DOI: 10.31577/ahs-2026-0027.01.0008

ACTA HYDROLOGICA SLOVACA

Volume 27, No. 1, 2026, 72 – 83

Hydrological response to climate change: Dam inflow dynamics in the Côtier Constantinois East and Medjerda-Mellegue basins

Chehla SAADOUN*, Abdesselem KABOUR, Lotfi ZEGHADNIA

In a context of increasing climate change, this study evaluates the impact of climate variability on water resources. To achieve this, it analyses annual inflows were analysed at 15 stations located upstream of dams in the Côtier (Coastal) Constantinois East and Medjerda-Mellègue watersheds between 1958 and 2024. Several statistical methods were employed, including Pettitt's breakpoint test, the Mann-Kendall trend test, Sen's slope, the Standardised Runoff Index (SRI) and Innovative Trend Analysis (ITA). The results reveal a significant and persistent decrease in annual inflows, with breaks in the data identified as early as the 1970s in the south and from the 1990s onwards in the north. Reductions observed range from 38% to 47% in the north, exceeding 70% in the south. The SRI index indicates a predominance of drought periods in the south, whereas the north experiences a more balanced cycle of wet and dry periods. The Mann–Kendall test and Sen's slope estimator consistently indicate significant decreasing trends in annual inflows at most stations. This is further supported by the Innovative Trend Analysis (ITA), which confirms a generalized decline across the study area. These results emphasise the clear impact of climate change on regional hydrological regimes and the necessity of adapting water resource management strategies.

KEY WORDS: climate change, Constantinois East Coastal watershed, Medjerda-Mellegue watershed, inflows, Pettitt test, Mann-Kendall test, Innovative Trend Analysis, Standardized Runoff Index

Introduction

Documentary investigations into climate studies carried out in Mediterranean countries indicate a general trend towards rising temperatures, decreasing precipitation, an increased frequency of extreme weather events and more severe hydrological droughts (Spinoni et al., 2020; Méndez et al., 2023). Algeria is considered to be one of the Mediterranean countries that is most vulnerable to the effects of climate change. Numerous studies have been conducted to characterise the variability of hydro-climatic parameters at the national level based on in-depth statistical analyses (Taibi et al., 2013; Khoualdia et al., 2014; Drouiche et al., 2019; Regad and Tatar, 2019; Hallouz et al., 2019; Benzater, 2021; Berhail and Katipoğlu, 2023; Merabti et al., 2023; Kabour and Chebbah, 2023; 2024). These studies reveal that signs of significant climate change began to appear as early as the 1970s. In their study of rainfall patterns in northern Algeria between 1936 and 2009, Taibi (2013) observed a significant decline in precipitation from the mid-1970s onwards, particularly in the western part of the country, where the rainfall deficit was between 16% and 43%. Khoualdia (2014), in analysing climate variability in the Medjerda river basin in north-east Algeria, also notes a reduction in rainfall and an increase in temperatures over the periods 1913–1938 and 1969–2007. In their study of rainfall patterns in northern Algeria between 1936 and 2009, Taibi (2013) observed a significant decline in precipitation, particularly in the western part of the country, from the mid-1970s onwards. Drouiche (2019) reports that the Mitidja basin in northern Algeria experienced a drought from 1973 to 2001, resulting in an annual decrease in rainfall of between 16% and 24%. Hallouz (2019) also observed a decrease in precipitation and river flow, alongside a significant increase in maximum and minimum temperatures, in north-western Algeria between 1979 and 2013. Furthermore, Haouari (2024) demonstrates that the 2014–2023 period was the warmest decade ever recorded nationally, with an average temperature increase of 0.63°C above the estimated annual climate normal of 19.37°C. The author points out that the north of the country, which has a Mediterranean climate, is experiencing more pronounced warming than the Saharan regions in the south. Khoualdia et al. (2014) also notes a reduction in rainfall and an increase in temperatures over the periods 1913–1938 and 1969–2007 when analysing climate variability in the Medjerda river basin in north-east Algeria. In the face of intensifying climate change, the variability of water resources is a serious concern (Bendjema, 2020; Khedimallah, 2021; Adjissi et al., 2025). This directly affects the supply of water to strategic hydraulic infrastructure such as dams (Berhail Berhail and Katipoğlu, 2024), thereby compromising the sustainable management of water resources in watersheds.

Building on previous research into the impacts of climate change, this study aims to characterise, analyse and quantify the effects of this phenomenon on the water supply to dams in two strategic watersheds in north-eastern Algeria: the eastern Constantinois coastal basin and the Medjerda-Mellègue watershed. A statistical analysis covering the period from 1958 to 2024 was conducted to detect trends, quantify hydrological variations, and improve our understanding of how water resources respond to climate change.

Materials and methods

Presentation of the study area

The study area consists of two neighbouring watersheds located in north-eastern Algeria, near the Algerian-Tunisian border. It is part of hydrographic region (N°04): 'Constantinois-Sybouse-Mellègue' (Fig. 1). These are the WS.03 (WaterShed) basin, known as 'Côtier Constantinois Est', and the WS.12 basin, called 'Medjerda-Mellégue', named after the main wadis that cross it: the Medjerda wadi and the Mellégue wadi. These basins are bounded to the north by the Mediterranean Sea, to the south by Chott Melghir (06), to the east by the Tunisian border and to the west by the Seybouse basin (14) and the Constantinois Highlands (07).

The Constantinois Coastal east Basin (WS 03) covers an area of 3203 km² between longitudes 8° 00' and 9° 60' E and latitudes 36° 40' and 37° 50' N. It is subdivided into four sub-basins: Oued Bounamoussa (code 03-15), Oued El-Kebir East (code 03-16), Oued Mafragh (code 03-17) and Côtiers La Calle (code 03-18). The Medjerda-Mellègue watershed (WS 12) covers approximately 7877 km² between meridians 7°40' and 8°50' E, and parallels 35°30' and 36°40' N. It is divided into five sub-basins: the Oued Medjerda (code 12-01), the Oued Meskiana (code 12-02), the Oued Chabro (code 12-03), the Oued Mellègue Amont (code 12-04) and the Oued Mellègue Aval (code 12-05). These two basins are of the northern and exorheic type.They cover several wilayas, including Skikda, Annaba, El Tarf, Souk Ahras, Tébessa, Khenchela, Oum El Bouaghi and Guelma (Abdeddaim, 2018). Surface water mobilisation in the study area relies on a series of hydraulic structures, primarily dams, which are located on the main wadis of the two catchment areas. Their locations and main characteristics are presented in Table 1 and (Fig. 1), based on data from the 'El Tarf–Medjerda–Mellègue Water Transfer' project (hydrology section), which was carried out by the HPE (Hydro Projets Engineering) group.

