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Effect of climate change on water resources of the Algerian Middle Cheliff basin

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ABSTRACT

The influence of climate change on the water resources of the middle Cheliff basin in Algeria was assessed with particular emphasis on the major issues related to 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 expansion of industrial and agricultural activities with the population growth, on the one hand, and to a reduction in water resources caused by extreme droughts, on the other hand. The results of the current assessment showed a significant decrease in annual precipitation, ranging from 14 to 32%, and an increase in average temperature by 0.9˚C over the past 20 years. A mathematical model predicted a flow deficit ranging from 20 to 25% by the year 2050. Hydroclimatic characterization indicated that rainfall deficits and the increase in temperature will have an immediate and significant negative impact on the surface water flow and groundwater recharge. It was recommended that water resources managers need to develop effective strategies for the rational use of water since this will affect social and economic development.

Keywords: Precipitation; Climate change; Water resources; Middle Cheliff basin; Modeling

1. Introduction

In arid and semi-arid regions, rainfall is a major factor in climate characterization. Recently, much research has been conducted to address the impact of climate change on the environment and particularly on water resources [1–5]. During the last century, the average temperature across the Mediterranean basin and North Africa region has increased from 0.56 to 0.92˚C [5–15]. According to different emission scenarios [8–10, 16,17] several general circulation models (GCM's) predict an augmentation in temperature from 0.7 to 4˚C till 2100. Furthermore, Goubanova and

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Meddi [18,19] reported that the African northwestern region, and particularly Algeria, has experienced a decrease in mean annual precipitation. This decrease in rainfall is predicted to continue over the next century [8, 16–18, 20]. This phenomenon is particularly noticeable in areas characterized as semiarid. The Algerian middle Cheliff basin is a good example where there has been, in the last decades, a significant decrease in water reserve levels with dams due to drought accompanied by an intense exploitation of groundwater [21]. There is a need to better understand the complex phenomenon in relation to the interaction between climate change, water resources, and economic growth. In the case study of arid regions such as Algeria, the information about the effects of climate change on water resources are still very limited [22].

This paper aims to study and assess the effects of climate variability on the water resources of the Algerian middle Cheliff basin through an analysis of the temperature, and rainfall. In particular, the problems related to issues of weather variation, time scale, and their influence on water resources from rainfall data will be discussed. Rainfall fluctuations will be analyzed using statistical analysis tools and a mathematical model based on annual and seasonal data.

2. Materials and methods

2.1. Description of case study area

Situated in the north-west of the North African country of Algeria, the region belongs to the great basin of Cheliff and consists of two subbasins: the basin of the Middle West Cheliff and the Middle East Cheliff (Fig. 1).The study area consists of 1015.08 km^2 and is located between 35°97′and 36°36′ north latitude and 0°95′ and 2°04′ east longitude. The region is limited to the north by the mountain chains of Dahra and the coastal area, in the south by the Ouarsenis Mountains, in the east by the high Cheliff, and in the west by the low Cheliff. The climate of this region is semiarid Mediterranean type with hot summers and cold winters. The precipitation exhibits a large range of variability with a tendency for decreasing from north to south and from east to west. The annual average precipitation, potential evaporation, and temperature are 350, 1,500 mm, and 19°C, respectively.

2.2. Collecting data for annual rainfall and temperature

Subbasins of the Middle Cheliff were equipped with 20 rainfall stations. In this paper, only those having a long series of observations and few gaps were considered. The collected data were annual rainfall, temperatures, and flow rates. Table 1 summarizes data obtained from the National Agency for Water Resources [23] and the National Meteorological Office (NMO) [24].

Temperature anomalies were studied on the base period (1961–1990). The assessment of the variability of rainfall was performed using the accumulated rainfall deficit index as well as the Pettitt test. GR2 M conceptual model was used for the simulation of the monthly streamflow.

2.3. Cumulative rainfall deficit index and Pettitt test

The cumulative rainfall deficit index parameter measures the major trends in chronological series and visualizes the deficit and/or surplus periods referring to one-year calculation period according to the formula:

$$I_p = \frac{p - \bar{p}}{\sigma} \qquad (1)$$

where I_p = rainfall deficit index, p = annual rainfall (mm), $\bar{p}$ = interannual average rainfall over the reference period (mm), and σ = standard deviation of the interannual rainfall over the reference period (mm).

