each month are then calculated, and the time series of EP values is converted to deviations from the mean (DEP).

$$\mathrm{DEP}_j = \mathrm{EP}_j - \overline{\mathrm{EP}}_J \tag{12}$$

PRN values are then calculated as:

$$\mathrm{PRN}_j = \mathrm{DEP}_j \Big/ \sum_{i=1}^{N} 1/i \tag{13}$$

The summation term is the sum of the reciprocals of all the months in the duration (i.e., for 3 months: $1/1+1/2+1/3$).

Finally the EDI is calculated as:

$$\mathrm{EDI}_j = \mathrm{PRN}_j \Big/ \sigma \mathrm{PRN}_j \tag{14}$$

where EP is the effective rainfall, $\overline{\mathrm{EP}}$ is the average effective precipitation, DEP is the difference between EP and MEP, EDI is the effective drought index, P is the precipitation (mm), St is the standard deviation and 'j' is the particular month.

In this study, EDI is calculated for a time scale of 3 months using precipitation data from November as the current month and September and October as the previous months. On the same principle, EDI values for 6, 9, 12 and 24 months are derived (September is considered the beginning month of the hydrological year in Algeria).

Drought classification according to EDI values indicates severe drought when the index continuously presents a negative value from -1.99 to -1.0. An extreme drought with value of -2.0 and moderate drought at EDI greater than -1.49 and equal less than -1 or less while the near normal class is pronounced when the index becomes positive or greater than -0.99.

3.4 Drought exceedance probability index (DEPI) calculation

The calculation of the DEPI index is carried out according to the following steps: 1- the rainfall anomaly for each month of the time series is calculated using the expression:

$$\mathrm{AP}_i = \mathrm{P}_i - \mathrm{PMED}_i \tag{15}$$

where P_i is the precipitation of the month i and PMED_i is the median precipitation of the month i for the whole study period (Fig. 3) which is an example of calculating these monthly anomalies.

The cumulative precipitation anomaly is identified from the first month of the series (Fig. 3). Secondly, we add each monthly rainfall anomaly to the accumulation of the previous months. Because there is a cumulative surplus in the months, we find a monthly anomaly in the month where the cumulative anomalies are positive and then the accumulation is restarted in that particular month. During this month, the value of the cumulative deviations is exactly the negative monthly deviation for that month (Fig. 3). Thus, the

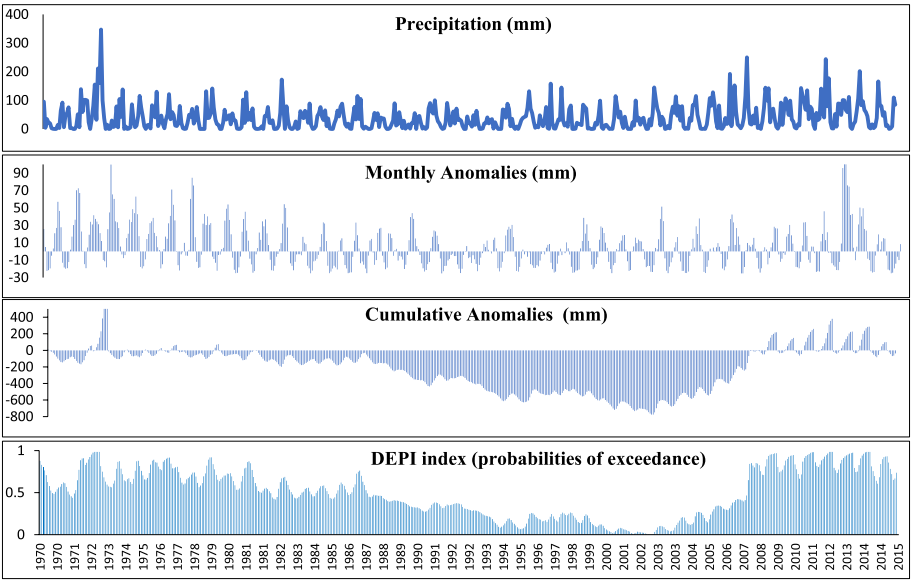


Fig. 3 Implementation of the drought exceedance probability index (DEPI) in the precipitation series of Chlef Anrh station, 1970–2015

calculation of this indicator confirms the fact that there is a deficit of precipitation. Once the cumulative anomalies become positive again, the test ends. In this wet run, the anomalies carried on adding until a new negative precipitation anomaly is found. As expected, at that point, a new dry sequence begins, which is estimated using the same method.

The methodology consists of the continuous addition of surpluses that allows for precise anomaly prioritization and stops in the condition of negative anomaly. The evaluation of this step matches with the following expression:

$$\mathrm{APAc}_1 = \mathrm{AP}_{1,} \tag{16}$$

$$\mathrm{APAc}_1 = \sum_{j=r}^{i} \mathrm{AP}_1 i > 1 \tag{17}$$

where APAc_1 is the precipitation cumulative anomaly of month i and r is the the value marking the start of the dry run and follows the expression:

r is the max $\{k{:}1 \le k \le i,\ \mathrm{APk} < 0,\ \mathrm{APAck} - 1 \ge 0\}$, k is the parameter from 1 to i to determine in which month the drought started. It is critical to mention that if $\mathrm{AP1} < 0$ and $\mathrm{APAck} - 1 \ge 0$, then $r = i$ and, as a result $\mathrm{APAc1} = \mathrm{AP1}$, specifying the beginning of a new dry series.

Finally, in the third step, it is required to sort the cumulative rainfall anomalies identified in the previous stage from the lowest to the highest, i.e., from the months with the largest negative cumulative anomalies, or deficits, to the months with the largest positive ones, or surpluses in order to obtain the empirical probabilities of exceedance matching with each month of the series. Once sorted, the method of Weibull (1939) is used to calculate the probability of exceeding the detected event each month:

$$\mathrm{Pexced}_{\mathrm{APAc1}} = \mathrm{DEPI}_i = \mathrm{M}_{\mathrm{APAc}i}/(\mathrm{n}+1) \tag{18}$$

where $\mathrm{Pexced}_{\mathrm{APAc1}}$ is the empirical probability of exceedance of the month i, namely the DEPI of the month i; $\mathrm{M}_{\mathrm{APAc}i}$ is the position of the precipitation cumulative anomaly of the month in the sorted series, from lowest to highest cumulative anomaly or largest observed deficit, n is the the total number of months in the series. Thus, the DEPI for a given month is exactly the probability of exceedance ascribed to its cumulative rainfall anomaly, determined as described above. The probability values not only contain an estimate of the hazard but also with DEPI values below 0.5 indicate significant accumulation of anomalies (not likely be exceeded).

