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Assessing the consequences of climate variability in the Wadi Saida watershed, Northwestern Algeria

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ABSTRACT

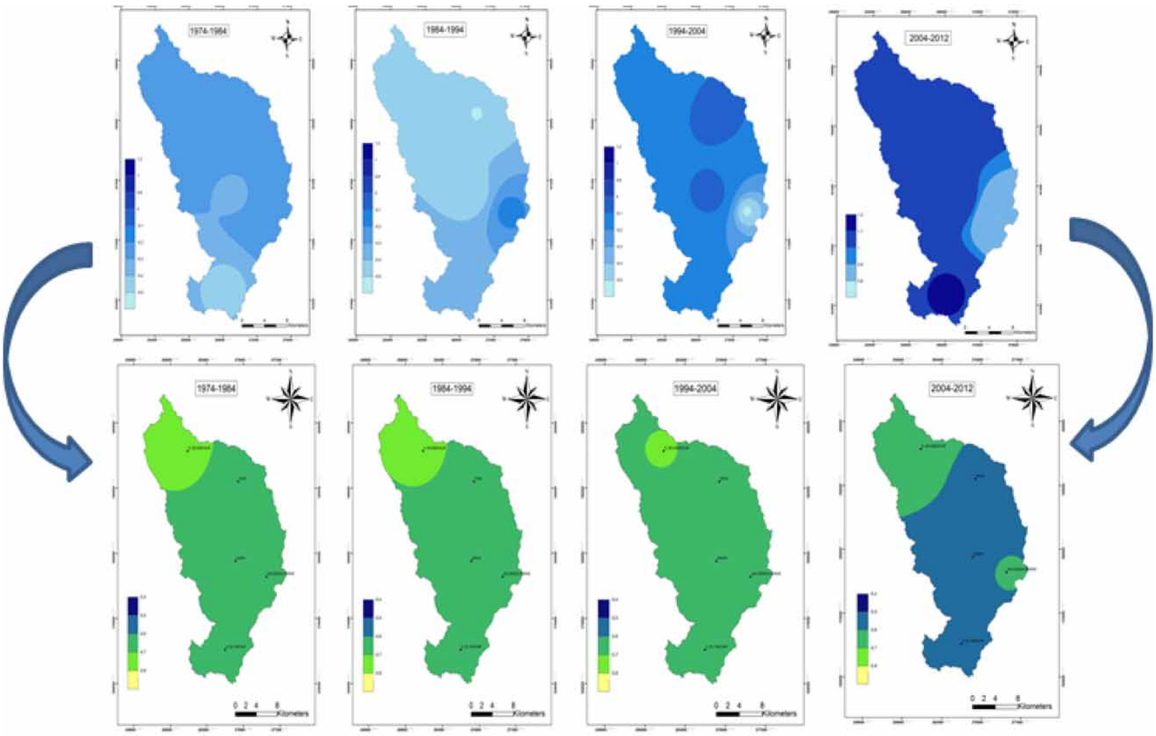
North Africa is identified as one of the most susceptible regions to the impacts of climate change. With potential consequences for food security, water supply, and extreme weather events, understanding climate variability is of paramount importance. This study delves into the Wadi Saida watershed in the Algerian highlands, a region vulnerable to such changes. The study employs a set of data and analytical tools to assess climate variability in the Wadi Saida watershed. These methods include the standardized precipitation index (SPI), climate moisture index (CMI), the Pettitt test, Bayesian modeling using the LEE and HEGHINIAN methods, and Hubert segmentation. Additionally, statistical tests for rupture detection are applied to identify abrupt changes in the climate data. The application of these methods and statistical tests has yielded noteworthy findings. Firstly, the study highlights climate variability characterized by alternating wet and dry periods. This fluctuation in precipitation and moisture conditions underscores the dynamic nature of the region's climate. Secondly, the study has successfully detected critical rupture points, particularly in the years 2002, 2005, and 2007. These years signify significant shifts in climate patterns and potentially hold the key to understanding the impacts on water resources and environmental stability in the region.

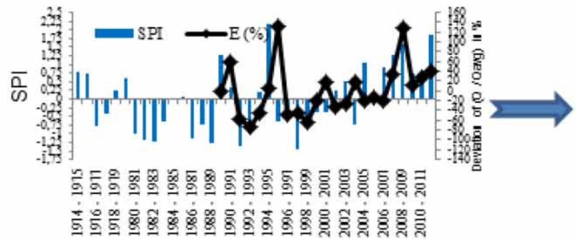
Key words: climate variability, droughts, floods, rupture, Wadi Saida

HIGHLIGHT

- The study employs a set of data and analytical tools to assess climate variability in the Wadi Saida watershed (1 – the standardized precipitation index, 2 – climate moisture index. 3 – the Pettitt test. 4 – Bayesian modeling using the LEE and HEGHINIAN methods, and Hubert segmentation. 5 – statistical tests for rupture detection are applied to identify abrupt changes in the climate data).

GRAPHICAL ABSTRACT





Variables	SPI range	Interpretation	% of years
Rainfall (1974-2012)	SPI>2	Extreme humidity	2
	1<SPI<2	high humidity	15
	0<SPI<1	Moderate humidity *	32*
	-1<SPI<0	moderate drought *	33*
	-2<SPI<-1	Severe drought	18
Hydrometry (1989-2012)	SPI>2	Extreme humidity	9
	1<SPI<2	high humidity	4
	0<SPI<1	Moderate humidity *	30*
	-1<SPI<0	moderate drought *	44*
	-2<SPI<-1	Severe drought	13

1. INTRODUCTION

Climate variability and change have become subjects of global concern, catalyzed by significant climate events, such as the prolonged droughts experienced in tropical regions since the 1970s, as noted by Sircoulon (1976). The implications of these climate shifts have led to extensive research endeavors, both worldwide and within Algeria, as evidenced by the comprehensive body of work by numerous scholars (Laborde 1993; Paturel *et al.* 1996; Haida *et al.* 1999; Meddi 2001; El Mahi 2002; Meddi & Hubert 2003; Talia 2003; El Mahi *et al.* 2004; Ketrouci *et al.* 2004; Talia & Meddi 2004; Khaldi 2005; Ghenim & Megnounif 2011; Soubeyroux *et al.* 2012; Ghenim & Megnounif 2013; Nouaceur *et al.* 2013; Farah 2014; Khoualdia *et al.* 2014; Soro *et al.* 2014; Cheikh *et al.* 2015; Belarbi *et al.* 2016; Djellouli *et al.* 2016; Merabti 2018; Otmane *et al.* 2018). This extensive bibliography underscores the critical importance of the phenomenon under investigation.

