



The impact of climate change on groundwater resources in northwestern Algeria

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Abstract

Algeria lies in one of the most vulnerable regions facing climate change impacts during the twenty-first century. Northwestern Algeria has experienced a persistent decline in annual rainfall associated with the significant increase in temperature during the twentieth century. This variability has been accentuated since the 1980s and has had a significant impact on water resources. The primary motto of the current study is to measure the impact of climate change on groundwater resources using time series of rainfall and runoff data measured in the Tafna Basin (7245 km²) of Algeria. The application of meteorological drought indices and statistical test of Pettitt shows that a rainfall regime modification occurred around the seventies. This modification reveals a decrease of rainfall between 8.21 and 38.85% according to the stations, with an average of 17.85%. The average recession coefficients obtained by Maillet's exponential model varies between 8.90.10 and 17.06.10⁻² day⁻¹ either side of 1987, with an average increase of 45.45% and highlight a much faster drainage of the aquifers supplying the baseflow after 1987. A shortening of 1 to 11 days with an average of 6 days of the duration of the recession after 1987 was highlighted. The average water volumes mobilized by the aquifers fluctuated between 11.38 and 3.62 hm³ before and after 1987, with an average decrease of - 69.06%. These results show a decrease in the water volumes mobilized by the aquifers after 1987 and suggest a considerable decline of groundwater resources under the influence of climate change.

Keywords Climate change · Water resources · Statistical tests · Maillet recession model · Tafna basin · Algeria

Introduction

Climate change refers to a change in average weather conditions occurring on the long time-scale that may range from decades to thousands of years. There are different factors causing climate change and there have been numerous debates about them in recent decades; however, there is now the unequivocal consensus that its main cause is the increase in anthropogenic greenhouse gases. Climate change has strong impacts on the various components of the hydrological cycle, including runoff and groundwater resources (Mileham et al. 2009; Aizebeokhai 2011; Kumar 2012; Bindra et al. 2013; Hashemi et al. 2015). IPCC (Intergovernmental Panel on Climate Change) published a report

in 2001 in which it was mentioned that African countries are facing the wrath of such environmental changes due to the absence of economic development and institutional capacity. The reports published by IPCC in the years 2001 and 2007 noted down that, in the twentieth century, 0.7 °C warmth increased coupled with 5–10% increased rainfalls. But the predictions informed that, by the year 2050, the temperature will be 1.5 °C warmer. There will be increased precipitation in equatorial Africa while it will be decreased by 10% in northern African regions (IPCC 2007; 2013). According to Joubert and Hewitson (1997), which inferred similar predictions, there is mean decreased summer rainfall expected in Africa by 10–20% at the end of the twenty-first century. Such changes lead to increased evaporation which in turn results in strong rainstorms, thus affecting the availability, quality, and quantity of water (IPCC 2001; Phoon et al. 2004). When there is heavy rainfall, that too during wet seasons, agriculture gets affected and engineering structures get damaged due to high runoff (Arnell 1999). By 2050s, Milly et al. (2005) predicted a 10–20% increased runoff in the east African region. But according to Arnell (1999), most African regions will face notable reduction in runoff during summer. Though the

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investigations are being conducted focusing surface water, the groundwater's important aspects are yet to be investigated further. The groundwater's impacts are far-reaching which needs a proper investigation especially in a country like Africa since most of the population rely on groundwater for drinking and domestic purposes (Taylor and Howard 1996; Kulabako et al. 2007). Seventy percent of the Algerian safe water supplies are from groundwater wells and boreholes (ABHCSM 2009). It represents the only available water resource in many towns and cities in the northwest region due to the scarcity or lack of sufficient available surface water resources. Being an important life resource, the awareness on groundwater must be increased since it faces a lot of threats such as pollution, climate change, and overexploitation. But some of the investigations were conducted regarding the climate change effects on groundwater resources.

Therefore, we attempt in this study to investigate the impact of climate change on groundwater resources in the Tafna basin. The methodological approach is based on the evaluation of recession coefficients, of the duration of recession, and the water volumes mobilized by the aquifers for a period of a 34-year time series of daily discharge measured in different sub-basins of the Tafna Basin.

Study area description

Geographic presentation of the Tafna

Being the final stream in Algerian northwestern parts, Tafna river basin is near the Moroccan border and have its source upon the Tlemcen mountains (1400 m). Dahmani et al. (2003) mentioned that with 7245 km², the river basin has eight sub-basins of which two are upstream in the Moroccan territory. With heights reaching up to 1843 at djebel Tenouchfi, the basin has boundaries on all ends, i.e., the main relief (Tlemcen mountains) between the Mediterranean and Oran's high plains, has Moroccan middle atlas by west, and has Daia mountains (Saida) to its east.

