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Research Article

Hydroclimatic Variability, Change Points and Drought Characteristics in the Upper and Middle Cheliff Basin, Algeria: A Multi-Station Analysis

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Abstract:

This research examines the hydroclimatic variability of precipitation in part of the Cheliff Basin, the largest basin in northern Algeria, over the period 1971–2016. The dataset consists of records from 17 rainfall stations located within the Upper and Middle Cheliff watershed, selected for their representativeness of the different hydrographic units and provided by the National Agency for Hydraulic Resources (ANRH). The time series were analyzed using a seven-year moving average to smooth interannual fluctuations and subsequently subjected to the non-parametric Pettitt and Mann–Kendall tests to detect change points and identify significant trends. The results reveal an alternation between wet periods (1972–1978) and dry periods (1979–2001 and 2005–2006) in 12 out of the 17 stations. Major breakpoints are primarily observed between the late 1970s and the mid-1980s. Seven stations exhibit a relatively stable rainfall regime, whereas the remaining ten record precipitation deficits ranging from 5% to 53%, reflecting the pronounced impact of prolonged droughts across the basin. These findings confirm the intensification of water deficit conditions and highlight the increasing vulnerability of the Cheliff Basin to climate change. They underscore the necessity of integrating hydroclimatic variability into water resource planning and sustainable management strategies in order to enhance the resilience of hydrological systems and ensure secure water supply for agricultural, industrial, and domestic uses.

1. Introduction

Natural climate variability, coupled with human intervention, has led to gradual changes in the hydrological and climatic characteristics of watersheds over the past decades. Key changes include rising local and global temperatures, altered precipitation patterns and amounts, increased drought and flooding, changes in surface runoff and groundwater recharge rates, and higher evaporation and transpiration rates. These changes have directly impacted the quantity and quality of water resources, as well as the balance of associated basin ecosystems.

The Cheliff Basin constitutes the largest hydrographic basin in northern Algeria, encompassing an area of approximately 44,000 km² nearly 2% of the national territory and extending from the foothills of the High Plateaus to the Mediterranean Sea, crossing several wilayas (Tiaret, Relizane, Chlef, and Aïn Defla). This basin plays a major strategic role in drinking water supply, irrigation of agricultural perimeters, hydropower production, and the preservation of aquatic ecosystems (Hadour et al., 2020). The Cheliff River, approximately 725 km in length, forms the main hydrological axis and is fed by several tributaries,

including the Rhiou, Mina, and Sly rivers, which significantly contribute to regional development, particularly in irrigated agriculture and industrial uses (Hadour et al.2020; Elmeddahi et al, 2016).

However, the hydrological regime of these watercourses is strongly influenced by climatic variability, characterized by irregular precipitation patterns in both space and time. At the national scale, Algeria, located in an arid to semi-arid zone, is particularly vulnerable to the impacts of climate change, with generally low rainfall along the coastal fringe and in the Tellian regions, and even more uncertain conditions toward the southern parts of the country, thereby increasing the fragility of water resources (Hadour et al., 2020; Sekina et al., 2023).

Climatic analyses indicate a general downward trend in precipitation since the mid-1970, with no sustained recovery observed in recent decades (Water, 2021, MDPI). Furthermore, several studies have demonstrated that drought events in the Cheliff Basin are recurrent and sometimes persistent; for instance, the period 1980–2007 has been identified as one of the driest intervals, characterized by significant rainfall deficits associated with alternating dry and wet sequences (Sekina et al., 2023).

Precipitation is one of the most critical climatic parameters for hydrology and human uses, and its relative ease of measurement explains the considerable attention it receives in climatological and hydrological studies. In a context of increasing climatic variability and instability of water resources, comprehensive statistical analyses of interannual rainfall series in the Upper and Middle Cheliff basin are essential. Such analyses enable the characterization of rainfall regime changes and the assessment of risks associated with extreme events, such as droughts and floods (Water, 2021).

The implementation of IWRM (Integrated Water Resources Management) is therefore a crucial approach to addressing these challenges. The Cheliff Basin is equipped with major hydraulic infrastructures namely the Oued Fodda, Sidi Yacoub, and Kramis dams designed for flow regulation, water storae, and mitigation of the impacts of recurrent droughts (Hadour et al., 2020).

Finally, the assessment of rainfall variability and climatic trends within the basin relies on the application of robust statistical methods, such as well as a moving average of seven years, enabling the detection of change points and trends within the rainfall series of the Upper and Middle Cheliff basin. This approach contributes to anticipating hydrological risks related to climatic hazards and to optimizing sustainable planning and management of the basin's water resources (Water, 2021; Elmeddahi et al., 2016).This article aims to clarify the link between hydro-climatic changes and climate change, and to address the need for environmental monitoring as a proactive measure to identify ongoing transformations within watersheds and assess their impacts on natural resources. The modeling framework integrates climate, hydrological, and environmental data, including temperature, precipitation, evaporation, surface runoff, groundwater levels, soil moisture, and water quality. It also incorporates GIS analysis, remote sensing, and hydrological models using spatiotemporal data. This methodology demonstrates how continuous monitoring is a key asset in facilitating sustainable water management and the suitability of water basins for adapting to climate change.

2 Material and methods

2.1 Remote Sensing and Geographic Information Systems

Remote sensing and geographic information systems (GIS) are valuable tools for river basin science, especially in areas lacking monitoring facilities. Specialized satellite imagery allows you to track changes in soil moisture and water bodies, vegetation cover, and urbanization. Spectral indices such as NDVI are useful for characterizing vegetation cover and relating it to precipitation and temperature variations.

GIS enables the layering of different data (e.g., a digital elevation model, drainage grid, and spatial datasets of soil, geology, land use, and climate) to produce maps that highlight areas with the greatest potential for drought, flooding, or erosion.The hydrological variability was constructed using the Rainbow hydrological modeling software under a prism-focused lens.

