Effects of Climate Variability on Groundwater Resources in Coastal Aquifers (Case of Mitidja Plain in the North Algeria)

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1 Introduction

Water is indispensable for life, but its availability at a continual quality and quantity is vulnerable by many factors, of which climate plays a leading role (Kumar 2012). In many regions in Algeria, groundwater is considered as a main resource for fresh water supply. The Intergovernmental Panel on Climate Change (IPCC) indicates that global earth surface temperature has increased and it will increase of 2–4 °C over the next 100 years, which has a direct effect on the hydrologic cycle by increasing evaporation and indirectly impact on groundwater. In addition, there are also other associated impacts, such as seawater intrusion and water quality deterioration.

The relationship between the climate variability and groundwater quality and quantity is more complicated and poorly understood, but the greater variability in rainfall for a longer period has as a consequence a decrease in the potentiometric levels, and saline intrusion in coastal aquifers. Quantifying the impact of climate change on groundwater resources requires not only reliable forecasting of changes in the major climatic variables, but also needs an estimation of groundwater recharge (Kumar 2012). Understanding climate variability and change is vital for society and ecosystems, particularly with regard to complex changes affecting the availability and sustainability of groundwater resources (Bouderbala 2015).

This article presents the impact of climate change on groundwater resources in the alluvial aquifer of Mitidja.

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2 Study Area

2.1 Presentation

The alluvial Mitidja plain, which has an average altitude of 100 m a.s.l., is an elongated depression extends from the east to west for a length of 100 km and a width between 3 and 18 km. It covers an area of 1450 km^2. It is limited in the north by the Mediterranean Sea in its eastern part, and by the Sahel mountains (260 m a.s.l.) in its western part. It is bordered in the south by the Blida Atlas (1630 m a.s.l.), and in the west by the mountains of the Dahra (1560 m a.s.l.). It lies between latitudes 36° 25′N and 36° 48′N, and between longitudes 2° 32′E and 3° 20′E.

The plain of Mitidja hosts a vivid agricultural economy, which is strengthened by the existing water resources and topography features, endowed with vast fertile and gently-sloping lands. It is occupied by cereals, vegetables, fruit trees and other crops (Khouli and Djabri 2011). The study area has a Mediterranean climate type, characterized by hot and dry summers and rainy winters, with an average rainfall about 600 mm, the average air temperature is 18.5 °C and the annual rate of evapotranspiration is 1200 mm. The hydrology of the basin is characterized by a set of watercourses that drain alluvium outcroppings; they are drained mainly by the four great rivers that flow into the plain to reach the Mediterranean sea are: wadi Nador, wadi Mazafran, wadi El-Harrach and wadi Hamiz.

2.2 Geology and Hydrogeology

The lithological succession in Mitidja plain appears from the bottom to top as follows (Fig. 1): The Pliocene: it is divided into upper and lower Pliocene. The lower Pliocene is formed of gray or blue-gray marls, including a high layer of blue marls, sometimes sandy, attributed to the Piacenzian. The upper Pliocene is composed of yellow marls, sandy, limestone and sandstone limestone, as well as the mollassus attributed to the Astian (Khouli and Djabri 2011).

The quaternary: it is formed by consolidated sedimentary formation, fluvial siliceous gravel and sandstone gravel with red clay of Cretaceous origin, alluvial deposits with silty lens alternating with pebbles; gravel and sand.

The geophysical study conducted in 1973 revealed the existence of two superimposed aquifers in the plain of Mitidja (Fig. 2):

(i) The Pliocene aquifer (Upper Pliocene) is a confined aquifer formed by the sandstone and sandy limestone. Its substratum is composed of the blue marls and its top is composed of semi permeable yellow marls named marls of El Harrach. This aquifer is very deep, generally located between 250 and 300 m in the major part of the plain.