Data

For this study, annual time series of inflows (in hm³) were used for the various dams located in the study area, as shown in Table 1 and (Fig. 1). These data were collected from fifteen stations (listed in Table 2) located upstream of the dams and distributed evenly throughout the relevant region, over the period from 1958 to 2024. The data were collected from several reliable sources, including the National Water Resources Agency (ANRH) in Algiers and Constantine, the technical documentation of the 'El Tarf-Medjerda Mellegue Transfer Study/Part 1: Hydrology' project and the Northwest Knowledge Network website (https://climate.northwestknowledge.net/). The choice

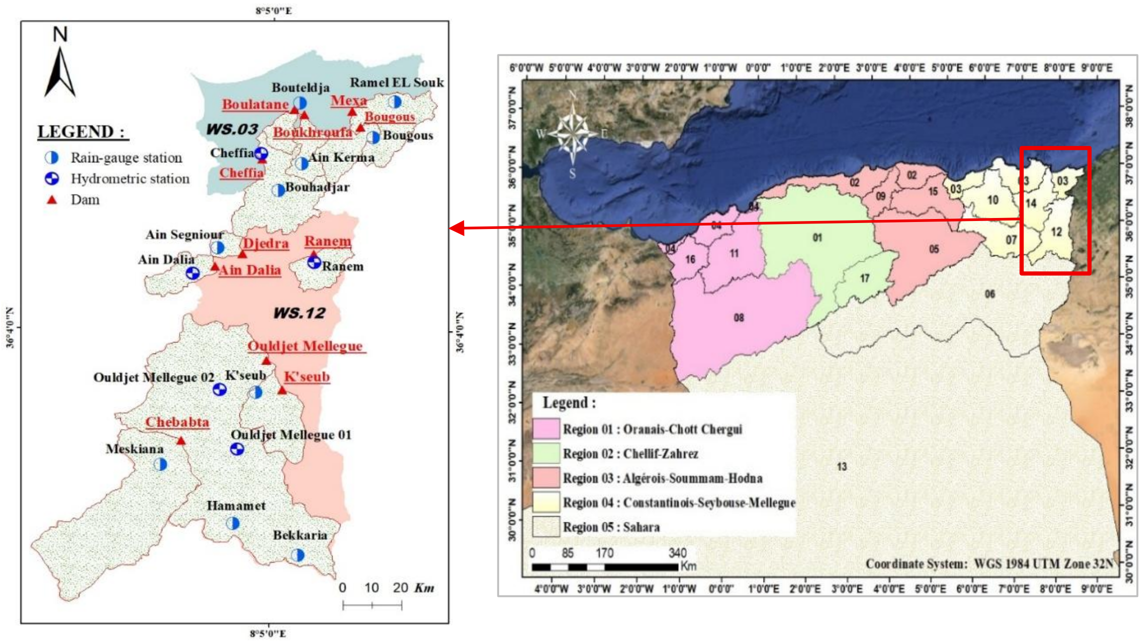


Fig. 1. . Map showing the geographical location of the study area, the dams, and the observation stations.

Table 1. Overview of dams located in the study area

Watershed (WS)	Dam name	Affected wadis	Controlled basin area [km²]
Côtier Constantinois Est (WS.03)	Cheffia	O.Bounamoussa,O.El Kebir,O.Bouhdjar, O.Soudain	575
	Mexa	O.El Kebir Est	647
	Bougous	O.Bougous	235
	Boukhroufa	O.Boukhroufa	173.2
	Boulatane	O.Boulatane	112
Medjerda – Mellégue (WS.12)	Ain Dalia	O.Medjerda	175
	Djedra	O.Djedra	119
	Ranem	O.Ranem	191
	Ouldjet Mellegue	O.Mellégue, O.Chabro, O.Ain Chabro, O.Ksob, O.Serdies, O.Fed Labba	4350
	Chebabta	O.Meskiana, O.Smar el houd, O.Melah	1326
	El K'seub	O.El K'seub, O.El Heleiba, O.El Baiad, O.ElHarch, O.BouChekoua	423

Table 2. Characteristics of used stations

Watershed (WS)	Station	Type	Code stations	X	Y	Observation period	inflows [hm³]
Côtier Constantinois Est (WS.03)	Cheffia	Hydrometric	031501	8.03	36.62	1958–2024	126.51
	Bouhadjar	Rain gauge	031503	8.10	36.50	1958–2024	42.99
	Ramel El Souk	Rain gauge	031602	8.53	36.79	1958–2024	211.35
	Bougous	Rain gauge	031603	8.45	36.67	1958–2024	133.57
	Ain Kerma	Rain gauge	031604	8.19	36.59	1958–2024	49.47
	Bouteldja	Rain gauge	031718	8.18	36.78	1958–2024	57.81
Medjerda – Mellégue (WS.12)	Ain Segniour	Rain gauge	120103	7.87	36.32	1958–2024	55.49
	Ain Dalia	Hydrometric	120114	7.78	36.24	1958–2024	25.4
	Ranem	Hydrometric	/	8.23	36.28	1958–2024	24.08
	Meskiana	Rain gauge	120201	7.66	35.63	1958–2024	57.98
	Hamamet	Rain gauge	120304	7.95	35.44	1958–2024	109.44
	Bekkaria	Rain gauge	120307	8.23	35.37	1958–2024	90.41
	Ouldjet Mellegue 01	Hydrometric	120309	7.98	35.68	1958–2024	34.23
	Ouldjet Mellegue 02	Hydrometric	120404	7.87	35.89	1958–2024	71.66
	K'seub	Rain gauge	120521	8.02	35.87	1958–2024	8.99

of stations was primarily based on the availability of long, continuous series an essential requirement for consistent statistical evaluation. Five of the stations are hydrometric and have direct measurements of inflows; for the remaining ten stations, inflows were estimated indirectly from rainfall data using empirical formulas identified through extensive bibliographic research. In the absence of direct hydrometric measurements, estimates of inflows are often based on empirical formulas derived from the relationship between climatic or hydrological parameters and the volume of flowing. In Algeria, several equations of this type are commonly used to reconstruct runoff series, particularly when data is limited (Kabouya, 1990; Meskine, 2009; Aouachria, 2023).

Methodology

Data were sourced from hydrometric stations and rain gauges, with empirical formulas (Medinger's method) being used to estimate inflows where direct measurements were unavailable (Meskine, 2009).

This formula is the most frequently used in Algeria, particularly for small catchments, as it provides reliable estimates in contexts where data is limited. It is expressed as follows:

$$Le = 1.024\ (P - 0.26)^2 \quad (1)$$

$$A = Le.S$$

Le: water level [mm],
P: average rainfall [m],
A: average annual input in [hm³],
S: catchment area in [km²].

Statistical analysis of hydro-climatic time series is a fundamental tool for studying climatic variability and detecting changes in hydrological regimes (Lubes-Niel et al., 1998; Kabour and Chebbah, 2023). From a statistical perspective, climate change can be identified when a significant shift occurs in the mean or variance of a time series at a particular time (Haidu, 2006). This study employed a multi-method statistical approach to evaluate the impact of climate change on inflows (measured in hm³) to dams within the Côtièr Constantinois Est and Medjerda-Mellègue catchments between 1958 and 2024. The Pettitt test (Pettitt, 1979) was used to detect breakpoints in the hydrological series (Boni et al., 2024; Boursali et al., 2025), revealing abrupt changes in inflow patterns. Trend analysis was conducted using the Mann–Kendall test (Mann,1945; Kendall, 1975) and Sen's slope estimator (Sen, 1968; Fossou at al., 2014) to identify and quantify monotonic trends. Meanwhile, the Standardised Runoff Index (SRI) characterised wet and dry periods, providing insights into drought dynamics (Shukla and Wood, 2008; Wu et al., 2018). Additionally, Innovative Trend Analysis (ITA) was employed to visually assess trends by comparing sub-series (Şen, 2012; Alifujiang et al., 2020).

Pettitt Test

The Pettitt test is based on two hypotheses: data homogeneity (H_0) and the existence of a change point (H_1). If H_0 is rejected, this indicates a significant change occurring at a specific date (Merniz, 2021):

$$Ut,N = \sum_{i=1}^{t} \sum_{j=t+1}^{N} Dji \tag{2}$$

with, $i=1, N$ and with $j=t+1, N$
or
$Dij = sgn(xi - xj)$
with,

$$\begin{cases} sgn(z) = 1 \text{ si } z > 0 \\ sgn(z) = 0 \text{ si } z = 0 \\ sgn(z) = -1 \text{ si } z < 0 \end{cases}$$

with, ($z=xi - xj$).

