Assessing the Climate Change Impact on Water Resources and Adaptation Strategies in Algerian Cheliff Basin

Yamina Elmeddahi and Ragab Ragab

Contents

Abstract The effect of climate change on the water resources of the Cheliff basin in Algeria was evaluated with a particular focus on the significant factors affecting the water reserves. The Cheliff basin, which is one of the largest basins in the north of Algeria, is affected by water scarcity due to the extension of industrial and agricultural activities with the population growth, on the one hand, and to a decline in water resources caused by extreme droughts, on the other hand. The results of the current climate change assessment revealed a downward trend in the precipitation ranging from

---

Y. Elmeddahi (✉)
Vegetable Chemistry-Water-Energy Research Laboratory, Faculty of Civil Engineering and Architecture, University Hassiba Ben Bouali of Chlef, Ouled Fares, Algeria
e-mail: y.elmeddah@univ-chlef.dz; elmeddahi-a@hotmail.fr

R. Ragab
Centre of Ecology and Hydrology, CEH, Wallingford, UK

Abdelazim M. Negm, Abdelkader Bouderbala, Haroun Chenchouni, and Damià Barceló (eds.), *Water Resources in Algeria - Part I: Assessment of Surface and Groundwater Resources*, Hdb Env Chem (2020) 97: 111–134,
DOI 10.1007/698_2019_398,

14 to 54% and a reduction in streamflows that exceeds 40% with a break observed at the beginning of the 1980s. According to different emission scenarios, several general circulation models (GCMs) predict an increase in temperature of +0.9°C to +5°C on average at the end of the twenty-first century, with a decrease in average rainfall of 10–30%. A conceptual model predicted a flow deficit ranging from 10 to 48% at different periods and in different scenarios.

This study found that the problem of water scarcity was exacerbated by poor management of available water resources and by the significant increase in the population, which exceeded five million in 2010. Intensive use of water for irrigation and economic development has put additional pressure on the limited water resources. All these facts call for a proper "fit for purpose" integrated water management policy for the whole country.

Keywords Cheliff basin, Climate change, Trend, Water resource

1 Introduction

Over the past three decades of the twentieth century, many scientists have argued that climate change could lead to major changes threatening the very existence of humans on the planet.

Recently, considerable research has been led to address the impact of climate change on the environment and particularly on water resources [1–10]. During the last century, the average temperature across the Mediterranean basin and the North Africa region has increased by 0.56–0.92°C [9–17]. According to different emission scenarios [4, 14, 17–22], several general circulation models (GCM's) predict an increase in temperature from 0.7 to more than 4°C by the end of the twenty-first century. Algeria, in particular, has experienced a decrease in average annual precipitation. Rainfall is predicted to further reduce during the coming century [9, 14, 23–25].

This situation is particularly noticeable in regions subject to a semiarid climate regime. This is particularly the case in the Cheliff basin, which is one of the largest basins in northern Algeria. It is affected by water shortage due to the expansion of industrial and agricultural activities with population growth, on the one hand, and the reduction of water resources caused by extreme droughts, on the other hand. Recent studies over the past few years have revealed a declining rainfall trend in most Algerian regions [17, 26, 27] and a significant decrease in flow to dams and significant groundwater level drop and high vulnerability to groundwater pollution [28].

Precipitation is the fundamental driver of the Earth's hydrological system. As a result, any change in intensity, frequency, and timing of precipitation will have a direct impact on water resources and therefore on economic development. The severe droughts of the early 1980s can testify to the magnitude of the effects that climate extremes can have on the national economy. The floods in recent decades in the north give a further idea of the damage that can be caused.

At present, the major concern of the country is to predict, with scientifically accepted margins of uncertainty, the potential impacts of climate change predicted by the IPCC on water resources.

In this context, it is necessary to put in place sound adaptation strategies aimed at minimizing the negative impacts that climate change would bring in the future. Decision-makers thus need objective assessments of the vulnerability of different socioeconomic sectors through the integration of climate information at the national and local levels. This information concerns, in particular, observed trends and projected future scenarios. This chapter aims to assess the direct and indirect impacts of climate change on water resources by identifying major trends in precipitation over time, annual flows, and the significant contribution of the dam in the study area.

2 Materials and Methods

2.1 Description of Case Study Area

The Cheliff basin, one of largest basins in Algeria, is located in the northwest of Algeria and lies between 34° and 36° N in latitude and between 0° 12′ and 3° 87′ E in longitude. The watershed covers an area of 43,750 km^2, being bordered to the north by the coastal-Dahra basin, in the south by the Zahrez basin, in the east by the Algiers basin, and in the west by the Oran basin. It consists of three subregions, the upstream Boughezoul basin, the Upper and Middle Cheliff basin, and the Lower Cheliff basin and Mina. The study area is characterized by the heterogeneity of large natural units, to which is added a significant latitudinal extension and diversified geography (such as plains, mountains, and Tellian plateaus). The basin is 20–70 km from the Mediterranean Sea. All these factors determine the region's climate, which ranges from semi-humid to semiarid. The climate of the case study region itself is the semiarid Mediterranean with warm summers and cold winters. The rainfall has a wide interval of variability with a trend of decline from north to south and from east to west. The mean annual rainfall ranges from 300 mm in the high plains to 600 mm in the coastal watershed, except in the Zaccar massif where about 800 mm have been recorded.

Average annual temperatures decrease gradually from north to south with a minimum 14.2°C and a maximum 18.7°C. Average monthly temperatures follow the same pattern, but the decline is faster in the cold season than in the hot season, because of the particularly harsh effect of continentally winter and the regulating influence of the sea in summer. The hot season, months during which average monthly temperatures are higher than the annual average, extends from May to October, while the cold season lasts from November to April. The maximum temperatures of 27–28°C are reached in August or July, and the minimum temperatures are in January and February (3–10°C).

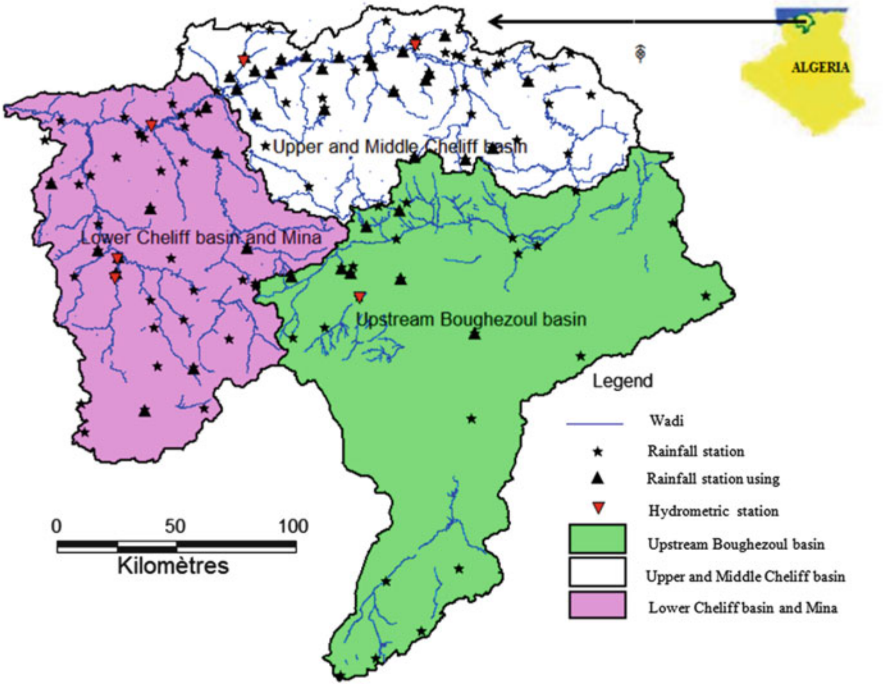

Fig. 1 Location of the study area including the sub-basins

The Cheliff Wadi is 750 km long and is the longest "river" in Algeria. Wadi refers to a dry (short-lived) riverbed that only contains water during periods of heavy rain. The Cheliff Wadi source is in the Saharan Atlas, with 70% of its annual runoff occurring from December to April. The large variability of hydrological regimes can be observed in the large range of variation of mean annual flow which varies from 0.06 to 15.36 $m^3 s^{-1}$. Extreme values of the flows are of great interest to hydrologists as they constitute a major concern due to their scale, aggressiveness, and negative impact on societies and economic and social development.