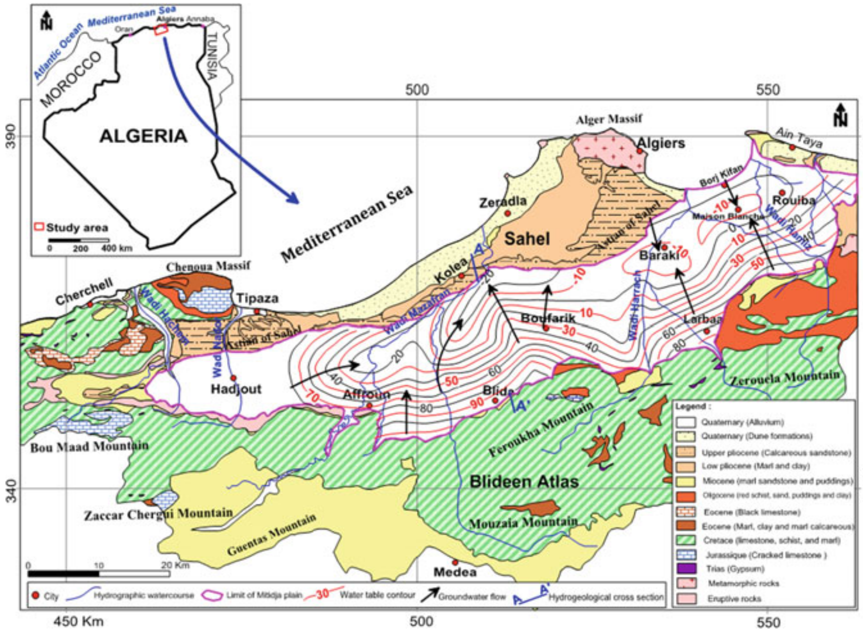

Fig. 1 Map showing the geology of the study area and the water table map of dry season 2013

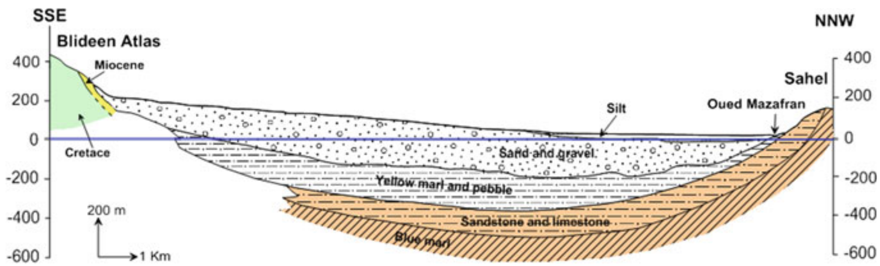

Fig. 2 Hydrogeological cross section A-A′ in the study area

(ii) The quaternary alluvial aquifer is overlain almost the entire basin. It is mainly composed of sand and gravel alternating with silts and clays. Apart from the zone of Mazafran, this aquifer is entirely unconfined and based on the marls of El Harrach wich constitute the substratum of the alluvial aquifer. Its thickness varies from 100 to 200 m. Its eastern and western limit is ensured by the rise of the blue marls of the Pliocene. The depth of the water table ranges between 4 and 30 m. For irrigation and the drinking water supply, the aquifer is exploited by more than 3000 wells.

The water table map (Fig. 1) reveals a general groundwater flow from south to north. It shows also tight isolines in the south part of the alluvial plain due to the influence of the recharge area, the low thickness of the aquifer and the high slopes of the substratum. The map shows also three depression cones in this aquifer. The first is located in the coastal sector, in the city of "Maison Blanche", the wells in this area have high salinity due to seawater intrusion after an overexploitation accompanied by reverse flow. The second and third depression cones are located in the well fields of Baraki and Mazafran respectively, where the exploitation of groundwater is important.

Groundwater recharge is essentially due to rainfall, but also by an underground supply from the Blidean Atlas. Agriculture, which is the region's main economic activity, is impacting the quality of groundwater, particularly through the leaching of nitrate and pesticides. Nitrate (NO_3^-) content exceeded 50 mg/L in water samples from many boreholes during the last years.