The ramifications of climate change and variability, with their immediate and long-lasting effects on the natural environment and human populations, have prompted the global scientific and political communities to prioritize these issues. Of the various components of the climate system, the water cycle plays a pivotal role, making changes in rainfall patterns of particular significance. Precipitation stands as the most influential climate factor, profoundly impacting both human societies and ecosystems. Moreover, its measurability makes it a focal point of research, with numerous studies primarily focused on precipitation patterns.

In hydrology, two major forms of non-stationarity are of interest: trends and disruptions. It can also be noted that a breakup refers to a sudden change in the properties of a random process; a trend is a change progressive properties of a random variable.

The development of different statistical analysis methods has enabled better knowledge of the hydrological regime and the mode of operation of the systems hydrological. Indeed, the application of statistical tests made it possible to identify ruptures, which mark a modification of the hydrological regime. These ruptures are accompanied by a decrease in temperature and an increase in precipitation, generating deficit and excess flow frequencies that explain the more marked irregularity of the flow regime of Wadi Saida.

In the current context, climate variability is no longer a theoretical concept but an evident reality, exerting substantial influence on water resources at a time when the demand for water is continuously rising. Climate change introduces constraints on water availability, a critical resource for various sectors (DaCosta *et al.* 2002; Ardoin-Bardin *et al.* 2003). Consequently, understanding the impact of climate variability on rainfall patterns is of paramount importance, especially when crafting sustainable development solutions.

This research aims to enhance understanding of rainfall variability and emerging drought patterns within the Wadi Saida watershed. Our primary focus involves a thorough examination of annual rainfall data using indices and breakpoint analyses. This investigation is essential for devising targeted strategies suitable for development project needs and effective management of water resources amidst an evolving climate.

2. MATERIALS AND METHODS

2.1. Study area

The Wadi Saida watershed is situated within the extensive Macta watershed, spanning the northwestern region of Algeria and encompassing an area of approximately 644 km^2 (Figure 1). This watershed predominantly runs in a south–north orientation, with the exception of its northernmost section, which extends in a SE-NW direction. The unique topography of the area is marked by a substantial and varied relief, characterized by three major geomorphological formations: a mountainous region, a plateau zone, and a central valley known as Wadi Saida.

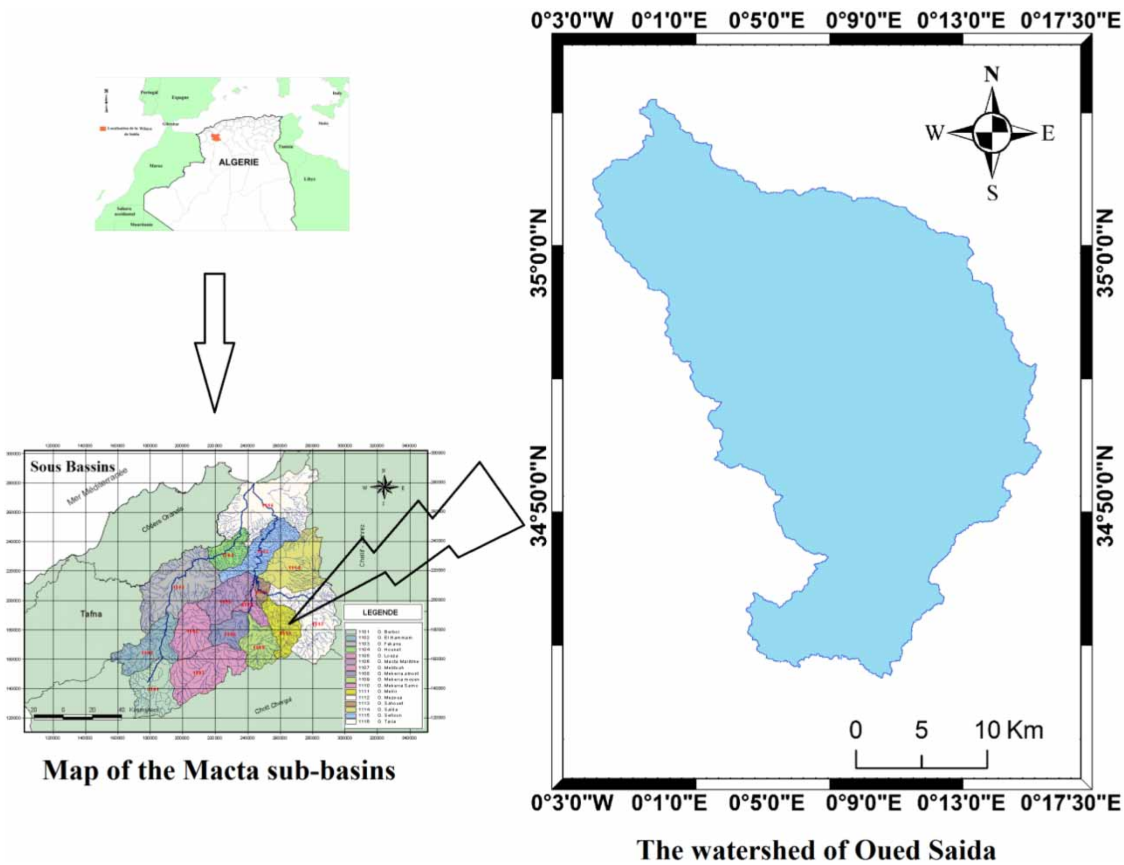


Figure 1 | Location of the Wadi Saida watershed.

The watershed of Wadi Saida is further distinguished by its geographical position within the High Plateaux and its elongated shape, extending from the northern to the southern boundaries. These geographic attributes contribute to the region's climatic characteristics, which fall within the category of semi-arid. Precipitation in the area is notably irregular, featuring rainy periods during the winter months and extended dry spells throughout the summer season.

Geologically, this region is primarily characterized by Paleozoic rocks, forming the foundational layer of the epihercynian platform. These foundational rocks are overlain by Meso-Cenozoic formations, constituting the cover of the geological composition (Pitaud 1973).

2.2. Data acquisition

The data for this study were provided by the National Office of Meteorology (ONM) and the National Agency for Hydraulic Resources (ANRH). These two institutions are essential sources of climate and hydrological data in Algeria, ensuring the reliability and accuracy of the dataset. The dataset in focus pertains to the Saida Wadi basin, and it includes rainfall information. These data consist of measurements collected from five different meteorological stations within the basin, as illustrated in Figure 1.