In the basin, the south region mostly had mountains (800–1400 m altitude) with dominant north region and plain regions of Hannaya, Maghnia, and Sidi Abdelli. Taras mountains (1081 m) dominated this orographic structure in the north side and with a narrow width, there is an effective barrier to avoid precipitation. The aridity of the maghnia plains is explained best through this scenario. The Tafna basin's hydrographical network mainly has two river arteries such as the western Oued tafna and eastern Oued isser, both originate from Tlemcen mountains (Fig. 1).

There is a variation in basin climate from usual Mediterranean along the coast to semi-arid. The mean annual precipitation values are between 300–700 mm with monthly maximum between 70–120 mm in December or January. In July or August, the minimum and maximum temperatures are

26 °C and 30 °C, whereas during December or January, it is less than 10 °C. The average annual infiltration is 162 mm, whereas 79 mm/yr is the usual surface runoff.

Methodology

Data used

In the current study, a number of studies were reviewed and exploited in order to acquire sufficient knowledge. Further, a number of trips were arranged to (National Office of Meteorology) and ANRH (National Agency of Hydraulic Resources) along with repeated field surveys for the study. Annual precipitation data were collected from 11 meteorological stations covering different time periods; they meet the criteria for each station to cover at least 3 decades (Table 1).

For a period of 34 years, the data for daily river discharge was collected in order to evaluate the impact created by climate change upon groundwater resources in various sub-basins of the Tafna basin. The complete and consecutive daily flow data drawn from the five chosen stations were analyzed in order to represent the whole field (Table 2) on the basis of criteria required for the study reliability such as existence of complete sets for the duration of our study and their location in the five sub-basins that form the area of study.

Drought indices

Drought indices are generally used to detect, monitor, and evaluate the drought events. The most commonly used drought indices are the Palmer Drought Severity Index (PDSI) (Palmer 1965), Standardized Precipitation Index (SPI) (McKee et al. 1993), Standardized Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al. 2010), Soil Moisture Index (SMI) (Hunt et al. 2009), Water Surplus Variability Index (WSVI) (Gocic and Trajkovic 2015), and so on. Among these, the SPI and SPEI were selected to describe temporal drought fluctuations for our study (Table 3). These indices are perceived to be more broadly useful and easy to implement and are typically calculated from time series measurements of precipitation and temperature (Heim 2002; Hayes et al. 2011). McKee et al. (1995) mentioned that SPI is calculated on the basis of statistical analysis of precipitation data at the given location. During a specific time period, the precipitation sums, or otherwise aggregation scale, are utilized to generate a cumulative probability of these time series.

According to Stagge et al. (2015), in general, a gamma distribution is fitted with the help of maximum likelihood approach to the observed precipitation tools though one can use other distributions too. The quantiles of estimated gamma distribution are transformed to standard normal variables so as to compare the SPI values with different locations. As a result, the negative SPI