2.2 Study Area

Located in northwestern-central Algeria (Fig. 1), the Cheliff Basin is bounded to the north by the Western Algerian Coast, to the west by the Macta Basin, to the south by the Oranian High Plateaus, the Sahara, Chott Melrhir, and the Zahrez, and to the east by Chott Hodna and the Isser. The region is framed by two major mountain chains: the Tellian Atlas to the north and the Saharan Atlas to the south.The Upper and Middle Cheliff Basin covers an area of 10,930 km², extending from the upstream narrowing near Boughzoul to the Boukadir threshold, which marks the origin of the Lower Cheliff and Mina basins. According to the recent national structuring of hydrographic units, it belongs to the Cheliff-Zahrez unit. The total Cheliff Basin, the largest in northern

Algeria, spans 43,900 km², between 0°12' and 3°87' E longitude and 33°91' and 36°58' N latitude. Its main course measures approximately 725 km and is subdivided by the National Agency for Hydraulic Resources (ANRH) into 36 sub-basins.The study area of the Upper and Middle Cheliff includes 11 sub-basins, coded from 0113 to 0123 (Fig. 2). These sub-basins have an elongated morphology, with compactness indices ranging from 1.45 for the Arib Ebda River to 2.3 for the Tighzal River (El Abadia).

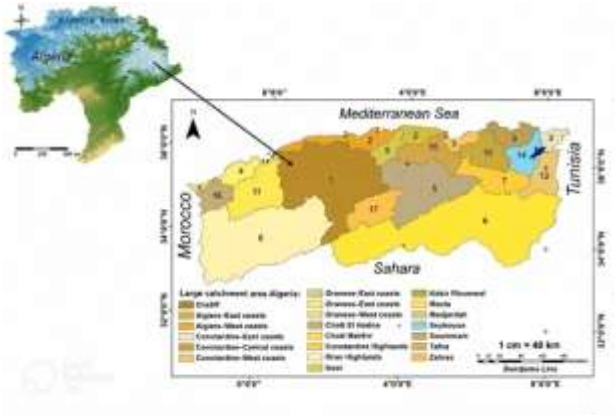


Figure 1. *Location Of The Cheliff Watershed*



Figure 2. *Territorial Context Of The Study Area*

2.3 Data presentation

The analysis of hydroclimatic variability in a watershed depends critically on the availability and quality of data. For the Cheliff Basin, rainfall series from 17 stations were collected in collaboration with the National Agency for Hydraulic Resources (ANRH) and the Chéliff-Zahrez Basin Agency (ABH), primarily covering the upstream and middle sections of the Upper and Middle Cheliff (Fig. 3). The selection of stations was guided by geographic representativeness and the continuity of the time series, despite the limited availability of long-term historical data and the presence of gaps in some stations.

Annual series were analyzed based on the hydrological year (September–August), corresponding to the Mediterranean rainfall cycle. Key statistical characteristics including mean, median, standard deviation, and extreme values are presented in Table 1, which indicates a relatively symmetrical distribution and the absence of significant outliers.

Between 1971 and 2016, annual precipitation exhibited substantial variability depending on topography and exposure to Mediterranean influences, with totals ranging from 100 to 880 mm. Mountain stations recorded the highest rainfall: El Anneb (572 mm), Zoubiria Mongorno, and Theniet El Had (519–544 mm). In the Cheliff Valley and surrounding plains, totals were lower (100–345 mm), with Boughezoul recording the lowest mean (240 mm), reflecting the local semi-arid conditions. These variations illustrate the sheltering effects of mountain ranges, distance from the sea, and the semi-arid topography of lowland areas.

2.4 Issues related to data collection

The collection of rainfall and hydrological data in the Cheliff Basin faces several major constraints that can affect the analysis of hydroclimatic variability. First, some stations lack long-term historical records, limiting the temporal continuity required for the identification of trends and change points. Second, numerous gaps exist within the available series, resulting from measurement interruptions or technical issues, which complicates the harmonization of data for reliable statistical analysis. Third, certain monitoring stations cover only a portion of the basin, restricting the spatial representativeness of the data. Finally, the basin's topographic and climatic variability necessitates a sufficiently dense spatial distribution of stations to capture rainfall contrasts, which is not always feasible due to the limited station network.

To address these constraints, this study selected 17 stations, primarily located in the upstream and middle sections of the Upper and Middle Cheliff, chosen for their continuity and spatial representativeness. This selection ensures a robust characterization of rainfall variability at the basin scale, despite the inherent limitations in data availability.



Figure 3. *Spatial Distribution Of The Studied Rainfall Stations*

Table 1. *Data from the chosen stations precipitation statistics (1971–2016). Transverse Mercator projection. WGS 1984. UTM Zone 31 North.*

Watershed	The station	The code	Altitude m	Longitude m	Latitude m	P_{min} mm	P_{max} mm	P_{Mean} mm	Medina mm	σ mm	CV %
Upper Cheliff	Boughezoul	11208	485 863.00	3 951179.0	643	100	345	240.2	243	63	26
	Zoubiria Mongorno	11404	486 634.28	3996 285.59	932	220	790	518.7	533	134	25.1
	Bordj El Amir AEK	11603	433 951.74	3969 592.79	1074	240	640	440.6	444	103	23
	Theniet El Had	11605	412 557.08	3969 995.72	1162	305	805	544.3	556	142	25.5
	Arib Cheliff	11702	413 954.07	4016 184.92	246	230	685	441.3	441.30	112.7	25.5
	El Khemis INRA	11706	432 140.68	4012 092.86	285	190	610	426.0	426.09	90.7	21.3
	Ain Defla	11804	408 451.47	4013 695.89	271	180	610	437.1	437.1	92.3	21.1
	El Anneb	11806	400 921.71	4028 175.56	1088	315	845	571.8	571.8	140.9	24.6
	El Touaibia	11901	404 261.20	3997 469.23	376	160	475	305.8	305.8	78.2	25.5
	Rouina Mairie	11904	393 441.91	4012 490.55	216	170	650	352.6	348	93.5	26.9
Middle Cheliff	El Abadia	12001	380 853.85	4012 119.23	158	170	660	359.4	357.6	99.2	27.7
	Tikezal	12004	388 770.83	4005 865.68	215	170	670	362.3	362.4	99.7	27.5
	Ouled Fares	12201	341 490.70	4011 118.12	116	210	550	359	359.2	88.1	24.5
	Ponteba Bge	12203	367 625.30	4011 990.47	140	190	730	403.9	403.9	107.5	26.6
	Benairia	12205	352 640.46	4023 230.06	320	230	880	742.6	472.6	128.9	27.2
	Asnam (Chelf) Dda	12219	351 863.10	4005 425.48	130	200	525	350	350	86.9	24.8
	Souk El Had	12304	368 456.80	3957 438.33	550	160	530	370.7	370.7	89.9	24.2

Pmin : minimal rainfall (mm); Pmax : maximum rainfall (mm); Pmean : average rainfall (mm); $\bar{P}$ Medina : Median annual rainfall (mm); σ : Standard deviation (mm); CV : Coefficient of Variation (%)