Standardized Runoff Index (SRI)

Is a hydrological drought index whose principle is similar to that of the Standardized Precipitation Index (SPI) (Sediqi and Komori, 2024). It is computed using the following formula:

$$SRI = \frac{Xi - Xj}{\sigma} \tag{3}$$

with,
xi: represents the runoff for the period under consideration,
xj: is the mean of the series,
σ: is the standard deviation of the series.

Man-Kendall test

It is based on two hypotheses: the null hypothesis (H_0), which assumes the absence of a significant trend, and the alternative hypothesis (H_1), which suggests the existence of a significant trend, either increasing or decreasing (Ahmad et al., 2015). It is calculated as follows:

$$S = \sum_{i=1}^{x-1} \sum_{j=i+1}^{x} sign\ (x_j - x_i) \tag{4}$$

and:

$$sign\ (x_j - x_i) = \begin{cases} 1 \ if\ (x_j - x_i) > 0 \\ 0 \ if\ (x_j - x_i) = 0 \\ -1 \ if\ (x_j - x_i) < 0 \end{cases}$$

with: xi and xj are the observations at times *i* and *j*, respectively.
The *Z* statistic is then calculated using *S* and the variance $Var(S)$.

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{k=1}^{n} t_k\ (k-1)(2k+5)}{18} \tag{5}$$

$$Z_{MK} = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} \ if\ S > 0 \\ 0 \quad if\ \ S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} \ if\ S < 0 \end{cases}$$

Results and discussion

Table 2 shows data from 15 hydrological stations associated with dams and located across the two catchment areas within the study region (Fig. 1). The Côtier Constantinois Est basin (WS.03) has six stations and the Medjerda-Mellègue basin (WS.12) has nine stations. Inflows are estimated using Medinger's empirical formula or measured directly by the hydrometric stations. The average volumes recorded vary significantly from station to station. The stations with the highest average inflows are Ramel El Souk, Bougous and Cheffia, with volumes of 211.35 hm³, 133.57 hm³ and 126.51 hm³ respectively. In contrast, stations such as K'seub (8.99 hm³) and Ramel (24.08 hm³) had much lower volumes.

Pettitt test

The Pettitt test (Table 3) was used to analyse the time series of annual inflows (1958–2024), revealing significant breaks in the majority of the studied stations. Analysis of the time series of annual inflows at stations in the WS.03 (Constantinois East Coastal watershed) revealed significant breaks (*P*-value ≤ 0,05**)** in 1987, 1993 and 2006, respectively, at the Ramel El Souk, Bouteldja and Bougous stations. These were followed by a marked decrease in inflow volumes. Conversely, no breaks were detected (*P*-value > 0.05) in the time series at the Cheffia, Bouhadjar and Aïn Kerma.

Table 3. Results of the Pettitt test applied to the annual series of inflows (1958–2024)

Station	Code	Alpha	P-value	Break year	Mean before BP	Mean after BP	Reduction rate [%]
Cheffia	031501	0.05	0.66	/	/	/	/
Bouhadjar	031503	0.05	0.602	/	/	/	/
Ramel El Souk	031602	0.05	0.0118	1987	273.30	161.11	41.05
Bougous	031603	0.05	0.0326	2006	152.80	81.24	46.83
Ain Kerma	031604	0.05	0.4872	/	/	/	/
Bouteldja	031718	0.05	0.0142	1993	70.06	43.57	37.81
Ain Segniour	120103	0.05	0.0094	2004	66.75	29.02	56.52
Ain Dalia	120114	0.05	0.0006	1987	36.05	16.77	53.48
Ranem	/	0.05	0.008	1985	30.89	19.20	37.84
Meskiana	120201	0.05	0.039	1977	89.68	44.49	50.39
Hamamet	120304	0.05	0.0074	1977	228.99	58.57	74.42
Bekkaria	120307	0.05	0.0066	1997	133.03	27.26	79.51
Ouldjet Mellegue 01	120309	0.05	0.0001	1973	85.87	18.03	79.00
Ouldjet Mellegue 02	120404	0.05	0.0034	1970	164.61	49.29	70.06
K'seub	120521	0.05	0.0216	1973	25.87	3.69	85.74

For the stations in WS.12 (the Medjerda-Méllegue watershed), all of the analysed stations show a significant break. The Ouldjet Mellegue 01 and 02 hydrometric stations, and the K'seub, Meskiana, and Hammamet rainfall stations all exhibited significant disruptions in the 1970, particularly in 1970, 1973, and 1977. Conversely, the Ranem and Aïn Dalia stations exhibited significant breaks in 1985 and 1987, respectively. A marked break was also observed in the estimated series of inflows from the Bekkaria station in 1997 and the Aïn Segniour station in 2004.

Cartographic and quantitative analysis of the decrease in inflows

Figure 2 shows a marked spatial variability of inflows in the WS.03 and WS.12 basins. Before the breakpoint, volumes ranged from 25.87 to 273.30 hm³, with higher values in the northeastern area and in the mountainous regions of the Medjerda basin. After the breakpoint, they dropped to 3.69–161.11 hm³, indicating a generalized decrease, more pronounced in the Medjerda basin (WS.12), particularly in its southern parts.

The map (Fig. 03) illustrates this reduction in terms of the reduction rate, stations located in the north, such as Bougous, Bouteldja and Ramel El Souk, show moderate reductions of between 38% and 47%. In contrast, a significant reduction of over 70% is observed at dams located in the south of the Medjerda basin, notably at Hammamet (74.42%), Ouled Mellegue (70.06% and 79.01%), Bekkaria (79.51%), and up to 85.73% at K'seub.

Identifying hydrological crises and water surpluses using the SRI Index

The SRI (Standardized Runoff Index) makes it possible to detect both hydrological crises (dry periods) and excess water (wet periods) based on standardized water inflows. Depending on the drought index category used, SRI values ≥0 indicate wet conditions; values between −0.99≤SRI<0 correspond to mild drought; values between −1.49≤SRI<−1.00 indicate moderate drought; values between −1.99≤SRI<−1.50 indicate severe drought, and SRI values ≤−2.0 indicate extreme drought (Soľáková et al., 2022; Rattayová et al., 2024). The graphs in Figure 4 show a clear alternation between dry and wet periods within the study area. In the Eastern Constantinois Coastal watershed, the stations generally experienced wet conditions during the early decades, particularly at Bouhadjar (1958–1965), Aïn Kerma (1958–1978), Ramel El Souk (1958–1987), and Bougous. The latter recorded a prolonged wet phase between 1971 and 1999, framed by two dry periods (1958–1970 and 2000–2024). In contrast, the Bouteldja station shows a gradual transition toward mild to moderate drought conditions over the period 1994–2024. A similar pattern is observed in the northern part of the Medjerda-Mellegue basin, particularly at Aïn Dalia, Aïn Segniour, and Ranem stations. Furthermore, the stations located in the southern parts of the study area, belonging to the Medjerda-Mellegue basin—such as Meskiana, K'seub, Hammamet, Bekkaria, as well as Ouldjet Mellegue 01 and 02–exhibit a prolonged drought period from the 1970s to 2024, reflecting a more