As a result, as they approach zero, droughts become more severe. It restarts with the measurement of cumulative anomalies whenever a new dry month ($\mathrm{AP1} < 0$) arises within a surplus period $\mathrm{APAc}i \ge 0$. This ensures the proper identification of dry runs of different lengths from a single calculation of the index. According to Limones et al (2022), drought classifications using DEPI values is shown in Table 2.

4 Results and discussion

Searching for break points in the monthly precipitation series from 1970 to 2015 using the Mann–Kendall test application showed a break at the 5% threshold at a majority of stations. Monthly rainfall in the study basin decreases significantly (Kendall's test at -2.20, Fig. 4). We also note that stations closest to the sea have a significantly positive trend relating to

Table 2 Drought classifications according to DEPI values (Limones et al. 2022)

DEPI values (probabilities of exceedance)	Drought severity level	% months of a series within the interval	Return period (years)
DEPI ≥ 0.5	Wet conditions	50	2
0.5 > DEPI ≥ 0.16	Mild drought	34	6
0.16 > DEPI ≥ 0.07	Moderate drought	9	15
0.07 > DEPI ≥ 0.02	Severe drought	5	20
DEPI < 0.02	Extreme drought	2	50

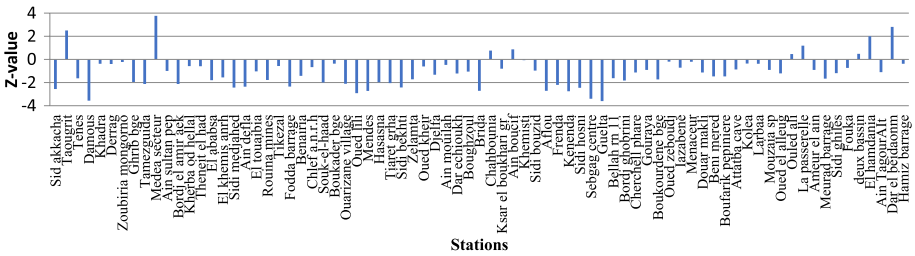


Fig. 4 Monthly rainfall trends in the Cheliff-Zahrez basin and in the Algerois basin

wet conditions. On the other hand, the trends are significantly negative and correspond to an important drought for the stations furthest from the sea. This result is in concordance with the study of Zekouda and Meddi (2015) confirming these breaks in the early 1980s. Elmeddahi et al. (2016), on the other hand, found that the rainfall in the Middle Cheliff basin is highly irregular on an interannual distribution. Since 1980, average annual precipitation has decreased. Therefore, the years 1979, 1978 and 1980 have been identified with the most important breaks in the Cheliff Basin. Hallouz et al. (2019) confirmed using the Mann–Kendall test, a decreasing trend in total annual precipitation and an increase in average temperatures over the period 1979–2013.

4.1 SPI, EDI and DEPI in the study basin

The calculation results of the considered indices derived from 77 rainfall stations over the study basin allowed us to note that this region has experienced a negative trend with the existence of different periods of drought. However, drought monitoring is crucial in a semi-arid climate. To explain the variance of SPI, IDE and DEPI indices, 3 and 12 months of time scale we selected in this part. SPI and EDI indices analysis shows that a severe drought occurs when the index continuously presents a negative value from −1.99 to −1.0. An extreme drought when the index value is equal or less than −2.0 while the near normal class is pronounced when the index becomes positive or greater than −0.99. EDI-3 index evolution from 1970 to 2015 showed severe to moderate drought conditions in most selected stations. It has experienced alternating wet and dry spells with more dominant long dry periods in October, November and December and for the months of March, April and May. It is also noted that the index for this period can reach values < −3), which

explains the existence of extremely dry years. For example, Fouka Marine station (Algerois Basin, Fig. 5) indicated a wet period in the years 1971 to 1972, a moderate dry period between 1986 and 1990 and 1996 to 1998. The situation was normal to wet from 2000 to 2015. It is noted that during this period, there were a few months where index values exceeded −2. The SPI-3 index (Fig. 5) analysis indicates severe drought conditions (SPI-3 < −2) at almost all stations over the study area (e.g., September 1970 to October 1970, November 1973 to January 1974 and January 2003 to October 2003). It is also found during the study period that extreme drought events were recorded (SPI < −2) for the years 1973, 1977, 1988, 1995, 2003 and 2011 for different months. For example, Fouka Marine station (Basin of Algerois, Fig. 5) recorded severe drought for consecutive months, from October 1995 to October 1997, and for the years 1989 to 1990. The study period was marked by alternating normal and wet periods with a long period of moderate drought (1.00 < SPI < 1.49) from 1985 to 1988. Figure 5 shows, using a threshold lower than 5% of the DEPI-3 index, the characterization of severe drought from 2000 to 2008. On the other hand, when a threshold is higher than 5%, the DEPI index -3 showed a wet period from 1970 to 1988. This wet period is similar for the majority of stations at different time scales.

The 12-month time scale figures analysis showed that the study basin is marked by an increase in drought events over the past few decades. The analysis of Fig. 6 showed several dry and wet sequences over the period 1970–2015 for the Chlef ANRH station. SPI-12 and EDI-12 analysis (Fig. 6) allows the detection of similar drought periods, but with different amplitudes. For example, SPI-12 index values showed an extreme drought situation < 2) for consecutive months, beginning in 1989 and ending in 1990 and 1993 to 1994. On the opposite, the EDI-12 index indicated moderate drought conditions in the same years previously mentioned. It is observed at the same station an alternation of drought classes for SPI-12 and EDI-12. For the DEPI-12 index (Fig. 6), the wettest months were from 1970 to 1990 (> 0.5), while the driest months were recorded from 2001 to 2009. In addition, a monthly moderate drought was recorded from 1995 to 2001 and from 2009 to 2015.