The cumulative rainfall deficit can be calculated according to the formula:

$$Z_i = I_{pi-1} + I_{pi} \qquad (2)$$

where Z_i = cumulative rainfall deficit index, I_{pi-1} and I_{pi} = rainfall deficit index for year $i-1$ and i.

It is possible to demonstrate the nonstationary in the rainfall series during the observation periods and by the fact isolate periods with rainfall anomalies. For this purpose, the non-parametric test of Pettitt (1979) [25] was used for the positioning of break points in the rainfall series. The absence of a break in the series (x_i) of size N represents the null hypothesis. 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 [25]:

$$U_{t,N} = \sum_{i=1}^{t} \sum_{j=t+1}^{N} D_{ij} \qquad (3)$$

where:

$$D_{ij} = \operatorname{sgn} x_i - x_j$$

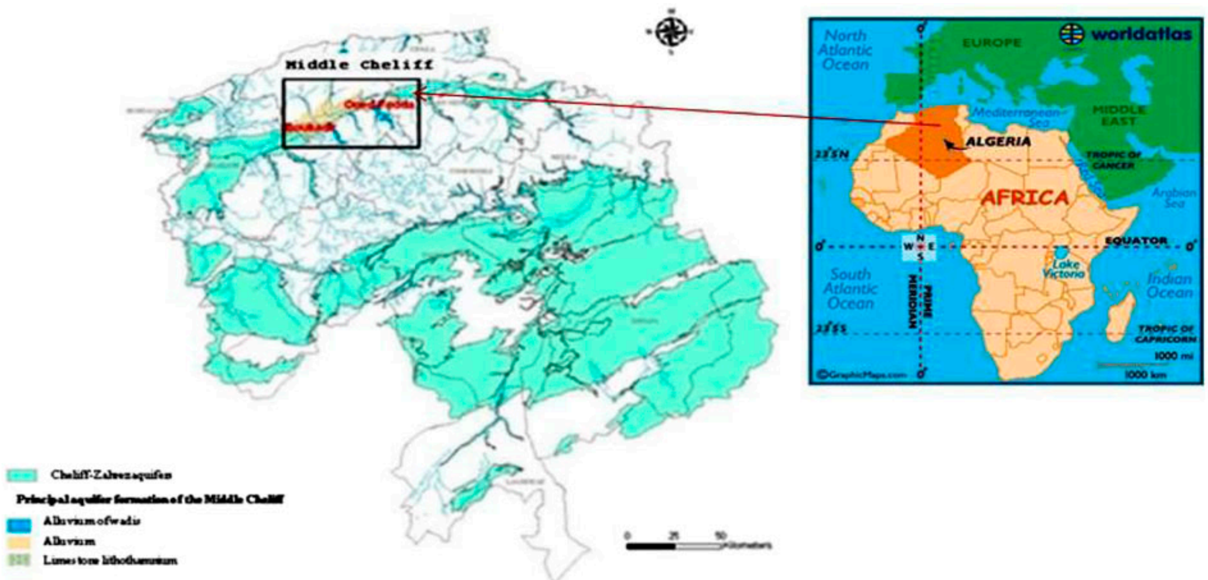

Fig. 1. Location of the Middle Cheliff Basin.

Table 1
Characteristics of the stations in the study area [23,24]

Station	Period of observation	Longitude	Latitude	Altitude (m)	Parameters
Fodda bge	1943–2010	1°61´E	36°24´ N	430	Precipitation
Oued Sly	1926–2010	1°21´E	36°11´N	95	Precipitation
ONM de Chlef	1936–2010	1°20´E	36°12´ N	143	Precipitation
Chetia chambre F	1968–2010	1°28´E	36°19´N	84	Precipitation
Ponteba Bge	1967–2010	1°52´ E	36°25´N	140	Precipitation
Merdja Amel	1967–2008	0°95´ E	36°01´ N	61	Precipitation
El ABadia	1968–2010	1°68´ E	36°25´N	162	Precipitation
ONM de Chlef	1936–2010	1°20´E	36°12´ N	143	Temperature
Ouled Farés	1984–2000	1°24´ E	36°24´ N	116	Flow

with:

$$\begin{cases} \operatorname{sgn}(x) = 1 & \text{if } x>0 \\ \operatorname{sgn}(x) = 0 & \text{if } x=0 \\ \operatorname{sgn}(x) = -1 & \text{if } x<0 \end{cases}$$

