



The impact of climate change on groundwater resources in coastal aquifers: case of the alluvial aquifer of Mitidja in Algeria

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Abstract

The climate change has an effect on groundwater aquifers in some parts of the world. Algeria is considered as a vulnerable country in the world regarding the availability of water resources. The water supply is the main challenge of the public institutions under these natural conditions and human activities. The goal of this work is to assess the impact of climate change on groundwater resources, especially in the coastal aquifers, case of Mitidja in northern Algeria. In this study area, rainfalls were decreased at about 20% from 1905 to 2011, with a significant irregularity in this period. The analysis of piezometric map shows a decrease of groundwater levels from 1974 to 2010 at more than 10 m in average. It shows also high salinity in the coastal sector due to seawater intrusion after the overexploitation of groundwater in the catchment fields. It shows a high value of electrical conductivity (average of 2200 $\mu\text{S}/\text{cm}$), and high concentration of chlorides (an average of 386 mg/l). The analysis of physicochemical parameters of groundwater shows also high concentrations of nitrate for the major part of the plain, they are moderately higher than the standard value (50 mg/l). It is due to the anthropogenic activities in Mitidja plain such as the agricultural origin, primarily linked to the intensification and abusive uses of fertilizers. We can also report urban pollution in this plain, which comes from the discharge sewerage networks without treatment.

Keywords Anthropogenic pollution · Algeria · Climate change · Coastal aquifers · Water quality index · Water resources

Introduction

The increase of global temperature and the decrease of rainfall with an irregularity in the time lead to dry seasons and violent rainy and afterwards delicate risks of frequent droughts and floods. This climate change has an impact on the diminishing of produce yields, which oblige thousands of people to leave their agricultural works without the aptitude to generate enough food supplies (Pathak et al. 2014; Bouderbala 2018). This climate change can refer to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to

natural internal processes or external factors such as persistent changes to the atmosphere or changes in land use (Smit and Skinner 2002).

The IPCC (2008) report on climate change discusses briefly the case of groundwater. It notes that the parametric levels of many aquifers in the world tend to decrease in recent years due to the overexploitation of groundwater and the decrease of the natural recharge of these aquifers (Bernstein et al. 2008). The accessibility of groundwater resource depends closely on climate conditions and the human activities (Dallas and Rivers-Moore 2014).

Algeria, like several countries in the world, is confronted with severe water problems, in term of quantity as well as quality (Bouderbala 2018). According to some experts, in 2025, Algeria will know a diminution of precipitation between 5 and 15% and an increase in temperatures between 0.5 and 1.1 °C, and it will augment from 2 to 4 °C over the next 100 years, which has a direct consequence on the global weather by rising evaporation and an indirect effect on surface and groundwater resources. Algeria has a semi-arid climate for the most part in the north of the country. It will suffer droughts, recursive flooding, desertification,

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soil salinization and water supply under the pressure of population growth and continued urbanization. The country already knows a progressive degradation of water resources (Mohammed and Al-Amin 2018).

The connection between the climate change and groundwater resources in coastal aquifers is more difficult. The diminution of precipitation for a longer period can decrease groundwater piezometric levels, and has as a consequence the degradation of groundwater quality. Understanding that is fundamental to the ecosystems and our environment, especially with respect to the changes touching the sustainability and vulnerability of aquifers to the pollution (Bouderbala 2018).

This objective of this study is to assess the impact of climate change on groundwater resources within the alluvial aquifer of Mitidja, using an analysis of the annual rainfall data recorded at four pluviometric stations distributed on the plain, and by the analysis of piezometric map of the alluvial aquifer. The characterization of groundwater quality in this coastal aquifer using the physicochemical data is also studied in this work.

Study area

Geographic and climatic situation

The alluvial plain of Mitidja is the largest plain in the northern Algeria, with an area of 1450 km², it is used entirely for agriculture. It has an average elevation of 100 m a.s.l, and it extends for a length of 100 km from the east to west and between 3 and 18 km for a large.