Hydrologic data monitoring stations of the three sub-basins of the Cheliff bowl are illustrated in Fig. 1. Monthly rainfall data and monthly flow data over the study area were obtained from the National Meteorological Office (NMO) and the National Agency of Hydraulic Resources (NAHR).

In this study, a total of 42 hydro-climatic variables were selected for the study. The stations considered are those with a long series of observation and few gaps. Data of surface water was obtained from the Ministry of Water Resources (MWE).

2.2 Methodology

The assessment of the rainfall variability was performed using the nonparametric test of Mann-Kendall (MK). This test is to confirm whether there is a positive or negative trend for a certain confidence level. The magnitude of linear tendency was calculated using Sen's estimator. The step change (break date) is detected by the Pettitt test. GR2M conceptual model has been applied to simulate the monthly streamflow. The simulation was performed with seasonal and annual rainfall data recorded at 36 stations covering a period of 38–105 years, while seasonal and annual flow data of six gauging stations covered a period of 26–46 years.

2.2.1 Mann-Kendall Test

The nonparametric test of Mann-Kendall [29, 30] was used for determining monotonic trends in hydrometeorological and other non-normal distribution series [31–33]. This test allows for testing of the correlation between the ranks of a time series and their time sequence [34]. It measures the degree of significance of the trend at a level of 0.05.

Let $(x_1 \ldots x_n)$ be a sample of independent values from a random variable X of which is to assess the stationarity. The null hypothesis H_0 is the hypothesis of stationarity of the series (no trend). The alternative hypothesis H_1 corresponds to the non-stationarity of the series. The Mann-Kendall S statistic is defined as:

$$S = \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} \operatorname{sgn}(X_k - X_i) \tag{1}$$

with:

$$\operatorname{sgn}(X_k - X_i) = \begin{cases} +1 \text{ si } (X_k - X_i) > 0 \\ 0 \text{ si } (X_k - X_i) = 0 \\ -1 \text{ si } (X_k - X_i) < 0 \end{cases} \tag{2}$$

where X_k and X_i are of the time series and n is the length of the data sequence. The variance of S and test statistic Z is given by:

$$\operatorname{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)}{18} \tag{3}$$

$$Z = \begin{cases} \dfrac{(S-1)}{\sqrt{\mathrm{Var}(S)}} \text{si } S > 0 \\ 0 \text{ si } S = 0 \\ \dfrac{(S+1)}{\sqrt{\mathrm{Var}(S)}} \text{ si } S < 0 \end{cases} \tag{4}$$

where q is the number of tied groups and t_p is the size of the pth tied group.

The null hypothesis is accepted or rejected at α depending on whether $\alpha_1 > \alpha$ or $\alpha_1 < \alpha$. Generally, the 0.05 level is largely used. In this study, the analysis of precipitation variability, 0.05 and 0.01 levels, was employed. When the statistical value of z is positive, the trend is increasing, while a negative value indicates a declining trend.

2.2.2 Sen's Median Slope Estimator

When the hypothesis of no trend is rejected by Mann-Kendall test, the Theil-Sen's slope [35] allows determining the magnitude of the linear trend. The slope is estimated for N pairs of data points, Q, as:

$$Q_i = \frac{X_j - X_k}{J - k}, \quad \text{For } i = 1 \ldots n \tag{5}$$

where X_j and X_k are the data values at time j and k, respectively, with $j > k$. The median of the slope between all pairs of data of Q slope estimates is Sen's linear slope.

2.2.3 Pettitt Test

The Pettitt [36] approach derived from the Mann-Whitney test makes it possible to test the significance of the breaks in the rainfall and hydrometric series considered from a null hypothesis [36]. This test is known for its robustness [37].

The implementation of the test requires that for any time t ranging from $1 - n$, the series (x_i), $i = 1 - t$ and $t + 1 - n$ belong to the same population. The statistic test is the maximum absolute value of the variable $U_{t,n}$ defined by:

$$U_{t,n} = \sum_{i=1}^{t} \sum_{j=t+1}^{n} D_{ij} \tag{6}$$

where

$$D_{i,j} = \operatorname{sgn}\left(x_i - x_j\right) = \begin{cases} 1 \text{ si } x_i > x_j \\ 0 \text{ si } x_i = x_j \\ -1 \text{ si } x_i < x_j \end{cases} \tag{7}$$

Pettitt proposes to test the null hypothesis using the K_n statistic defined by the absolute maximum of $U_{(t,n)}$. From the rank theory, it shows that if k denotes the value of K_n taken on the studied series, under the null hypothesis, the probability of exceeding the value k is given approximately by the relation (8) [37–39]:

$$\mathrm{Prob}(K_n > k) \approx 2 \exp\left[\frac{-6k^2}{(n^3 + n^2)}\right] \tag{8}$$

On the other hand, for a given risk α of the first kind, if the estimated probability of exceedance is less than α, the null hypothesis, H_0, is rejected, and the estimated value of the break date is given by the time t defining the maximum absolute value of the variable $U_{t,n}$.

2.2.4 Conceptual Model GR2M

The GR2M model consists of a production reservoir that governs the production function, characterized by its maximum capacity, and a reservoir (gravity water) that governs the transfer function [40, 41]. This monthly model of water balance was based on two main optimizable parameters: $X1$ (mm), which represents the maximum capacity of the soil moisture reservoir, and $X2$ ($0 < X2 < 1$), the underground exchange coefficient. Rainfall (P) and potential evaporation (E), which is calculated by the Thornthwaite method, are both the main input parameters of the model which are modulated in the same portion. The outputs' results represent the streamflow in mm.

3 Results and Discussion

3.1 Precipitation

3.1.1 Spatiotemporal Variation in Rainfall

Rainfall distribution is heterogeneous across the Cheliff basin and is characterized by a decreasing average annual rainfall from north to south, with a change in altitude of Tellian chains that show the important role of the altitude. Rainfall varies from 778.8 mm in the north to 249.1 mm in the south. Calculating the standard deviation and coefficient of variation (CV %) for each station shows that for all selected stations the annual coefficient of variation is between 17.0 and 60.3%. The coefficient of variation of annual rainfall is generally increasing from north to south of the study area. This spatial variability is aggravated by heavy rains in association with northwesterly directional winds for the northwest and southwest regions. The variability is also due to the heavy winter and spring rains that affect the mountainous regions where the altitude exceeds 1,000 m as is the case of the Dahra mountains compared to the Lower Chellif plain and the western part of the basin (the basin of Mina).

Precipitation rarely exceeds 250 mm/year in upstream Boughezoul basin. This region is particularly semiarid to arid, and the effect of the latitude is very important.

3.1.2 Evolution of Rainfall

As reflected in Fig. 2, the representative stations of three characteristic regions of the study area show an excess of rainfall until the late 1970s and early 1980s. However, downward episodes are recorded during this period not exceeding 3 consecutive years (periods from 1930 to 1933, 1941 to 1944, and 1968 to 1970).