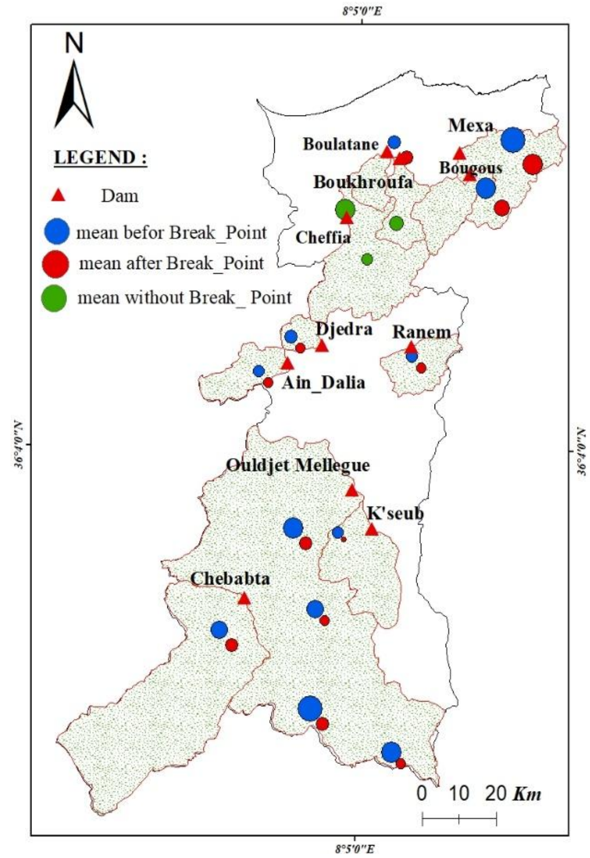


Fig. 2. *Spatial distribution of mean annual inflows before and after breakpoints (1958–2024).*

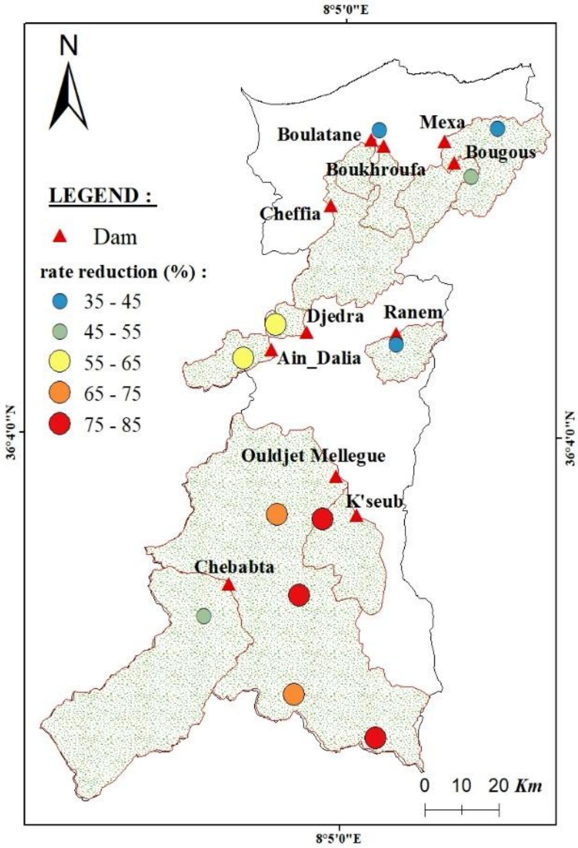


Fig. 3. Spatial distribution map showing the reduction rates of inflow at dams in the study area between 1958 and 2024.

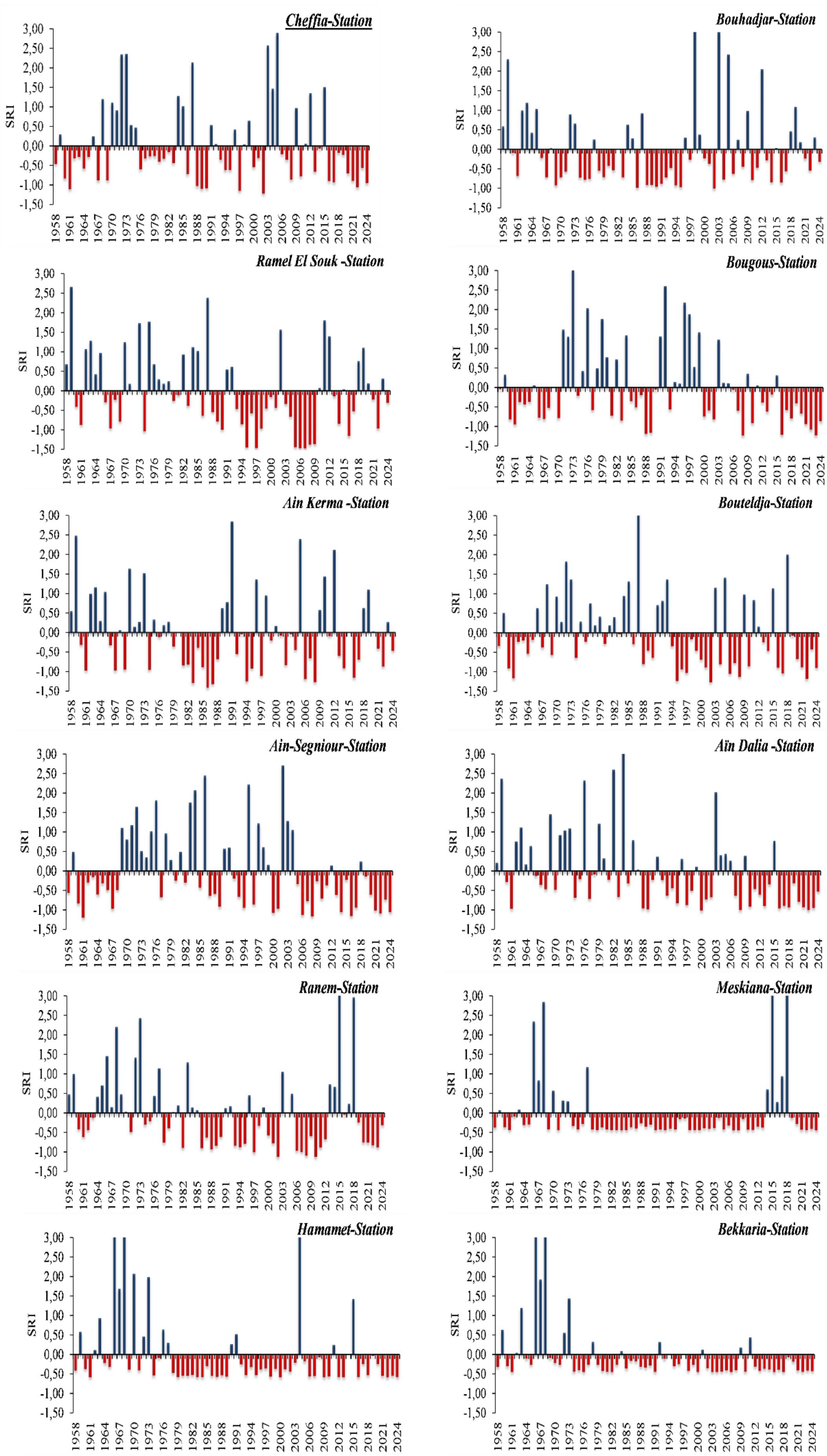
pronounced structural drought in this part of the basin.
The analysis of hydrological condition frequencies based on the SRI index reveals a widespread predominance of mild drought conditions across all stations in the two studied basins (Fig. 5). In the eastern coastal Constantinois basin, wet periods remain relatively moderate (36% to 45%), while mild drought conditions dominate (43% to 60%), with limited but noticeable occurrences of moderate drought (1% to 12%). In contrast, the Medjerda basin exhibits a more critical situation, characterized by a low proportion of wet periods (21% to 43%) and a strong dominance of dry conditions, reaching up to 79%, particularly at the Meskiana, Hamamet, Bekkaria, and K'seub stations. These results indicate an intensification of hydrological deficit in this basin, reflecting a higher hydrological vulnerability compared to the eastern coastal Constantinois basin.