If the null hypothesis is rejected, an estimate value of the break date is given by the time t defining the maximum absolute value of the variable $U_{t,N}$. On the other hand, the probability of k is given approximately by the formula:

$$\text{pob}(KN>k^{\circ} \approx 2\exp(-6K^2/(N^3+N^2)) \quad (4)$$

2.4. Conceptual model GR2M

A theoretical model was developed based on two main optimizable parameters: X_1 (mm), which represents the maximum capacity of the soil moisture reservoir; and X_2 $(0<X_2<1)$, the underground exchange coefficient. The model works with a monthly time step [26]. Rainfall (P) and potential evaporation (E), which is calculated by the Thornthwhite method are both the main input parameters of the model which are modulated in the same portion (Fig. 2).

The outputs' results represent the streamflow in mm. The model validation was verified by comparison between calculated and observed flows through the Nash and Stucliffe criterion (1970) [27], which are expressed by the following equation:

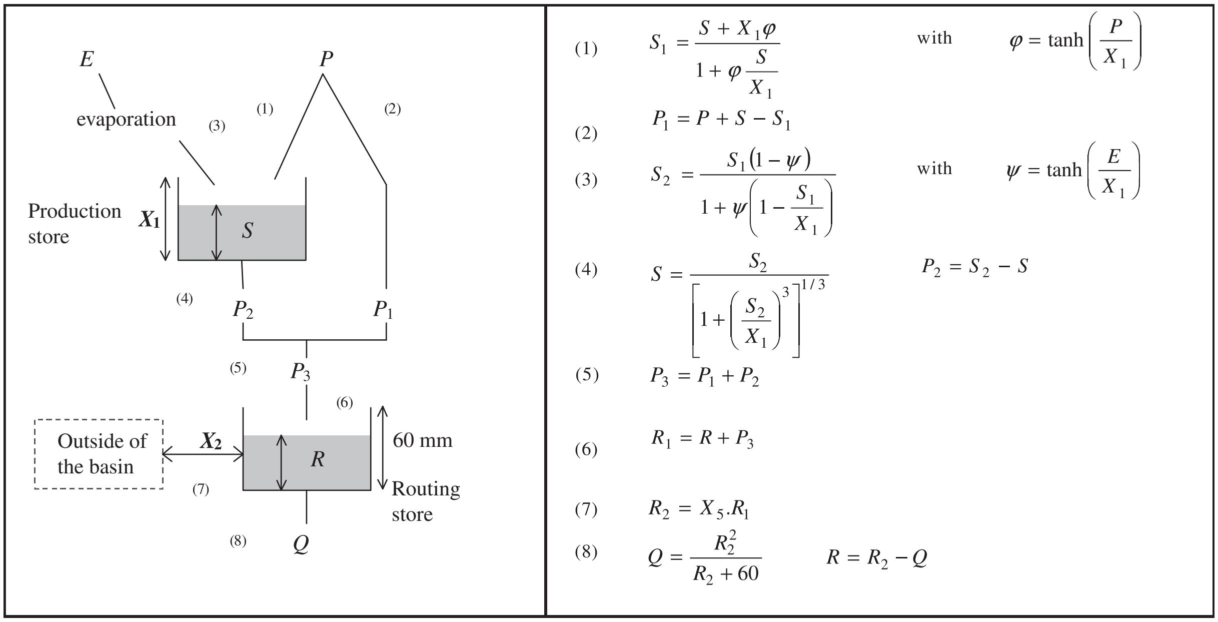

Fig. 2. Diagram of the GR2M [26].

$$\text{Nash}(Q) = 100\left[1 - \frac{\sum_i (Q_o^i - Q_c^i)^2}{\sum_i (Q_o^i - Q_m)^2}\right] \quad (5)$$

where Q_o^i = observed flow in mm/month; Q_c^i = calculated flow in mm/month, and Q_m = mean observed flow over the whole observation period in mm/month.