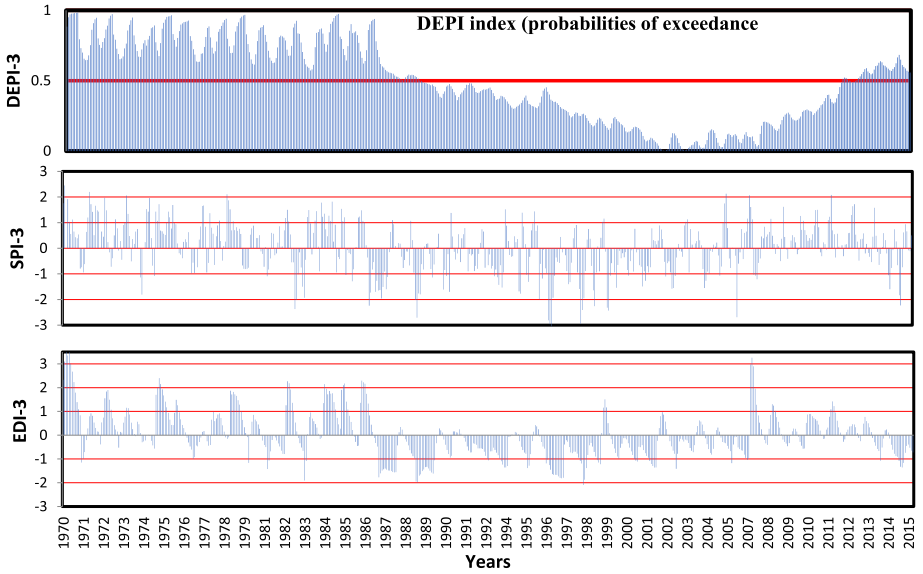


Fig. 5 SPI-3, EDI-3 and DEPI-3 variation for the Fouka Marine rainfall station (basin coastal basin 2)

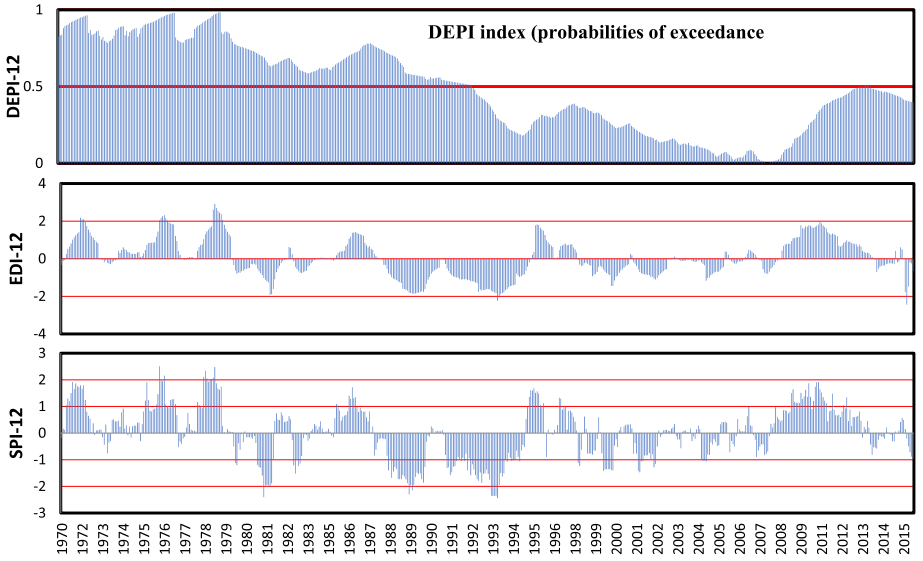


Fig. 6 SPI-12, EDI-12 and DEPI-12 variation for the rainfall station of Fouka Marine (basin coastal basin 2)

4.2 Frequency comparisons of three indices

This part examines drought frequencies from 1970 to 2015 for different time scales using three indices. Drought frequency is defined as the number of occurrences of dry or wet events. We adopted a frequency approach in order to follow the historical evolution of this risk by comparing the frequencies of the selected indices. The chosen indices in this study (SPI, EDI and DEPI) are based exclusively on rainfall data. For extreme drought situations defined by these indices at the 3-month scale (Table 3), it is shown that the frequencies vary from 0 to 4% in the study basin, which explains the number of extreme drought events that appeared between 0 and 20. However, there is an increase in the frequency of severe drought conditions due to an increase in dry events between 1.00 and -1.49, whereas the frequency is between 0 and 6% (0 to 30 events). Furthermore, moderate drought is marked by higher frequencies than severe drought events, which vary between 6 and 13% (28 to 70 events). According to these results, SPI index at different aggregation time scales gives higher frequencies of drought than the other indices in the majority of the stations.

The results of mild drought frequencies indicate that the maximum number of 3-month dry sequences was recorded by using both the SPI-3 and EDI-3 indices from 66 to 77% (365 to 425 events). However, the obtained frequencies using DEPI-3 index present a minimum number of 33% to 36% (175 to 190 events) in all study stations. EDI-3 index (Fig. 7) presents a high number of mild drought events (>60) compared to the SPI-3 and DEPI indices in the majority of considered stations.

The six basins of the study area (Table 4) are characterized by a low frequency of extreme drought events (SPI-12 and EDI-12 < -2 and DEPI-12 < 0.02) varying between 0 and 4%. Therefore, severe droughts frequencies using these indices at 12-month are between 0 and 6%. However, a high number of events in the study area (4% to 15%) mark the moderate drought class.

Table 3 Drought frequency of SPI, EDI and DEPI (3 months)

Basin	Coastal 2 basin						Coastal 1 basin					
Stations	Fouka Marine			Dar El Beida ONM			Tenes			Benairaia		
Index	SPI	EDI	DEPI	SPI	EDI	DEPI	SPI	EDI	DEPI	SPI	EDI	DEPI
Extreme drought	3%	0%	2%	2%	0%	2%	3%	1%	2%	2%	2%	2%
Severe drought	5%	4%	5%	4%	0%	5%	4%	4%	5%	5%	4%	5%
Moderate drought	6%	9%	9%	10%	8%	9%	9%	8%	9%	8%	9%	9%
Mild drought	71%	74%	35%	69%	78%	35%	68%	75%	34%	68%	77%	33%