Man-Kendall test

The application of the non-parametric Mann-Kendall test to the annual series of inflows (1958–2024) revealed a decreasing trend ($Z<0$) across the entire study area (Table 4). Nine stations, namely: Ramel El Souk, Bougous, Ain Segniour, Hammamet, Bekkaria, K'seub, Bouteldja, Ain Dalia and Ramel. These stations show a significant decreasing trend ($Z<0$ and $p<0.05$). The results obtained from the Sen slope were used to quantify the annual trend in inflows to the dams in the two basins within the study area. Analysis revealed a negative slope at all stations, with significant drops at most of them and annual losses of up to -2.035 hm^3 $year^{-1}$ (Ramel El Souk station). These results indicate a marked downward trend, which is confirmed by the significant results of the Mann–Kendall test.

Innovative trend analysis (ITA)

The results of the Innovative Trend Analysis (ITA) of the water inflow series, presented in Fig. 6, show that the majority of the stations exhibit a decreasing trend, characterized by a concentration of data points below the 1:1 line. In the East Constantine Coastal watershed, the Aïn Kerma station shows data points generally concentrated around the 1:1 line, indicating the absence of a significant trend. The Bougous station presents a similar configuration, with a slight displacement of points below the reference line, suggesting a weak decreasing trend. The Bouteldja and Ramel El Souk stations exhibit a more pronounced negative trend, with a progressive change in intensity ranging from low to moderate for Bouteldja and from low to high for Ramel El Souk. The Cheffia and Bouhadjar stations also display a decreasing trend in water inflows, despite the presence of a few points above the 1:1 line, indicating slight increases in high-flow values. In the Medjerda–Mellegue watershed, all stations exhibit a significant decreasing


Cheffia-Station
Bouhadjar-Station
Ramel El Souk -Station
Bougous-Station
Ain Kerma -Station
Bouteldja-Station
Ain-Segniour-Station
Aïn Dalia -Station
Ranem-Station
Meskiana-Station
Hamamet-Station
Bekkaria-Station
SRI
3,00
2,50
2,00
1,50
1,00
0,50
0,00
-0,50
-1,00
-1,50
1958
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
2015
2018
2021
2024

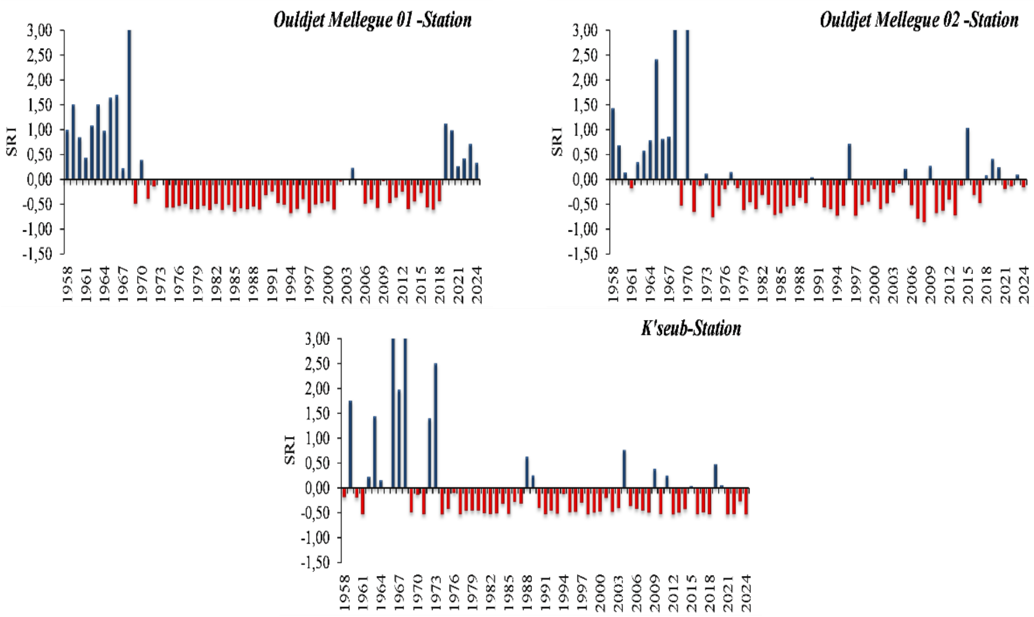


Fig. 4. *Diagrams of the temporal distribution of the SRI for the annual series of inflows (1958–2024).*