From the 1980s to the present day, this region experienced one of the most rain-deficit periods, both in intensity and persistence.

3.1.3 Annual Precipitation Trends

The results of the statistical analysis obtained are presented in Table 1. The analysis of trend by MK test shows that annual rainfall is trending downward across the basin.

Some of these trends are statistically significant. Several of the trends are significant at the 5% level, and two of the trends are significant at the 10% level. The value of the Sen's slope at the 0.05 level of significance reflects the magnitude of this trend. The decrease in annual rainfall varies from −0.75 mm/year in the southeast to −4.58 mm/year in the west with significant decreasing trends in the annual mean precipitation z-value: 5.22. The season's rainfall pattern and trends were very similar to the annual ones.

Significant decreasing trends were observed in seasonal average rainfall in winter for the southeast (at z-value −1.78 and −0.58 mm/year) to the west (at z-value −4.77 and −2.18 mm/year). The significant decreasing trends of average seasonal rainfall had the highest value of decreasing slope (i.e., −3.34 mm/year) in the west of the study area for Oued Lili station in spring.

However, the results of the two tests (Spearman and Mann-Kendall) applied to the series of annual rainfall in western Algeria, including some stations in our study area, revealed a downward trend in most of the studied stations [42], which is in agreement with the results obtained in this study. The results of a study conducted [26] in the northwest of Algeria showed a general downward trend in annual rainfall, which is consistent with the one obtained in this study.

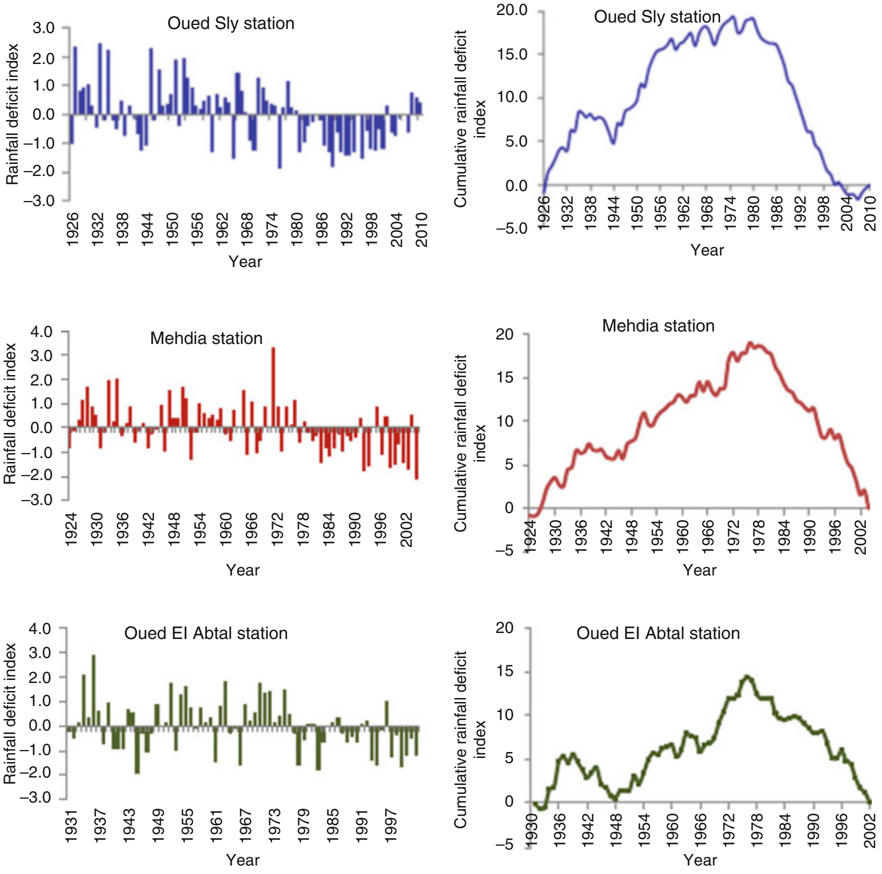

Fig. 2 Evolution of the rainfall deficit and accumulated deficit in the three stations of the study area

Analysis of precipitation series showed the importance of identifying local trends that differ from national or global trends. The results indicate that for the periods analyzed, there is a decrease in rainfall across the basin studied. Significant trends are appearing in the west and southeast parts of the region.

3.1.4 Break Detection

The analysis of long series makes it possible to detect possible changes in the rainfall regime. In the Cheliff basin, several significant trends have been identified for rainfall parameters. Several studies [17, 27, 43, 44] indicated a break during the 1970s for almost all the stations studied. The results obtained are presented in Fig. 3.

Table 1 Statistic *Z* of Mann-Kendall test for mean annual rainfall, winter (DJF) mean rainfall, spring (MAM) rainfall, and Sen's slope

Station	Years of record	MK *Z*-value (p ann)	Sen's slope (mm/year)	*Z*-value (DJF)	Sen's slope (mm/year) (DJF)	*Z*-value (MAM)	Sen's slope (mm/year) (MAM)
ONM Chlef	75	−1.35	−0.78	−1.49	−0.58	+0.09	+0.02
Chlef DDA	43	−1.08	−1.88	−0.87	−0.95	−0.72	−0.48
Essoula	43	−1.33	−1.46	−0.85	−0.58	−1.46	−0.63
O. Fares	43	−1.50	−2.86	−1.37	−1.39	−1.83[a]	−1.30
Ponteba Bge	44	−1.60	−2.64	−1.60	−1.40	−1.57	−1.20
El Abadia	43	−1.79[a]	−2.90	−0.91	−0.96	−1.96[a]	−1.34
Khmesti	98	−1.04	−0.75	−1.78[a]	−0.58	−1.60	−0.37
Merdja Amel	41	−1.57	−2.20	−2.11[b]	−1.51	−1.48	−0.86
Rouina Mines	43	−1.60	−1.88	−1.06	−0.79	−1.98[b]	−1.11
Arib Ebda	43	−1.77[a]	−2.98	−0.70	−0.90	−1.77[a]	−1.51
Harreza	43	−1.23	−1.93	−1.14	−1.01	−1.33	−0.93
O. Lili	38	−2.50[b]	−3.76	−2.50[b]	−2.02	−3.36[b]	−3.34
Sidi Medjahed	95	−4.42[b]	−3.62	−3.43[b]	−1.72	−2.31[b]	−0.83
El Ababsa	43	−1.37	−1.64	−0.95	−0.91	−1.64	−0.88
Ain Defla	101	−2.62[b]	−1.26	−1.33	−0.37	−1.08	−0.22
Ain Boucif	84	−3.76[b]	−2.97	−2.43[b]	−0.99	−3.90[b]	−1.12
Ammi Moussa	90	−2.73[b]	−1.34	−2.25[b]	−0.61	−0.85	−0.20
Derrag	93	−2.10[b]	−1.42	−1.33	−0.51	−0.88	−0.31
Fodda Bge	68	−3.40[b]	−2.65	−2.66[b]	−1.10	−0.95	−0.34
Frenda	75	−2.91[b]	−1.87	−2.58[b]	−0.91	−1.89[a]	−0.31
Grib Bge	66	−3.31[b]	−2.53	−2.24[b]	−1.21	−1.84[a]	−0.93
Mehdia	95	−3.81[b]	−1.95	−3.51[b]	−1.05	−2.39[b]	−0.54
O. Sly	85	−3.54[b]	−1.76	−2.15[b]	0.66	−1.38	−0.32
Rosfa	54	−3.93[b]	−3.39	−3.14[b]	−1.56	−3.05[b]	−1.07
O. El Abtal	72	−2.44[b]	−1.38	−4.14[b]	−1.26	+0.66	+0.18
Sidi AEK Djillali	38	−3.32[b]	−2.12	−0.72	−0.37	−2.76[b]	−1.23
Ain Amara	38	−2.45[b]	−1.35	−1.12	−0.75	−3.06[b]	−1.88
Rouina Mairie	85	−2.78[b]	−1.30	−2.06[b]	−0.61	−1.21	−0.26
B. Amir AEK	85	−2.72[b]	−1.55	−1.03	−0.43	−1.40	−0.46
Tissemsilt	89	−1.97[b]	0.79	−1.72[a]	−0.43	−0.65	−0.16
El Touaibia	43	−1.27	−1.70	−0.58	−0.43	−1.75[a]	−0.88
Kenenda Farm	79	−5.22[b]	−4.58	−4.77[b]	−2.18	−3.00[b]	−1.21