2.3. Methods adopted

Various approaches have been applied to assess the drought in the Wadi Saida watershed: SPI, CMI, Pettitt test, the Bayesian method of LEE and HEGHINIAN and Hubert's segmentation, which provide a quick overview of hydroclimatic variability. According to Eriksen & Kelly (2006), these approaches facilitate the comparison of situations at different periods and therefore the highlighting of possible changes.

Statistical analyses were carried out with Khronostat software from the Research and Development Institute (IRD). The results were spatialized with Arcgis software.

2.3.1. Standardized precipitation index

The standardized precipitation index (SPI) is a widely used drought index that measures precipitation anomalies over various time scales. It provides a systematic way to categorize drought events and assess their severity. By applying SPI, our study likely evaluated the historical precipitation patterns in the Wadi Saida basin and identified periods of drought.

The SPI created by Mckee *et al.* (1993) responds to the following formula: (Lamb 1982)

$$\mathrm{SPI} = \frac{(P_i - P_m)}{\sigma_i}$$

where P_i is the rainfall for year *i*, P_m is the average interannual rainfall over the reference period, and σ_i is the standard deviation of the interannual rainfall over the reference period.

The SPI has been used by many authors (Wu *et al.* 2001; Giddings *et al.* 2005; Bodian 2014).

This rainfall index defines the severity of the drought in different classes (Table 1) (Bergaoui & Alouini 2001; Ardoin-Bardin *et al.* 2003; Ardoin-Bardin 2004; Ali & Lebel 2009; Lebel & Ali 2009), on the basis of this

Table 1 | Percentage of years for each SPI class for all the stations selected in relation to a given period

		Period				
SPI class	**Degree of dryness**	**1974–1984**	**1984–1994**	**1994–2004**	**2004–2012**	**1974–2012**
SPI > 2	Extreme humidity	0	0	6	2.5	2
1 < SPI < 2	High humidity	6	18	6	32.5	15
0 < SPI < 1	Moderate humidity	36	20	28	47.5	32
−1 < SPI < 0	Moderate drought	34	28	48	17.5	33
−2 < SPI < −1	Severe drought	25	34	12	0	18
SPI < −2	Extreme drought	0	0	0	0	0
Total		100	100	100	100	100

classification, it is possible to determine the percentage of years by SPI class and consequently the corresponding significance in terms of the magnitude of the climatic phenomenon (Table 1).

2.3.2. Climatic moisture index

The crop moisture index (CMI) is a useful tool for studying changes in the climatic regime, as it takes into account both potential evapotranspiration and annual rainfall. The CMI has been employed by several researchers, including Willmott & Feddema (1992) and Vörösmarty *et al.* (2005). This index helps represent the ratio of annual rainfall to annual potential evapotranspiration and is often expressed within the range of −1 to 1. The formula for calculating the CMI is typically defined as:

$$\mathrm{CMI} = P + \mathrm{PET}/P - \mathrm{PET}$$

where CMI is the crop moisture index; P stands for annual rainfall; PET is the annual potential evapotranspiration.

The resulting CMI value can fall between −1 and 1, where:

If CMI < 0, it indicates that potential evapotranspiration exceeds annual rainfall, suggesting a moisture deficit or drought conditions.
If CMI > 0, it signifies that annual rainfall exceeds potential evapotranspiration, suggesting moisture surplus or wet conditions.
CMI $= 0$ suggests a balance between rainfall and potential evapotranspiration.

This index can be a valuable tool for assessing and understanding changes in local and regional climate patterns, especially with regard to their impact on agriculture and water resource management.

$$\begin{cases} \mathrm{CMI} = (P/\mathrm{ETP}) - 1 \text{ if } P<\mathrm{ETP} \\ \mathrm{CMI} = 1 - (\mathrm{ETP}/P) \text{ if } P>\mathrm{ETP} \end{cases}$$

Like that of the SPI, the CMI values fall into three classes representing three climatic phenomena (Table 2). It is therefore necessary to determine the percentage of years by CMI class to know what type of climate prevails in the basin for a given period of time (Table 2).

Table 2 | Percentage of years for each CMI class for all the stations selected in relation to a given period

		Period				
CMI class	Degree of dryness	1974–1984	1984–1994	1994–2004	2004–2012	1974–2012
CMI > 0	Wet	0	0	0	0	0
−0.6 < CMI < 0	Dry	26	24	16	57	29
CMI < −0.6	Severe dry	74	76	84	43	71
Total		100	100	100	100	100

2.3.3. Breakage detection tests

Detecting breaks in time series data is crucial for identifying significant changes in climate patterns, which can help in pinpointing pivotal years of climate change. A "break" in a time series data refers to a change in the statistical characteristics or probability distribution of the data at a specific point in time, which is often unknown beforehand (Bois 1971; Brunet-Moret 1977; Buishand 1982; Lubes *et al.* 1994). Various methods have been developed for detecting these breaks:

- Pettitt test (Pettitt 1979): This test is used to identify a single, maximum break point in a time series. It is designed to detect a significant change in the probability distribution of the data, which could indicate a shift in the climate regime.

It makes it possible to check the stationarity of the rainfall series. A statistical study is defined from the two sums thus determined and tested under the null hypothesis that the two sub-samples belong to the same population. This test is based on the calculation of the variable U_t (Equation (1)):

$$U_{t,N} = \sum_{i=1}^{t} \sum_{j=t+1}^{N} D_{ij} \tag{1}$$

The Pettitt test is non-parametric and considers a sequence of variables random $X_1, X_2, \ldots, X_N$, which would have a change point at τ if X_t for $t = 1, \ldots, \tau$ have a common distribution function $F_1\ (x)$ and X_t for $t = \tau + 1, \ldots, N$ has a function of common distribution $F_2\ (x)$, and $F_1\ (x) \neq F_2\ (x)$. Pettitt makes no assumptions about the shapes functional of F_1 and F_2, except that they are continuous.