3. Results and discussion

3.1. Assessment of the effects of temperature and precipitation on water resources

An assessment of the temperature and precipitation changes in the middle Cheliff Basin over the last decades indicated a greater occurrence of droughts. There has been in increase in temperature in the basin. For example, Fig. 3(a) represents the variation of the annual temperature in the period from 1936 to 2010. The shape of the curve shows minimum and maximum temperatures along the study period. One can observe a relative stability till the year 1977. Starting from this point, we can observe a clear tendency towards rising temperatures. Compared to the reference period, an anomaly of 1.3˚C of the maximum temperature and 2.5˚C for minimum temperature were recorded (Fig. 3(b)). The evolution of the average temperature shows an increase of 0.9˚C. The analysis of this curve shows that 1997 was the warmest year (20.7˚C), whereas 1956 was the coldest one (17.4˚C).

In addition to rising temperatures, a decrease in annual rainfall was also observed. For instance, the curve plotted in Fig. (4) shows a decrease in the rainfall and thus a greater occurrence of droughts in recent decades. Rainfall was very irregular in interannual level and a decrease in average annual rainfall appeared from 1979 and 1980, according to seven stations (Figs. (4), 5(a) and (b)). Excess rainfall was observed until the late 70s and early 80s. However, episodes of rainfall decrease were also recorded during this period with no more than three consecutive years (periods 1941–1944 and 1968–1970). Furthermore, the probability associated with the Pettitt statistic test confirmed the appearance of a significant break at each of the studied station (Table 2). This failure occurred in the late 70s and early 80s for Ponteba Bge, Merdja Amel, Fodda dam, and El Abadia stations. The correspondent break year for these stations was identified in 1979, whereas it appeared for Oued Sly and Chettia room F stations in the early 80s. The rainy intakes for NMO Chlef station

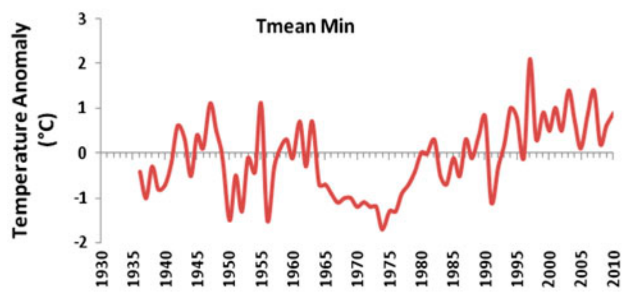

Fig. 3(a). Maximum, mean and minimal temperatures for the period 1936–2010 (collected from NMO Chlef station).

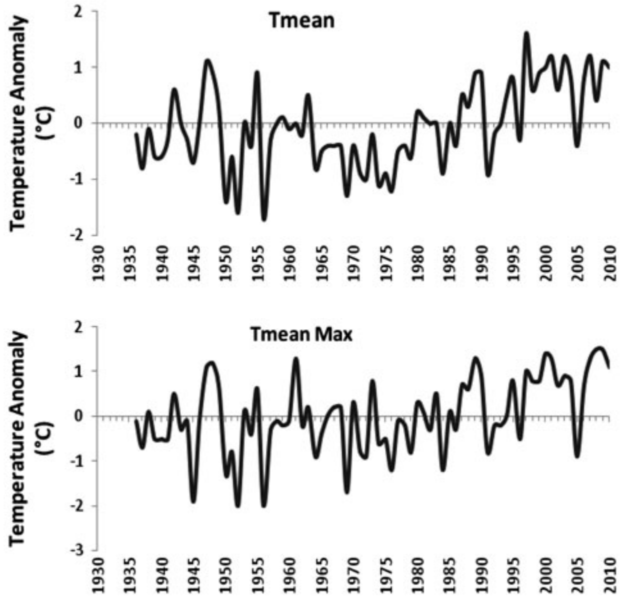

Fig. 3(b). Temperature anomalies over the reference period (1961–1990)) at NMO Chlef station.

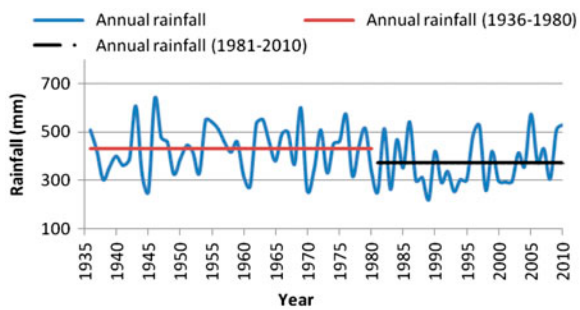

Fig. 4. Annual variation of rainfall in station NMO of Chlef (1936–2010).

decreased from 432.5 to 372.8 mm, which constituted a difference of 59.8 mm (14%). For Oued Sly station, the total rainfall varied from 367.5 to 258.2 mm which corresponds to a decrease of 109.3 mm (30%). In general, the last decades were characterized by a significant precipitation decrease with a greater occurrence of droughts.