Concernant le pourcentage 41.24%, il s'agissait d'une erreur de ma part : j'avais additionné les valeurs 15,19 % et 26,05 %, alors que je souhaitais indiquer que les valeurs se situaient dans l'intervalle compris entre ces deux valeurs. Cette erreur a été corrigée.15.19% to 26.05%

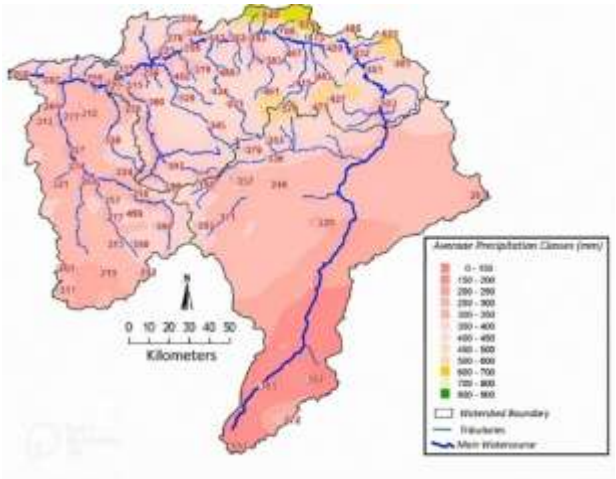


Figure 4.*Rainfall map and average precipitation classes*

2.5 Methods

The analysis of variability in a rainfall time series requires the use of appropriate statistical tools to highlight potential changes in the precipitation regime over time. Such variations may manifest as abrupt shifts, indicating a discontinuity within the series, or as gradual changes, reflecting the presence of long-term trends.

In this context, several statistical tests can be employed to evaluate the existence of significant trends in rainfall series. In the present study, two non-parametric tests particularly suited to hydroclimatic data were applied: the Pettitt test and the Mann-Kendall test. The Pettitt test is used to identify potential breakpoints or discontinuities in the time series, whereas the Mann-Kendall test detects monotonic trends either increasing or decreasing without imposing strict assumptions regarding the data distribution.

Furthermore, to better assess the overall evolution of precipitation and to mitigate the influence of interannual fluctuations, a seven-year moving average smoothing method was applied. This approach enables the identification of underlying trends and enhances the interpretation of observed climatic variations.

Consequently, the combination of the moving average with the Pettitt and Mann-Kendall tests provides a robust methodological framework for characterizing rainfall evolution, detecting potential discontinuities, and determining significant trends within the analyzed series.

Study of evolution rainfall

Seven-year moving average

The moving average method is a widely used statistical smoothing technique in time series analysis. Its primary objective is to reduce the influence of random fluctuations and to attenuate the effect of very short-term variations that may obscure the true evolution of the phenomenon under study.

This approach thus minimizes the impact of random or periodic components present in the series while preserving the overall trend and underlying trajectory. In other words, it facilitates the identification of the general evolution of a variable by filtering out interannual or seasonal irregularities. The method is based on replacing the original series with a new series composed of average values calculated over a rolling temporal window. Each value of the moving average corresponds to the arithmetic mean of observations within a defined interval surrounding the point of interest.

In its simplest form, the moving average is defined by the following equation:

$$y_k = \frac{1}{2_{n+1}} \sum_{i=-n}^{n} (y_{k+i}) \quad (1)$$

Trend analysis

Mann-Kendall test

The Mann-Kendall test is a non-parametric statistical method commonly used to detect the presence of a monotonic trend (increasing or decreasing) in a time series. It is particularly well suited for the analysis of hydrological and climatic series (e.g., precipitation, temperature, streamflow), as it does not require assumptions regarding the distribution of observations and is robust to outliers (Mann, 1945; Kendall, 1975). Recent applications have confirmed its usefulness for studying rainfall and climate trends at both regional and global scales (Uwizewe et al., 2024).

Let $\{x_1, x_2, \ldots, x_n\}$ be a time series of length (n). This method allows for the computation of the standardized Mann-Kendall statistic (UMK), which approximately follows a standard normal distribution for sufficiently long series, as follows:

$$S = \sum_{i=1}^{n-1} \cdot \sum_{j=i+1}^{n} sgn(x_j - x_i) \quad (2)$$

With :

$$sgn(x_j - x_i) = \begin{cases} +1 \; si \; x_j - x_i > 0 \\ 0 \; si \; x_j - x_i = 0 \\ -1 \; si \; x_j - x_i < 0 \end{cases} \quad (3)$$

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n} t_i(t_i-1)(2t_i+5)}{18} \quad (4)$$

The normalized U_{MK} statistic is then formulated as follows:

$$U_{MK} = \frac{S}{\sqrt{Var(S)}} \quad (5)$$

Or :

(S) denotes the relationship between the number of pairs of observations,

(n) is the total number of samples.

For sufficiently long time series ($n \geq 10$), the standardized Mann–Kendall statistic U_{MK} approximately follows a standard normal distribution:

- ✓ $U_{MK} > 0$: upward trend
- ✓ $U_{MK} < 0$: downward trend

The statistical significance of the trend is assessed either using the p-value or by comparing U_{MK} to the critical value of the normal distribution for a given confidence level.

It should be noted that the Pettitt and Mann–Kendall tests are designed to detect a single breakpoint or trend within a time series. Indeed, these methods rely on assumptions of monotonicity or a single change and are not capable of efficiently identifying multiple successive structural changes within the same series (Pettitt, 1979; Ondo. J.C, 2002; Harris et al., 2019). This limitation must be considered when interpreting the results, as overlooking multiple breakpoints can lead to a partial or biased assessment of temporal variations.

In the present study, analyses were conducted using a 5% significance level to ensure that only statistically significant trends or breakpoints were considered in the interpretation of the results.

Pettitt Test

The Pettitt test is a non-parametric statistical method, derived from the Mann–Whitney test, and is widely used to detect the presence of a single change point in a time series (Pettitt, 1979). This approach is particularly relevant in hydrological and climatic studies, where it enables the identification of abrupt changes associated with climatic variability or the impacts of global change (Azzi, 2013; Belarbi et al., 2017).

The principle of the test involves dividing a series of n observations into two sub-periods at each time t ($1 \leq t \leq n-1$). A change point is identified when the statistical distributions of the two segments differ significantly. The statistic Ut, is calculated for each time step, and the change point corresponds to the maximum absolute value, thereby indicating the year or period of transition (Table 2).