(continued)

Table 1 (continued)

Station	Years of record	MK *Z*-value (p ann)	Sen's slope (mm/year)	*Z*-value (DJF)	Sen's slope (mm/year) (DJF)	*Z*-value (MAM)	Sen's slope (mm/year) (MAM)
ThneitEl Had	106	−1.76[a]	−0.79	−0.79	−0.24	−1.47	−0.37
Rechagha	74	−4.07[b]	−1.99	−2.97	−0.61	−2.23[b]	−0.52
Ksar Chellala	100	−3.43[b]	−1.03	−4.10[b]	−0.46	−1.89[a]	−0.35
Dahmoni Trumulet	79	−5.07[b]	−3.12	−4.21[b]	−1.62	−2.95[b]	−0.91

[a] Trend statistically significant at 10%
[b] Trend statistically significant at 5%

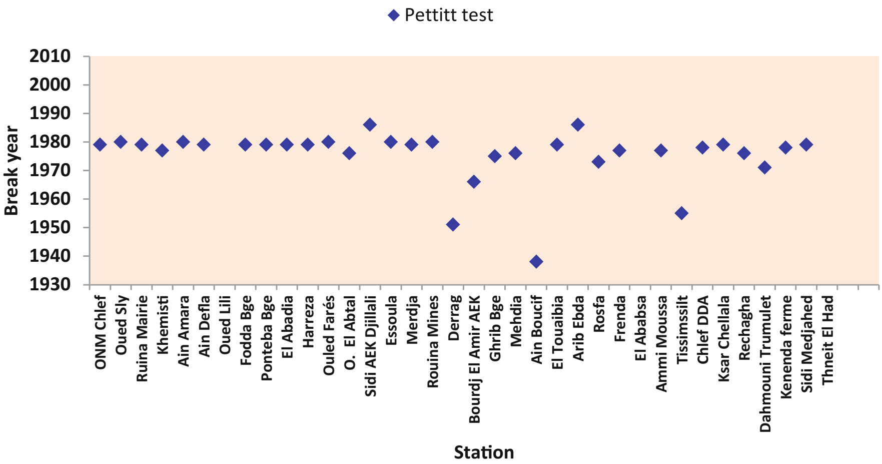

Fig. 3 Pettitt test in the study area

The analysis of these results shows that the majority of the series analyzed show breaks. In 73% of the stations, there is a break between 1970 and 1980. From one break to another, the average of rainfall decreases. These observations are consistent with the results of a number of studies, including [45], which are, for northern Algeria, most of the ruptures are between the beginning of the 1970s and end of the 1980s.

The study of the interannual variability of rainfall then allows to better quantify the deficit in the period after rupture compared to before rupture as shown in Fig. 4. Maximum reductions of around 54.8% were recorded at the Rosfa station in the south, and a minimum reduction rate of 14% was observed at the Theniet El Had station in the east.

A significant reduction, over 30%, was recorded in the west and south of the study area; the most of this region has less rainfall. Over the study's period, this

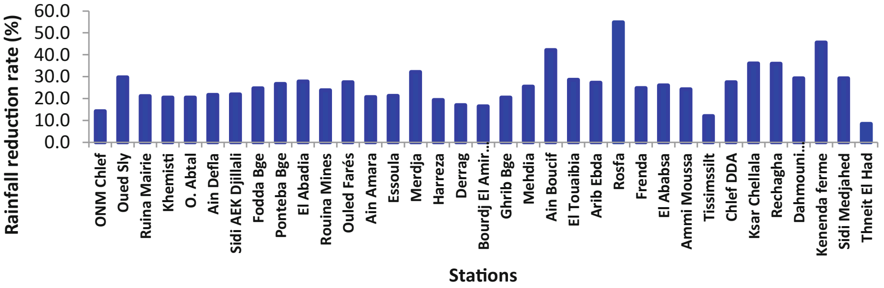

Fig. 4 Rainfall reduction rate in the study area

decline averages around 26% nationally; the end of the rainy season (February–April) shows more pronounced trends. The beginning of the rainy season shows, on the contrary, an upward trend but which remains low and statistically insignificant. Interannual rainfall variability increases as it approaches arid regions. The increase in variability follows the increase in longitude and the decrease in latitude. Altitude attenuates this increase.

Generally, there is a decrease in precipitation and a greater occurrence of droughts in recent decades. This break, in the sense of a decrease in the annual rainfall, gives an idea for thought to better manage an ever-dwindling water resource in the face of an ever-increasing demand.

3.2 Hydrometric Network and Presentation of Hydrometric Stations Selected

The Cheliff basin has few stations with the capacity to do hydrometric measurements. The archives reveal that the network is old; the first gauging station in the basin was established in 1925, but the number of hydrometric stations available and likely to provide sufficient good quality information for water resource management is insufficient. Cheliff basin, with an area of 43,750 km^2, has 43 gauging stations of which only 24 are operating hydrometric stations; this means 1 station for every 1,560 km^2.

For this study, six gauging stations were selected for having data over long periods with few data gaps.

3.2.1 Study of the Variability Hydrometric

The study of the hydrometric series conducted over a long period allows the assessment of the sensitivity of river flows to climate change. The average interannual discharge of the basin (Fig. 5) varies between 0 and 60.19 m^3 s^{-1} with