It is limited in the north by the Sahel of Algiers (260 m a.s.l), in the south of the Blidian Atlas Mountains (1630 m a.s.l), and in the west by Bou Mad mountain (1560 m a.s.l), and in the east is border by sand dunes of Ain Taya and the Mediterranean Sea. It lies between longitudes 2° 19' E and 3° 33' E, and latitudes 36° 24' N and 36° 49' N (Fig. 1).

The study area is characterized by the Mediterranean climate type due to its close in the Mediterranean Sea, with dry summers, and wet winters. The average of annual precipitation in the plain is about 590 mm, and the average annual temperature is 18.3 °C (Khoulou and Djabri 2011).

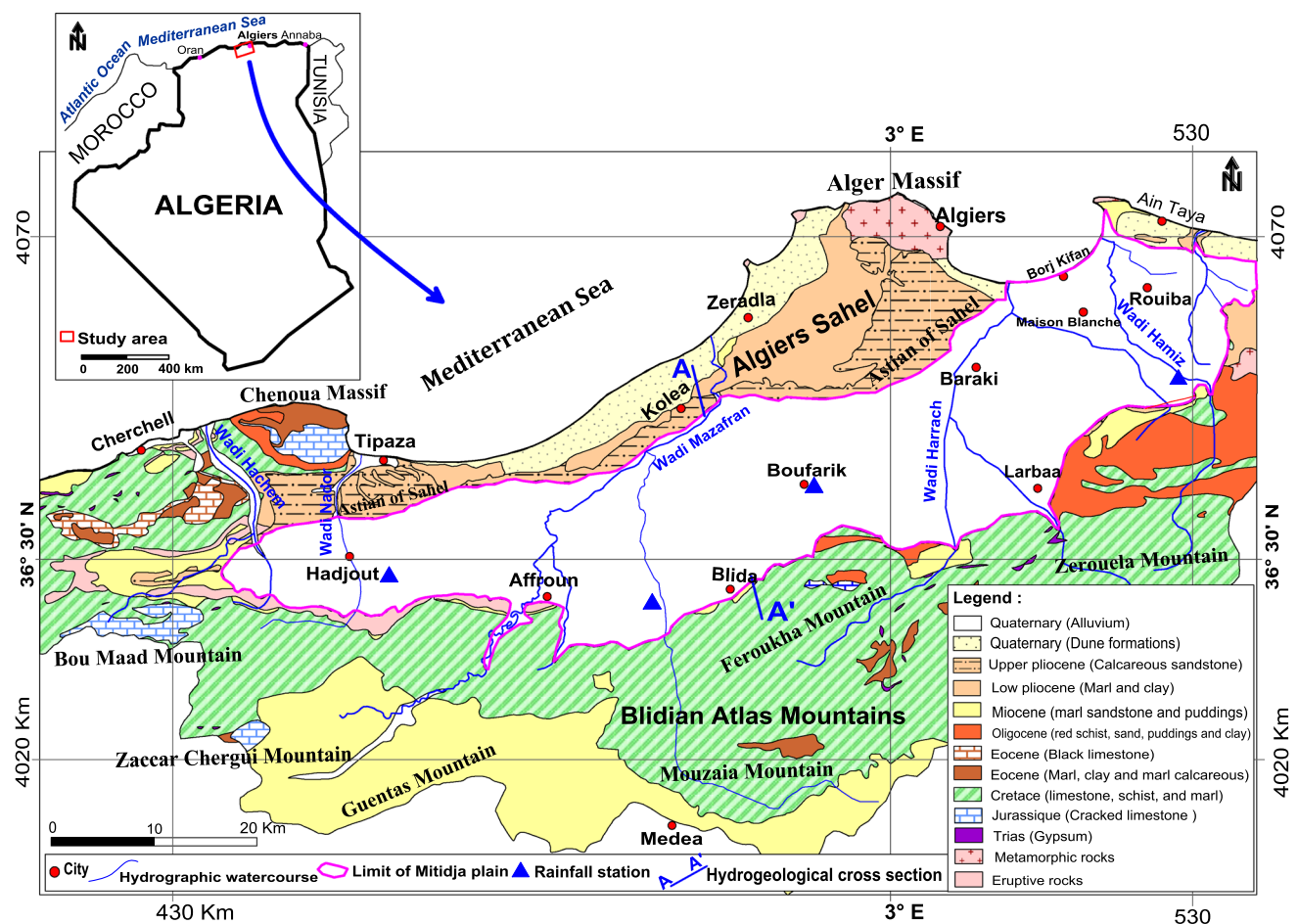


Fig. 1 Geological map of the study area (Bouderbala 2018)

In point of view hydrology, the basin is marked by dense watercourses which drain the surface water of the watershed basin. The main rivers (wadis) in the plain reach the Mediterranean Sea with irregular flow, such as the rivers of: Mazafran, Nador, Hamiz, and Harrach. The precipitation and these rivers constitute the main sources of natural recharge of this alluvial aquifer.

Geology and hydrogeology context

The lithological successions of layers in this area, in order from the bottom to top are (Fig. 1).

The Pliocene is divided into two parts. Lower Pliocene deposits consist of sandstone or blue marls, and sand, it is referred to the Pliacenzian. While, the Upper Pliocene is composed by marls, sand, limestone and sandstone-limestone, in addition to the molasses of the Astian.

The quaternary is composed of sedimentary formations, as: gravel, sand, sandstone gravel with red clay, alluvial deposits with silty lens (Khouli and Djabri 2011).

The geophysical investigation of subsurface carried out in the Mitidja plain in 1973 has shown two superimposed aquifers (Fig. 2). The confined pliocene aquifer, which is formed by sandstone and sandy limestone, and sandwiched between the bedrock of blue marls (Pliacenzian marls of Lower Pliocene) and the semi-permeable yellow marls of villafranchian. This aquifer is so deep, usually situated between 250 and 300 m, in the most part of the plain.