Due to its lack of assumptions regarding the data distribution, the Pettitt test is particularly robust against extreme values and non-normal distributions, which are common in hydroclimatic series. It thus constitutes a reliable tool for analyzing breakpoints in precipitation, temperature, or streamflow series at the scale of a watershed or a hydrometeorological station (Ondo. J.C, 2002).

The Pettitt variable Ut,n is defined by the following equation:

$$Ut,n = \sum_{i=1}^{t} \cdot \sum_{j=t+1}^{n} sgn(x_j - x_i) \quad (6)$$

Or :

$$sgn(x) = \begin{cases} +1 \; si \; x > 0 \\ 0 \; si \; x = 0 \\ -1 \; si \; x < 0 \end{cases} \quad (7)$$

- Xi and Xj are the values of the time series.

- Ut,n measures the difference between the two sub-series (1 to t and t+1 to n).

The break is located at time t^* where the absolute value of $U_{t,n}$ is maximum:

$$t^* = \arg \max_{1 \le t \le n-1} |U_{t,n}| \quad (8)$$

Pettitt (1979) proposed testing the null hypothesis using the statistic Kn, defined as the maximum absolute value of $U_{t,n}$ for t=1,…,n−1. Based on rank theory, he demonstrated that if k represents the observed value of Kn for the series under consideration, the probability that the statistic exceeds k under the null hypothesis can be determined.

The statistic is defined as k= max |Ut,n|, where Ut,n measures the differences between the sub-series before and after each time t. For large series, Pettitt proposed a simplified approximation of the p-value, thereby facilitating the assessment of the statistical significance of the detected change.

Perhaps approximated by the following equation:

$$P \approx Prob(K_n > k) \approx 2exp\left(-\frac{6k^2}{n^3+n^2}\right) \quad k = \max|U_{t,n}| \quad (9)$$

With n representing the total number of observations in the series.

This approximation allows for the rapid determination of whether a detected change point is statistically significant, without resorting to complex combinatorial calculations (Ondo. J.C, 2002). It is particularly useful for long-term series of precipitation, temperature, or streamflow, where the objective is to identify abrupt changes or sudden trends over several decades (Azzi, 2013; Belarbi et al., 2017).

In practice, if the obtained p-value is lower than the chosen significance level (e.g., 0.05), the change point is considered significant, indicating a real shift in the series (Pettitt, 1979). This approach makes the Pettitt test both accessible and effective, even for large datasets, while maintaining its robustness against non-normal distributions and outliers. Table 2 presents the results of the various statistical tests applied to the annual total precipitation series.

The Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) is a statistical and probabilistic indicator based exclusively on precipitation data, initially proposed by McKee et al. (1993) for the identification and quantification of drought episodes at various temporal scales. This index characterizes precipitation anomalies by comparing observed rainfall to long-term climatic averages, expressed in units of standard deviation.

The calculation of the SPI is based on fitting the cumulative precipitation to a continuous probability distribution, typically the gamma distribution, followed by a transformation to a standardized normal distribution (Guttman, 1998). This probabilistic approach ensures the spatiotemporal comparability of wet and dry conditions, regardless of local climatic characteristics. According to Hayes et al. (1999), this property provides a major advantage for regional and global drought monitoring.

Owing to its standardized formulation and multi-scale analytical capability, the SPI can be applied to meteorological, agricultural, and hydrological drought studies, depending on the temporal scale considered. For these reasons, it is widely used in climatological and hydrological research and is recommended by the World Meteorological Organization (WMO) as a reference tool for monitoring and analyzing drought events (WMO, 2012).

In a simplified formulation, the SPI calculation can be approximated by the following expression:

$$SPI = \frac{P_i - \overline{P}}{\sigma} \quad (10)$$

3.Results and discussion

Analysis of the evolution of rainfall patterns and their relationship with climate variability

The analysis of annual precipitation data from the 17 studied stations highlights strong interannual variability across the Upper and Middle Cheliff watershed. The rainfall series are characterized by significant year to year fluctuations, reflecting a pronounced irregularity in the precipitation regime throughout the study period.

The application of a seven year moving average smoothing method allows for the filtering of interannual variability and facilitates the assessment of medium term temporal trends. The results, illustrated in Figure 5, reveal successive phases of wet and dry conditions, suggesting the presence of persistent trends within the region's rainfall regime. These patterns can be interpreted as manifestations of regional climatic variability, influenced by large-scale atmospheric circulation mechanisms, and contribute to a better understanding of the hydroclimatic changes affecting the basin.

For all the analyzed stations, the rainfall series exhibit a generally homogeneous evolution, characterized by alternating wet and dry periods. However, the analysis reveals a clear distinction between the periods preceding and following the change points identified by the Pettitt test. Prior to these breakpoints, the series are marked by relatively wetter conditions and moderate interannual variability. In contrast, the post break period is characterized by a significant decline in

precipitation, accompanied by a notable increase in the frequency of deficit years.

At the scale of the Upper and Middle Cheliff Basin, this evolution translates into a pronounced rainfall deficit affecting 12 out of the 17 stations during the periods 1979-2001 and 2005-2006, which largely correspond to the post-break phase. The extreme drought observed during this period appears more persistent and spatially extensive than that recorded during the pre-break phase. For certain stations particularly Souk El Had, Boughezoul, El Abadia, Bordj El Amir Abdel Kader, Zoubiria Mongorno, Theniet El Had, and El Anneb dry conditions extend beyond 2000-2001 and 2002, suggesting the establishment of a new, persistently deficit rainfall regime. These developments reinforce the hydrological vulnerability of the Upper and Middle Cheliff Basin and highlight the increased risks it may face under future climatic conditions.

The chronological analysis of annual total precipitation recorded at the studied stations over the period 1971-2016 highlights two main trends. The first corresponds to a phase of relative increase in precipitation, observed between the late 1970 and the early 2000, specifically over the interval 1977/1985-1986/2001. The second, longer and more dominant trend is characterized by a general decline, which began in the late 1970s and continued until 2005-2006.

This deficit phase is, however, interrupted by a wetter period between 1992 and 1995, particularly pronounced at six stations (Benairia, El Khemis INRA, Arib Cheliff, Rouina Mairie, Tikezal, and Ponteba Bge), reflecting a spatially differentiated rainfall response within the basin. The recent period, covering 2003-2016, is marked by a modest and slight recovery in precipitation, observed relatively consistently across all 17 stations. Nevertheless, this improvement remains insufficient to sustainably reverse the overall long-term deficit trend identified across the basin.

