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Assessing the Impact of Climate Change on Groundwater Resources in Northeastern Algeria: A Case Study of Seybouse Basin

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Abstract: The objective of this study is to evaluate the impact of climate change on groundwater resources on the Seybouse basin using the model of Maillet. The recession coefficients estimated average between $4.05.10^{-2}$ day^{-1} and $6.02.10^{-2}$ day^{-1} either side 1983, whether an average increase of 27.08% and highlight a drain much faster aquifers supplying base flow after 1983. Shortening of 3 to 9 days with an average of 6 days of drying time after 1983 was highlighted. The water volume mobilized by the average aquifer fluctuates between 0.54 and 8.70 Mm^3 before and after 1983 whether an average decrease of -34.71%. These results show a decrease in the water volume mobilized by groundwater after 1983 and suggest a considerable decline of groundwater resources under the influence of climate change.

Key words: Climate change · Water resources · Maillet model · Seybouse basin · Algeria

INTRODUCTION

Precipitation is one of the major factors in the water balance of a catchment and as such the water cycle is most sensitive to changes in rainfall [1]. In sub-humid, semi-arid and arid regions, evapotranspiration is the second largest component of the water balance and is affected not only by the availability of water but also by any change in other aspects of climate e.g. temperature [2]. Some of the most useful variables for monitoring the water cycle are river flows, ocean water level, rainfall, air and water temperatures, melting of ice cap and groundwater static level [3-5].

Analyses of hydrometric and rainfall data in Africa have demonstrated that climate is changing [4, 6,7]. This change is characterized by a dry period which began in the 1970s and continues until the present day. A decrease was observed in rainfall intensity [8,9], number of rainy days [10,11], annual rainfall [12-15] and consequently river flows [16-18] and lakes levels [19].

However, these studies do not take into account groundwater level measurements. Yet the direct contact of the water table with the ground surface, unconfined aquifers, especially surficial and shallow aquifers, is particularly sensitive to changes in rainfall variability and climatic conditions [20-22]. Moreover, little research has been done regarding the measurement of groundwater level, although groundwater water static level can serve as a variable to assess the impact of climate variability on groundwater [3,23].

The objective of this study is to assess the impacts of climate change on groundwater resources of the Seybouse basin. The methodology was based to analyze changes in recession coefficients of Maillet and the water volumes mobilized by aquifers either side of 1983, which is the break year of 33-year time series of daily discharge measured in the Seybouse basin (6450 km^2) of Algeria.

Study Area Description

Geographic Description of the Seybouse: The Seybouse Basin in north-eastern Algeria is the third largest basin by surface area in the country, after the El-kebir of Rumel and Mellegue rivulets.

The Seybouse Mediterranean rivulet, originates on the high semiarid plains on the southern flank of Tell Atlas Mountains and flows from south to north. The Seybouse Basin comprises three principal zones, as shown in Figure 1: the high Seybouse, middle Seybouse and low Seybouse sub-basins.

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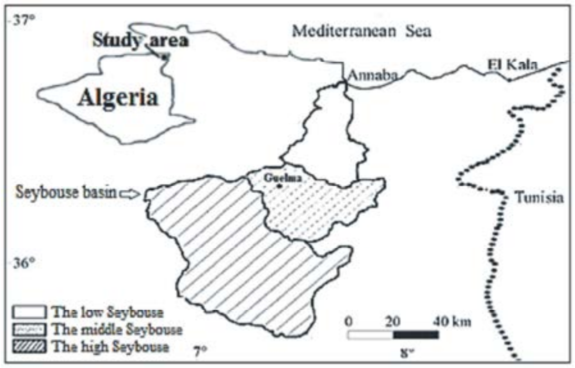

Fig. 1: Map of three Seybouse principal sub basins

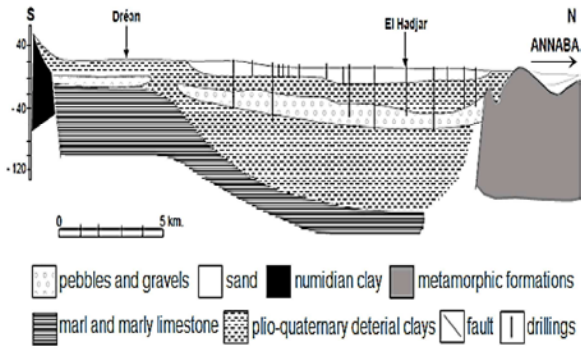

Fig. 2: Hydrogeology of the Seybouse riverbed in the plain of Annaba

The Seybouse Basin represents a ramified hydrographic system of more than 3000 km, with 42 rivulets of length l0 km. This system is a very heterogeneous natural group with different means of supply and flow pathways.