The hydrodynamic parameters obtained from the pumping tests show transmissivities varying between 10^{-3} and 1×10^{-2} m^2/s and hydraulic conductivity varying between 10^{-4} and 10^{-2} m/s. Whereas wells in this plain have a flow rate ranging between 10 and 60 L/s.

3 Impact of Climate Variability on Groundwater Resources

3.1 Climate Variability

The analysis of the annual rainfall data about Hamiz dam station located in the Mitidja plain for a long period (from 1905 to 2006) shows a marked decrease of annual precipitation, as shown by the trend line (Fig. 3). This reduction is estimated at about 20%. It shows also an important annual irregularity in time, with an alternation of drought and wet years. These drought years had as a consequence a low recharge of the alluvial aquifer and an the overexploitation of groundwater, which deteriorate the groundwater quality and advancement of the seawater intrusion in the coastal area of Mitidja plain. While the wet and rainy years contributed to the recharge and dilution of the aquifer, and when they are very heavy rainfall, they causes flooding (e.g. flood of Algiers in 2001). We may say that the climate variability observed during the last years is characterized by a rainfall return but with greater intensity.

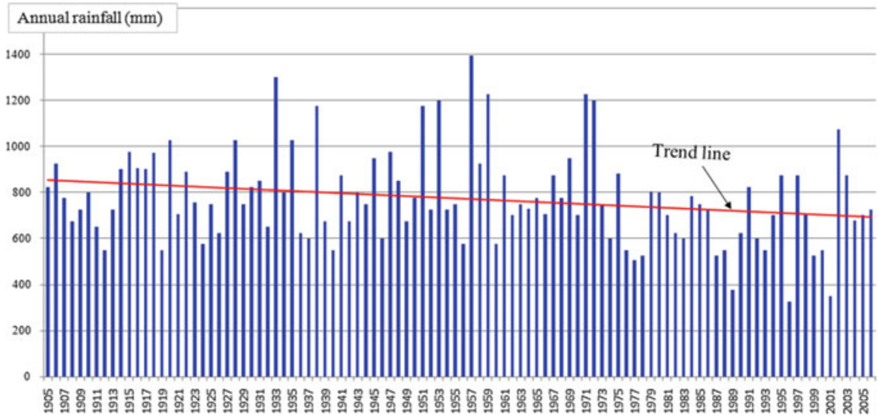

Fig. 3 Annual rainfall variability for Hamiz dam rainfall station (1905–2006)

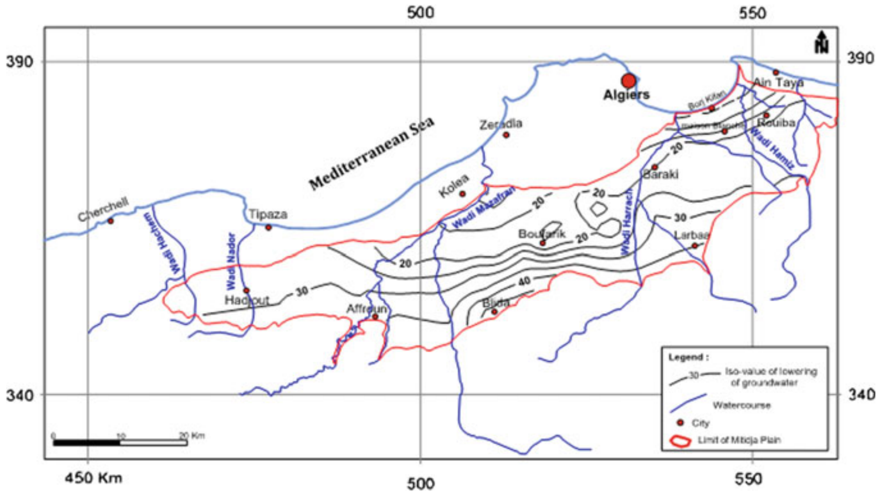

Fig. 4 Drawdown of groundwater levels from 1973 to 2013

3.2 Potentiometric Study

The proliferation of wells and the persistent drought (large rainfall deficit) in Mitidja plain for the last two decades had a negative impact on the quality and quantity of groundwater on the alluvial aquifer. The principal groundwater direction, follows the main depression oriented from West to East, towards the Mediterranean Sea.