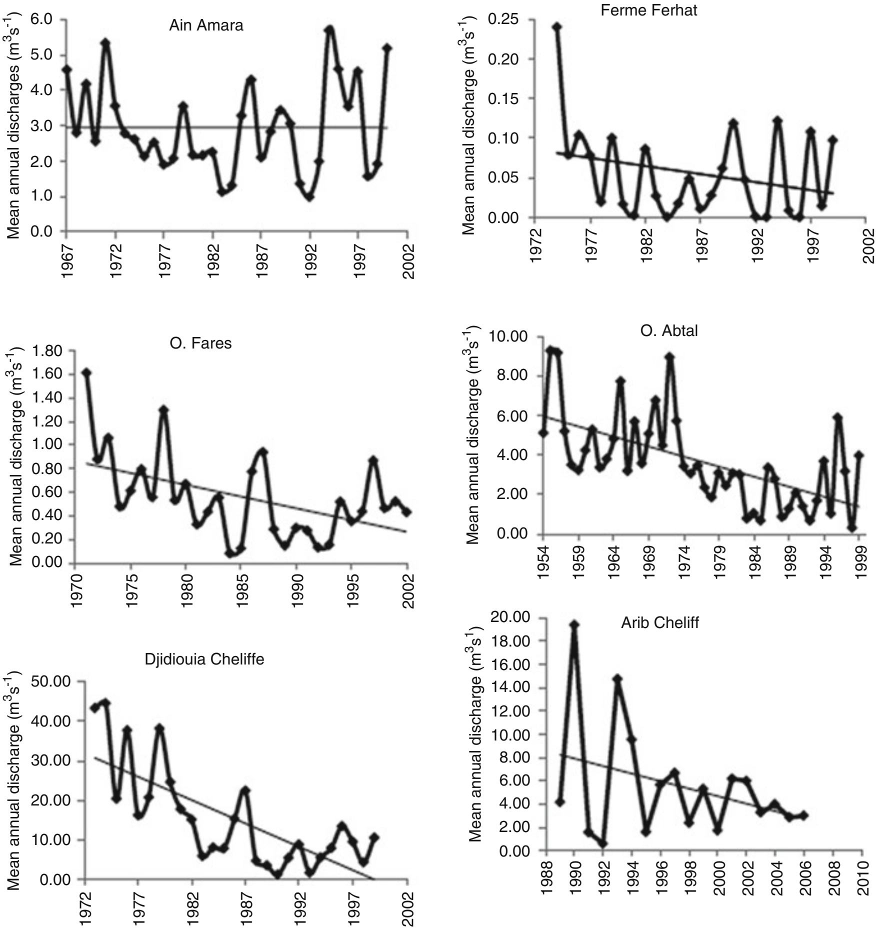

Fig. 5 Evolution of interannual reduced centered index discharges of six stations in the study area

a maximum of 952.20 m^3 s^{-1} in the eastern region and 0–1.15 m^3 s^{-1} with a maximum of 334.68 m^3 s^{-1} in the south of the region.

The high flows observed in the western part of the study area (the Ain Amara and O. El Abtal stations) are related to the importance of the Oued Mina inflow and the special morphometric characters. In this basin, altitude exceeds 1,200 m, which favors the generation of surface runoff. This gradual increase in inflow from east to west is consistent with climatic and physiographic data from the upstream Boughezoul Basin to Upper and Middle and Lower Cheliff to Mina. Flows are low in the high plains, due to low rainfall, high evapotranspiration, and high permeability of lithologic formations. On the other hand, they are relatively high in the Upper and Middle Cheliff, which combine abundant average precipitation and low permeability of geological outcrops. This suggests that the altitude parameter is an important factor.

Table 2 Statistic Z of Mann-Kendall test for mean annual streamflow, seasonal streamflow, and Sen's slope

Station	Z-value					Sen's slope (Qann) $m^3 s^{-1} y^{-1}$
	ANN	Autumn (Sep–Nov)	Winter (Dec–Feb)	Spring (Mar–May)	Summer (Jun–Aug)	
O. El Abtal	−4.54[a]	−2.94[a]	−4.34[a]	−3.32[a]	−4.17[a]	−0.103
Ain Amara	−0.67	+0.25	−2.92[a]	−1.80[b]	−3.48[a]	−0.015
Arib Cheliff	−1.68	−3.07[a]	−0.73	−0.99	−0.86	−0.32
Ferhat Farm	−1.30	+0.49	−3.76[a]	−0.02[a]	−0.02	−0.002
Djidiouia Cheliff	−3.61[a]	−2.32[a]	−3.44[a]	−2.98[a]	−2.44[a]	−1.05
O. Fares	−2.94[a]	2.23[a]	−2.20[a]	−3.02[a]	−3.95[a]	−0.03

[a] Trend statistically significant at 5%
[b] Trend statistically significant at 10%

3.3 Annual and Seasonal Flow Trends

Table 2 shows significant annual downward trends, which were observed in the western region (O. El Abtal station, Djidiouia Cheliff), with a maximum of −4.54 (O. El Abtal). Significant decreases in annual flow indicate a greater decreasing slope, respectively, for O. El Abtal and Djidiouia Cheliff (i.e., −0.103 and −1.18 m^3 s^{-1}). Same as the seasonal scale, a significant downward trend was observed in the west and south of the study area, with maximum z-values of −4.34 in winter (O. El Abtal station) and −3.42, −3.44, and −3.76 in summer and winter in Ain Amara, Djdiouia Cheliff, and Ferhat Farm, respectively.

3.4 Surface Water Resources

To meet a growing demand for water, the surface water storage capacity has been increased with the construction of new dams, going from 12 dams in 2000 to 15 dams at present with a capacity of 2.205 billion m^3 according to the Ministry of Water Resources [46].

There are 145 small dams in the Cheliff basin, but only 27 are in operation, and 118 are completely silted [47]. The available water resource corresponding to the capacity of the service reservoirs is 16 Hm^3 entirely intended for irrigation. There are seven canals and diversions from the dams in the study area. The derived volume is 13.4 Hm^3/year. Run-of-river sampling is estimated at an average of 57 Hm^3/year [46].

3.5 Impact of Climate Change on Surface Water Resources

The twentieth-century global warming in the study area has a negative impact on the precipitation cycle including all water resources. From 1968 to 2001, the interannual inflow of Cheliff basin was estimated at 1,025 Mm^3, consisting of 687 Mm^3 for Middle and Upper Cheliff, 242 Mm^3 for Lower Cheliff and Mina, and 96 Mm^3 in upstream Boughezoul. In 2009, precipitation decreased to less than 350 mm, and inflow decreased to 815 million m^3, so a rate of 20%. This decrease has resulted in a decreasing trend in runoff and consequently a reduction in dam capacity. To illustrate the decrease in storage of dams, three dams were chosen in the study area, Sidi Yakoub dam and Boughezoul dam located in the Middle and Upper Cheliff and Sidi M'Hamed Benaouda dam located in the Mina region (Figs. 6, 7, and 8).

The condition of the Sidi Yakoub dam filling ranged between 82% in 1994, 14% in 1998, and 65% in 2004. The contribution of runoff to surface water has consistently decreased due to the significant reduction in precipitation.

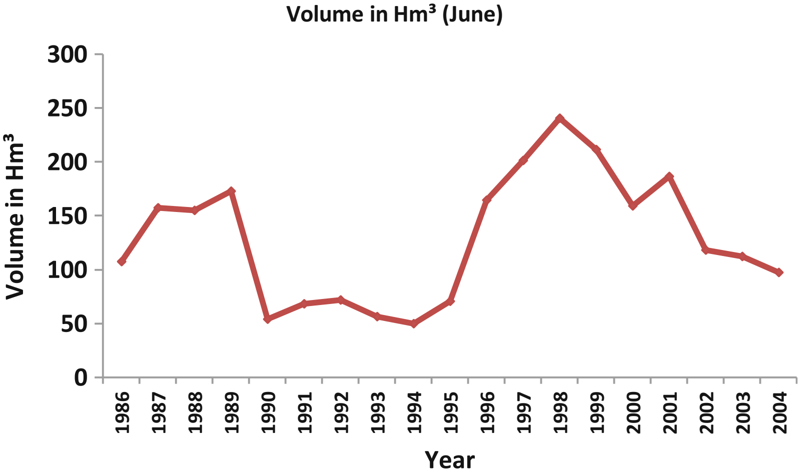

Fig. 6 Volume evolution in Sidi Yakoub dam (1986–2004)

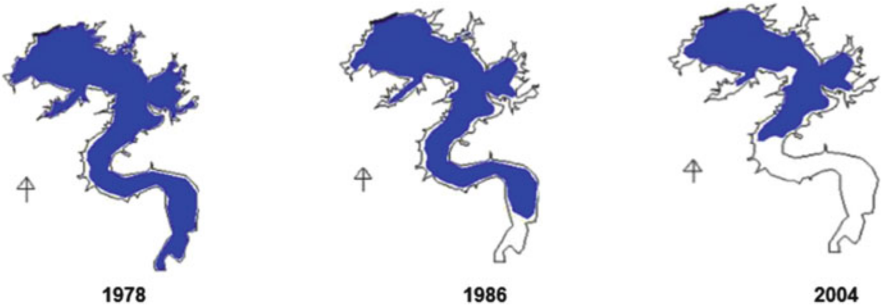

Fig. 7 Evolution of the capacity of Sidi M'Hamed Benaouda dam (Remini and Bensafia, 2011 in [48])

Fig. 8 Evolution of the capacity of Boughezoul dam [49]

Figures 7 and 8 shows the evolution of the capacity of the Sidi M’Hamed Benaouda dam and Boughezoul dam.