3.2. Comparison of observed and simulated streamflows

The average flow in the Ouahran Wadi subbasin was estimated at 0.45 m^3/s with a minimum of 0 m^3/s in the summer season and a maximum of 130.6 m^3/s registered for the year 1992. The GR2 M model was applied for the subbasin of Ouahran based on the monthly data from January 1984 to December 1990 for calibration and those from January 1991 to December 2000 for validation. The results obtained (Table 3 and Fig. 6) show a good correlation between observed and simulated flow. This can allow us to say that the model is properly calibrated and confirms the good performance of the model (Fig. 6).

3.3. Assessment of available water resources

In the case study region, water resources come from dams and the Cheliff groundwater reservoir located in the alluvial plain (Fig. 7). For surface water accumulation, two dams were in operation, namely Oued fodda and Sidi Yacoub. Their capacities were 404.4 Hm^3 in 2003. This dropped to 356 Hm^3 in 2006. The last survey conducted by NADT (National Agency for dams and transfer) in November 2009 estimated the total volume at only 120 Hm^3. Furthermore, the main exploited reservoirs in the Middle Cheliff basin belong to the alluvial aquifer, the lithothamnium limestone and the astiens sandstone. The groundwater potential of these main hydrogeological units was estimated at 39 Hm^3/year before 2002. This had decreased to 32 Hm^3/year in 2009, which corresponds to a decline of 18% (Fig. 7 and Table 4).

Since 1980, demographic growth, economic, and agricultural development combined with the observed water deficit led to an increase in water catchment systems (e.g. wells and drilling holes) driving overexploitation of groundwater. This caused an imbalance between the volume of water recharging the aquifer and the quantities of water withdrawn mainly due to the lower intakes. The amounts of mobilized groundwater increased from 3.75 million m^3

Table 2
Rupture tests detection (Pettitt Test) for seven stations

Station	Period of observation	*P* (mm)	Rupture (year)	Deficit from mean (%)
Fodda damm	1943–2010	430	1979	24.7
Oued Sly	1926–2010	328.9	1980	30
ONM de Chlef	1936–2010	407.8	1979	*14*
Chetia chambre F	1968–2010	347.2	1980	25
Ponteba Bge	1967–2010	424.7	1979	26
Merdja Amel	1967–2008	288.3	1979	*32*
El ABadia	1968–2010	383.8	1979	27.8

Table 3
Optimized parameters of the GR2 M model for 1984–1990 and 1991–2000 period

Station (O. Farés)	$X1$	$X2$ (mm)	Q_{obs} (mm/month)	Q_{simul} (mm/month)	Q_{obs}/Q_{simul}	R^2 (%)	Nash (%)
Calibration period (1984–1990)	0.63	250	2.34	2.26	1.03	0.89	87.5
Validation period (1991–2000)	0.63	250	2.39	2.24	1.06	0.87	85.2

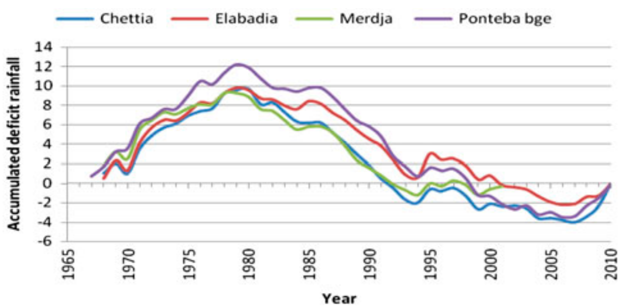

Fig. 5(a). Cumulative rainfall deficit for each station.