Climate, Hydrology and Hydrogeology: The basin climate varies from typical Mediterranean along the coast to semi-arid. Mean annual precipitation is between 400 mm and 700 mm, with a monthly maximum between 90-120 mm in December or January. Minimum and maximum temperatures are in December or January (less than 10°C) and July or August (between 25°C and 30°C), respectively. Average annual infiltration is about 162 mm and surface runoff is about 79 mm/yr.

Regarding hydrogeology, the Seybouse River flows through depressions with an alluvial water table [24]. These formations distinguish two aquifers (Figure 2), which communicate through the Oued Meboudja, the superficial aquifer of Annaba and the alluvial aquifer of high terraces [25]. In the Guelma region, identified aquifers are alluvial and calcareous.

Recession Coefficient and Water Mobilized by the Aquifer: We used the recession coefficient of Maillet (k) improved by dichotomous resolution and the volumes of water mobilized (Vm) by aquifer, presented by [26]. The equation of the recession coefficient is described by:

$$Q_t = Q_0 e^{-kt} \tag{1}$$

where Q_t is flow at the time t, Q_0: initial flow (discharge at the beginning of drying) and recession coefficient k of Maillet obtained by solving the equation (2) below:

$$\frac{e^{-kt}}{k} + \frac{V}{Q_0} - \frac{1}{k} = 0 \tag{2}$$

Integrating equation (2) on the interval [0, + 8] gives the volume of water mobilized by all aquifers in the watershed:

$$V_{mobilized} = \int_0^{+\infty} Q_0 e^{-kt} dt = \frac{86400 \times Q_0}{k} \tag{3}$$

Recession Coefficients Analysis: The average recession coefficients proportional to the rate of emptying of the aquifer were determined before and after the break of 1983, during the period 1970-2003, using data of 33-year time series of daily discharge measured in the Seybouse Basin. The results obtained were summarized in Table 1.

The results in Table 1 show that the average recession coefficients vary between 4.05.10-2 day^{-1} and 6.02.10^{-2} day^{-1} before 1983, identified as breaking year in hydrometric series. After 1983, the recession coefficients fluctuate between 5.44.10-2 day-1 and 8.61.10^{-2} day^{-1}. These results therefore demonstrate an increase in the coefficient of drying after 1983. The rate of increase of the recession coefficient varies between 19.75% (Ain Berda) and 36.81% (Bouchagouf).

The results of recession duration are shown in Table 2. These results show that the drying time varies on the different sub-basins and is from 12 to 25 days. The drying times prior to 1983 range from 16 to 24 days. After 1983, they fluctuate between 11 and 18 days. A shortening of the drying time ranging from 3 days to 9 days after 1983 is highlighted.

Analysis of the Water Volume Mobilized: The water volumes mobilized by aquifers were determined at different stations (Table 3).

Table 1: Average recession coefficients before and after 1983

Stations	Periods	Average recession (day^{-1})	Rate of increase (%)
Moulin Rochefort	1970-1983	$6.02.10^{-2}$	+30.08
	1984-2003	$8.61.\ 10^{-2}$	
Bouchagouf	1970-1983	$4.05.\ 10^{-2}$	+36.81
	1984-2003	$6.41.\ 10^{-2}$	
Ain Berda	1970-1983	$5.93.\ 10^{-2}$	+19.75
	1984-2003	$7.39.\ 10^{-2}$	
Mirebek	1970-1983	$4.26.\ 10^{-2}$	+21.69
	1984-2003	$5.44.\ 10^{-2}$	

Table 2: Average duration of drying (days) before and after 1983

Stations	Periods	Recession duration (day)	Variation in the recession duration (day)
Moulin Rochefort	1970-1983	16.61	-5.00
	1984-2003	11.61	
Bouchagouf	1970-1983	24.69	-9.09
	1984-2003	15.60	
Ain Berda	1970-1983	16.86	-3.33
	1984-2003	13.53	
Mirebek	1970-1983	23.47	-5.09
	1984-2003	18.38	