The reservoir of the Sidi M’Hamed Benaouda Dam had an initial total volume of 241 Hm^3, but this value was reduced over time to 226 Hm^3 in 1986 and 153 Hm^3 in 2004. The storage capacity of the reservoir is reduced by order of 4 Hm^3/year due to siltation. When it was built in 1934, the Boughezoul dam had a capacity of 55 million m^3. Its capacity decreased to 33 million m^3 in 1986 and 20 million m^3 in 2005. This development indicates the consequences of the decrease in precipitation and the severity of the siltation, which is mainly due to upstream erosion.

Other consequences of decreasing precipitation could be:

- Siltation of dams (concentrated precipitation and siltation accelerated by increased erosion)
- Unsteady river regime
- A decrease in the piezometric levels, inducing a decrease in the outflows of the natural outlets of groundwater
- The degradation of water quality
- Reduction in crop yields
- Increased water requirements for irrigated crops

It was observed that the problem of water scarcity was exacerbated by mismanagement of available water resources and a significant increase in the population that has exceeded five million in 2010 [44]. Intensive use of surface water for irrigation and water use for economic development has put additional pressure on limited water resources. Vital capacities are lost in urban water distribution systems, and networks of irrigation are dilapidated or badly maintained. All these failures reflect an inadequate mastery in the management of water resources policy of the country. Better water demand management that would control, reduce, and adjust consumption, while avoiding water losses and waste, is imperative [50].

3.6 Water Resources Management

Since independence 1962, the mobilization of water resources has been focused on groundwater resources. The rapid increase in water demand in the irrigation and industry sectors, as well as the progressive needs of the population, has led the public authorities to mobilize more and more the superficial resources. Thus, the efforts undertaken during the current decade have led to significant improvements.

Faced with these challenges, the country has introduced a new policy to more efficiently manage water resources via the building new dams. There are now 15 dams in the study area having a total capacity of 2.205 million m^3 according to the Ministry of Water Resources [46]. Other projects are in progress (i.e., five new dams) which will provide an additional volume of 1,608 Mm^3/year intended for the irrigation and domestic water supply. The use of nonconventional water resources is also being considered with the construction of small seawater desalinization plants in the year 2001. Two large stations with an estimated production capacity of 109.5 Hm^3 are also being built. Studies have also been launched on the reuse of treated wastewater for agricultural use.

3.7 Projected Climate Change and Adaptation on Surface Water Resources

Several sources can be used to obtain a consensual image of climate projections for Algeria and the study area at various time horizons. Climate change in Algeria was analyzed based on the UKHI and ECHAM3TR GCMs and the IPCC GIEC IS92a scenario. Other work has been done by [50] to assess the impacts of climate change on water resources, using HadCM3 low-resolution general circulation model (GCM) scenarios [51]. This involves the development of local-scale climate change scenarios using the statistical downscaling method performed by the LARS-WG stochastic generator [52, 53].

The seasonal and annual temperature changes simulated by the UKH1 and ECHAM3TR model for Algeria are qualitatively similar to those obtained by the HadCM3 model, although a little less important in terms of intensity. Projections by UKH1 model for the different horizons on the Cheliff basin would indicate a warming of the order of 0.6–1.1°C in 2020 and of 0.95–2.2°C for 2050. Similar trends were observed for the two scenarios HadCM3-A2 and HadCM3-B2. Overall, the simulations of temperature changes by different global and regional climate models are extremely homogeneous and still have the same order of magnitude of +2°C to +5°C on average at the end of the twenty-first century.

For precipitation (Fig. 9), the annual changes simulated by the UKH1 model show the decrease in rainier areas and the increase in less rainy areas compared to the

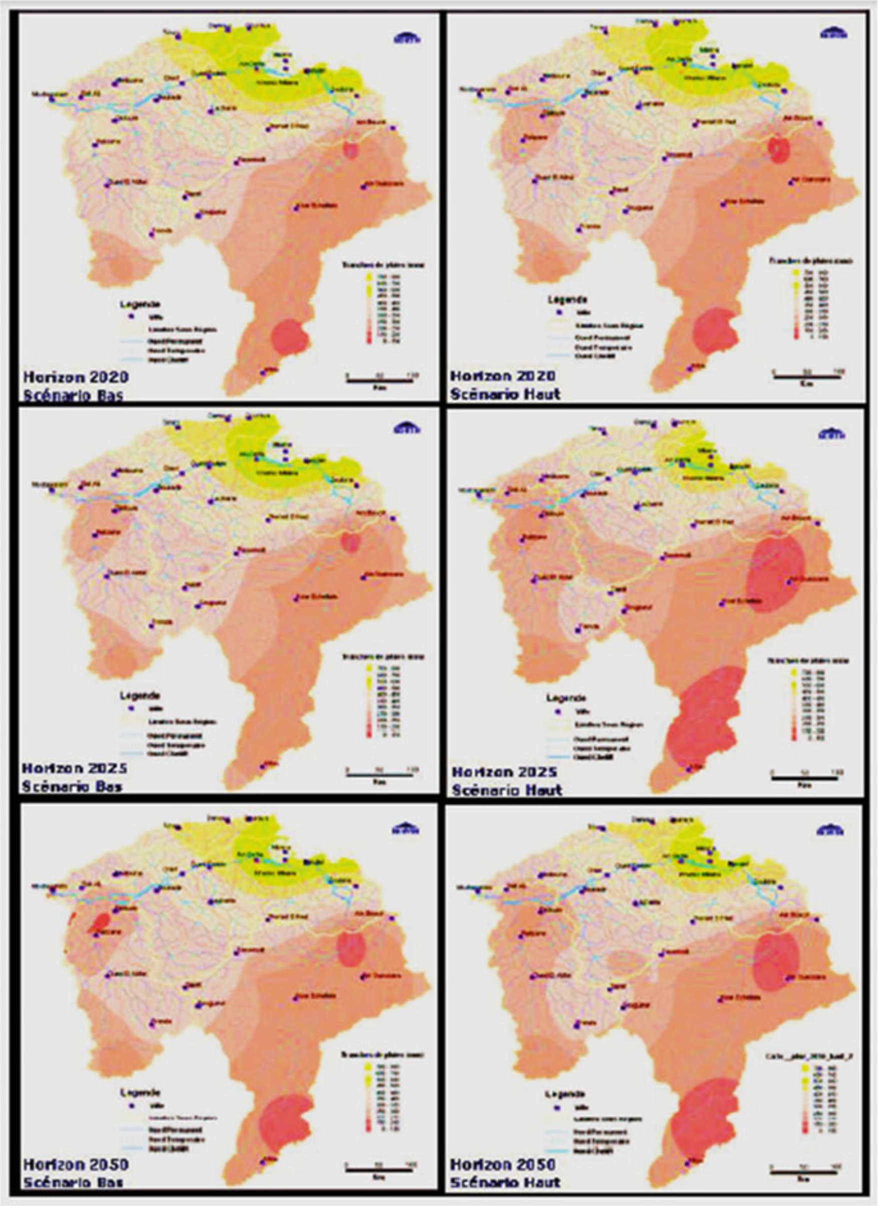

Fig. 9 Rainfall map of the Cheliff basin for 2020, 2025, and 2050 [54]

reference period (1961–1990). These different rainfall maps for the different horizons (2020, 2025, and 2050) reveal the same remarks about the spatial distribution of annual average rainfall but with values lower than the average relative to the reference period (1961–1990).