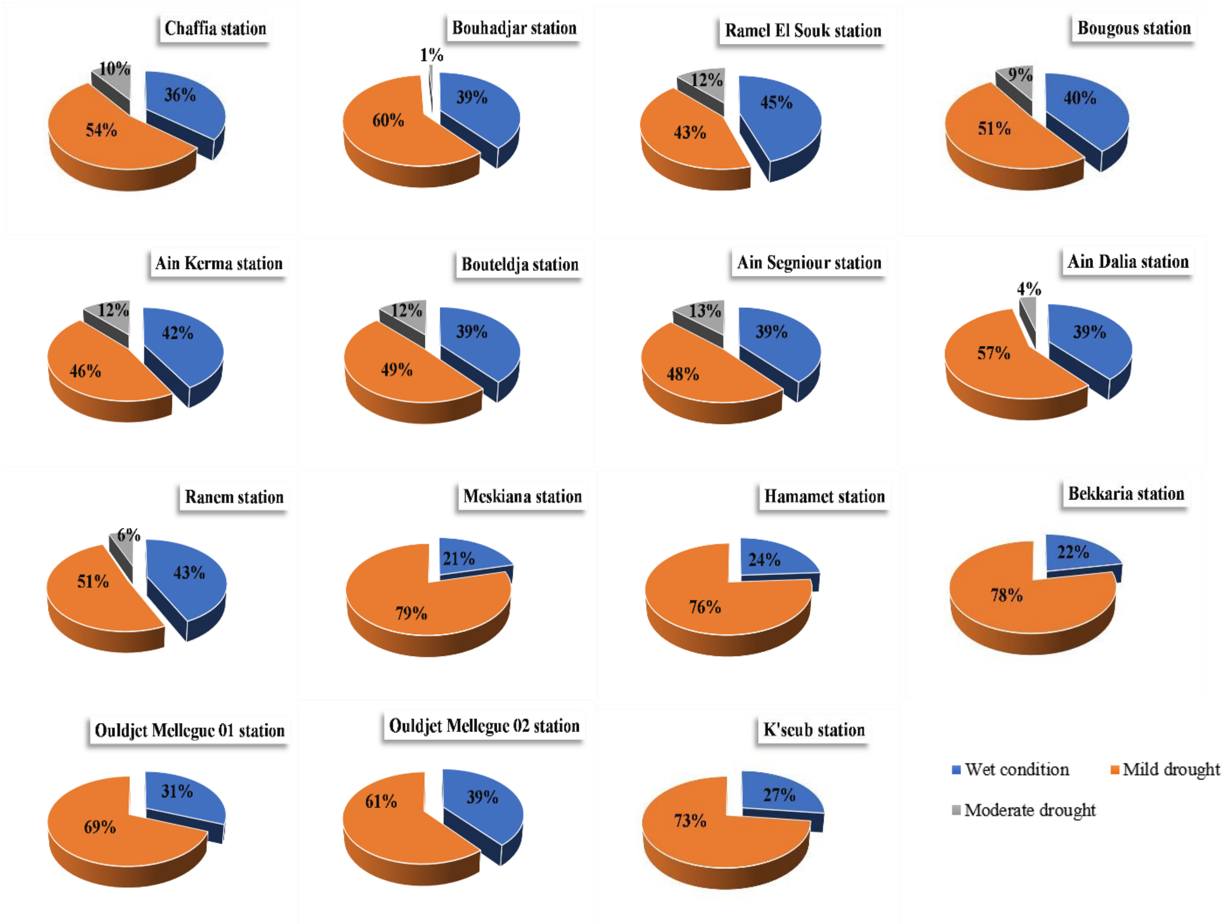
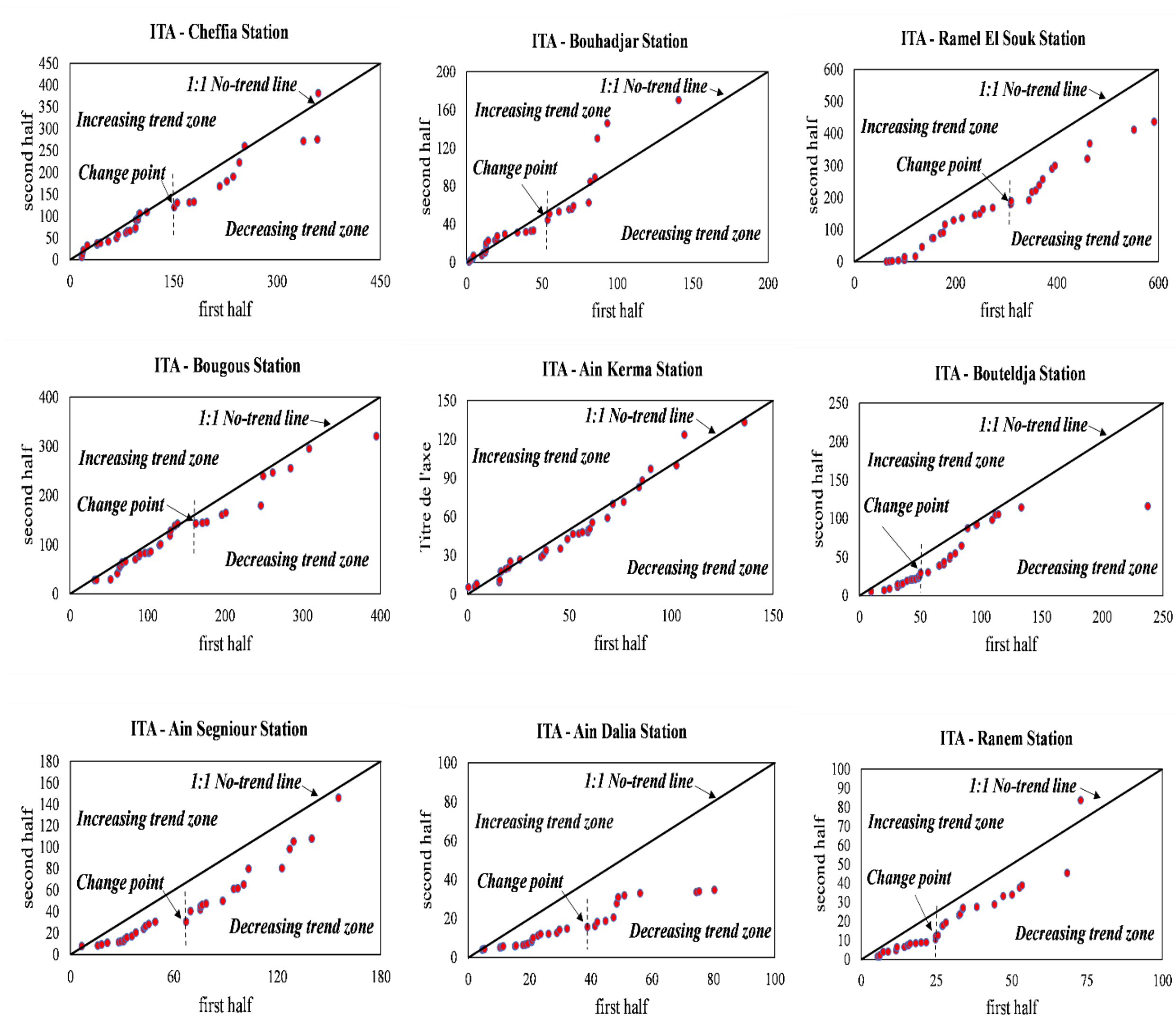


Fig. 5. *Graphs of the frequencies of dry and wet periods detected by the SRI index (1958–2024).*

trend in water inflows. Most of the data points are distributed below the 1:1 line, reflecting a generalized decline in inflow volumes. The change in direction observed in several graphs indicates a progressive intensification of the negative trend, generally ranging from low to moderate intensity.

Table 4. **Results of the Mann-Kendall test applied to the annual series of inflows (1958–2024), (*): Significant trend**

Station	Code	*Z*	*P*-value	Alpha (*α*)	Sen's slope	Trend
Cheffia	31501	-1.07	0.284	0.05	-0.596	Negative
Bouhadjar	31503	-0.32	0.745	0.05	-0.068	Negative
Ramel El Souk	31602	-2.11	0.035	0.05	-2.035	Negative*
Bougous	31603	-2.01	0.044	0.05	-0.792	Negative*
Ain Kerma	31604	-1.02	0.309	0.05	-0.227	Negative
Bouteldja	31718	-1.96	0.050	0.05	-0.401	Negative*
Ain Segniour	120103	-2.26	0.024	0.05	-0.463	Negative*
Ain Dalia	120114	-3.84	0.000	0.05	-0.361	Negative*
Ranem	/	-2.47	0.014	0.05	-0.234	Negative*
Meskiana	120201	-1.15	0.251	0.05	-0.050	Negative
Hamamet	120304	-2.5	0.012	0.05	-0.652	Negative*
Bekkaria	120307	-3.27	0.001	0.05	-0.825	Negative*
Ouldjet Mellegue 01	120309	-0.83	0.408	0.05	-0.108	Negative
Ouldjet Mellegue 02	120404	-1.61	0.107	0.05	-0.445	Negative
K'seub	120521	-2.63	0.009	0.05	-0.050	Negative*