Pettitt's test is based on the sign function Equation (3), where the sign of the difference of each pair of values in the sequence is given by Equation (2).

$$D_{ij} = \mathrm{sgn}(X_i - X_j) \tag{2}$$

$$\mathrm{sgn}(X) = \begin{cases} 1, & X > 0 \\ 0, & X = 0 \\ -1, & X < 0 \end{cases} \tag{3}$$

$$K_N = \max_{1 \leq t < N} |U_{t,N}| \tag{4}$$

He proposes to test the null hypothesis using the K_N statistic defined by the maximum absolute value of $U_{t,N}$ for t varying from 1 to $N - 1$ Equation (4). From the theory of ranks, Pettitt shows that if k designates the value of K_N taken from the series studied, under the hypothesis zero, the probability of exceeding the K value is given approximately by:

$$\mathrm{Prob}(K_N > K) \approx 2\, e^{\frac{-6K_N^2}{N^3 + N^2}} \tag{5}$$

For a given risk α of the first kind, if Prob $(K_N > k)$ is less than α, the hypothesis null is rejected. The series then includes a localized break at time τ where is observed K_N.

A primary break is defined as a heterogeneity identified by a break test at from the initial series. A secondary break is a break obtained from a sub series from the basic series.

- Bayesian method of Lee & Heghinian (1977): similar to the Pettitt test, this method also aims to detect a single significant break point in a time series by considering the Bayesian framework. It helps identify when a notable change in the data distribution occurs (Hubert 2000; Claudie 2009)

This is a parametric approach which requires a normal distribution of variables studied. Consider a series X of N random variables Xi such that:

$$X_i = \begin{cases} \mu + \varepsilon_i & i = 1, \ldots, \tau \\ \mu + \delta + \varepsilon_i & i = \tau + 1, \ldots, N \end{cases}$$

where ε_i represents independent variables identically distributed according to $N\ (0, \sigma^2)$, of zero mean and constant variance σ^2. X is, therefore, a series of normal variables of the same variance which change in the mean by a quantity δ between τ and $\tau + 1$. τ, μ, δ, and σ are unknown parameters, $1 \leq \tau \leq N - 1, -\infty < \mu < \infty, -\infty < \delta < \infty, \sigma > 0$. We admit the distributions a priori of τ, δ, μ, and σ, respectively:

$$P(\tau) = \frac{1}{N - 1}\, \tau = 1, 2, \ldots, N - 1$$

$$P(\delta) = N(0, \sigma_\delta^2) = \left(\sigma_\delta \sqrt{2\pi}\right)^{-1} e^{-\frac{1}{2}\left(\frac{\delta}{\sigma_\delta}\right)^2}$$

$$P(\mu) = N(0, \sigma_\mu^2) = \left(\sigma_\mu \sqrt{2\pi}\right)^{-1} e^{-\frac{1}{2}\left(\frac{\mu}{\sigma_\mu}\right)^2}$$

$$P(\sigma) = \frac{1}{\sigma}$$

τ and δ represent, respectively, the position in time and the amplitude of a change possible average. The Bayesian procedure is based on the marginal distribution a posteriori of τ and δ. When the distribution is unimodal, the date of the break is estimated by the mode with all the more precision as the dispersion of the distribution is low.

The breaking point τ and the parameters μ and δ are unknown. The method determines the posterior probability distribution function of the parameters μ and δ, considering their prior distributions and assuming that the pause time follows a uniform distribution. There range of the pause time corresponds to the values of the modes of the posterior distributions of m and δ, respectively.

- Segmentation of Hubert *et al.* (1989): Hubert's segmentation method is unique in that it can detect multiple break points in a time series if they exist. This is particularly useful when there are multiple significant changes in the climate regime within the data.

The principle of this procedure is to "cut" the series into m segments ($m > 1$) such that the average calculated for the entire segment is significantly different from the average of the segment(s) neighbors.

$$N_K = i_K - i_{K-1}$$

$$\bar{X}_K = \frac{\sum_{i=K-1+1}^{i=K} X_K}{n_K}$$

$$D_m = \sum_{K=1}^{K=m} d_K$$

$$d_K = \sum_{j=i_{K-1}+1}^{i=jK} (X - \bar{X}_K)^2$$

where i_K, $K = 1, 2, \ldots, m$, is the rank in the initial series from the terminal end of the kth segment; $\bar{X}_K$ is the average of the kth segment; D_m is the quadratic difference between the series and the segmentation considered.

These methods are employed to assess and identify abrupt changes in rainfall or hydrological regimes over time. While the Pettitt test and Lee and Heghinian's method are suited for identifying a single major change, Hubert's segmentation can capture several if they exist in a time series.

The KHRONOSTAT software developed at IRD-HSM in Montpellier is a valuable tool for implementing these statistical procedures (Boyer 2002). It facilitates the analysis of time series data, helps visualize the results, and allows for the storage of these results in digital format. This software is likely a valuable resource for researchers working on climate change analysis and the detection of pivotal years in climate data.

3. RESULTS AND DISCUSSION

The information provided indicates a noteworthy shift in climate conditions as assessed by the SPI for a particular period and region (1974–2012) with five rainfall stations (Figure 2).

1. Increase in high humidity (6–32.5%): the SPI's observation of a substantial increase in high humidity levels suggests that there has been a significant rise in precipitation or wetter conditions in the region. This is likely to impact various aspects of the local environment, such as increased water availability, changes in ecosystems, and possibly an elevated risk of flooding in the region.
2. Increase in moderate humidity (36–47.5%): similarly, the increase in moderate humidity signifies a trend toward more consistent and moderate levels of precipitation. This can have implications for agriculture, water resources, and ecosystem health. Farmers might need to adapt their practices to accommodate changing conditions.