Basin	Boughzoul basin						Upper and Middle Chelif basin					
Stations	Bougzoul			Brida			Chief ANRH			Khemis		
Index	SPI	EDI	DEPI	SPI	EDI	DEPI	SPI	EDI	DEPI	SPI	EDI	DEPI
Extreme drought	2%	0%	2%	1%	0%	1%	2%	1%	2%	2%	1%	2%
Severe drought	5%	2%	5%	4%	1%	4%	4%	3%	5%	5%	4%	5%
Moderate drought	7%	10%	8%	9%	11%	9%	7%	12%	9%	8%	9%	9%
Mild drought	69%	74%	35%	66%	75%	35%	68%	69%	35%	68%	71%	34%

Basin	Lower Cheliff and the Mina basin						Zahrez basin					
Stations	Ouarizane village			Tiaret GRAH			Ain Mouilah			Djelfa		
Index	SPI	EDI	DEPI	SPI	EDI	DEPI	SPI	EDI	DEPI	SPI	EDI	DEPI
Extreme drought	2%	0%	2%	1%	3%	0%	3%	0%	2%	4%	1%	2%
Severe drought	3%	4%	5%	2%	4%	5%	5%	4%	5%	4%	4%	5%

Table 3 (continued)

Basin	Lower Cheliff and the Mina basin						Zahrez basin					
Stations	Ouarizane village			Tiaret GRAH			Ain Mouilah			Djelfa		
Index	SPI	EDI	DEPI	SPI	EDI	DEPI	SPI	EDI	DEPI	SPI	EDI	DEPI
Moderate drought	10%	9%	9%	12%	7%	9%	8%	6%	9%	8%	11%	9%
Mild drought	70%	70%	33%	70%	69%	35%	68%	78%	34%	66%	68%	33%

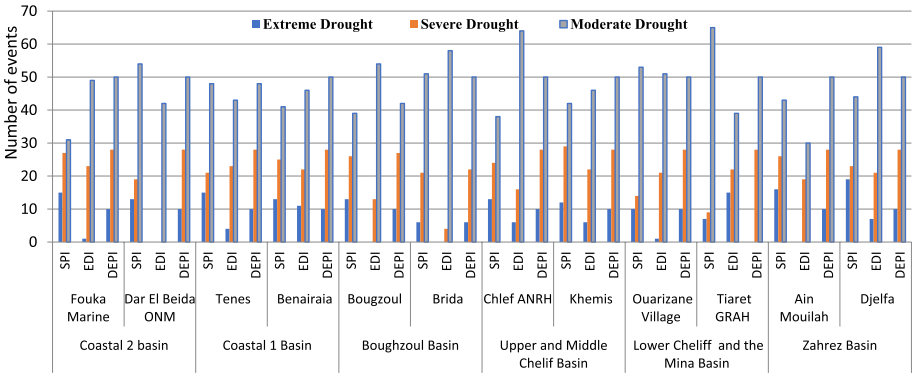


Fig. 7 SPI-3, EDI-3 and DEPI-3 events assessment

For the mild droughts class, DEPI-12 index presents a low frequency of 33% to 35% compared to the SPI-12 and EDI-12 results for all stations. Furthermore, a mild drought (Fig. 8) is explained by a number of events greater than 70 calculated using EDI in some stations of the study area.

Meteorological drought analysis showed a distinct frequency over different rainfall accumulation periods. In addition, dry and wet period frequencies change according to the chosen time scales and the number of events. It is noted that the frequency of the SPI for the different categories decreases when the time scale increases. According to Vicente-Serrano and Lopez-Moreno (2005), for a longer time scale, droughts are less frequent and last for a long time. The period from 1970 to 2015 analysis showed that the study region is the most vulnerable to drought.

In light of these results, we retain that the Cheliff-Zahrez basin and Algerois basin were affected by several dry sequences over the period from 1975 to 1990. Thus, the results obtained after the calculations of the meteorological indices (SPI EDI and DEPI) can allow making a strategy for effective drought management over the study basin.

4.3 Correlation coefficient map of DEPI and SPI

Interpolation is a mathematical operation consists of using known values to determine the value of other points at unknown (unsampled) sites. To explain the variance between these drought indices for periods of 3, 9, 6, 12 and 24 months, the results of the coefficients of determination were mapped and visualized using the ArcGIS package. The relationship between these three indices at different scales times was performed in a correlation matrix. Inverse distance weighted (IDW) as the most widely used method was selected to interpolate the values of the coefficients of determinations of three indices.

The coefficient of determination (R^2) is defined as the proportion of explained variance in the total variance. If we multiply these two variances by the number n, we can also write [(1–residual sum of squares)/total sum of squares]. The coefficient of determination is between 0 and 1. To describe and analyze the variation of the coefficients of determination at different time scales (3, 6, 9, 12 and 24 months) in the 06 regions, we use a cartography representing R^2 values.

Figures 9, 10, 11, 12 and 13 present the spatial distribution of R^2 values at different scales (3, 6, 9, 12 and 24 months). This type of representation permits better viewing the

Table 4 Drought frequency of SPI, EDI and DEPI (12 months)

Basin	Coastal 2 basin						Coastal 1 basin					
Stations	Fouka Marine			Dar El Beida ONM			Tenes			Benairaia		
Index	SPI	EDI	DEPI	SPI	EDI	DEPI	SPI	EDI	DEPI	SPI	EDI	DEPI
Extreme drought	4%	1%	2%	0%	0%	2%	2%	1%	2%	2%	2%	2%
Severe drought	4%	3%	5%	5%	0%	5%	4%	5%	5%	5%	6%	5%
Moderate drought	6%	13%	9%	13%	14%	9%	10%	8%	9%	3%	4%	9%
Mild drought	69%	64%	34%	65%	72%	35%	65%	68%	34%	88%	86%	35%

Basin	Boughzoul basin						Upper and Middle Chelif basin					
Stations	Bougzoul			Brida			Chlef ANRH			Khemis		
Index	SPI	EDI	DEPI	SPI	EDI	DEPI	SPI	EDI	DEPI	SPI	EDI	DEPI
Extreme drought	2%	1%	2%	2%	0%	0%	2°%	0%	2%	3%	2%	2%
Severe drought	3%	3%	5%	5%	0%	3%	6%	7%	5%	6%	6%	5%
Moderate drought	8%	13%	9%	9%	14%	11%	9%	7%	9%	7%	7%	9%
Mild drought	68%	67%	35%	35%	67%	66%	64%	65%	34%	68%	68%	34%