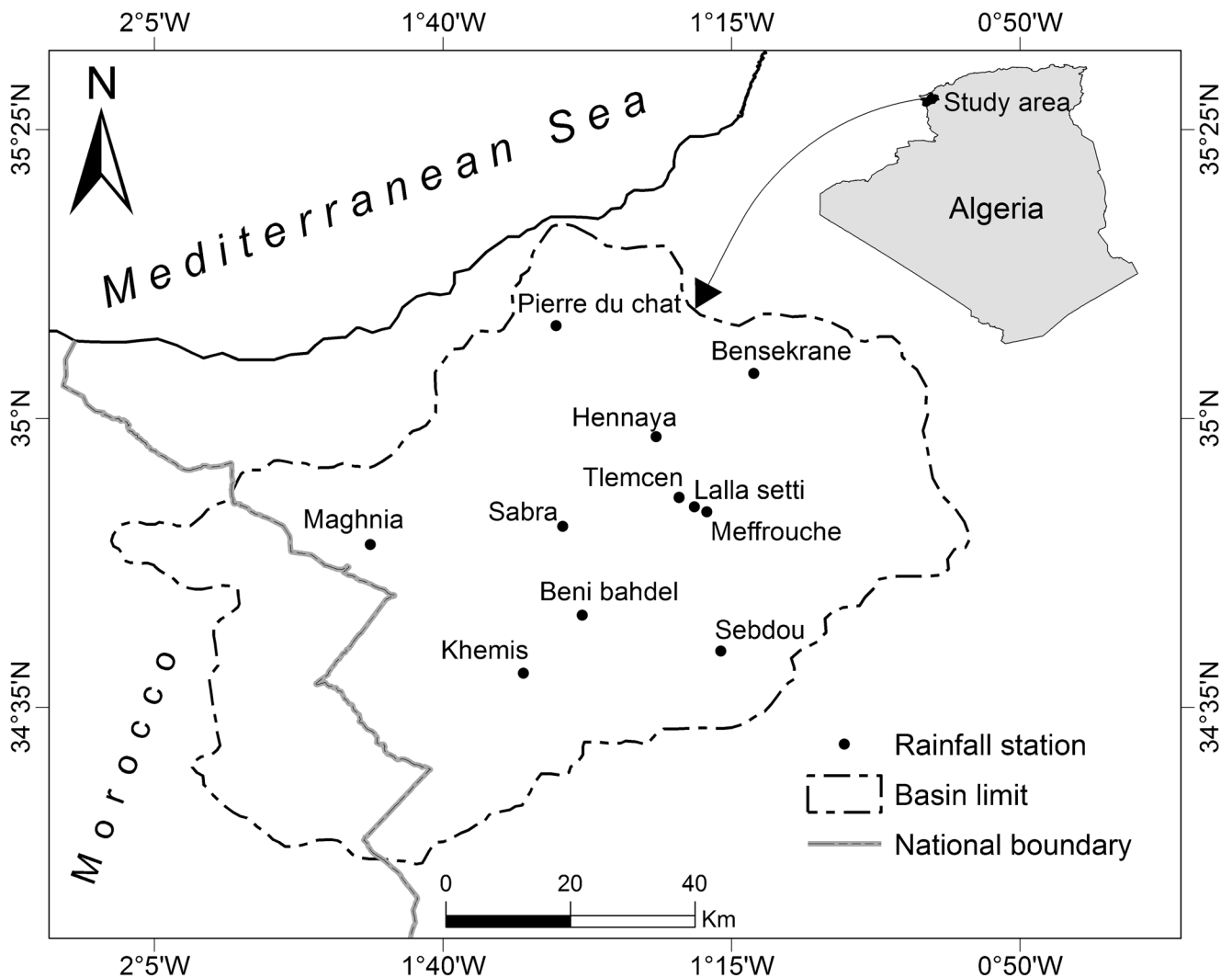


Fig 1. Geographical situation and rainfall station of the Tafna basin

values denote less than median precipitation while positive values denote wetter than median conditions.

Table 1 List of analyzed rainfall stations in the Tafna basin (Gocic and Trajkovic 2014)

Rainfall station	Longitude	Latitude	Altitude	Period analyzed
Beni behdel	34° 42'	01° 29'	666	1941–2006
Bensekrane	35° 04'	01° 13'	247	1924–2006
Meffrouche	34° 51'	01° 17'	1110	1943–2009
Maghnia	34° 48'	01° 48'	435	1972–2004
Lalla Setti	34° 51'	01° 19'	1007	1964–2004
Tlemcen	34° 52'	01° 19'	810	1965–2008
Sebdou	34° 38'	01°19'	875	1940–2014
Hennaya	34° 55'	01° 23'	515	1965–2003
Sabra	34° 49'	01° 32'	608	1970–2003
Pierre du chat	35° 08'	01° 26'	60	1967–2003
Khemis	34° 38'	01° 33'	1000	1969–2003

Similar to the procedure for the SPI calculation, the SPEI considers the difference between precipitation and potential evapotranspiration, which is a simple methodology of water balance and can be calculated, as well, at different time scales. Therefore, SPEI calculation is used a comprehensive set of data characterizing atmospheric precipitation, temperature, and the potential evapotranspiration. The details of the SPEI computation, more thoroughly, are described in Vicente-Serrano et al. (2010). In the current article, the SPI and SPEI were analyzed with the help of 12 months' consolidated precipitation and potential evapotranspiration sums. The best performance showed by the correlation of inter-annual changes in precipitation choose the best aggregation scale after comparing such different scales.