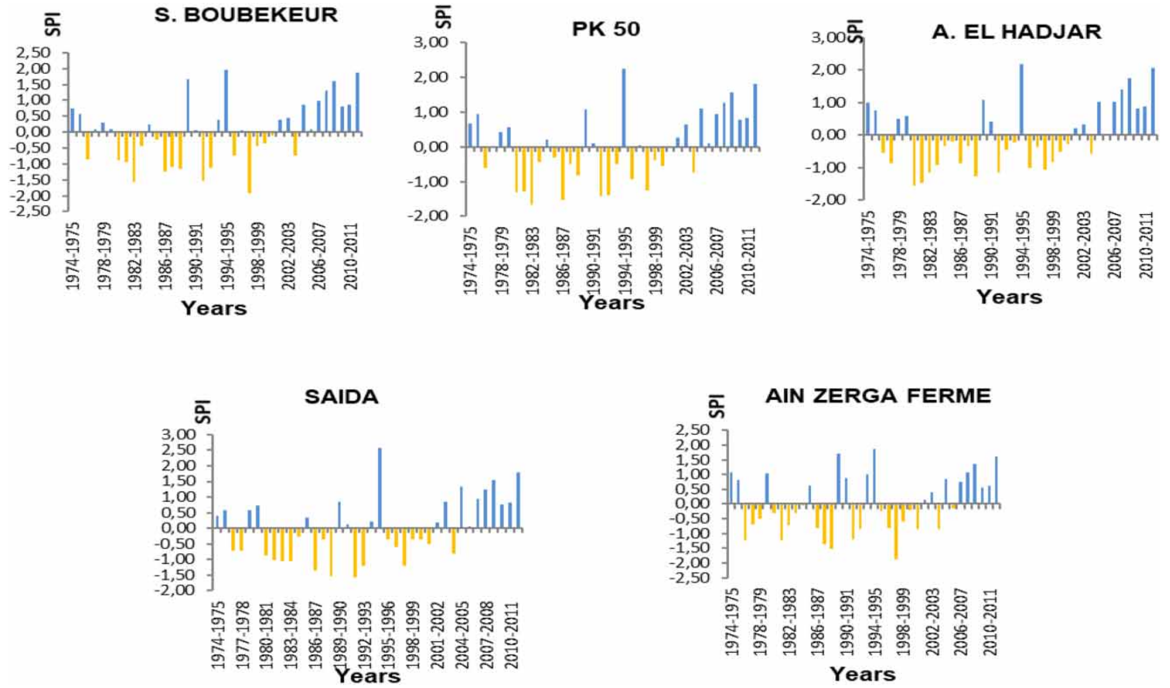


Figure 2 | Annual values of the standardized precipitation index of five rainfall stations over the period 1974–2012.

3. Decrease in severe dryness (25–0%): The striking reduction in severe dryness is a positive finding. A decrease in severe dry conditions implies that the region has experienced fewer extreme drought events, which is advantageous for agriculture, water supply, and overall resilience to climate-related challenges.
4. Climatic irregularity between dryness and pronounced humidity: The mention of climatic irregularity between dryness and pronounced humidity indicates fluctuations in climatic conditions over the study period. This kind of variability can have complex and sometimes challenging effects on local ecosystems, agriculture, and water management.
5. Same variability in humidity and drought across stations: The analysis suggests that the five rainfall stations exhibit similar patterns in terms of humidity and drought. This might be indicative of a regional climate trend affecting all the stations. Identifying common trends is important for understanding larger-scale climate phenomena.
6. Absence of extreme drought: The statement underscores that extreme drought conditions were not experienced during the study period. This is a notable observation, as extreme droughts can have significant societal and environmental repercussions, such as water shortages, crop failures, and ecosystem disruptions.

Spatial analysis

The spatial analysis is a valuable approach to understanding how climate conditions have varied across different regions within the study area over these distinct time periods. It helps identify localized climate trends, which can be vital for regional planning, resource management, and disaster preparedness.

The spatialization of average values of the index over different periods, as depicted in Figure 3, reveals significant trends in humidity and drought across the study region. Let's break down this observation:

Humidity increase (2004–2012): The data indicate that the period from 2004 to 2012 experienced higher humidity levels compared to the preceding three decades. This rise in humidity is likely due to increased precipitation or other factors that enhance moisture availability. Higher humidity can impact the region in several ways, including potential benefits for agriculture and water resources.

Severe drought (1984–1994): Conversely, the data suggest that the region encountered a period of notable drought severity from 1984 to 1994. This could be due to extended periods of reduced precipitation, leading to water shortages, crop failures, and other adverse impacts on the local environment and society.