Table 3: Water volume mobilized by the aquifer before and after 1983

Stations	Periods	Water volume mobilized (Mm^3)	Reduction rate (%)
Moulin Rochefort	1970-1983	0.81	-22.22
	1984-2003	0.63	
Bouchagouf	1970-1983	3.15	-33.97
	1984-2003	2.08	
Ain Berda	1970-1983	1.45	-62.77
	1984-2003	0.54	
Mirebek	1970-1983	8.70	-19.88
	1984-2003	6.97	

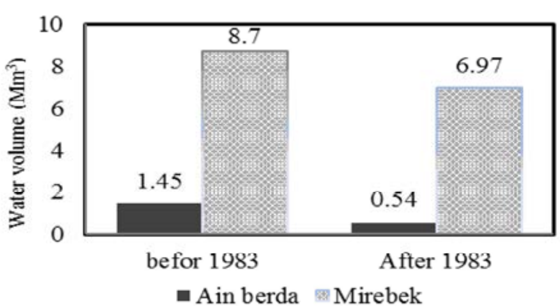

Fig. 3: Interannual variations of water volume mobilized (1970-2003) at the Ain Berda and Mirebek gauging stations

The results in Table 3 show that the water volume mobilized by aquifers varies between 0.81 and 8.70 Mm^3 befor 1983. After 1983, the water volume mobilized by aquifers fluctuates between 0.54 and 6.97 Mm^3. The rate of reduction in water volumes mobilized by aquifers varies from 19.88% (Mirebek) to 62.77% (Ain Berda). These results show a reduction in water volumes mobilized by the aquifer after 1983, as shown in Figure 3.

DISCUSSION

The recession coefficients estimated from hydrometric stations Moulin Rochefort; Bouchagouf; Ain Berda and Mirebek during this study varying between $4.05.10^{-2}$ day^{-1} and $6.02.10^{-2}$ day^{-1} before 1983. After 1983, the recession coefficients fluctuate between $5.44.10^{-2}$ day^{-1} and $8.61.10^{-2}$ day^{-1}. These results show that the recession coefficients experiencing a significant increase in the Seybouse basin after 1983. Draining groundwater depletion follows a law of exponential decay it is much easier to study the dry season well marked [27]. The analysis of the evolution of the annual recession coefficients over the period 1970-2003 showed that they vary greatly from one year to another before 1980. After 1980, changes are lower. The average values ??around which oscillate coefficients of 0.0674 day^{-1} before 1980 and 0.0483 day^{-1} after this year.

The water volumes mobilized by aquifers vary between 0.81 and 8.70 Mm^3 before 1983. After 1983, the volumes mobilized by aquifers fluctuate between 0.54 and

6.97 Mm^3. The water volumes mobilized by aquifers thus experiencing a decline due to the reduction in rainfall observed from the end of the 1980s. Sustainable depletion contribution of base flow is related to a reduction in the water volume in aquifers. Indeed, there is a considerable depletion of groundwater supplies that provide normally feed streams in dry period. These changes in the water volume mobilized aquifers suggest considerable regression of groundwater reserves. It would explain the high magnitude of the recent drought on the lower flows.

Recession analysis is carried out from different hydrometric stations and we observed a variability of recession coefficient along the river, including stronger upstream basin values. This variability within the basin could be explained by major anthropogenic removals in some places during the dry periods.

The study of the recession and volume mobilized by aquifers confirms that the low contribution of baseflow, due to reduced water tables flows, is a lasting phenomenon. This growing depletion of groundwater reserves of the Seybouse basin result of cumulative rainfall deficits, vegetation cover degradation, which results generally rapid groundwater depletion.

CONCLUSIONS

The recession coefficients estimated in different sub-basins of the Seybouse basin in Algeria vary between $4.05.10^{-2}$ day^{-1} and $6.02.10^{-2}$ day^{-1} before 1983. After 1983, they fluctuate between $5.44.10^{-2}$ day^{-1} and $8.61.10^{-2}$ day^{-1}. These results show an increase in the coefficient of drying after 1983, ie much faster draining aquifers supplying base flow. Shortening of 3 to 9 days with an average of 6 days of drying time after 1983 was highlighted. The water volume mobilized by the average aquifer fluctuates between 0.81 and 8.70 Mm^3 before 1983. After 1983, the water volume mobilized by aquifer fluctuates between 0.54 and 6.97 Mm^3. These results show a reduction in water volumes mobilized by the aquifer after 1983. These changes in the volume of water mobilized aquifers suggests considerable decline of groundwater resources under the influence of climate change.

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