The quaternary alluvial aquifer is essentially formed by: pebbles, gravel, sand silts and clays.

Except in Mazafran, where the aquifer is completely unconfined, and the marls of villafranchian constitute the bedrock of this aquifer. The thicknesses of this aquifer vary from 100 to 150 m. The water table levels range from 4 to 30 m.

The recharge of the aquifers is mainly being done by effective rainfall and by the infiltration of surface water flowing in the watercourses (in some places), as well as by the excess of irrigation water, and by the underground supply

from the Blidean Atlas, mainly in the borders formed by Miocene sandstone, or the Cretaceous limestone.

The different pumping tests conducted in the alluvial quaternary aquifer indicate values of transmissivities ranging from 1.0×10^{-2} to 2×10^{-2} m²/s, and the hydraulic conductivities are varying between 10^{-4} and 10^{-2} m/s.

Methodology

Hydrological regime

The examination of the available data of precipitations, piezometry, and hydrochemistry allowed us to explain the impact of climate change on groundwater resources, mainly in the alluvial coastal aquifer of Mitidja.

Four rainfall stations spread over the plain were used in this study to see if there is a climate change in the region of Mitidja, and this by the use of statistical methods generally used for detecting breaks in the pluviometric series. The data are covering the last decades, and there is no gap for more than five consecutive years in this rainfall data recorded at these stations. The period of rainfall observation is from 1951 to 2011 for the stations of Boufarik, Chiffa and Ameer El-Ain. While, for the station of Hamiz dam, the period of rainfall observation is from 1905 to 2011.

A rainfall series can be homogeneous if the observations are made during the same period of time. A break can be broadly defined as a change in the probability of a time series which is the most often unknown. This rupture marks a modification of hydrological regime. The detection of one or more breaks provides information on the rainfall trend in a given region.