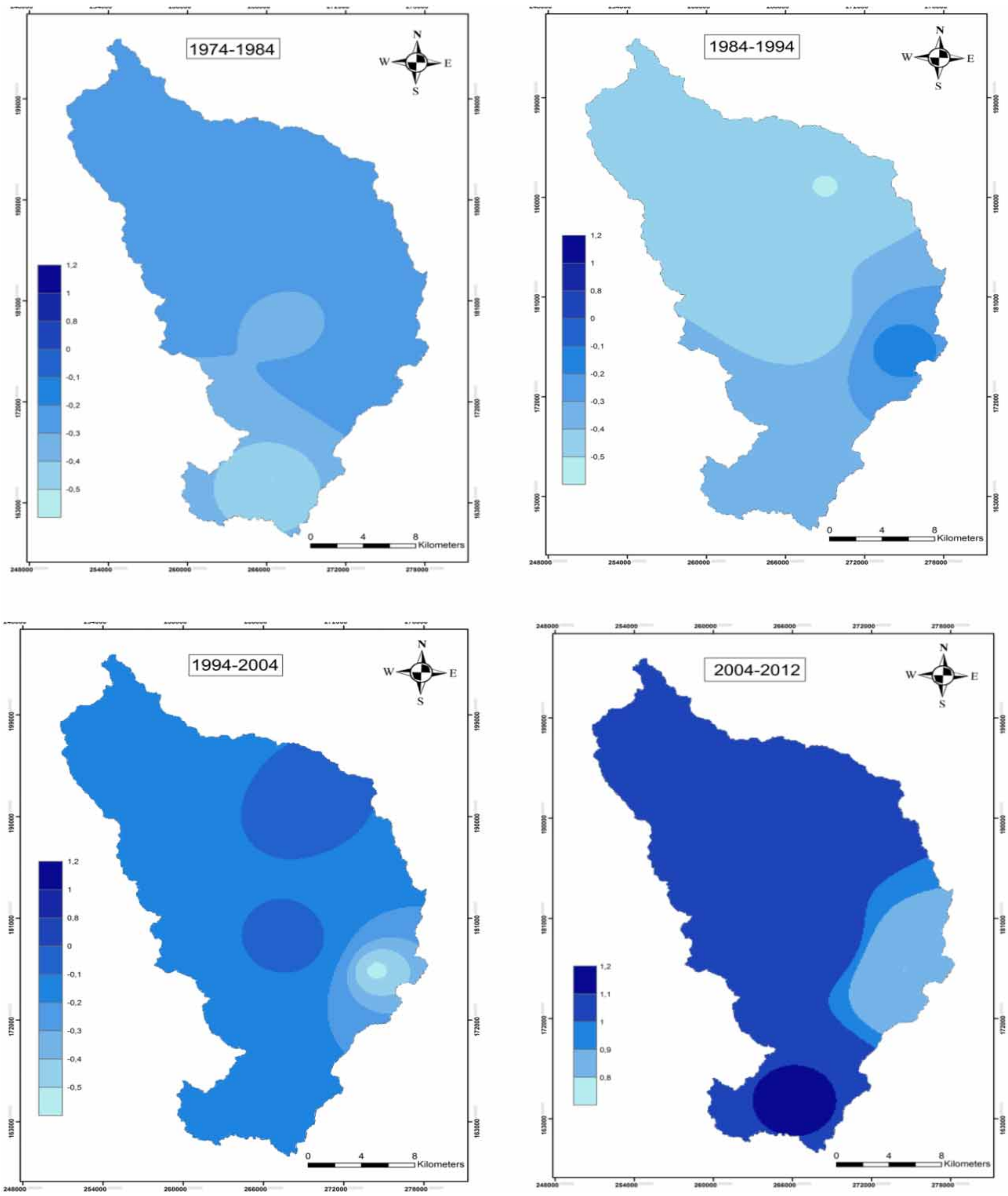


Figure 3 | Spatial distribution of average SPI values over different time periods.

Table 2 and Figure 4 depict the climate moisture index (CMI) values, which fall within the ranges associated with semi-arid and arid conditions. These values reflect the aridity of the region and are indicative of limited moisture availability.

The analysis indicates that the region has experienced significant climatic variability. Specifically, the transition from an arid climate during the period 1974–2004 (84%) toward a semi-arid climate for the decade 2004–2012 (57%) reflects changes in the moisture balance within the region.

Figure 4 shows the annual CMI values for the five stations used for the SPI analysis. These stations consistently display negative CMI values, suggesting an overall deficit in moisture availability over the years. Negative CMI values are indicative of dry conditions.

The fact that the CMI values frequently drop below −0.6 and reach as low as −0.84, as observed at the Sidi Boubekeur station, further underscores the arid nature of the region and the challenges posed by limited moisture availability.

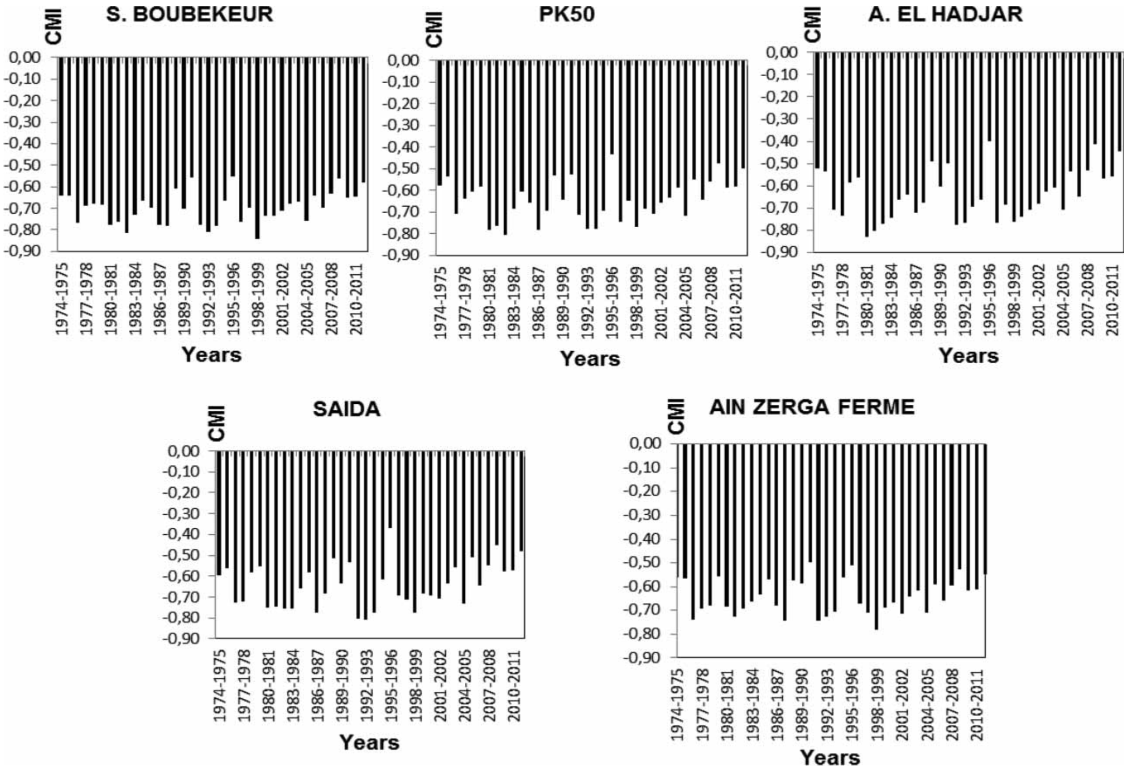


Figure 4 | Annual values of the climatic moisture index (CMI) of five rainfall stations over the period 1974–2012.

The transition from an arid climate to a semi-arid climate can have various implications for the region, including impacts on water resources, agriculture, and ecosystems. It is important to note that climatic variability and changes in aridity can affect the local community's adaptation strategies and resource management practices.

For a more comprehensive analysis and to gain a deeper understanding of the causes and potential consequences of these climatic changes, it is essential to consult the specific CMI data and conduct further research. Additionally, referring to relevant climatological studies and scientific literature on arid and semi-arid regions can provide valuable insights into the broader climatic context and potential measures to address these changing conditions.

Figure 5 likely shows the spatial distribution of CMI values for various time periods. It indicates that as you move north in the basin, the climate becomes progressively more arid. This suggests that the northern areas experience drier conditions compared to the southern regions.

Figure 6 appears to depict changes in the degree of humidity over time. From 2004/2005 to 2011/2012, there is an increase in humidity, suggesting a period of relatively wetter conditions. However, in the years spanning from 1974/1975 to 2003/2004, the region experienced multiple episodes of drought, with the most severe drought recorded in 1997/1998.

The temporal pattern starts with wet years in 1974/1975 and 1975/1976, followed by a prolonged period of drought from 1976/1977 to 2003/2004. The subsequent years are characterized as more or less wet.

The recent studies by Khoualdia *et al.* (2014) show a trend toward a return of precipitation for the period 2001–2007. This implies that after the period of drought, there has been an increase in precipitation, possibly indicating a shift in climate conditions.

The SPI highlighted two distinct periods; a period of deficit (1974–2004), followed by a period of surplus (2005–2012).