The map of groundwater level decline in this aquifer from the year 1973–2013 (Fig. 4) shows a marked decrease in the potentiometric level. This is a consequence of the significant exploitation of groundwater. The potentiometric level declined by more than 10 m near the coastal area, where the seawater intrusion was observed at more than 1.5 km inland. In the central part of the plain, the recorded decrease of potentiometric level is about 20 m, while the decline of groundwater level in the recharge area localized in the southern part of the plain (Blida and Larbaa) exceeded 35 m.

3.3 Groundwater Quality

The analysis of groundwater quality before 1995 showed two water types in Mitidja plain: fresh and relative hard water controlled by the dissolution of dolomitic and calcitic sediments of the Atlas Mountains, mainly observed in the recharge areas and in the most of plain. The second water type observed is between brackish and saline water, with important influence of the sea and containing a considerable fraction of chlorides.

The process of salinization in this coastal sector is due to the seawater intrusion into the aquifer, this is the result of its overexploitation and large rainfall deficit, with the dominance of sodium-chloride water type.

This coastal sector shows also high values of electrical conductivity with the dominance of sodium-chloride type facies of groundwater. The geoelectrical prospection carried out in 2001 showed a low resistivity in the coastal sector of the plain, which confirms the persistence of seawater intrusion phenomenon, existed since the eighties in this region.

After the salinization of the boreholes located near to the coast, they were closed and only a few wells at small depths remained. These wells were monitored seasonally by the National Agency of Hydraulic Resources (ANRH-Blida), and the groundwater samples are usually taken from the surface of water table and not after a pumping time, for this reason we cannot use these groundwater analyses as a means to study the seawater intrusion.

The physic-chemical analyses for the dry period 2015 (Table 1) of the aquifer, show pH ranges from 7.6 to 8.3, indicating that the groundwater in this area is slightly alkaline. It shows more than 80% of samples have TH > 40 °F which indicates a very hard groundwater quality in this aquifer, while the electrical conductivity (EC) shows a measured values ranging from 900 to 2600 μS/cm, with an average of 1709 μS/cm. So, the majority of water samples exceed the standard recommend by WHO (2008), i.e. 1500 μS/cm, thus undrinkable. The Cl^- concentration ranges from 84 to 395 mg/L, SO_4^{2-} from 46 to 391 mg/L, HCO_3^- from 61 to 458 mg/L and NO_3^- from 22 to 106 mg/L. The Na^+ from 19 to 144 mg/L, Mg^{2+} from 1 to 94 mg/L; and Ca^{2+} from 115 to 258 mg/L.

The high bicarbonate concentrations in this area can be due to the occurrence of oxidation of organic matter of the soil layers at emerging land (Bouderbala 2015). The contents of chlorides in the study area indicate more than 33% exceed the standard limit 250 mg/L. The very high concentrations of chlorides are probably

Table 1 Statistics of the physic-chemical analyses made in 32 wells in the aquifer of Mitidja (dry season 2015)

	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^{+} (mg/L)	K^{+} (mg/L)	Cl^{-} (mg/L)	SO_4^{2-} (mg/L)	HCO_3^{-} (mg/L)	NO_3^{-} (mg/L)	pH	EC (µ/Cm)	TH (°F)
Min	115	1	19	2	84	46	61	22	7.6	900	32
Max	258	74	144	9	395	391	458	106	8.3	2600	95
Moy	188.3	28.3	73.8	3.6	222.4	190.6	260.3	57.7	8.14	1709	59
Norm OMS	100	75	150	12	250	200	–	50	6.5–8	1500	40
% > norm	100	0	0	0	40	30	–	60	0	70	80

due to marine pollution. The high values of nitrates exceeding the limit recommended for drinking water (50 mg/L), indicate the degradation of groundwater quality, and they can be mainly attributed to the excess of fertilizers and pesticides used in agricultural activities in this area (Saida et al. 2017). The most common source of the high values of calcium in the study area is due to the lithological alluvial deposits, and to the dissolution of the consolidated detrital sedimentary rocks. The high concentrations of sulphates are due probably to the use of some fertilizers in agriculture or the discharge of untreated wastewater.