Table 3 Rate of precipitation variation (%) at horizons 2020, 2050, and 2080 compared to the reference period (1961–1990) in the study area

	A2	B2	A2	B2	A2	B2
Rate of change in precipitation (%)	2010–2039		2040–2069		2070–2099	
Annual	−10.35	−12.23	−20.78	−19.1	−33.65	−28.1
Autumn	−9	−12.1	−23.4	−16.7	−30.8	−27.3
Winter	−6.5	−9.9	−17.4	−15.1	−28.6	−24.9
Spring	−11.5	−8.1	−12.5	−17.9	−25.5	−20.3
Summer	−14.4	−18.8	−29.8	−26.7	−49.7	−39.9

The north region, whose rains were more than 450 mm for the period 1961–1990, becomes less important and would no longer exceed 400 mm for different scenarios and different horizons.

In the northeast region of the Cheliff basin and particularly the Zaccar massif, rainfall is becoming less important. A larger part of the basin will experience a reduction in precipitation; it includes the regions of Lower Cheliff and Mina and the upstream Boughezoul. This region will be between the isohyets 300 mm in the north and 100 mm in the south, where the semiarid to arid climate becomes more pronounced by occupying more surfaces faster.

The climate scenarios agree on a decrease in annual precipitation, on average, between 10.4 and 33.7% and between 12.2 and 28.1% for the A2 and B2 scenarios, respectively (Table 3). The decrease in annual precipitation is greater in summer and exceeds 40% by 2080. It should also be noted that the seasons would be more contrasting and the trend of decreasing precipitation would be stronger in autumn and winter for the A2 scenario. In general, the model predicts significant downward trends, suggesting that droughts are expected to increase substantially at the end of the twenty-first century in our study area.

This continuing decrease in rainfall at different horizons and in different scenarios confirms previous studies in the Mediterranean and Algeria, such as climate projections for rainfall in Algeria by 2071–2100 under three IPCC scenarios adapted from Giorgi and Lionello study [25] will indicate: 2011–2040 and 2041–2070, rainfall reductions range between 0 to 30% and from 1 to 40% for the scenarios B1 and A1B respectively and a decrease in the order of 25–40% by the period 2071–2100 for the A2 scenario.

The hydrologic model GR2M has been used to simulate flows over the next century. However, the results obtained must be treated with great caution because of some unavoidable difficulties related to both hydrological modeling and climate model uncertainty.

The two HadCM3 scenarios predict a decrease in flows for the three horizons (2020, 2050, and 2080) but with higher rates of variation (12, 30, and 45%) obtained with the A2 scenario. These results of the flow reduction for the A2 and B2 scenarios confirm the previous studies carried out in the Mediterranean basin, Algeria, and the Cheliff basin [18, 54, 55].

Also, an increase is expected in the frequency of droughts and a deficit of the surface water contribution of about 15% in the short term, resulting in a drop of groundwater of 4.4% in 2020 and 6.6% in 2050 [54]. So, the region is heading toward a much more severe water scarcity over the next few decades.

The sector most vulnerable to climate change is water resources and agriculture. In Algeria, adaptation initiatives are already in use and will have important consequences in several sectors. These actions must be integrated into a global adaptation policy of the country. The implementation of an adaptation plan:

- Water saving, it is a question of reducing the losses of water in the distribution and irrigation networks and of optimizing the consumption to adapt it to the needs of the different crops.
- Use of water-saving techniques, particularly in agriculture, such as drip irrigation and controlled suction, and the choice of crops that consume less water.
- Improvement of industrial water management methods (recycling, reuse).
- Use of unconventional waters.
- Protection of water resources.
- Mobilization of new water resources.
  - Collection and use of rainwater.

4 Conclusion

Climate change in the study area has had an adverse effect on the precipitation cycle, including all water resources. The reduction in the precipitation produced a downward trend in water inflow as shown by recording annual decreases from 1,025 to 815 Mm^3 between 1968–2001 and 2009. The consequences of water shortages are changes in the environmental balance which will consequently affect various human activities especially the available water supply for domestic and industrial consumption as well as for the agricultural economy.

Climatic scenarios agree on a decrease in annual precipitation, averaging between 10% and more than 30% at the end of the twenty-first century. These results reflect the availability of surface water resources, which will tend to decrease, with longer and more severe periods of low water. The Cheliff basin is considered particularly vulnerable to acute water scarcity in the coming years. A large water deficit due to population growth and an increase in water demand by different sectors of the economy are also expected (e.g., agriculture, industry).

Faced with these challenges, the country has implemented a new water resource management policy through the construction of new dams and use of unconventional water resources. It is hoped that the current investigation will help policy makers to make better decisions in developing water management strategies for the watersheds of Algeria.

5 Recommendations for Future Work

Future work on the impacts of climate change would benefit from integration of groundwater and surface water resources.

Better assessment of the effect of climate change on water resources at regional scale would require the application of the relevant regional models and the use of weather generator data for other future climate scenarios based on changes of different meteorological parameters (e.g., wind speed, radiation, relative humidity, number of cloudy days, etc.) in addition to temperature and rainfall. The results of these models may be used to simulate the runoff pattern by using a suitable hydrological model. The findings of such studies are important in preparation of regional water management plans.

Other benefits could be:

- Regionalization of parameters of hydrological models to assess hydrological behavior in ungauged basins
- Development of new drought forecasting tools based on new approaches

References

1. Arnell NW (1999) Climate change and global water resources. Glob Environ Chang 9:S31–S49
2. Vörösmarty CJ, Green P, Salisbury J (2000) Global water resources. Vulnerability from climate change and population growth. Science 289(5477):284–288
3. Muttiah RS, Wurbs RA (2002) Modeling the impacts of climate change on water supply reliabilities. J Water Int 27(3):407–419
4. Norrant C, Douguédroit A (2005) Monthly and daily precipitation trends in the Mediterranean (1950–2000). Theor Appl Climatol 83:89–106
5. Iglesias A, Garrote L, Diz A, Schlickenrieder J, Martin-Carrasco F (2011) Re-thinking water policy priorities in the Mediterranean region in view of climate change. Orig Environ Sci Policy 14(7):744–757
6. Alper B, Tayfur G, Gündüz O, Howard K-WF, Friedel MJ, Chambel A (2011) Climate change and its effects on water resources. Issues of national and global security. Springer, Berlin
7. Griffin MT, Montz BE, Arrigo JS (2013) Evaluating climate change induced water stress: a case study of the lower cape fear basin, NC. Appl Geogr 40:115–128
8. Bethoux JP, Gentili B, Tailliez D (1998) Warming and freshwater budget change in the Mediterranean since the 1940s, their possible relation to the greenhouse effect. Geophys Res Lett 25:1023–1026
9. Intergovernmental Panel on Climate Change IPCC (2001) Climate change, synthesis report (summary for policymakers). United Nations Environment Program, Geneva
10. Nicholson SE (2001) Climatic and environmental change in Africa during the last two centuries. Clim Res 17(1):123–144
11. Ragab R, Prudhomme C (2002) Climate change and water resources management in arid and semi-arid regions, prospective and challenges for the twenty-first century. Biosyst Eng 81 (1):3–34
12. Folland CK, Karl T, Salinger M (2002) Observed climate variability and change. Weather 57:269–278