Indeed the result obtained shows that at the level of our entire study region and for all the tests, the rupture occurred during the periods 2002, 2005, and 2007 (Table 3). Precipitation increased significantly after the rupture years.

The hydroclimatic variability in terms of the SPI and its impact on both rainfall and streamflow data over the period from 1974 to 2012 shows an alternation of wet and dry years. 33% of the years are characterized by

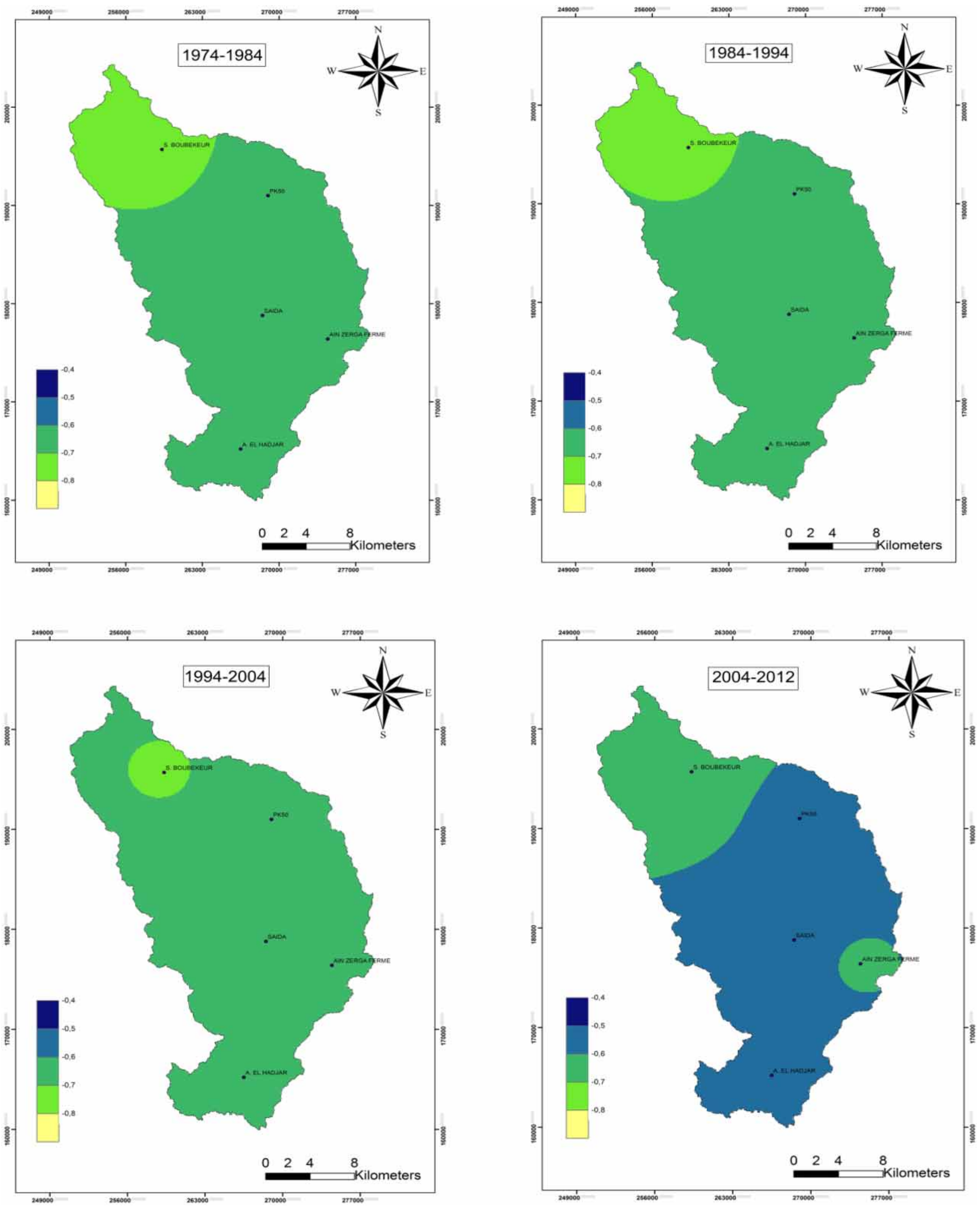


Figure 5 | Spatial distribution of mean CMI values over different time periods.

moderate drought, indicating a deficiency in precipitation. Only 18% of the years correspond to a more severe drought regime. In contrast, 32% of the years are under a moderate humidity regime, and the remaining 17% represent high to extreme humidity levels (Table 4).

The SPI calculated from streamflow data indicates that 57% of the years fall under a drought regime, with 13% experiencing strong drought conditions and 44% facing moderate drought. The remaining 43% of the years exhibit variable intensity humidity.

It is noted that drought, in general, is more moderate when assessed using both hydroclimatic parameters (rainfall and streamflow). However, there is a significant number of years that suffered from very severe drought, and this number appears to be higher when using rainfall data as a basis for assessment.

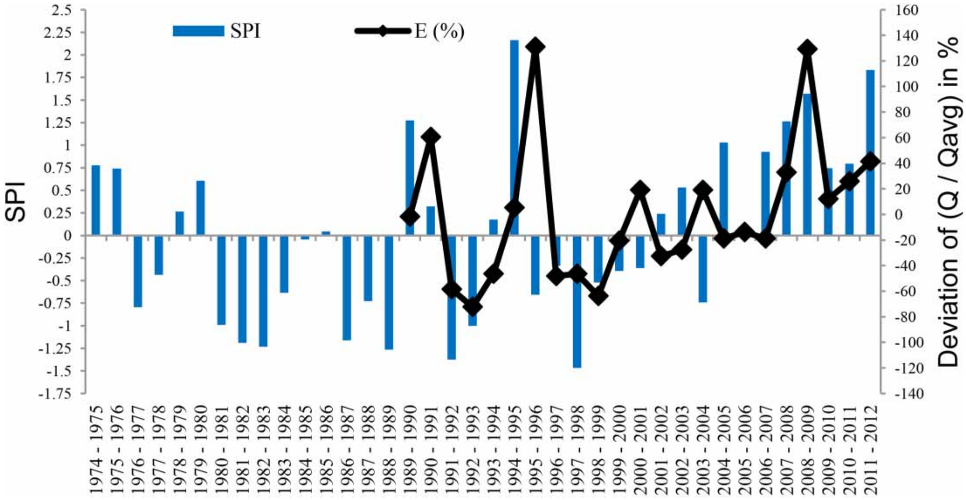


Figure 6 | The evolution of the standardized precipitation index of five rainfall stations over the period 1974–2012, according to the relative deviation of the average annual flows compared to the interannual average for the station of Sidi Boubekeur (Outlet of the basin) between 1989 and 2012.