Study of climate variations and trends

The results of the Pettitt and Mann–Kendall statistical tests applied to the precipitation series are presented in Table 2. The Pettitt test identified statistically significant change points in several precipitation series. Among the 17 rainfall stations analyzed, six exhibited a relatively stable rainfall regime, whereas the remaining eleven were characterized by rainfall deficits ranging from 15.19% to 26.05%. The detected change-point years ranged from 1978 to 2005 in the Upper Cheliff and from 1979 to 2002 in the Middle Cheliff. These results indicate a marked temporal variability in precipitation patterns across the study area.

These periods of breakpoints coincide with phases of pronounced climatic variability, widely observed across North Africa and the Mediterranean Basin, particularly from the late 1970 onward. They reflect a long-term modification of the rainfall regime, characterized by decreased precipitation and increased interannual irregularity. These changes can be attributed to the combined influence of large-scale climatic factors, such as fluctuations in Mediterranean and North Atlantic atmospheric circulation, as well as regional climatic forcings. Thus, the breakpoints detected in the precipitation series of the Upper and Middle Cheliff Basin fit within a broader context of climate change and variability, impacting water resource availability and the hydrological functioning of the basin.

According to Taibi (2011) and Taibi et al. (2015), the influence of orographic barriers plays a decisive role in the spatial variability of precipitation within the Upper Cheliff Basin. Certain stations that are well-exposed to precipitation-bearing airflows and not obstructed by topographic features do not exhibit significant breakpoints in their rainfall series. In contrast, other stations located in the central and middle Cheliff display distinct breakpoints accompanied by a strong downward trend in precipitation. This discrepancy can be attributed either to the presence of reliefs that modify the direction and intensity of rainfall or to the trapping of clouds between the Dahra range and the Beni Chougrane mountains, which act as a barrier to cloud masses coming from the northwest of the Cheliff.

These observations confirm that the spatial distribution of precipitation in the basin is strongly influenced by local topography, in agreement with the findings of Khanchoul et al. (2014), who highlighted that rainfall variations in semi-arid regions are largely modulated by orographic barriers and exposure to dominant atmospheric flows. Such spatial differentiation is critical for understanding the location of drought-prone areas and for adapting water resource management strategies within the basin.The analysis of the precipitation series from the 17 studied stations reveals that only a few exhibit notable regularity in their annual rainfall regime. In contrast, the majority of stations show a significant decline in annual totals, reflecting a precipitation deficit that varies across sites, ranging from 5% to 53%. This deficit reaches its maximum at the Zoubiria Mongorno station, where the cumulative precipitation decrease over the analyzed period is estimated at 53%, illustrating the magnitude of local hydrological stress.The results of the Mann-Kendall test indicate that none of the studied stations exhibited a statistically significant breakpoint in their precipitation series. This statistical stability suggests that annual precipitation has maintained a certain degree of temporal homogeneity and

regularity, despite the observed interannual variations.

Analysis of the precipitation series for the Middle Cheliff watershed, in agreement with ElMeddahi (2016), reveals strong interannual irregularity in rainfall. A declining trend in mean annual precipitation becomes noticeable from 1980 onward, while the years 1978, 1979, and 1980 are identified as having recorded the most pronounced breakpoints in the basin's rainfall regime.

In his study of the Cheliff Basin using the KhronoStat software, Amrani (2011) highlighted that the majority of rainfall stations exhibited a shift in their precipitation regime between the late 1970s and the mid-1980s. In contrast, some sub-basins in the northeast appeared to have maintained relative stability, with precipitation series remaining stationary in their rainfall patterns.

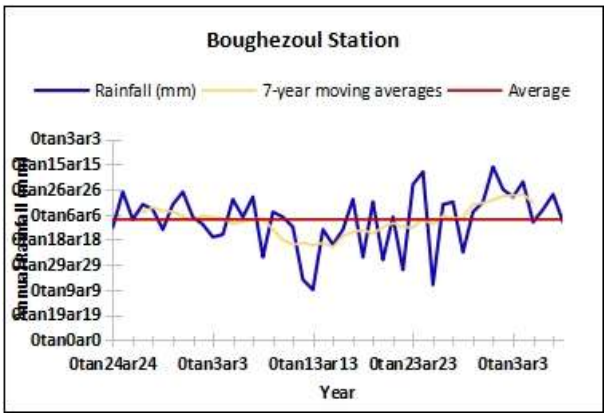
In their investigation of climate variability in the Upper and Middle Cheliff Basin, Zekouda and Meddi (2015) applied the Pettitt and Buishand tests, revealing significant breakpoints in the early 1980. These changes correspond to a clear downward trend in precipitation, with a 27% reduction observed at the Média Secteur station and a decrease exceeding 18% at the Fodda Dam station.These findings fully corroborate the earlier observations of Meddi and Meddi (2007) conducted in northwestern Algeria, in which ten precipitation series were analyzed using the Pettitt test, the Bayesian method of Lee and Heghinian, and Hubert segmentation to detect potential changes. Their study revealed a notable breakpoint during the 1970, characterized by a widespread decline in rainfall across nearly all analyzed stations.

***Table 2**. The presentation of the statistical tests that were applied to the cumulative series of annual rainfall.*

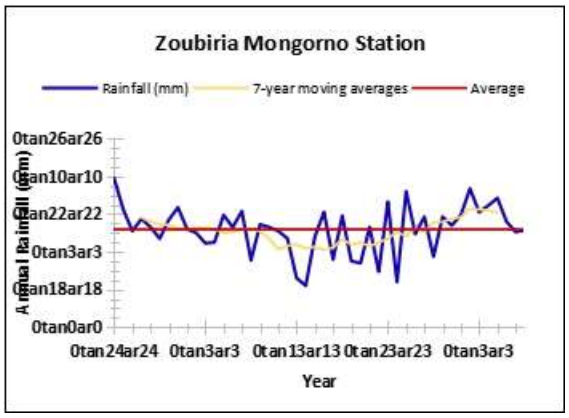
Watershed	The station	**Pettitt test**				**Mann-Kendall test**		The SPI drought index
		Pettitt test K_n	Prob (K_n)	breakup year (gap year)	Relative deficit (%)	Mann-Kendall test $U(t')^b$	Significance threshold	
Upper Cheliff	Boughezoul	268	0.0262	2000	41.71	0.5	1.96	-1.73
	Zoubiria Mongorno	204	0.162	2002	53.73	1.2	1.96	-2.39
	Bordj El Amir AEK	165	0.386	1997	33.89	1.16	1.96	1.62
	Theniet El Had	165	0386	1997	35.94	0.9	1.96	1.49
	Arib Cheliff	248	0.049	1978	26.89	-0.1	1.96	1.09
	El Khemis INRA	182	0.271	2004	10.80	-0.2	1.96	-0.47
	Ain Defla	249	0.047	1985	14.00	0.5	1.96	1.11
	El Anneb	177	0.302	1997	35.52	0.1	1.96	1.45
	El Touaibia	254	0.040	1978	27.50	-0.1	1.96	1.20
	Rouina Mairie	205	0.158	1985	9.24	-1.2	1.96	-0.33
	El Abadia	253	0.042	1985	5.41	0.5	1.96	-0.21
	Tikezal	197	0.192	1985	6.65	0.7	1.96	-0.20
Middle Cheliff	Ouled Fares	199	0.183	1983	19. 69	-1.1	1.96	0.72
	Ponteba Bge	213	0.129	1979	6.45	-0.1	1.96	0.30
	Benairia	232	0.077	2002	11.13	-1.2	1.96	-0.34
	Asnam (Chelf) Dda	247	0.050	1979	14.28	-0.9	1.96	0.59
	Souk El Had	255	0.039	2001	42.01	0.7	1.96	-1.63