13. Hansen J, Sato M, Ruedy R, Lo K, Lea DW, Medina-Elizade M (2006) Global temperature change. Proc Natl Acad Sci 103:14288–14293
14. Hasanean HM, Abdel Basset H (2006) Variability of summer temperature over Egypt. Int J Climatol 26:1619–1634
15. IPCC Intergovernmental Panel on Climate Change (2007) The physical science basis, summary for policymakers (contribution of WG I to the fourth assessment report of the IPCC). Cambridge University Press, Cambridge
16. Camuffo D, Bertolin C, Barriendos M, Dominguez-Castro F, Cocheo C, Enzi S, Sghedoni M, della Valle A, Garnier E, Alcoforado M-J, Xoplaki E, Luterbacher J, Diodato N, Maugeri M, Nunes MF, Rodriguez R (2010) 500-year temperature reconstruction in the Mediterranean basin by means of documentary data and instrumental observations. Clim Chang 10:1169–1199
17. Collins JM (2011) Temperature variability over Africa. J Clim 24:3649–3666
18. Elmeddahi Y, Issaadi A, Mahmoudi H, Tahar abbes M, Goossen M-FA (2014) Effect of climate change on water resources of the Algerian Middle Cheliff basin. Desalin Water Treat 52 (9–12):2073–2081
19. Hulme M, Doherty R, Ngara T, New M, Lister D (2001) African climate change: 1900–2100. Clim Res 17(2):145–168
20. Goubanova K, Li L (2007) Extremes in temperature and precipitation around the Mediterranean basin in an ensemble of future climate scenario simulations. Glob Planet Chang 57:27–42
21. Hertig E, Jacobeit J (2008) Downscaling future climate change: temperature scenarios for the Mediterranean area. Glob Planet Change 63:127–131
22. Marcos M, Tsimplis M (2008) Comparison of results of AOGCMs in the Mediterranean Sea during the twenty-first century. J Geophys Res 113:C12028. https://doi.org/10.1029/2008JC004820
23. Navarra A, Tubiana L (2013) Regional assessment of climate change in the Mediterranean volume 1: air, sea and precipitation and water. Springer, Berlin
24. IPCC (Intergovernmental Panel on Climate Change) (2013) Climate change 2013: the physical science basis. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) Contribution of Working Group I to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge
25. Giorgi F, Lionello P (2008) Climate change projections for the Mediterranean region. Glob Planet Chang 63:90–104
26. Meddi H (2013) Annual variability of precipitation of the north west of Algeria. APCBEE Proc 5:373–377
27. Elmeddahi Y, Mahmoudi H, Issaadi A, Goosen MFA, Ragab R (2016) Evaluating the effects of climate change and variability on water resources: a case study of the Cheliff Basin in Algeria. Am J Eng Appl Sci 9:835–845. https://doi.org/10.3844/ajeassp.2016.835.845
28. Meddi M, Boucefiane A (2013) Climate change impact on groundwater in Cheliff-Zahrez basin (Algeria). APCBEE Proc 5:446–450
29. Mann H-B (1945) Non-parametric tests against trend. Econometrica 13:245–259
30. Kendall M-G (1975) Rank correlation methods4th edn. Charles Griffin, London
31. Hirsch R-M, Helsel D-R, Cohn T-A, Gilroy E-J (1993) Statistical analysis of hydrologic data. Handb Hydrol 17:11–55
32. Yue S, Pilon P, Cavadias G (2002) Power of the Mann-Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. J Hydrol 259(1–4):254–271
33. Hamed K-H (2008) Trend detection in hydrologic data: the Mann-Kendall trend test under the scaling hypothesis. J Hydrol 349(3–4):350–363
34. Helsel DR, Hirsch RM (2002) Statistical methods in water resources techniques of water resources investigations. Book 4- Chapter A3. US Geological Survey, Reston
35. Sen PK (1968) Estimates of the regression coefficient based on Kendall's Tau. J Am Stat Assoc 63(324):1379–1389
36. Pettitt AN (1979) A non-parametric approach to the change-point problem. Appl Stat 28(2):126–135

37. Lubès H, Masson JM, Servat E, Paturel JE, Kouame B, Boyer JF (1994) Characterization of fluctuations in a time series by statistical test applications – bibliographic study. Report No 3 ICCARE programs. ORSTOM, Montpellier
38. Paturel JE, Servat E, Kouamé B, Lubès H, Masson JM, Boyer JF, Travaglio M, Marieu B (1996) Rainfall variability in humid Africa along the Gulf of Guinea. Integrated regional approach. First scientific workshop FRIEND AOC. PHIV. Technical documents in hydrology no 16, pp 1–31
39. Lubès-Niel H, Masson JM, Paturel JE, Servat E (1998) Climate variability and statistics. Simulation study of the power and robustness of some tests used to check the homogeneity of chronicles. J Water Sci 3:383–408
40. Perrin C, Michel C, Andréassian V (2003) Improvement of a parsimonious model for streamflow simulation. J Hydrol 279:275–289
41. Kouassi AM, N'guessan BTM, Kouamé KF, Kouamé KA, Okaingni JC, et Biémi J (2012) Application of the cross-simulation method to the analysis of trends in the rainfall-discharge relationship from the GR2M model, case of the N'Zi-Bandama watershed (Côte d'Ivoire). Compt Rendus Geosci 344(5):288–296
42. Hamlaoui-Moulai L, Mesbah M, Souag-Gamane D, Medjerab A (2013) Detecting hydro-climatic change using spatiotemporal analysis of rainfall time series in Western Algeria. Nat Hazards 65:1293–1311
43. Meddi H, Meddi M (2007) Spatial and temporal variability of rainfall in north west of Algeria. Geograph Tech 2:49–55
44. Meddi MM, Assani AA, Meddi H (2010) Temporal variability of annual rainfall in the Macta and Tafna catchments, northwestern Algeria. Water Resour Manag 24:3817–3833
45. Ministry of Water Resources (MWE). Note of synthesis, activity in 2012. www.mre.dz/
46. National Statistics Office (NOS) (2013) Series C – regional statistics and mapping environmental statistics. Statistics collections no 177
47. Toumi S (2013) Application of nuclear techniques and remote sensing to the study of water erosion in the Wadi Mina basin. PhD thesis, National School of Hydraulics
48. Remini B, Bensafia D, Nasroun T (2015) Impact of sediment transport of the Chellif River on silting of the Boughezoul reservoir (Algeria). J Water Land Dev 24(I–III):35–40
49. Benblidia M, Thivet G (2010) Water resources management: the limits of a supply-side policy. International Centre for Advanced Mediterranean Agronomic Studies-CIHEAM
50. Elmeddahi Y (2016) Climate change and its impacts on water resources, the case of the Cheliff basin. PhD thesis, University Hassiba Ben Bouali of Chlef
51. Semenov MA, Brooks RJ, Barrow EM, Richardson CW (1998) Comparison of the WGEN and LARS-WG stochastic weather generators for diverse climates. Clim Res 10:95–107
52. Wilks DS, Wilby RL (1999) The weather generation game – a review of stochastic weather models. Prog Phys Geogr 23:329–357
53. Pope VD, Gallani ML, Rowntree PR, Stratton RA (2000) The impact of new physical parametrizations in the Hadley Centre climate model – HadCM3. Clim Dyn 16:123–146
54. PNUD 00039149 (2010) Second national communication of Algeria on climate change
55. PNUD, Project ALG/98/G31 (2001) Development of the national climate change strategy and action plan