The methods that highlight these breaks are: Pettitt, Buisand, Mann-Kendall and Hubert's segmentation procedure. The statistical analyzes were conducted by the XLStat software.

The hydrologic drought is defined by a prolonged weakening of rainfall inputs in watersheds with a runoff deficit at watercourses and a low natural recharge rate of aquifers.

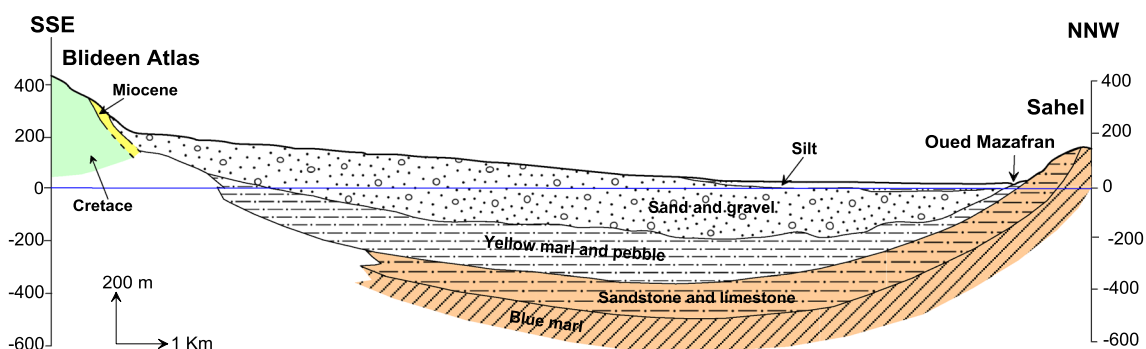


Fig. 2 Hydrogeological cross section A–A' in the Mitidja plain (Bouderbala 2018)

Table 1 Standardized precipitation index (SPI) values and the associated drought categories (McKee et al. 1993)

SPI class	Drought category
SPI > 2.0	Extremely dry
1.5 < SPI < 1.99	Very wet
1 < SPI < 1.49	Moderately wet
-0.99 < SPI < 0.99	Near normal
-1.0 < SPI < -1.49	Moderately dry
-1.5 < SPI < -1.99	Very dry
SPI < -2.0	Extremely dry

The Standardized Precipitation Index (SPI) is often used for the assessment of short, medium, and long-term drought. Its estimation is based on long rainfall series spread over 40–60 years (Guttman 1998), and it has the great advantage of operating at various time scales (McKee et al. 1993).

The World Meteorological Organization adopted the SPI in 2009 as an index to measure meteorological droughts (WMO 2012). Very often, the standardization consists of subtracting the average from the data and dividing the result by the standard deviation of the series. In addition to being a drought index, this index can also tell us about the severity of drought. A scale of severity was given by McKee et al. (1993). It is represented in Table 1.

Groundwater geochemistry

This work exploits the analytical results of 36 water samples, which were collected in June 2010 in different parts of the plain, simultaneously with piezometric measurements. The major ionic parameters analyzed were Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Cl^- , SO_4^{2-} , HCO_3^- , NO_3^- and of the physical parameters were pH and electrical conductivity. Water samples were collected from wells after a minimum of several minutes of pumping prior to sampling. Samples were collected in clean 1,5 polyethylene bottles.

All samples were stored in an ice chest at a temperature lower than 4 °C, and later transferred to the laboratory. Immediately after sampling, physical parameters such as the electric conductivity (EC), water temperature (T) and pH were measured in the field using a multi-parameter WTW Universal Conductivity Meter. Chemical analysis was carried out in the laboratory of the National Agency of Hydraulic Resources (ANRH-Blida). All the results are compared with standard limits recommended by the World Health Organization (WHO 2008). Nitrate was analyzed by colorimetry with a UV–visible spectrophotometer. Calcium, magnesium, chloride, and bicarbonate were analyzed by volumetric titrations. Concentrations of sodium and potassium were measured using a flame photometer and that of sulfate by the turbidimetric method.