3.4 Vertical Conductivity Profiles

The electrical conductivity profiles (at 25 °C) were carried out by National Hydraulic Resources Agency in 2009 at the piezometers Pz58 and Pz61 located approximately at a distance of 1.7 km from the coast. These conductivity profiles have made in the goal to confirm the existence of marine intrusion in this coastal aquifer (Fig. 5).

The vertical conductivity profile carried out in the piezometer Pz 58 shows a significant increase in the conductivity, from 3 mS/cm in the top to 15 mS/cm at the bottom of the well. It is explained by the significant flow of water transiting the permeable formations of Quaternary (sand and gravel). Moreover, it seems clear that the piezometer Pz 58 is in an area heavily contaminated by marine intrusion.

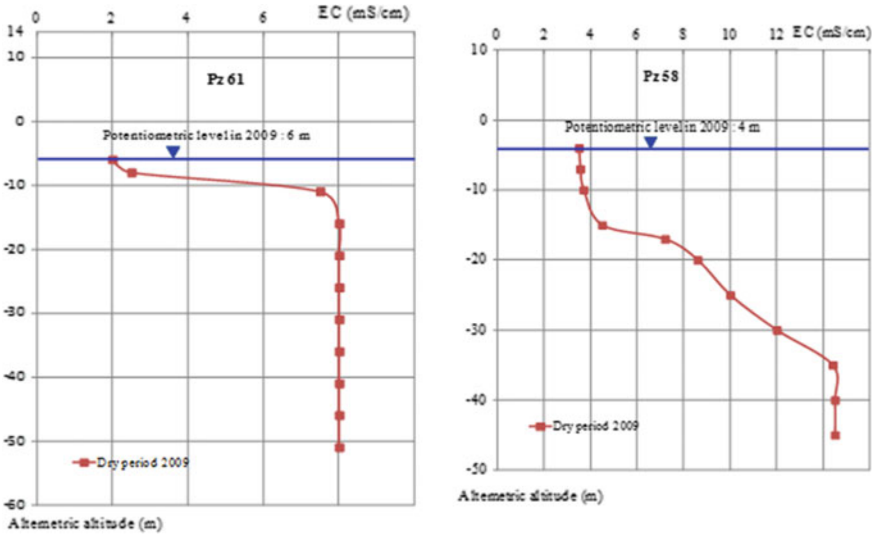

Fig. 5 Conductivity profiles in the piezometers PZ 61 and PZ58

In the case of piezometer Pz 61, the vertical conductivity profile shows a significant increase of the conductivity in this well from the top to the bottom. This conductivity profile has the characteristic of having a linear profile over the entire water column except for the first 4 m where the conductivity is lower, it could be related to the incidence of vertical recharge by less mineralized rainwater. But it confirms that the aquifer is contaminated by the marine intrusion.

4 Conclusion

Mitidja aquifer constitutes an important reservoir of groundwater that used for more than a century for the domestic, agricultural and domestic purposes. However, the anarchical exploitation accompanied with the drought periods in this last decade, caused a decrease of potentiometric levels and deterioration of groundwater quality in this plain.

The analysis of the annual rainfall data of pluviometric station located in this area for a long period shows a marked decrease of annual precipitation, with a reduction about 20%. This caused a decrease of potentiometric level for more than 20 m and seawater intrusion in the coastal sector of the plain near to 2 km inside the aquifer.

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