Basin	Lower Cheliff and the Mina basin						Zahrez basin					
Stations	Ouarizane village			Tiaret GRAH			Ain Mouilah			Djelfa		
Index	SPI	EDI	DEPI	SPI	EDI	DEPI	SPI	EDI	DEPI	SPI	EDI	DEPI
Extreme drought	2%	0%	2%	1%	0%	2%	1%	2%	2%	1%	0%	2%
Severe drought	4%	3%	5%	6%	7%	5%	2%	6%	5%	7%	3%	5%

Table 4 (continued)

Basin	Lower Cheliff and the Mina basin						Zahrez basin					
Stations	Ouarizane village			Tiaret GRAH			Ain Mouilah			Djelfa		
Index	SPI	EDI	DEPI	SPI	EDI	DEPI	SPI	EDI	DEPI	SPI	EDI	DEPI
Moderate drought	9%	14%	9%	7%	8%	9%	11%	6%	9%	10%	13%	9%
Mild drought	66%	66%	34%	70%	71%	34%	70%	18%	34%	60%	62%	34%

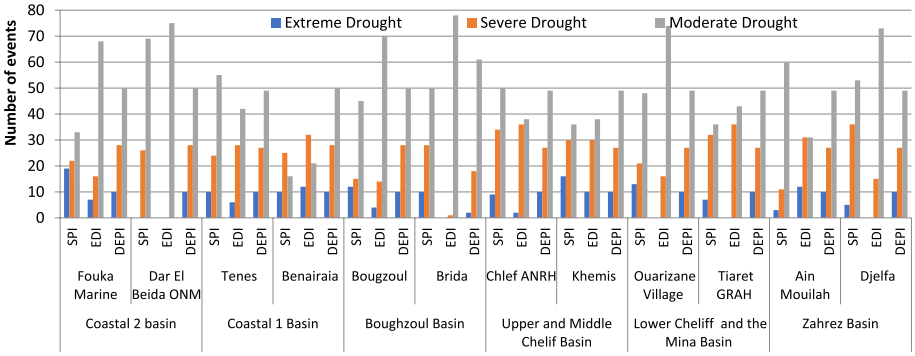


Fig. 8 SPI-12, EDI-12 and DEPI-12 events assessment

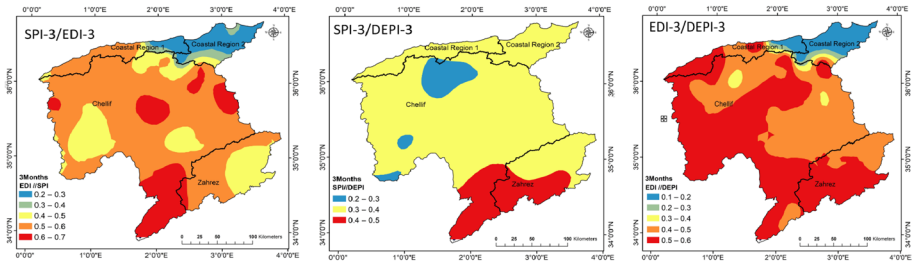


Fig. 9 Map of coefficients of determination between SPI-3, EDI-3 and DEPI-3

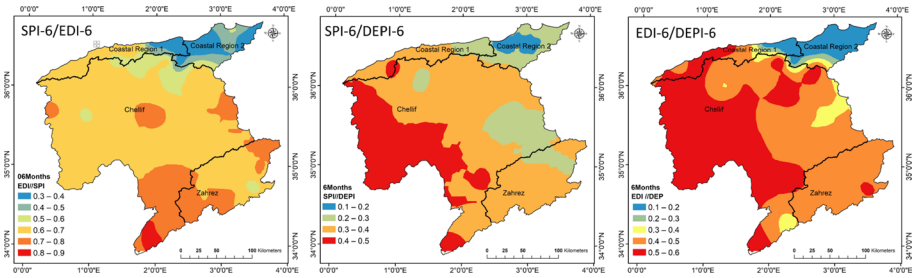


Fig. 10 Map of coefficients of determination between SPI-6, EDI-6 and DEPI-6

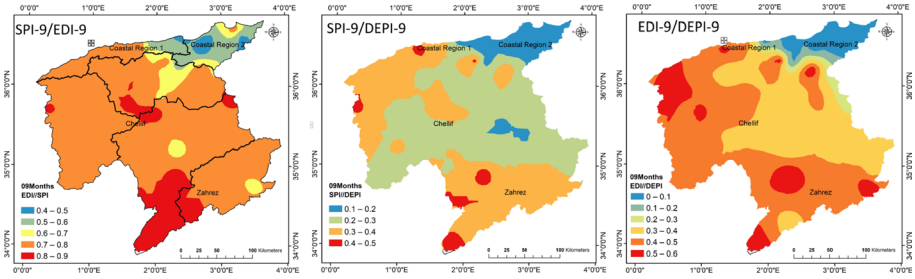


Fig. 11 Map of coefficients of determination between SPI-9, EDI-9 and DEPI-9

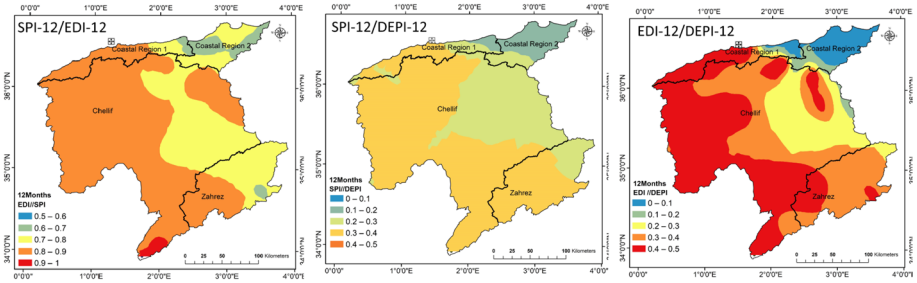


Fig. 12 Map of coefficients of determination between SPI-12, EDI-12 and DEPI-12

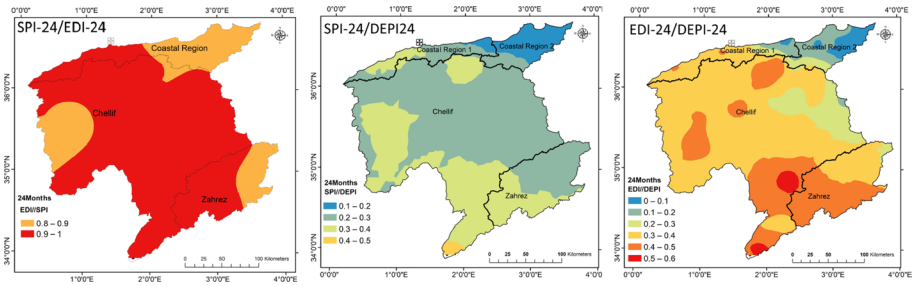


Fig. 13 Map of coefficients of determination between SPI-24, EDI-24 and DEPI-24

spatial distribution of R^2 classes. Figure 9 analysis (map on the left), which corresponds to the R^2 between SPI-3 and EDI-3, indicates an increasing variance of 20% to 70% from northwest to southwest. Coastal basin 2 presents a low variance of 20% to 40%, which means that the prediction of dry and wet events is not coherent over the same period for both indices. However, the stations located in the Cheliff-Zahrez basin are characterized by a variation of 40% to 70% in the center and the extreme (e.g., Chlef-Anrh station (55% south) and Brida station (70%). The R^2 between SPI and DEPI (map in the center) at 3-month aggregation time showed that the southernmost Boughzoul basin has a high variance (40% to 50%) compared to the other basins that have a variance of less than 40%. We also note that EDI-3 index sequences are unrelated to DEPI-3 sequences in coastal basin 2 (variance < 40%, Fig. 9, map at right). Cheliff-Zahrez basin recorded R^2 values varying between 40 and 60%.

The spatial variance of the R^2 between the selected drought indices at 6-month scale reveals that there is a significant relationship between the SPI-6 and the EDI-6 where R^2 values range between 30 and 84% (Fig. 10, map on the left). More than 50% of EDI-6 index variance can be explained using the SPI index and vice versa over four basins (Coastal 1, Middle and Upper, Lower and the Mina and Zahrez).

This strong correlation indicates a concordance between SPI-6 and EDI-6 in the forecast periods for the drought classes, but with different frequency amplitudes, as shown in Tables 3 and 4. For example, Ain Defla station (Upper and Middle Cheliff basin) was characterized by a period of moderate drought conditions from 1987 to 1990 with different amplitudes using SPI-6 (−1.5) and EDI-6 (−1.30).

The R^2 results between SPI-6 and DEPI-6 (map on the right) show that there is a slight variation between 14 and 51%. The map in the center also explains a very low

variance (15% to 30%) between SPI-6 and DEPI-6 in the Algerois basin; this means that there is a low correlation between different drought classes of these two indices.