Change point test

In order to analyze the effects brought by climate change and human activities, the change point identification is one of the most critical and important statistical methods in streamflow series analysis. Pettitt (1979) developed a non-parametric method

Table 2 List of analyzed streamflow gauging stations in the Tafna basin

Gauging station	Longitude	Latitude	Altitude	Drainage area (km ²)	Period analyzed
Beni Behdel	115	164.60	666	255.5	1973–2007
Bensekrane	143.40	205.35	260	1139.74	1973–2007
Pierre du Chat	123.10	213.35	80	6908	1973–2007
Remchi	133.95	185.80	430	1245	1973–2007
Sidi Belkhir	101.90	205.20	285	2650	1973–2007

which was utilized to find the occurrence of a change point in the current study. This is the widely accepted and adopted method to find the abrupt change points in hydrological as well as climatic records (Mavromatis and Stathis 2011). In this method, there is a significant change that occurs in mean of a time series when the exact time of change remains unknown. The test uses a version of the Mann-Whitney statistic $U_{t,N}$, which verifies whether two samples x_1, \dots, x_i and x_{i+1}, \dots, x_n are from the same population. The test statistic $U_{t,N}$ is given by:

$$U_{T,N} = \sum_{i=1}^t \sum_{j=t+1}^N D_U \quad \text{where } D_U = \begin{cases} \text{sgn}(X) = 1 & \text{if } X > 0 \\ \text{sgn}(X) = 0 & \text{if } X = 0 \\ \text{sgn}(X) = -1 & \text{if } X < 0 \end{cases} \quad (1)$$

In the case where the null hypothesis is rejected, an estimation of break date is given by t , instant defining the maximum in absolute value of variable $U_{t,N}$.

Recession coefficient and water mobilized by the aquifer

The recession curve is the specific part of the hydrograph after the crest (and the rainfall event) that is in the hydraulic connection with an aquifer and is known as a simple but reliable technique that supplies valuable information regarding the storage properties of groundwater reservoir (Brutsaert and Nieber 1977; Kresic and Stevanovic 2010). Recession analysis is based on an appropriate mathematical relationship between spring discharge Q and time t , which then allows predicting the discharge rate after a given period without precipitation and so to calculate the volume of discharged water. However, ideal recession conditions require a long period of several months without

Table 3 Classification of drought according to the SPI and SPEI values

Category	Index value
wet condition	≥ 0
Mild drought	-0.99 to 0
Moderate drought	-1.49 to -1.00
Severe drought	-1.99 to -1.50
Extreme drought	≤ -2.0

precipitation, which is rare in moderate, humid climates. Consequently, frequent precipitation events can cause various disturbances in the recession curve that may not be removed unambiguously during the analysis. It is, therefore, desirable to analyze as many recession curves from different years as possible. Larger samples then allow for a derivation of an average recession curve as well as the envelope of the minima, which enables a more accurate quantification of the expected long-term minimum discharge (Tallaksen 1995). A number of ways are available to showcase the recession curve. Maillet (1905) suggested that the highly preferred mathematical function used is simple exponential decay to describe flow depletion during recession period (Toebes and Strang 1964; Tallaksen 1995; Stella 2013; Eslamian 2014; Hingray et al. 2015; Di Matteo et al. 2017). The following equation expresses the model

$$Q_t = Q_0 e^{-kt} \quad (2)$$

where Q_t denotes the streamflow at time t , Q_0 denotes the initial streamflow at the beginning of the recession segment, and K represents the recession coefficient of Maillet, which depends on the aquifer's transmissivity and specific yield (Szilagyi et al. 1998; Savane et al. 2003) obtained by solving the equation (3) below:

$$\frac{e^{-kt}}{k} + \frac{V}{Q_0} - \frac{1}{k} = 0 \quad (3)$$

We can formulate the expression of the duration of recession T (days) (Vissin 2007; Amoussou 2010):

$$T = \frac{1}{k} \quad (4)$$

Integrating Eq. (2) into the interval $[0, +\infty]$ gives the volume of water mobilized by all aquifers in the basin:

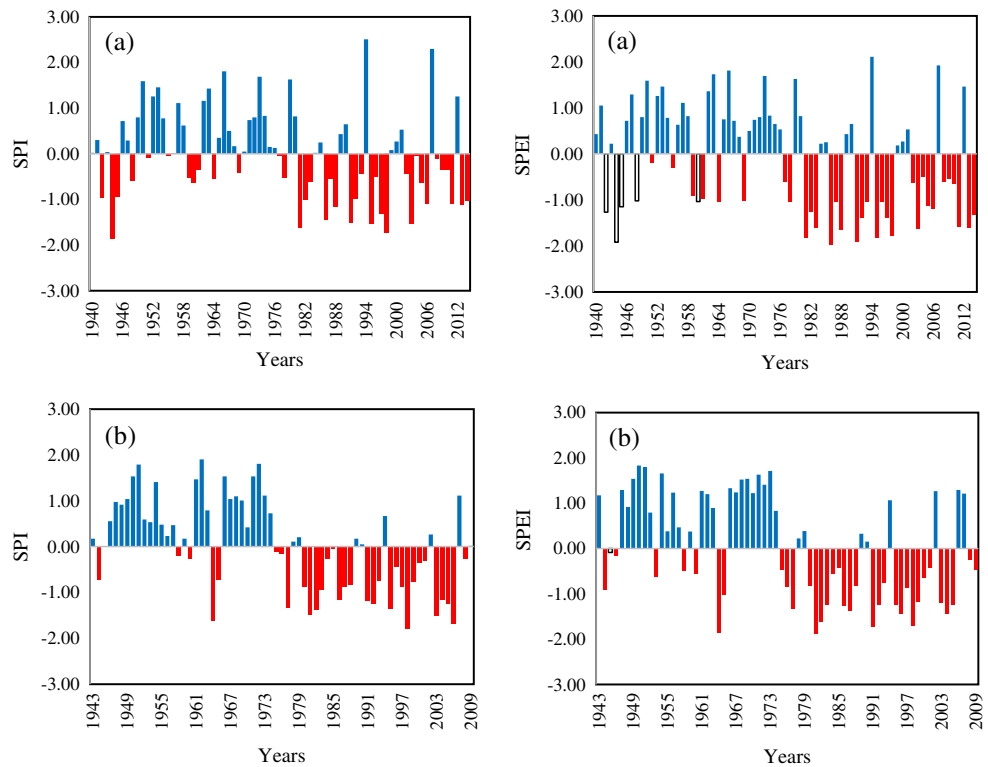
$$V_{\text{mobilized}} = \int_0^{+\infty} Q_0 e^{-kt} dt = \frac{86400 \times Q_0}{k} \quad (5)$$

Results and discussion

Calculation procedure for the SPI and SPEI

From 1 month onwards, the SPI and SPEI may be assessed at various accumulation periods. The current study utilized a 12-

Fig 2. Temporal variation of SPI and SPEI indices at **a** Sebdu rainfall station and **b** Meffrouche rainfall station



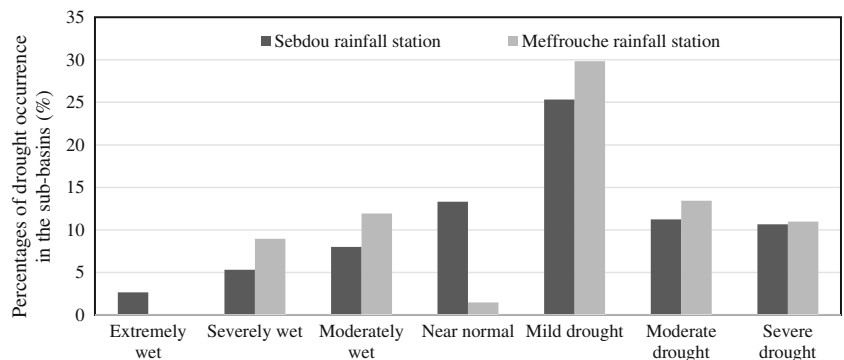
month accumulation period so that the whole year cycle can be integrated. It is based solely on precipitation, temperature, and the potential evapotranspiration to describe the meteorological drought.

In Fig. 2a and b, the temporal patterns of SPI and SPEI for two regions such as Sebdu rainfall station (Fig. 2a) and the Meffrouche rainfall station (Fig. 2b) were illustrated. In this chart, wet conditions can be interpreted through blue color, i.e., higher than median from that period whereas the dry conditions can be interpreted through red color. From the charts, one can easily distinguish three different types of 3–5-year clusters such as (i) mostly wet, (ii) mostly dry, and (iii) annually alternating between dry and wet. The results also show that both drought indices being on the same time scale have very similar shapes, but the duration and intensity differ as SPEI takes into account not only the amount of precipitation but also the evapotranspiration.

When SPI and SPEI for Sebdu and Meffrouche were compared, one can infer that both wet and dry periods do not occur simultaneously in both sub-basins. During the period 1980–1981, there was a precipitation deficit at Sebdu. But, in case of Meffrouche, the SPI and SPEI pattern of this rainfall station shows inverted dry and wet conditions. It is interesting to note that, during 1974–1975, Meffrouche experienced meteorological drought whereas Sebdu experienced wet climate. This scenario can be explained through sub-basins’ location (northeast for Meffrouche and south for Sebdu). Though Sebdu and Meffrouche sub-basins had a dry spell during the year 1980–1981, it is highly visible in Meffrouche than Sebdu.