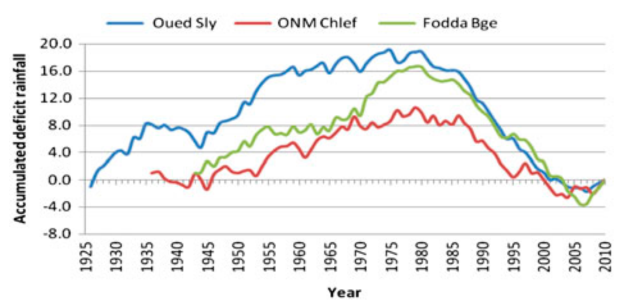

Fig. 5(b). Cumulative rainfall deficit for each station.

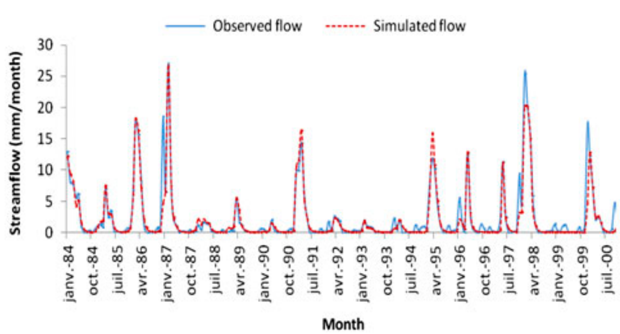

Fig. 6. Comparison of observed and simulated of monthly flow for the Ouahrane Wadi subbasin in the 1984–2000 period.

in 1970 to 110.7 million m^3 in 2005 [28]. According to a recent inventory, the alluvial aquifer located in the quaternary course alluvial of the middle Cheliff contained 21 drilled sites, 74 wells, and 13 piezometers. In addition, 41 sites between drillings and wells were operational, 41 wells were abandoned for various reasons, and 26 were dried.

A significant decrease was observed between the static piezometric levels for the period from August 1973 to March 1989 (Fig. 8). There was a variation of 3–14 m between the upstream and downstream parts of the aquifer. Time tracking of two wells numbered 82–13 and 105–91 located in the Western Middle Cheliff showed that the static water level dropped to 6.3 m in the 82–13 well between 1972 and 2001 during a period of high water and 14.6 m in low water period between 1988 and 2003 (Figs. 9(a) and (b)). In 2009, the well was dry. We can argue that this significant decrease was the result of the combined effects of drought and excessive exploitation of groundwater starting in 1994. The effect was less significant for the 105–91 well (Fig. 9(b)); there was a slight rise in the groundwater level of about 0.5–0.6 m despite low rainfall. This would have been the result of dam releases and re-infiltration of irrigation water. The renewal of the groundwater resource depends on the groundwater recharge which is a function of rainfall and evapotranspiration. Increased evaporation due to increased temperature causes a decrease in groundwater recharge and has a direct impact on the level and quality of the water.

3.4. Impact of climate change on groundwater resources

Climate change can have a negative impact on the entire rainfall cycle including the overall water resources balance. Its impact was particularly important for the Cheliff basin which was already suffering from a dry climate and a resulting inadequacy in groundwater recharge. The Global climate model UKHI (scenario «IS92» of GIEC) with both high and low assumptions [28] was carried out on a seasonal basis to predict climate projections for Algeria over the period 1961–1990. This simulation predicted an increase in temperature of about 1–1.3°C by 2050 for the low scenario and 1.6–2.2°C for the high scenario with a decrease in average rainfall of about 10–22% in 2050 (low and high). The basin flow