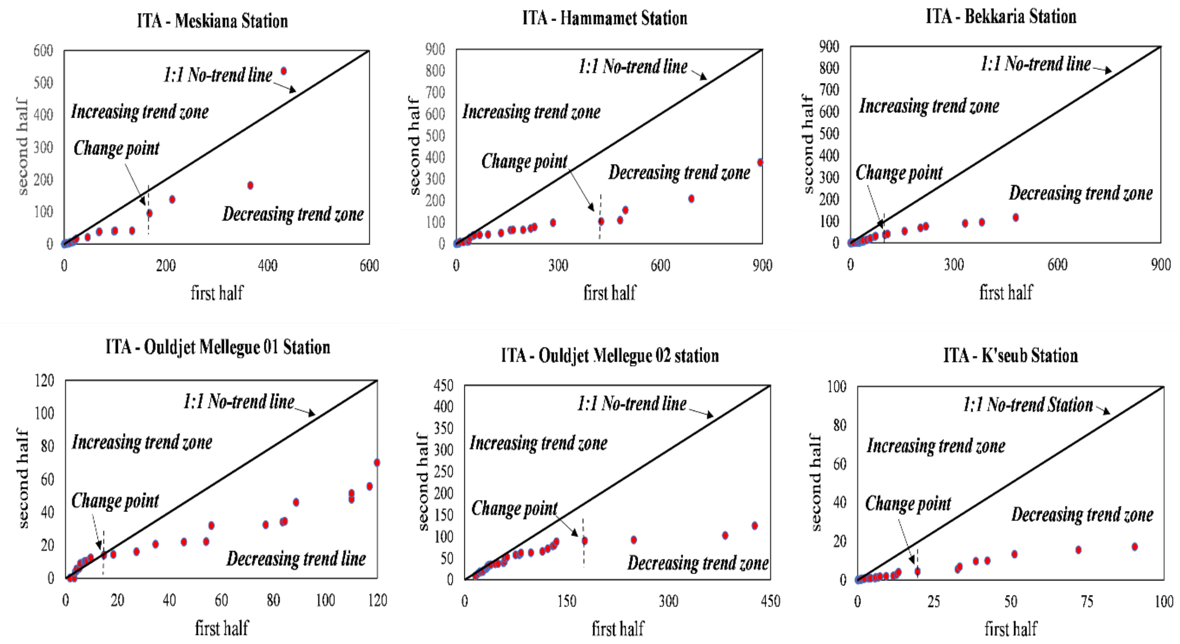


Fig. 6. Graphs illustrating the application of Innovative Trend Analysis (ITA) to the annual series of inflows (1958–2024).

Conclusion

The analysis of annual inflow series (1958–2024) from 15 stations located upstream of dams within the Eastern Constantinois Coastal and Medjerda-Mellegue basins revealed a significant and structural decline in water resources. The Pettitt test identified statistically significant change points in most stations, occurring earlier in the southern part of the study area (from the 1970) and later in the northern part (mainly from the 1990). These breakpoints were followed by substantial reductions in inflow volumes, with moderate decreases in the northern stations (38–47%) and much stronger declines in the southern, sometimes exceeding 70%.

The results of the SRI analysis reveal a clear spatial contrast in hydrological drought conditions across the study area. The northern sector of the Eastern Constantinois Coastal basin exhibits a relatively balanced alternation between wet and dry periods, whereas the southern and southeastern parts of the Medjerda-Mellegue basin are dominated by persistent drought conditions, with dry periods reaching up to 79% of the observation period. These findings indicate that the southern sub-basins, particularly the stations of Meskiana, K'seub, Hammamet, Bekkaria, and Ouldjet Mellegue, represent the most vulnerable areas and are the most exposed to the impacts of climate change.

The Mann–Kendall test reveals significant decreasing trends in the majority of the analyzed stations. The magnitude of this decline, estimated using Sen's slope, ranges from −2.035 to −0.050 Mm^3 $year^{-1}$, indicating a heterogeneous but overall marked reduction in inflows. The Innovative Trend Analysis (ITA) method confirms this pattern, showing a predominance of negative trends across all-time series.

Overall, the combined application of different statistical methods highlights a widespread degradation in water resource availability across the studied basins. The results indicate a persistent decrease in hydrological inflows throughout the study area, with a more pronounced intensity in the southern part. This spatial variability suggests a higher sensitivity of the southern sectors to the impacts of climate change. These findings underscore the growing vulnerability of the Medjerda–Mellègue basin and emphasize the urgent need to implement adaptation strategies and sustainable water resource management practices in order to mitigate future hydrological stresses in northeastern Algeria.

References

Abdeddaim, H. (2018): Contribution à l'étude de l'influence de la structure du réseau hydrographique sur le risque hydrologique " Cas des bassins de l'Est de l'Algérie " [PhD thesis, Université Mohamed Khider - Biskra]. http://archives.univ-biskra.dz/handle/123456789/23973 (in French)

Adjissi, O., Ghodbane, M., Ladjel, M., Madani, K. (2025): A new approach to modelling the average interannual streamflow in the watersheds of Northern Algeria. Journal of Water and Land Development, 24–35. https://doi.org/10.24425/jwld.2025.154247

Ahmad, I., Tang, D., Wang, T., Wang, M., Wang, B. (2015): Precipitation Trends over Time Using Mann-Kendall and Spearman's rho Tests in Swat River Basin, Pakistan, Advances in Meteorology, 2015, e431860. https://doi.org/10.1155/2015/431860

Alifujiang, Y., Abuduwaili, J., Maihemuti, B., Emin, B., Groll, M. (2020): Innovative Trend Analysis of Precipitation in the Lake Issyk-Kul Basin, Kyrgyzstan. Atmosphere, 11(4), 332. https://doi.org/10.3390/atmos11040332

Aouachria, M. (2023): Les signes de l'érosion hydrique à travers les sous bassins versants d'Oued El Arab : Causes et effets sur le barrage de Babar [Doctoral thesis.

Université Mohamed Khider - Biskra]. http://thesis.univ-biskra.dz/id/eprint/6232 (in French)

Bendjema, L. (2020): Contribution de la modélisation hydrologique l'évaluation de l'impact de la variabilité climatique sur la ressource en eau. Cas du bassin versant d'oued Mellah (NE algérien) [PhD thesis. Université Aboubakr Belkaid Tlemcen]. http://dspace.univ-tlemcen.dz/handle/112/16122 (in French)

Benzater, B. (2021). Evolution des précipitations dans le contexte des changements climatiques au Nord-Ouest Algérien [Doctoral thesis. Université Mustapha Stambouli Mascara]. http://dspace.univ-mascara.dz:8080/jspui/handle/123456789/488 (in French)

Berhail, S., Katipoğlu, O. (2024): Exploring hydrological and meteorological drought trends in Northeast Algeria: Implications for water resource management. Theoretical and Applied Climatology, 155, 9689–9712. https://doi.org/10.1007/s00704-024-05207-y

Berhail, S., Katipoğlu, O. M. (2023): Spatiotemporal detection of abrupt change in trends of rainfall and dry and wet periods at different time scales: The case of the Medjerda basin in northeast Algeria. Acta Geophysica, 71(5), Article 5. https://doi.org/10.1007/s11600-023-01097-2

Boni, L., Jean Sodji, S., Sabi tassigui sio, T. S., Pierre, O., Expédit, W. V. (2024): Indicateurs des risques climatiques majeurs dans les communes de 2KP (Kérou, Kouandé, Péhunco) au nord-ouest du Bénin. https://doi.org/10.5281/ZENODO.14022152 (in French)

Boursali, L., Baba Hamed, K., Bouanani, A. (2025): Analysis of climate variability and its impacts on water resources in the Oued Khemis catchment, Algeria. VertigO - la revue électronique en sciences de l'environnement. https://doi.org/10.4000/13hs5

Drouiche, A., Nezzal, F., Djema, M. (2019): Interannual variability of precipitation in the Mitidja plain of northern Algeria. Revue des sciences de l'eau, 32(2), 165–177. https://doi.org/10.7202/1065205ar

Fossou, R. M. N., Soro, N., Traore, V. B., Lasm, T., Sambou, S., Soro, T., Orou, R. K., Cisse, M. T., Kane, A. (2014): Climatic variability and its impact on surface the case of Bocanda and Dimbokro stations in Central-Eastern Cote d'Ivoire (West Africa), Revue Afrique Science, 10 (4), 118–134. https://dspace.univghardaia.edu.dz/xmlui/handle/123456789/6502

Haidu, I. (2006): Comparison of statistical tests for global climate change. Actes du colloque d'Épernay, 282–287.