Table 3 | Result of rupture tests applied to rainfall data (five stations) in mm '1974–2012' and hydrometric data (Sidi Boubekeur in m³/s) over the period 1989–2012

Stations	Break test	Break year or period	Average before first rupture (m1)	Average after first rupture (m2)	Relative variation between m1 and m2 (excess) (%)
SIDI BOUBEKEUR	Lee et Heghinian	2007	268.5 mm	368.8 mm	37.35
	Pettitt	2002	263.5 mm	332.7 mm	26.26
	Segmentation Hubert	[1975–2005] [2006–2012]	265.5 mm	353.5 mm	33.14
PK 50	Lee et Heghinian	2005	309.2 mm	422.2 mm	36.54
	Pettitt	2002	306.4 mm	396.1 mm	29.27
	Segmentation Hubert	[1975–2005] [2006–2012]	309.2 mm	422.2 mm	36.54
SAIDA	Lee et Heghinian	2005	308.9 mm	439.2 mm	42.2
	Pettitt	2002	305.6 mm	409.5 mm	33.99
	Segmentation Hubert	[1975–2005] [2006–2012]	308.9 mm	439.2 mm	42.2
AIN ZARGA	Lee et Heghinian	2007	323.4 mm	401.3 mm	24.08
	Pettitt	acceptée			
	Segmentation Hubert	1975–2012	333.6 mm		
A. EL HADJAR	Lee et Heghinian	2007	314.8 mm	474.6 mm	50.76
	Pettitt	acceptée			
	Segmentation Hubert	[1975–2005] [2006–2012]	310.01 mm	450.4 mm	45.28
Hydrometric station of SidiBoubekeur	Lee et Heghinian	2007	0.51 m^3/s	0.80 m^3/s	56.86 m^3/s
	Pettitt	acceptée			
	Segmentation Hubert	1990–2012			

The statistical analysis of the variability of the rainfall and hydrological series highlighted the emphasis on the presence of ruptures, evidence of a change in the rainfall and therefore hydrological regime. The application of SPIs made it possible to assess climate variability by highlighting an alternation of wet and dry phases and deficit and excess flow frequencies. In general, the basin experienced periods of humidity and drought linked to a change in atmospheric circulation with a tendency toward humidity during the period (2005–2012).

Table 4 | Extent of drought (and humidity) between 1974 and 2012

Variables	SPI range	Interpretation	% of years
Rainfall (1974–2012)	SPI >2	Extreme humidity	2
	1< SPI <2	High humidity	15
	0< SPI <1	Moderate humidity[a]	32[a]
	$-1<$ SPI <0	Moderate drought[a]	33[a]
	$-2<$ SPI <-1	Severe drought	18
Hydrometry (1989–2012)	SPI >2	Extreme humidity	9
	1< SPI < 2	High humidity	4
	0 < SPI< 1	Moderate humidity[a]	30[a]
	$-1<$ SPI <0	Moderate drought[a]	44[a]
	$-2<$ SPI <-1	Severe drought	13

[a]Dominant climatic phenomenon.

The use of statistical tests makes it possible to detect the years of break on the different series of pluviometric and hydrometric observations. Series analysis of precipitation over the period 1974–2012, from the Wadi Saida watershed, shows that the chronicles are not stationary and that they have undergone at least one break. These results corroborate those of the study by Khoualdia *et al.* (2014) where significant primary ruptures are detected in the rainfall series of the Medjarda watershed. The analysis of rainfall data showed an increase in the frequency of wet to very wet years. Observations made in 2007, 2008, 2009, and 2010 also confirm the predominance of wetter conditions, confirmed by the Ministry of Agriculture, Rural Development and Fisheries in Algeria which announced during this period a record cereal production of 6.2 million quintals, a figure never reached by Algerian agriculture. Figures published by the Ministry of Water Resources and the Environment of Algeria also show a filling rate of the various dams of more than 70% over the last 3 years.

4. CONCLUSION

In summary, the analysis of hydroclimatic data in the Wadi Saida watershed over a four-decade period (1974–2012) suggests:

- **Increase in rainfall and flow rates:**

There is a noticeable and persistent increase in rainfall and flow rates during the last decade of the observation series (2002–2012) compared to the earlier years (1974–2004).

- **Climatic variability**:

The period from 1974 to 2012 in the Wadi Saida watershed is characterized by climatic variability, with significant rainfall breaks in 2002, 2005, and 2007.

These breaks resulted in excess rainfall and a higher occurrence of heavy rains, indicating a shift toward surplus conditions.

- **Drought characteristics**:

Despite the observed increase in rainfall and flow rates, the analysis indicates that the drought primarily had a moderate character over the years.

- **Rupture in 2007**:

Rupture tests applied to hydrometric data confirm a single significant rupture in 2007, suggesting a significant change in hydroclimatic conditions during that year.

- **Rainfall regime analysis**:

A four-decade analysis of the rainfall regime in the Saida watershed reveals an increase in precipitation starting from 2005.

The SPI shows a deficit period from 1974 to 2004, followed by a surplus period from 2005 to 2012.

- **Climatic humidity and extreme rainfall events**:

The results from climatic humidity indices (CMI) indicate a transition toward a semi-arid climate over the last decade.

These findings align with a previous study by Nouaceur *et al.* (2013), which noted a return to more abundant precipitation after nearly two decades of drought, along with an increase in extreme rainfall events.

- **Wetter conditions and agricultural production**:

Observations from 2007 to 2012 confirm the predominance of wetter conditions.

The Algerian Ministry of Agriculture reported a record cereal production in 2010, and the Ministry of Hydraulics recorded high dam filling rates, both indicating the positive impact of increased precipitation (Khoualdia *et al.* 2014).

From the results obtained and for better management of water resources, it would be necessary to:

- Continuous monitoring of the evolution of drought by application of new indices which allow it to be highlighted,
- Improving observation systems is necessary to have reliable and sufficient data to better characterize the climate and make good forecasts which should contribute to better adaptation to the probable harmful effects of climate variability. These results can be used to predict droughts in watersheds which enable planning and management of water resources and agricultural activities, as well as the development of drought adaptation measures.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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