In Fig. 3, the percentage of drought occurrences in sub-basins with time scale on the basis of SPI and SPEI were tabulated. In general, the SPI and SPEI indices infer the fact that moderate drought became the common phenomenon in the basin during the past six decades. So, it can be concluded

Fig 3. The percentage of drought occurrences in SPI and SPEI indices in the Sebdu and Meffrouche rainfall stations



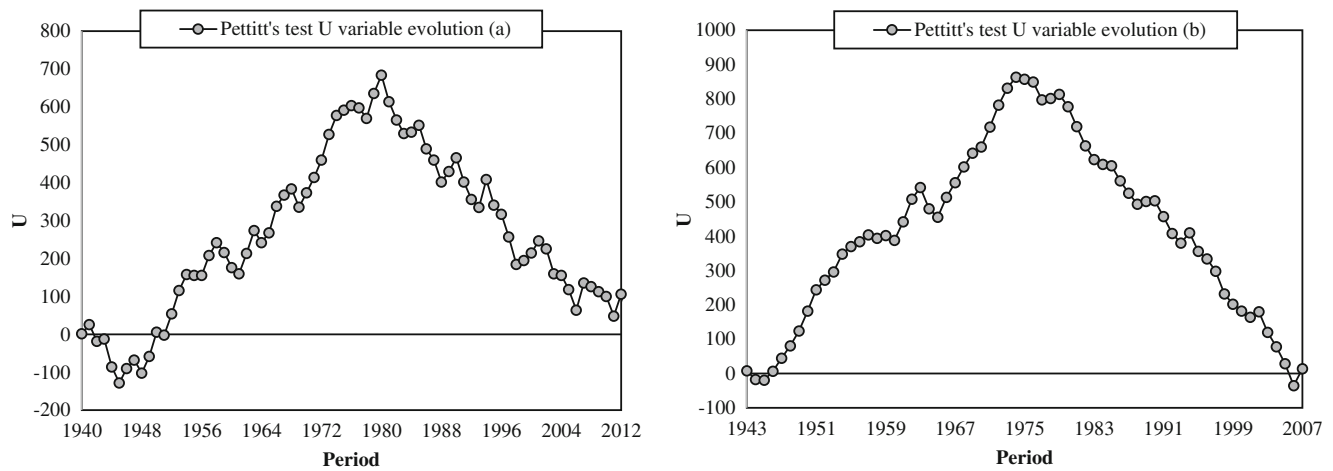


Fig. 4. The annual change in Pettitt's test *U* variable for the data stations a Sebdou and b Meffrouche

that these indices can capture the major droughts in Tafna basin.

Research of potential ruptures

In the statistical process, we have applied the Pettitt test to assess the heterogeneous or homogeneous character of the series, thanks to the Khronostat software used to that effect. In events where the series are heterogeneous, the rupture year and its direction altogether will be specified. The choice of this test is justified by its foundation, power, robustness, and success for such a study throughout the world.

The application of break test has allowed situating the periods that mark a modification of climate regime in chronological series. So, this notable decreased rainfall illustrated in Fig. 4 is confirmed through Pettitt test. Further, according to the test, this decrease scenario happened during the decade 1970–1980 for all stations (Table 4). Rainfall deficits have been calculated for a part of the break year. The impact of these modifications of the rainfall regime is translated into rainfall deficits ranging from 8.21 to 38.85% with an average of 17.85% for the entire basin.

These results are in accordance with those obtained by the authors of other studies in northwest Algeria (Meddi and Hubert 2003; Ghenim and Megnounif 2016; Ketrouti and Meddi 2013), who obtained some breaks around the 1970s. The studies of Meddi and Meddi (2009) showed an annual rainfall decrease over 36% in the Mascara area and to the extreme west of Algeria. Sebbar et al. (2011) noted a rainfall deficit around 1970 for 44 stations in septentrional Morocco during the 1935–2004 period. The pluviometric reduction was 30%, 25%, and 15%, respectively, for the “oriental” region, both the “Atlantic Southern” and “Mountain” sub-regions, and finally, both sub-regions “Atlantic Northern” and “Tangeroise.”

Analysis of the recession coefficients and water mobilized by the aquifers

The average recession coefficients proportional to the rate of emptying the aquifer were determined over a 34-year (1973–2007) time series of daily discharge measured in different sub-basins of the Tafna basin. After obtaining the results, we observed that a rupture of the recession coefficient appeared in

Table 4 Break and rainfall deficits in the Tafna basin

Rainfall station	Period analyzed	Break year	Average before break	Average after break	Reduction rate (%)
Beni Behdel	1941–2006	1974	461	379	17.79
Bensekrane	1924–2006	1964	440	373	15.23
Meffrouche	1943–2009	1975	659	403	38.85
Maghnia	1972–2004	1980	290	260	10.34
Lalla Setti	1964–2004	1976	580	476	17.93
Tlemcen	1965–2008	1979	453	361	20.30
Sebdou	1940–2014	1980	440	361	17.95
Hennaya	1965–2003	1979	452	397	12.17
Sabra	1970–2003	1976	390	358	8.21
Pierre du chat	1967–2003	1979	421	349	17.10
Khemis	1969–2003	1977	453	360	20.53