- Prob K_n: probability of exceeding the value of Kn.
- $U(t')^b$: statistical coefficient indicating the direction of the trend (if positive, the trend is upward; if negative, the trend is downward).
- SPI: the drought index (If SPI > 0: wet conditions; if SPI = 0: normal conditions; if SPI < 0: dry conditions, with the following classifications: $-1 \leq SPI < 0$: moderate drought, $-1.5 \leq SPI < -1$: severe drought, and $SPI \leq -2$: extreme drought).

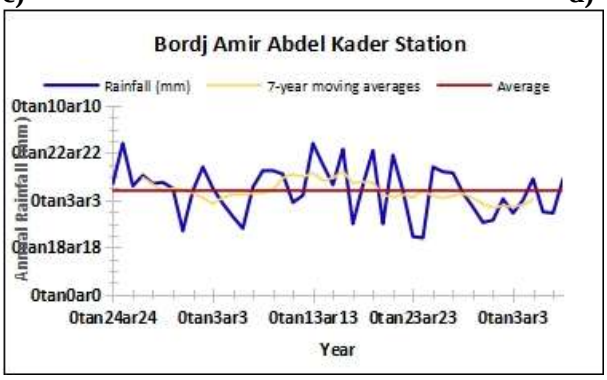
a) **b)**


Boughezoul Station
Rainfall (mm)
7-year moving averages
Average
Annual Rainfall (mm)
Year

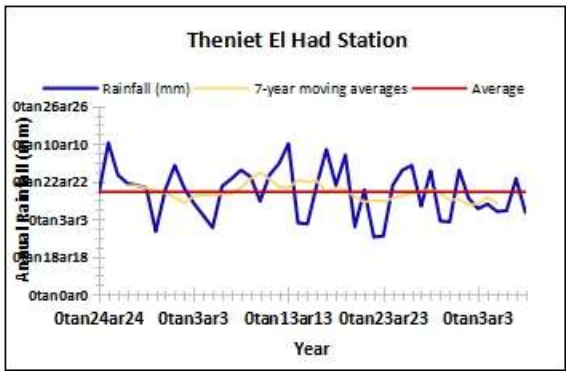
c)


Zoubiria Mongorno Station
Rainfall (mm)
7-year moving averages
Average
Annual Rainfall (mm)
Year

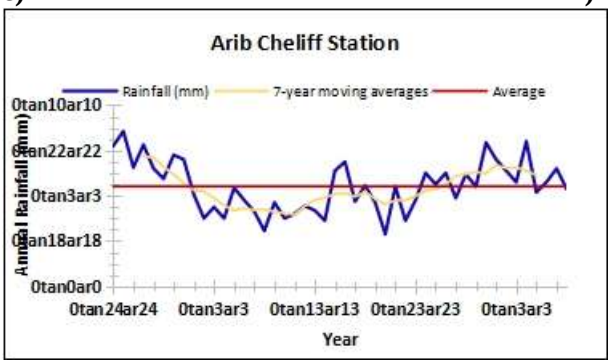
d)


Bordj Amir Abdel Kader Station
Rainfall (mm)
7-year moving averages
Average
Annual Rainfall (mm)
Year

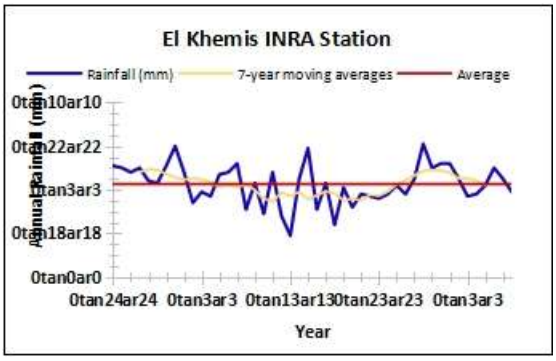
e)


Theniet El Had Station
Rainfall (mm)
7-year moving averages
Average
Annual Rainfall (mm)
Year

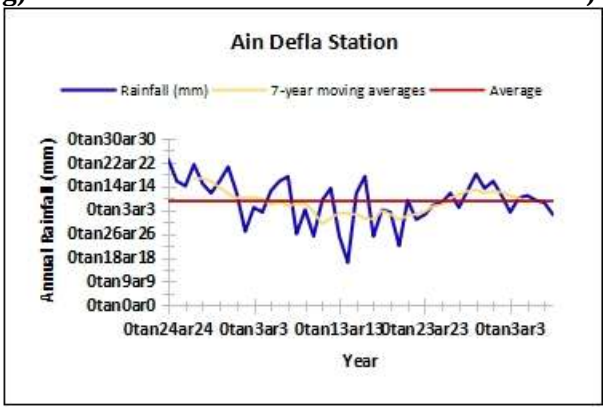
f)


Arib Cheliff Station
Rainfall (mm)
7-year moving averages
Average
Annual Rainfall (mm)
Year