The accuracy of the chemical analyzes was checked by calculation of the ionic balance, which was generally less than 5%. The entire ion concentrations were expressed in milligram per liter (mg/l) except otherwise indicated.

For the assessment of groundwater quality, the Water Quality Index (WQI) was used.

This index was used by several users in the evaluation of the groundwater quality of many aquifers (Bouderbala 2015, 2017a).

The calculation of WQI is based on the standards suggested for uses, where eleven (11) parameters of water were chosen (pH, EC, TDS, Ca^{2+} , Mg^{2+} , Na^+ , K^+ , HCO_3^- , Cl^- , SO_4^{2-} , and NO_3^-) in the assessment of groundwater quality.

The first step consists to introduce the weights of each parameter (w_i), based on their relative importance in the overall water quality of drinking purposes (Table 2). The maximum weight of 5 has been assigned for parameters like TDS, Na^+ , Cl^- , NO_3^- , and SO_4^{2-} due to their significance in the water quality assessment, and the minimum weight of 1 has been given to HCO_3^- because it plays a moderately less considerable role in water quality evaluation (Bouderbala 2017a; Khosravi et al. 2017).

In the second step, the relative weights (Rw_i) were calculated using the following equation:

$$Rw_i = w_i / \sum_{i=1}^n w_i$$

where Rw_i is the relative weight, w_i is the weight of each parameter, and “ n ” is the number of parameters.

In the third step, the quality rating scale (qi) for each parameter was attributed by dividing the concentration of each water sample by its respective standard according to the WHO guidelines (WHO 2008):

Table 2 The weight (w_i) and relative weight (W_i) of each chemical parameter (Bouderbala 2017b)

Parameters	WHO (2008)	Weight (w_i)	Relative weight (Rw_i)
EC ($\mu\text{S}/\text{cm}$)	1500	5	0.119
TDS (mg/l)	1000	5	0.119
Cl^- (mg/l)	250	5	0.119
SO_4^{2-} (mg/l)	200	5	0.119
Na^+ (mg/l)	150	5	0.119
NO_3^- (mg/l)	50	5	0.119
Mg^{2+} (mg/l)	75	4	0.095
Ca^{2+} (mg/l)	100	2	0.048
HCO_3^- (mg/l)	300	2	0.048
K^+ (mg/l)	12	1	0.024
pH	8.5	3	0.071
		$\sum w_i = 42$	$\sum RW_i = 1$

$$qi = \left(\frac{Ci}{Si} \right) \times 100$$

where qi is the quality rating; Ci is the concentration of each chemical parameter in each water sample in mg/l; Si is the concentration acceptable, for each chemical parameter according to the guidelines in mg/l.

The WQI is calculated by the following equation:

$$WQI = \sum R w_i \times qi$$

Water quality types were determined based on WQI (Table 3). The spatial distribution maps for values of WQI were prepared using inverse distance weighting (IDW) interpolation technique.

Results and discussion

Study of rainfall regime

Precipitation trend analysis The study of trend of rainfall series in a given region consists of studying the global evolution of rainfall series. This positive trend evolution means that the rainfall regime is increasing, or negative trend evolution means that the rainfall regime is decreasing (drought).

Table 3 Classes proposed for drinking water quality based on the water quality index (WQI) (Chaterjee and Raziuddin 2002)

Class	The range of WQI for drinking purposes	Type of water quality
1	<25	Excellent water quality
2	25.1–50	Good water quality
3	50.1–75	Permissible water quality
4	75.1–100	Doubtful quality
5	> 100	Water unsuitable for drinking uses