Table 5 Average recession coefficients before and after 1987

Gauging station	Periods	Average recession (day ⁻¹)	Rate of increase (%)
Beni Bahdel	1973–1987	5.42×10^{-2}	33.33
	1988–2007	8.13×10^{-2}	
Bensekrane	1973–1987	5.93×10^{-2}	63.86
	1988–2007	16.41×10^{-2}	
Pierre du chat	1973–1987	8.71×10^{-2}	55.29
	1988–2007	19.48×10^{-2}	
Remchi	1973–1987	10.26×10^{-2}	57.55
	1988–2007	24.17×10^{-2}	
Sidi Belkheir	1973–1987	14.19×10^{-2}	17.26
	1988–2007	17.15×10^{-2}	

1987. For this purpose, the year 1987 was chosen as the year of rupture during the study period in the whole Tafna basin. The results obtained are summarized in Table 5.

The results in Table 5 show that the average recession coefficients vary between $5.42.10^{-2} \text{ day}^{-1}$ and $14.19.10^{-2} \text{ day}^{-1}$ before 1987, identified as breaking year in the hydrometric series. After 1987, the recession coefficients fluctuate between $8.13.10^{-2} \text{ day}^{-1}$ and $24.17.10^{-2} \text{ day}^{-1}$. These results, therefore, demonstrate an increase in the recession coefficient after 1987, which is explained by small volumes of water stored in the aquifers. The rate of increase of the recession coefficient varies between 17.26% at Sidi Belkheir gauging station in the High Tafna and 63.86% at Bensekrane gauging station in the Middle Tafna sub-basin.

The results of the duration of the recession are shown in Table 6. These results show that the duration of the recession varies from 4 to 18 days in different sub-basins of the Tafna basin. The duration of the recession prior to 1987 range from 7 to 18 days, which is explained by the fact that the basin takes a long tank drain time. Further, large amount of water is stored in the aquifer in order to supplement during drought time when there is less flow (Corbonnois 2000; Juilleret et al. 2005). After 1987, they fluctuate between 4 and 12 days. A

Table 6 Average duration of the recession (days) before and after 1987

Gauging station	Periods	Duration of recession (day)	Variation in the duration of recession (day)
Beni Bahdel	1973–1987	18.45	6.15
	1988–2007	12.3	
Bensekrane	1973–1987	16.86	10.77
	1988–2007	6.09	
Pierre du chat	1973–1987	11.48	6.35
	1988–2007	5.13	
Remchi	1973–1987	9.74	5.61
	1988–2007	4.13	
Sidi Belkheir	1973–1987	7.04	1.21
	1988–2007	5.83	

shortening of the duration of the recession ranging from almost 1 to 11 days after 1987 is highlighted.

The water volumes mobilized by aquifers were determined at different hydrometric gauging stations in the Tafna basin over the entire period 1973–2007, as shown in Table 7.

The results in Table 7 show that the water volumes mobilized by aquifers vary between 4.44 and 20.31 hm³ before 1987. After 1987, the water volumes mobilized by aquifers fluctuate between 1.77 and 6.18 hm³. The rate of reduction in water volumes mobilized by aquifers varies from 60% at Sidi Belkheir gauging station in the high Tafna sub-basin to 79.31% at Bensekrane gauging station in the Middle Tafna sub-basin. These results show a considerable reduction in water volumes mobilized by the aquifer after 1987.

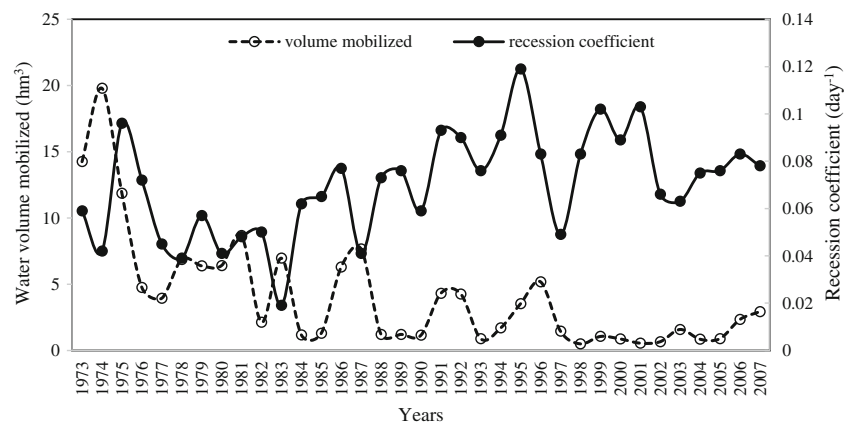
Our results are also consistent with those of many authors (Khettab 2001; Mebarki 2010; Ghenim 2013) which have also shown that 1987 to 1988 was the year most marked by hydrological drought followed by years 1993–1994 and 2000–2001, as shown in Fig. 5. Thus, during the hydrological year 1988–1989, the situation of drinking water has become increasingly more difficult to manage.