While the R^2 values over the five basins (Coastal 1, Middle and Upper, Lower and Mina and Zahrez) showed a variation ranging from 30 to 51%, R^2 of the SPI-6 and DEPI-6 indices explains between them a very low variance ($R^2 < 16\%$) in the basin of Algerois (Coastal 2). On the other hand, the Cheliff-Zahrez basin was characterized by R^2 values greater than 40% with a maximum value of 68% at the station of Sidi Mjahed (Middle and Upper basin).

The analysis of R^2 (Fig. 11) between the SPI-9 and EDI9 derived from the observed data indicates a significant result ranging between 60 and 88% in the Cheliff-Zahrez basin. In other words, there is a significant relationship between the wet and dry sequences using these two indices. The stations of the Algerois basin (Coastal 2) explained a variance between 40 and 50%.

The highest R^2 values are found in the southern extremes of the basin (for example, the station of Sebgag center ($R^2 = 88\%$). However, the stations of the Algerois basin (Coastal 2) are also marked by R^2 values lower than 15% between SPI-9/DEPI-9. These results are similar to R^2 values between EDI-9 and DEPI-9 ($< 15\%$). The stations in the Cheliff-Zahrez basin revealed R^2 values ranging from 13 to 63% from northeast to southwest between SPI-9 and DEPI-9 as well as EDI-9 and DEPI-9.

For 12 months of time scale, the results showed that R^2 between SPI and EDI (Fig. 12, map on the left) change between 50 and 90%, whereas the basin of Algerois presents the lowest variance compared to the other basins. The variation of the gradient from northeast to southwest (50% to 90%) is also observed in the study basin, while R^2 values between SPI-12 and DEPI-12 (Fig. 12, map in the middle) differ from west to east by 10% to 50%. This variance demonstrates that the events of the dry and wet sequences between SPI-12 and DEPI-12 do not always coincide along the time series from 1970 to 2015 while R^2 values of the Algerois basin (Coastal 2, map on the right) are always the lowest in the study basin ($< 20\%$). Figure 12 presents a variation of R^2values ranging from 30 to 50% (EDI-12/DEPI-12) in Cheliff-Zahrez basin and values ranging from 10 to 30% distributed at Algerois basin (Coastal 2).

The spatial variance of R^2 values on a 24-month scale (Fig. 13) showed that there was a high correlation between EDI-24 and SPI-24 ($> 80\%$). This variance means that the prediction of the drought sequence by these two indices is identical throughout the time series from 1970 to 2015. On the other hand, the variability represented by SPI-24 and DEPI-24 (map in the middle) in the study basin is explained by the gradient from northeast to southwest (10% to 50%). The maximum values of R^2 were also recorded in the southern extremes of the basin, for example the Brida station with 48%, whereas the R^2 between EDI-24 and DEPI-24 (map on the right) showed a gradient which goes from the North to the South (Fig. 13). It explains a low variance in the Algerois basin between EDI-24 and DEPI-24 (less than 20%), while the Cheliff-Zahrez basin is characterized by a variance greater than 50% for some southern stations, the same as Ain Mouilah (50%) and Sebgag Center (62%).

The results of SPI and EDI indices showed that for time scales of 6 and 9 months, there was a strong variance of 50% to 88% from North to South in the Chleliff-Zahrez basin. The longest time scales (12 and 24 months) have significant results with variance of 60% to 97% observed in all the stations of the study region. The obtained results showed that the 3-month time scale had a variance between 40 and 70% in the Cheliff-Zahrez region. On the other hand, the Algerois basin has a nonsignificant variance of 20% to 30%. The R^2 values between SPI-3 and DEPI-3 as well as EDI-3 and DEPI-3 in

the Algerois basin (Coastal 2) indicated a very low correlation with a variance of less than 40%.