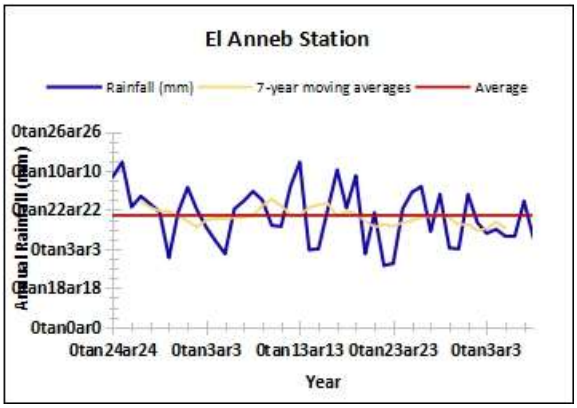
g)


El Khemis INRA Station
Rainfall (mm)
7-year moving averages
Average
Annual Rainfall (mm)
Year

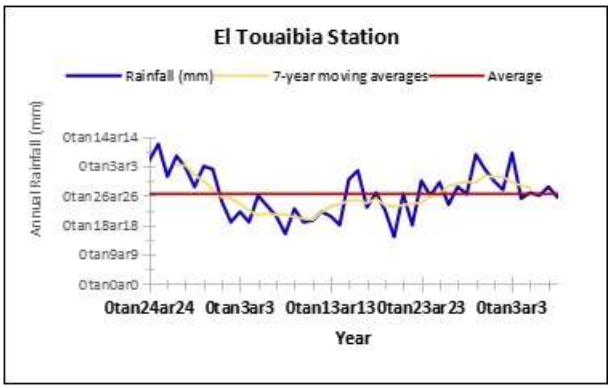
h)


Ain Defla Station
Rainfall (mm)
7-year moving averages
Average
Annual Rainfall (mm)
Year

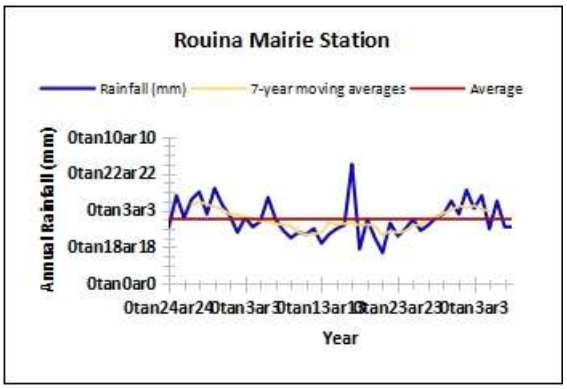
i)


El Anneb Station
Rainfall (mm)
7-year moving averages
Average
Annual Rainfall (mm)
Year

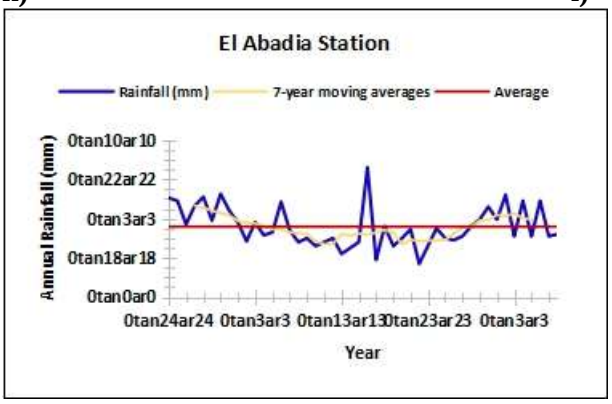
j)


El Touaibia Station
Rainfall (mm)
7-year moving averages
Average
Annual Rainfall (mm)
Year

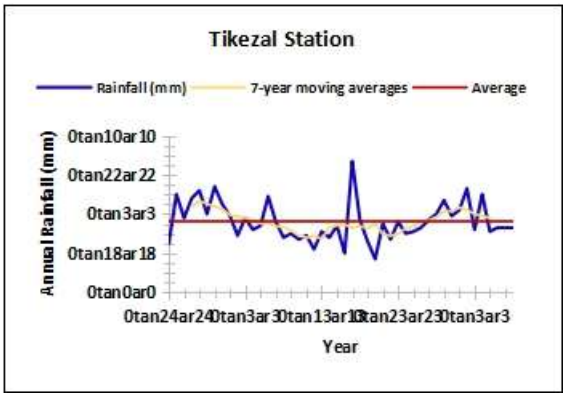
k)


Rouina Mairie Station
Rainfall (mm)
7-year moving averages
Average
Annual Rainfall (mm)
Year

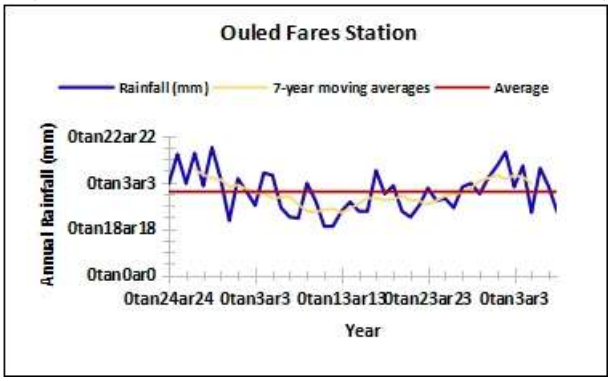
l)


El Abadia Station
Rainfall (mm)
7-year moving averages
Average
Annual Rainfall (mm)
Year

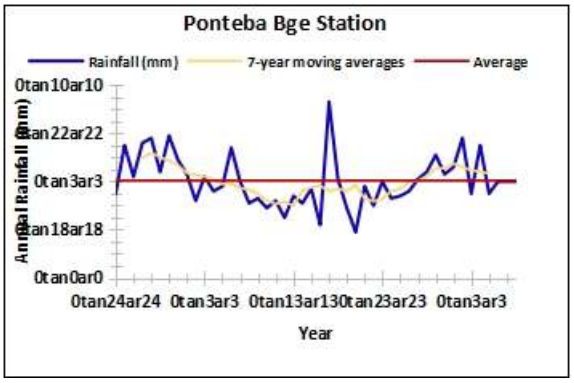
m)


Tikezal Station
Rainfall (mm)
7-year moving averages
Average
Annual Rainfall (mm)
Year

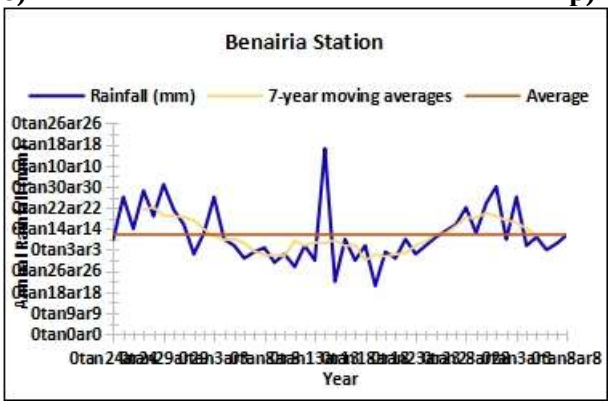
n)