Hallouz, F., Meddi, M., Mahe, G., Karahacane, H., Ali Rahmani, S. E. (2019): Rainfall trends and runoff evolution in a climate oued Mina watershed in Algeria. Revue des sciences de l'eau, 32(2), 83–114. https://doi.org/10.7202/1065202ar

Haouari, M. (2024): Recent evolution of mean temperatures in Algeria. JAMA, 8, 1–8.

Kabour, A., Chebbah, L. (2023): Highlighting climate change by applying statistical tests and climate indices to the temperature of Kébir Rhumel watershed, Algeria. Theoretical and Applied Climatology, 155(2), 805–814. https://doi.org/10.1007/s00704-023-04660-5

Kabour, A., Chebbah, L. (2024): Assessing climate change in the Kébir Rhumel catchment (Algeria) using statistical analysis of spatiotemporal rainfall variability. Acta Geophysica, 72(4), 2941–2953. https://doi.org/10.1007/s11600-023-01282-3

Kabouya, M. (1990): Rainfall-flow modelling at monthly and annual time steps in northern Algeria. Université Paris-Sud, Paris, France.

Kendall, M. G., (1975): Rank Correlation Methods 5th edn, London: Oxford University Press.

Khedimallah, A. (2021): Impact des changements climatiques et anthropiques sur les ressources en eau dans les bassins du Cheliff et de la Medjerda [Doctoral thesis. L'Ecole Nationale Supérieur d'Hydraulique]. (in French)

Khoualdia, W., Djebbar, Y., Hammar, Y. (2014): Caractérisation de la Variabilité Climatique: Cas du Bassin Versant de La Medjerda (Nord-Est Algérien) = Characterization of Climate Variability: Case of Watershed Medjerda (North East of Algeria). Synthèse: Revue des Sciences et de la Technologie, 29, 6–23. https://doi.org/10.12816/0027871 (in French)

Lubes-Niel, H., Masson, J. M., Paturel, J. E., Servat, E. (1998): Climatic variability and statistics. Study by simulation of the power and robustness of some tests used to verify the homogeneity of chronicles. Rev Sci Eau 11: 383–408. https://doi.org/10.7202/705313ar.

Mann, H. B. (1945): Non parametric Tests Against Trend, Econometrica, 13(3), 245. https://doi.org/10.2307/1907187

Medinger, G. (1948): Tableau général de l'hydrologie algérienne in Hydrologie Algérienne, recueil des observations de 1924 à 1946. SCEGGT Algiers, Algeria. (in French)

Méndez, C., Simpson, N., Johnson, F., Birt, A. (2023): Climate Change 2023: Synthesis Report (Full Volume) Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. https://doi.org/10.59327/IPCC/AR6-9789291691647

Merabti, A., Darouich, H., Paredes, P., Meddi, M., Pereira, L. S. (2023): Assessing Spatial Variability and Trends of Droughts in Eastern Algeria Using SPI, RDI, PDSI, and MedPDSI-A Novel Drought Index Using the FAO56 Evapotranspiration Method. Water, 15(4), Article 4. https://doi.org/10.3390/w15040626

Merniz, N. (2021): Etude de la variation spatiotemporelle des précipitations dans le Nord-Est algérien [Doctoral thesis. Université des frères Mentouri Constantine1]. http://depot.umc.edu.dz/handle/123456789/4971 (in French)

Meskine, A. (2009): Étude d'avant-projet détaillé d'un évacuateur de inondes du barrage de Bounachi sur oued Rabta (w. Tizi Ouzou). [Thesis, École Nationale Supérieure D'hydraulique - Alger]. (in French)

Pettitt, A. N. (1979): A non -parametric Approach to the chage -point. Problem, Applied Statistics, 28N°2, 126–135.

Rattayová, V., Garaj, M., Hlavčová, K. (2024): How did the aridity of the climate in Slovakia change over last decades? Acta Hydrologica Slovaca, 25(1), 64–72. https://doi.org/10.31577/ahs-2024-0025.01.0007

Regad, N., Tatar, H. (2019): Rainfall trend and variability in a semi-arid region: a case study of the "Timgad catchment". Sciences et Technologie, 37-44.

Sediqi, M. N., Komori, D. (2024): Assessing Water Resource Sustainability in the Kabul River Basin: A Standardized Runoff Index and Reliability, Resilience, and Vulnerability Framework Approach. Sustainability, 16, 246. https://doi.org/10.3390/su16010246

Sen, P. K. (1968): Estimates of the Regression Coefficient Based on Kendall's Tau. Journal of the American Statistical Association, 63(324), 1379-1389. https://doi.org/10.1080/01621459.1968.10480934

Şen, Z. (2012): Innovative trend analysis methodology. J Hydrol Eng 17: 1042–1046. https://doi.org/10.1061/(ASCE)HE.1943- 5584.0000556

Shukla, S., Wood, A. W. (2008): Use of a standardized runoff index for characterizing hydrologic drought. Geophysical Research Letters, 35.137, L02405, http://dx.doi.org/10.1029/ 2007.gl032487, 2008.

Soľáková, T., Zeleňáková, M., Mikita, V., Hlavatá, H., Simonová, D., Abd Elhamid, H. (2022): Assessment of meteorological and hydrological drought using drought indices: SPI and SSI in eastern Slovakia. Acta Hydrologica Slovaca, 23(2), 267–272. https://doi.org/10.31577/ahs-2022-0023.02.0030

Spinoni, J., Barbosa, P., Bucchignani, E., Cassano, J., Cavazos, T., Christensen, J., Christensen, O., Coppola, E., Evans, J., Geyer, B., Giorgi, F., Hadjinicolaou, P., Jacob, D., Katzfey, J., Koenigk, T., Laprise, R., Lennard, C., Kurnaz, L., Li, D., Dosio, A. (2020): Future Global Meteorological Drought Hot Spots: A Study Based on CORDEX Data. Journal of Climate, 33, 3635–3661. https://doi.org/10.1175/JCLI-D-19-0084.1.

Taibi, S., Meddi, M., Souag, D., Mahe, G. (2013): Evolution and regionalisation of rainfall in northern Algeria (1936–2009). Climate and Land Surface Changes in Hydrology, 191–197.

Wu, J., Chen, X., Yao, H., Liu, Z., Zhang, D. (2018): Hydrological Drought Instantaneous Propagation Speed Based on the Variable Motion Relationship of Speed-Time Process. Water Resources Research, 54(11), 954939565. https://doi.org/10.1029/2018WR023120

Chehla Saadoun*, PhD (*corresponding author, e-mail: c.saadoun@univ-soukahras.dz)
Mohamed-Chérif Messaadia University
Souk Ahras
Laboratory of Modeling and Socio-Economic Analysis in Water Science – MASESE Lab.
Algeria

Prof. Abdesselem Kabour
Mila University Centre
Laboratory of Modeling and Socio-Economic Analysis in Water Science – MASESE Lab.
Algeria

Prof. Lotfi Zeghadnia
Mohamed-Chérif Messaadia University
Souk Ahras
Laboratory of Modeling and Socio-Economic Analysis in Water Science – MASESE Lab.
Algeria