The analysis of the SPI, EDI and DEPI indices at different accumulation periods showed that the study basin experienced an increase in droughts during the period 1975–2000. However, SPI index showed extreme drought events (<2) for consecutive months, between 1989 and 1990 and for the period 1993–1994. In contrast, EDI values variation from 1970 to 2015 indicates severe drought conditions at most of the selected stations. Wet and moderate drought sequences alternated with increasingly dominant long periods (severe drought) for the months of October, November, December and for the months of March, April and May. We also note that the EDI values for this period can reach (< -3), which explains the existence of extremely dry years.

These results are similar to many works concerning the north of Algeria; for example, Djellouli et al. (2016), demonstrate using the EDI index that the Wadi Louza basin (NW-Algeria) experienced severe and extreme drought events. Among these studies are also those of (Taibi et al. 2017; Habibi et al. 2018) that showed a decrease in rainfall pattern in northwestern Algeria. Ladji et al. (2019) confirmed using SPI index that moderate or severe droughts in the region of Algerois have produced during the period 1967–2015, particularly the last three decades (80s, 90s and 2000s). Bendjema et al. (2019) showed that Mellah basin, northeast of Algeria experienced dry sequences from 1979 to 2001, and a wet sequence from 2002 to 2009 and there was a critical level of water deficit during the period 1987/1988–2001/2002 and 2005/2006–2009/2010. The results derived from the study of Wadi Chlef basin in Algeria showed that SPI was able to detect historical drought occurrences for the years 1982–1983, 1983–1984, 1989–1990, 1992–1993, 1993–1994, 1996–1997, 1998–1999 and 1999–2000, 2004–2005 and 2006–2007. Wet years were observed in 1971–1972, 1972–1973, 1995–1996, 2008–2009 and 2009–2010 (Achite et al. 2022).

In the semi-arid basin, the projection of the results of R^2 on the geographic map of the studied area made it possible to represent and visualize the spatial distribution of the variance for these chosen indices. The results showed that the SPI had a high correlation with EDI index for time scales of 9 and 12 months. The results analysis confirms a similarity between the categories of extreme drought obtained in the EDI and the SPI over a period of 12 months. However, at the 24-month scale, the variance between SPI and EDI was explained by more than 80%, which means a high performance of drought prediction. Adisa et al. (2021) showed that SPI and EDI are the best indices to monitor and predict drought in some parts of South Africa. The time scales of 9, 12 and 24 month allowed better knowledge of water resources while SPI-3 values showed nonsignificant variance with the EDI-3 index. This correlation showed a decreasing trend for small periods. According to Smakhtin and Hughes (2007), drought indices, such as SPI3 or EDI3, can similarly capture dry areas and wet events, but at the same time, there may be differences in the beginnings and ends of drought events. Mishra et al. (2019a, b) showed that the agricultural drought threshold limit was different depending on the values estimated by EDI-3 (June, July and August), SPI-3 (June, July and August) and EDI-3 (July, August and September) and SPI-3 (July, August and September) in Cuttack zone, Odisha, India. However, Pandey et al. (2008) demonstrated that using SPI, EDI and deciles indices at 1- and 3-month time scales to analyze and quantify the duration and severity of drought events, the obtained results present a similar trend in terms of drought severity. Morid et al. (2007) compared the prediction of droughts using two indices (SPI and EDI) over the medium and long term (3 to 12 months). The correlation results based on coefficient of determination show that the best-developed models present values of 0.66 and 0.79 for

SPI-6 and EDI-6, respectively, indicating high prediction accuracy, especially for the EDI index. Djellouli et al. (2016) concluded that the correlation between SPIs and EDIs is better over considered time scales where the best result was found for 9-month period, which is a better choice to detect the severity of drought in the Wadi Louza Basin (Algeria). The results of Quesada-Montano et al. (2018) showed correlation values above 0.80 between SPI and EDI indices over accumulation periods of 1, 3, 6, 9 and 12 months in the Central America region. Khan et al. (2018) used different month-time intervals (3, 6, 9 and 12 months) in drought indices (SPI, EDI, RDI and SPEI) for drought identification in the Songhua River basin (SRB) in China and the Indus River Basin (IRB) in Pakistan. The correlation coefficients matrix for different indices showed that 12 months for SRB and 6 months for IRB were the best time steps to assess drought conditions. The results of Herdita et al. (2020, 2023) in a comparative study of the SPI and EDI indices evolution at 1, 3, 6, 12 and 24 months showed that both indices produce similar drought forecast performance. Banimahd and Khalili (2013) studied the similarities/differences between SPI, RDI, EDI and SPEI indices (over 3.6, 9 and 12 months) using Markov chains in different climatic regions, where the EDI index, especially for 3-month time scale, shows significant correlation, across all climate zones. The EDI values corresponding to wet and dry periods were higher and lower than other drought indices, respectively. On the other hand, Mi et al. (2023) showed using the principal component analysis method (PCA) applied for the comparison of different drought indices (EDI, PDSI, SPI and SPEI) for different scales (3, 6, 9 and 12 months) that EDI can describe more accurately the major historical drought events and has a strong correlation. Khairani et al. (2018) concluded a similarity between SPI and EDI at different timescales to detect the beginning and end of drought events but with a different number of episodes. According to the results of Wambua et al. (2014), the drought forecasting using artificial models of neural networks based on SPI and EDI indices over 1, 3, 6, 9, 12, 18 and 24 months shows that the predicted model's performance for EDI was superior to that with SPI, whereas the correlation coefficient values ranging from 0.82 to 0.51 and 0.79 to 0.57, respectively, over a period of 6 months. The study of Pinto et al. (2022), based on four drought indices (SPI, PPN, DEC and EDI over 12 months) to explain the drought scenario in Chile, showed that the SPI model is the most efficient.

There are also studies comparing the monthly usage of the EDI with other indices such as SPI, SPEI, RDI, Z-score, etc. For example, Swain et al. (2017), these indices gave similar results in characterizing moderate or severe drought situations from 1979 to 2014. Wambua et al. (2018) showed that SPI and EDI were effective in detecting drought onset, describing temporal variability, severity and spatial extent characteristics. Adeola et al. (2021) showed that the severity of drought/wetness of EDI and SPI-3, 6 and 12 values had increasing trends during corresponding return periods. Vergni et al. (2021) showed a moderate concordance between SPI and EDI indices using Cohen's Kappa test during 1951 to 2018. Mondol et al. (2021b) also showed that EDI index is strongly correlated with SPI index. Li et al. (2019) indicated a significant gap between SPI and EDI ($R^2 > 0.55$) in Northeast China. Studies have shown that EDI index performs better than SPIs in assessing both short-term and long-term droughts in different regions (Jain et al. 2015; Kamruzzaman et al. 2019b). Yildirim and Rahman (2022a, b) confirmed the similarity between extreme drought categories obtained using EDI and SPI.