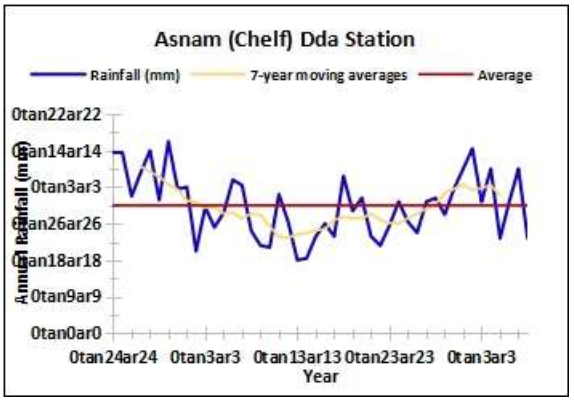

Ouled Fares Station
Rainfall (mm)
7-year moving averages
Average
Annual Rainfall (mm)
Year

o)


Ponteba Bge Station
Rainfall (mm)
7-year moving averages
Average
Year

p)


Benairia Station
Rainfall (mm)
7-year moving averages
Average
Year


Asnam (Chelf) Dda Station
Rainfall (mm)
7-year moving averages
Average
Year

q)

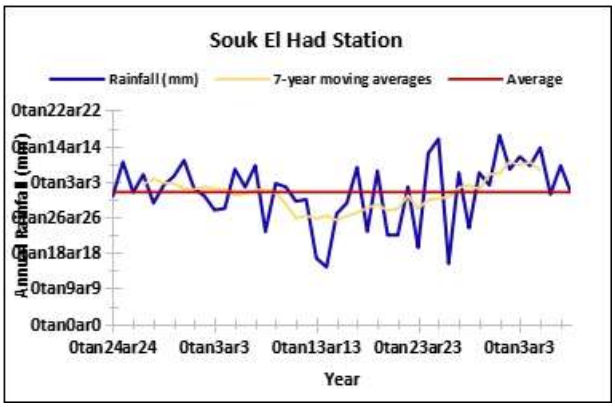


***Figure** 5. Curves illustrating the evolution of mean annual precipitation smoothed using a seven-year centered moving average in the Upper and Middle Cheliff basin: a)Boughezoul station, b) zoubiria Mongorno station, c) Bordj Amir Abdel Kader Station, d) Theniet El Had Station, e) Arib Cheliff Station, f) El Khemis INRA Station,g) Ain Defla Station, h) El Anneb Station, i) El Touaibia Station, j) Rouina Mairie Station, k) El Abadia Station, l) Tikezal Station, m) Ouled Fares Station, n) Ponteba Bge Station, o) Benairia Station. P) Asnam (Chelf) Dda Station, q) Souk El Had Station*

River basins are natural units that provide a fundamental framework for exploring the interactions between climate, water resources, soil, vegetation, and human activities. The basin's hydrological system is characterized by the continuous interaction of precipitation, surface runoff, infiltration, evaporation and/or transpiration, seepage, and groundwater recharge—processes dependent on prevailing climatic conditions.

Climate change is manifesting globally through marked alterations in a number of climatic and hydrological variables. Higher temperatures increase evaporative demand, and changes in rainfall time series may reduce available supplies in some areas but contribute to flooding in others. Furthermore, an increase in short-duration rainfall events can exacerbate surface runoff and erosion even if the total annual rainfall remains largely unchanged.

This issue is particularly relevant in arid and semi-arid regions, where water resources are naturally limited and climatically distinct. Any change in the timing, duration, or intensity of precipitation in these regions can significantly impact surface runoff, groundwater recharge, agricultural production, and ecosystems.

Therefore, the need arises to study hydroclimatic variations as a unified approach to analyzing the impacts of climate change on watersheds. This approach not only examines climate itself but also the relationship between climate variables and their hydrological and environmental responses within the basin.

4.Conclusions

The in-depth analysis of the chronological precipitation series, combined with the rigorous application of appropriate statistical tests, reveals the presence of partially convergent hydrological behaviors among the studied stations. These findings highlight coherent spatio-temporal dynamics and provide valuable insights into the processes governing variability and transformation of hydrological regimes within the Cheliff Basin. This methodological approach enables the identification and characterization of the hydrological processes responsible for the observed variations, by highlighting trends, potential breakpoints, and changes in flow regimes within the watershed.

Regarding precipitation evolution, the analysis of the time series using a seven-year centered moving average smoothing method indicates, for 12 of the 17 stations, an initial wet phase spanning 1972 to 1978. This humid period is followed by a pronounced deficit phase, characterized by persistent dry conditions lasting nearly twenty-four years, primarily between 1979 and 2001, with an extension observed during 2005-2006. From 2006 onwards, the series indicate a gradual return to near-normal precipitation conditions, reflecting a relative stabilization of the rainfall regime.

The application of the non-parametric Pettitt test identified statistically significant breakpoints Among the 17 rainfall stations analyzed, six exhibited a relatively stable rainfall regime, whereas the remaining eleven were characterized by rainfall deficits ranging from 15.19% to 26.05%. The detected breakpoints occurred primarily between 1978 and 2005 in the Upper Cheliff region and between 1979 and 2002 in the Middle Cheliff. Post-break deficits ranged from 5% to 53%, with the maximum deficit observed at

the Zoubiria Mongorno station. In contrast, the application of the Mann-Kendall test did not reveal any statistically significant monotonic trends in the precipitation series, indicating the absence of an overall generalized shift across all stations studied. The results of this study are consistent with those reported in previous research conducted in northwestern Algeria. The identified trends and patterns corroborate these earlier findings, particularly regarding the spatio-temporal variability of precipitation and structural changes in the regional hydroclimatic regime. This convergence of results strengthens the reliability of the conclusions drawn and highlights a relatively homogeneous regional hydroclimatic dynamic, characterized by coherent and comparable evolutions of the main hydrological parameters studied.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.
- **Author contributions:** The authors declare that they have equal right on this paper.
- **Funding information:** The authors declare that there is no funding to be acknowledged.
- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.
- **Use of AI Tools:** The author(s) declare that no generative AI or AI-assisted technologies were used in the writing process of this manuscript.

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