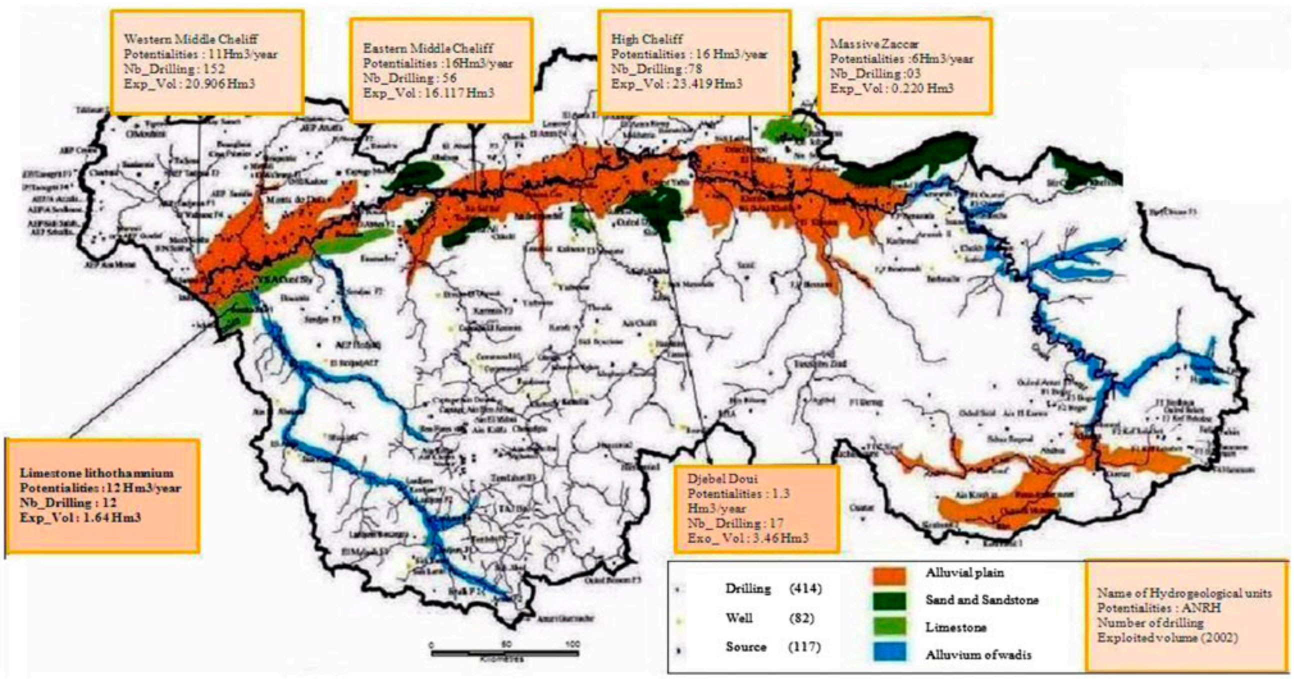

Fig. 7. Main hydrogeological units and their groundwater potential [29].

Table 4
Principal hydrogeological units and their groundwater potential

Hydrogeological unit	Groundwater potential (Hm^3/year)
Plain of Western Middle Cheliff	8.75
Plain of Eastern Middle Cheliff	13.95
Wadi sly	0.66
Limestone lithothamnium	8.66
Total	*32.02*

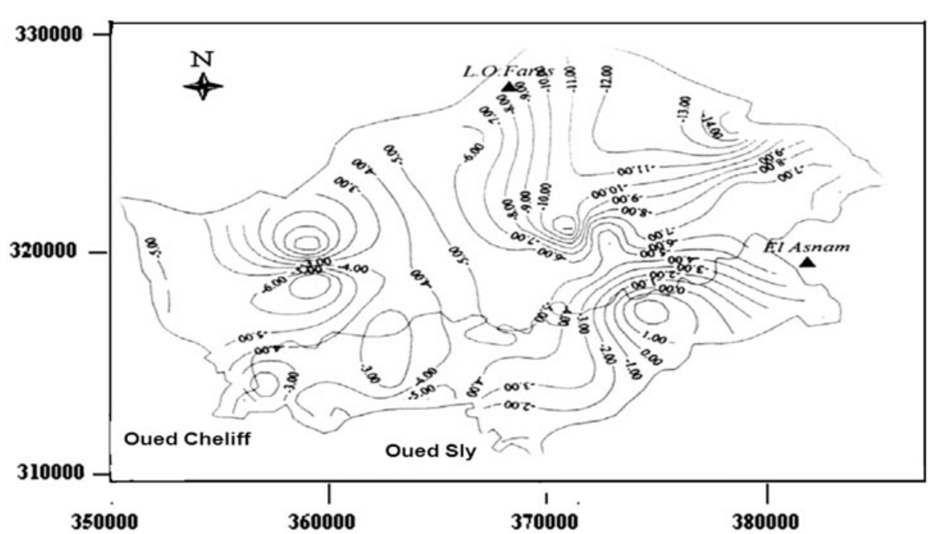

Fig. 8. Map of the piezometric variations in the Western Middle Cheliff basin (1973–1989) [30].