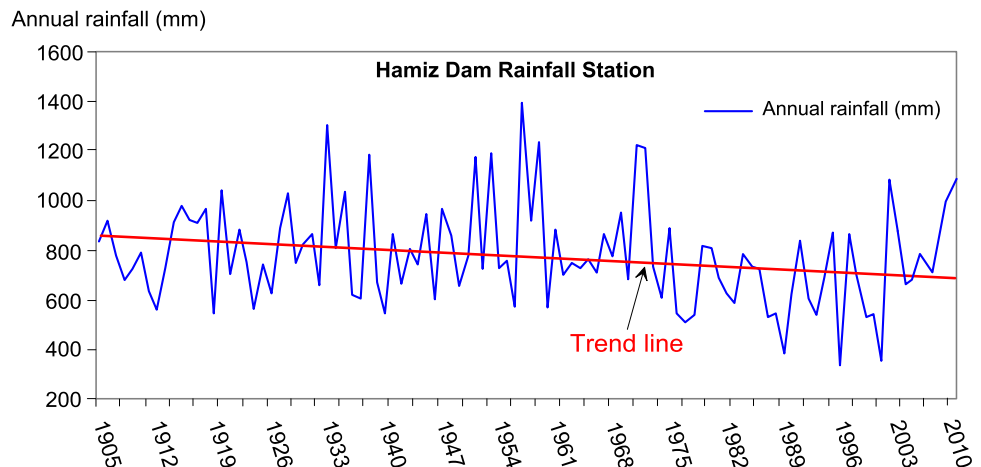
The Fig. 3 shows the interannual rainfall observations of Hamiz dam station, which has the longest observation period (from 1905 to 2011). It is located in the East of plain. It marks a trend toward decreasing of precipitation in general, as it is shown by the trend line.

The analysis of the yearly precipitation data of the four (04) rainfall stations, in Mitidja plain, shows a reduction of the annual rainfall in general. The same evolutionary tendency is observed in the three other rainfall series of Chiffa, Ameer El-Ain and Boufarik, which have a period observation from 1951 to 2011. The analysis of all rainfall series shows decreases on the annual precipitation for the last decades near than 20%.

The average reduction of rainfall each 10 years is estimated near than 13 mm, in this rainfall station, from 1905 to 2011. It shows a significant annual variation in time, accompanied by alternation of droughts in dry years, and floods in wet years. The drought years reduce the natural recharge of the alluvial aquifer and as a result overexploitation of groundwater, which has an impact on the degradation of groundwater quality and progress of the seawater intrusion in this coastal aquifer, due to the hydrodynamic disequilibrium between fresh and salt water. While, the rainy years contributed to the recharge and the dilution of mineralized groundwater, accept the very heavy rainfall and torrential, which caused flooding in many parts in this region (e.g., Flood of Bab El-Oued in Algiers near this plain in 2001). We may say that the climate change observed during the last years was characterized by a rainfall return, but with great and rapid rainfall intensity.

The hydrological budget in the basin of the Mitidja shows that the rates of infiltrating water and the runoff in this area are 6% and 8.5% of precipitation, respectively (Bouderbala 2018). But this is due to the geomorphological characteristics of the watershed and the predominance of impermeable layers in the surface, which thus promote runoff. The interaction river aquifer has a high influence on water recharge,

Fig. 3 Annual rainfall variability in Hamiz dam rainfall station (1905–2011)



however, in the last years, the hydraulic construction of the river has reduced the effective recharge via rivers.

Homogeneity test of precipitation time series The XLStat software was used to correctly locate the years of ruptures within the rainfall series in the Mitidja plain.

The analysis of ruptures of observation series of the four stations showed us that two stations are non-stationary (Boufarik and Hamiz) according to the tests of Pettitt and Buisnant (the most known), with breaks of decreasing, which start from 1975 for the station of Boufarik (Fig. 4) and from 1972 for Hamiz station, and a level of significance equal to 5% following the Buisnant test and 10% of the Pettitt test. This result is also verified by the Mann-Kendall test with a downward trend and a level of significance equal to 10%, for both stations.

Variation of standardized precipitation index (SPI) The Fig. 5 shows the interannual variability of precipitation for the four rainfall station, according to the standardized precipitation index (SPI). This variability is characterized by the alternation of wet–dry periods and periods close to normal, with a similitude of deficit years and wet years for the majority of rainfall stations.