Figure 5 shows that the water volume mobilized by the aquifer experienced a decline due to the reduction in rainfall observed from the end of the 1980s. It can be remarked that the recession coefficient and the water volumes mobilized are inversely varied since 1987. In other terms, when the recession coefficients increase, the volume of water mobilized decreases and vice versa. The highest values of recession occur after the 1980s, most precisely in 1995 ($11.9 \times 10^{-2} \text{ j}^{-1}$), 1999 ($10.2 \times 10^{-2} \text{ j}^{-1}$), and 2001 ($10.3 \times 10^{-2} \text{ j}^{-1}$). Therefore, the decline of groundwater volume can be due to the overexploitation of this resource for drinking water supply and especially for agriculture and industry. So, due to the increased pumping from aquifer, it resulted in decreased water level across the basin. The combination of depleted groundwater levels and modified land-use practices may be considered among the main causes of decreases in stream discharge.

Table 7 Water volumes mobilized by the aquifers before and after 1987

Gauging station	Periods	Water volume mobilized (hm ³)	Reduction rate (%)
Beni Bahdel	1973–1987	7.23	– 74.96
	1988–2007	1.81	
Bensekrane	1973–1987	10.02	– 79.31
	1988–2007	2.07	
Pierre du chat	1973–1987	20.31	– 69.58
	1988–2007	6.18	
Remchi	1973–1987	14.88	– 61.35
	1988–2007	5.75	
Sidi Belkheir	1973–1987	4.44	– 60.1
	1988–2007	1.77	

Fig 5. Example of recession coefficient and water volume mobilized by aquifers in the high Tafna between 1973 and 2007



According to a recent study conducted by Meddi and Boucefiane (2015), based on their findings on the impact of rainfall reduction on groundwater resources during the period 1960–2000 with the use of 221 rainfall stations, the reduction in rainfall has resulted in a decrease of the water volumes stored at the level of Algerian dams. This resulted in overexploitation of groundwater specifically for agricultural practices. Generally, there is a close relationship between evolution of groundwater potential and rainfall fluctuations. Such overexploitation negatively impacted the resource management which also negatively affected the groundwater recharge.

Conclusions

The drought prevailing in the northwestern Algerian regions for the past 30 years impacted all water resources and groundwater resource specifically. Most methods of drought assessment try to determine the probability of finding abnormal sequences in rainfall distribution on the regional scale. In this study, we have attempted to investigate the effect of climate change on groundwater in different sub-basins of the Tafna basin. The application of meteorological drought indices and statistical test of Pettitt shows a rainfall regime modification occurred around the 1970s at all the study area stations. This modification reveals a decrease of rainfall between 8.21 and 38.85%, with an average of 17.85%. The average recession coefficients obtained by Maillet's exponential model vary between $8.90 \cdot 10^{-2} \text{ day}^{-1}$ and $17.06 \cdot 10^{-2} \text{ day}^{-1}$ either side of 1987, an average increase of 45.45%, and highlight a much faster drainage of the aquifers supplying the baseflow after 1987. A shortening of 1 to 11 days with an average of 6 days of the duration of recession after 1987 was highlighted. The impact of this rainfall decrease is reflected in aquifer recharge. As proof, the average of water volumes mobilized by the aquifers dropped from 11.38 hm^3 (1973–1987) to 3.62 hm^3 (1988–2007), an average decrease of 69.06%. These results show a decrease in the water volumes mobilized by the aquifers after 1987 and suggest a considerable decline of

groundwater resources under the influence of climate change. Our results should be considered by the national agency for hydraulic resources to implement various strategies against droughts such as transferring the knowledge upon conventional and unconventional resources into implementation such as seawater desalination, recycling the wastewater so that the current and future water needs can be met since there is an increase predicted for population by 40 to 50% within 2030 (45 to 50 million) and for agricultural, industrial activities which need expansion and modernization.

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