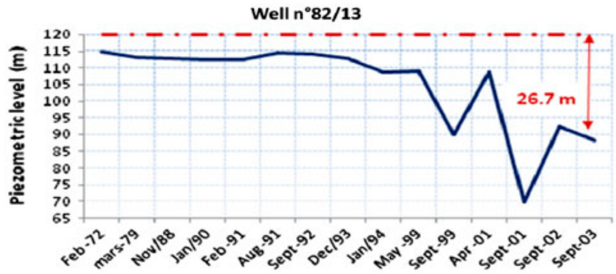

Fig. 9(a). Variation and progression of piezometric levels for well 82–13.

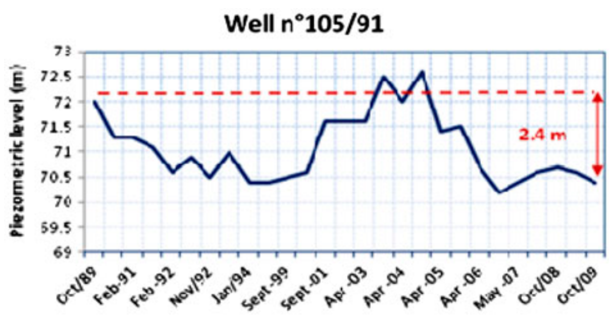

Fig. 9(b). Variation and progression of piezometric levels in well 105–91.

evolution in 2050 compared to the reference period (1984–1990) showed a decrease of 16% in autumn, 20% in winter, and 23–23.7% in summer and spring for the low scenario. For the high scenario, the flow decrease rises for all seasons recording 17, 34, 36, and 33%, respectively, for the autumn, winter, spring, and summer (Fig. 10). There was a general downward trend in flow predicted for 2050 ranging from 20 to 25% for the low and high scenarios, confirming the previous studies of the Mediterranean basin. Furthermore, the groundwater potential of the Middle and High Cheliff area was predicted to be 73.9 Hm^3 [28], which represents a reduction of 9.2% by 2050

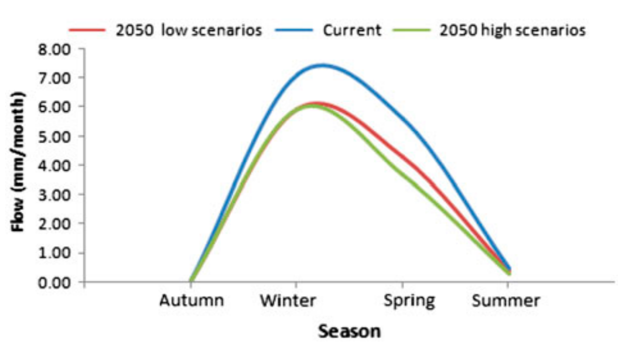

Fig. 10. Seasonal flow trend (High & low scenarios in 2050) over the reference period (1984–1990).

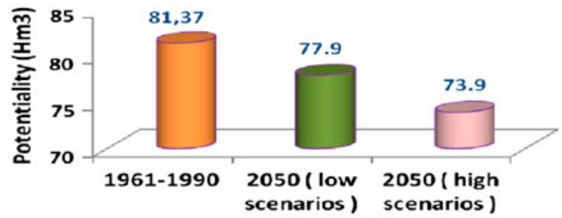

Fig. 11. Progression in groundwater resources potential for the High and Middle Cheliff Basin (High & low scenarios for 2050).

(high scenario), compared to the reference period (1961–1990). For the low scenario, the potential was reduced approximately by 4.3% (Fig. 11).

4. Concluding remarks

Significant changes in climate conditions were recorded during the study period resulting in a decrease in annual precipitation ranging from 14% to 32% depending on the region, and an increase in average temperatures by 0.9˚C compared to the reference period (1961–1990). This will cause additional stress on public services responsible for water resources management and on the population due to constraints on drinking water supplies. The mathematical simulation model indicated that the Ouahrane subbasin will register a flow deficit ranging from 20 to 25% by 2050, both for the low and high scenarios.

Hydroclimatic characterization indicated that rainfall deficits and the increase in temperature will have an immediate and significant negative impact on the surface water flow and groundwater recharge. It is recommended that water resources managers need to develop effective strategies for the rational use of water since this will affect the social and economic development. Water resources management represents an indispensable tool for finding optimal solutions to the problems associated with water demand and availability. Finding/Researching good balance between these two elements mainly depends on their consideration as inseparable from the physical and social environment.

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