The analysis of the coefficients of determination between SPI and DEPI as well as EDI and DEPI explained a low variance (< 30%), in the Algerois basin at different time scales. However, the variance was quite well explained (40% to 60%) in the Cheliff-Zahrez basin. DEPI presents an excellent ability to reflect the real severity and duration of drought events, at different time scales, unlike to SPI and EDI indices. According to Limones et al. (2022),

DEPI is complementary to SPI and vice versa and it is applicable in various climates across the world. Topçu's (2021) research on drought using DEPI and SPI indices in Turkey for the period 2000–2021 showed that the correlation is significant between DEPI and SPI-12 ($r=0.75$) while the lowest correlation is between DEPI and SPI-24 ($r=0.62$). This result can be explained by the fact that SPI index had been developed to monitor meteorological drought conditions (Akhtari et al. 2009). Noting that, SPI is the most efficient index for different climates and at different time scales (WMO 2012). SPI in its original formulation is applied to reliably estimate drought episodes in order to develop strategies to mitigate its effects (Moccia et al. 2022). According to Niaz et al. (2022), this index is one of the most widely used indices for characterizing and monitoring drought in various regions.

The SPI is a powerful drought index that only requires precipitation as an input (United Nations 2022). Finally, the SPI was the first index, whereas the EDI was the second best index for monitoring the drought and the complementary DEPI reflected the duration of the drought. EDI and SPI indices are considered effective tools for monitoring drought at different timescales. According to Mishra and Singh (2010), both indices have gained popularity as important drought indices in recent years in space and time. The SPI index is quite popular and widely used to monitor drought conditions. It also has advantages over other indexes (Mishra et al. 2019a, b).

Droughts events become more and more frequent in the region, which is reflected by the low cereal production in Algeria. During the disastrous year of 1994, a production of 9.7 million quintals (≈1 million tons) was recorded, in comparison with 52.5 million quintals produced in 2009 (FAO 2013). According to statistics from 1995 to 2005, the Algerian population consumed, on an annual average, 4,244,903 tons of wheat, including 70.44% durum wheat, equivalent to 858 million dollars, including 60.36% of durum wheat, or $578 million (Chehat 2007). National cereal production during the 2012–2013 campaign reached 49.1 million quintals, with a drop of 900,000 quintals compared to the previous campaign. This drop in production is explained by the drought affected the country during this period (FAO 2021). On the other hand, the bill for wheat imports amounted to 1.84 billion dollars during the first ten months of 2014 compared to 1.71 billion dollars in the same period in 2012, with an increase of 7.6% (FAO 2021). The drought that occurred in 2015–2016 in the Maghreb affected all of these countries and caused a significant drop in cereal production. In 2015, Algeria's cereal imports increased by 14% to ensure the availability of stocks (FAO 2021; Maki et al. 2021). National forest land degradation is estimated at an *annual* rate of 45,000 to 50,000 ha per year. This decline in forest cover is 90% due to forest fires (Directorate General of Forests 1997). Frequent droughts have also had a negative impact on the temporal evolution of vegetation coverage (such as forests). Between 1910 and 2010, forest area decreased by 22% due to frequent forest fires (Meddour-Sahar and Bouisset 2013). Concerning water resources, in general, an analysis of the water flow from hydrometric stations shows that the flow of rivers toward dams has decreased in northern Algeria due to low precipitation (Meddi et al. 2009; Ghenim and Megnounif (2013); ;).

5 Conclusion

This study highlights the similarities and dissimilarities between the most used meteorological drought indices, SPI and EDI and the new DEPI by comparing the values using the coefficient of determination to explain the variance. The assessment of the performance of these indices in monitoring drought over the study basin allowed us to draw

conclusions. The drought event has occurred throughout the basin; however, it was more frequent in the five regions of the Cheliff-Zahrez Basin. In addition, severe drought conditions affected the southeastern and central parts of the basin.

The relationship between EDI and SPI is significant for 9 and 12-time, whereas 24 months of accumulation is the most appropriate time scale to detect drought conditions severity using SPI or EDI. It is noted that EDI-24 reacts more uniformly than SPI-24 in drought events evaluation. DEPI index is a good predictor of drought risk duration in semi-arid climates where the monthly precipitations are relatively low. Finally, the Chellif-Zahrez basin experienced severe meteorological drought in all regions. However, this phenomenon caused a negative impact on the agricultural sector.

The Cheliff-Zahrez basin experienced severe meteorological drought events. However, this phenomenon has had a negative impact on the agricultural sector. According to FAO (2021), cereal production in 2020–2021 recorded a decline due to meteorological conditions, including rainfall deficit. Predictions of future global climate estimate that in coming decades, droughts will be even more frequent, more severe, longer and more widespread in space. These same predictions indicate that the African continent will be among the most vulnerable regions in terms of climate change (UNCCD 2019). This confirms the persistence of drought in northern Algeria. Drought early warning and management have advanced significantly in recent decades, largely due to advances in drought monitoring tools (Johnson et al. 2020). Drought indices can help to improve drought mitigation efforts through more timely, efficient and accurate measurements. The results of this work will provide the authorities of the Cheliff-Zahrez basin or other basins the basis to improve drought management and planning, including the development of long-term drought adaptation strategies (e.g., improve water conservation and irrigation equipment, change practices and select crops that require less water). The results of this study can constitute a useful scientific contribution to drought monitoring and water resources management in this region and other similar areas. Drought information from this study will help researchers understand recent spatial and temporal patterns of drought events over the Chellif-Zahrez basin. The results can be also used in the development of anticipatory strategies aimed at reducing socioeconomic damages as well as declining rates of crop and livestock productivity in drought-prone areas of Cheliff-Zahrez.

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Declarations

Conflict of interest This manuscript has not been published or presented elsewhere in part or entirety and is not under consideration by another journal. There are no conflicts of interest to declare. The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

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