It is very clear that the period between 1970 and 1973 has a rainfall in excess, with extreme wet years ($SPI > 2.0$), whereas the period between 1975 and 2011 shows a transition between dry and wet years while the years moderately dry are dominant.

Piezometric perturbation

The Piezometric level measurements of the alluvial aquifer of Mitidja, for the dry period 2010, shows groundwater flow from South to North (Fig. 6). The groundwater divide is located between the cities of Boufarik and Baraki. This map shows two depressions in this plain (cone of depression), it is due to the overexploitation of groundwater in the catchment fields (the Mazafran catchment fields, the catchment fields of Baraki and of Maison Blanche).

The high hydraulic gradients of groundwater in the southern parts of the plain are related to the high slope of substratum and the low thickness of the alluvial aquifer, it is due also to the recharge effect in this part of the plain. Whereas, the high hydraulic gradients in the west part of the plain (near to Affroun city) are explained by the low permeability of the aquifer. While the high hydraulic gradients in the

Fig. 4 Homogeneity test on Boufarik rainfall Station

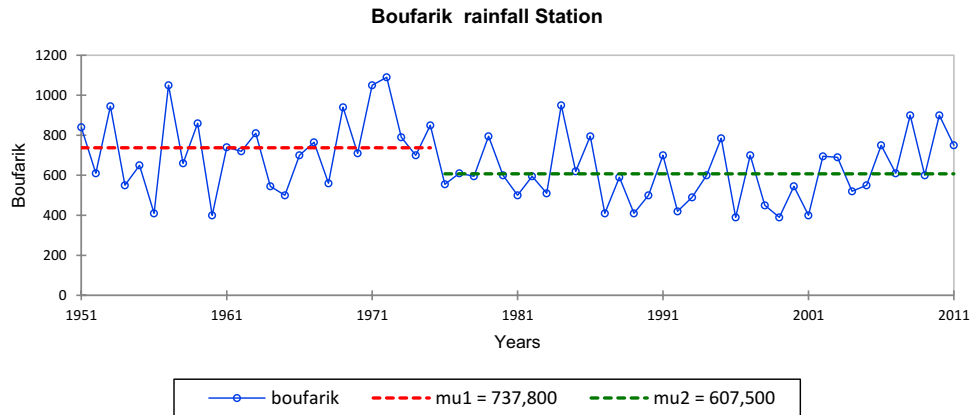
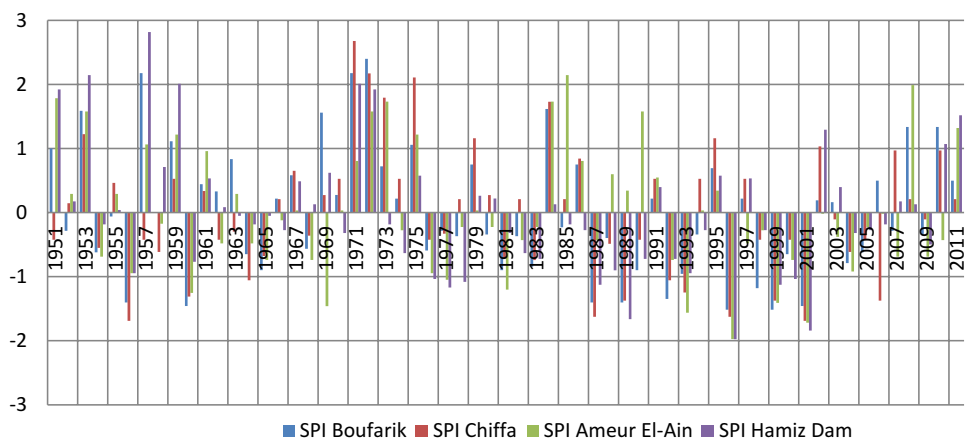


Fig. 5 Variation of standardized precipitation index in the rainfall stations of Mitidja plain



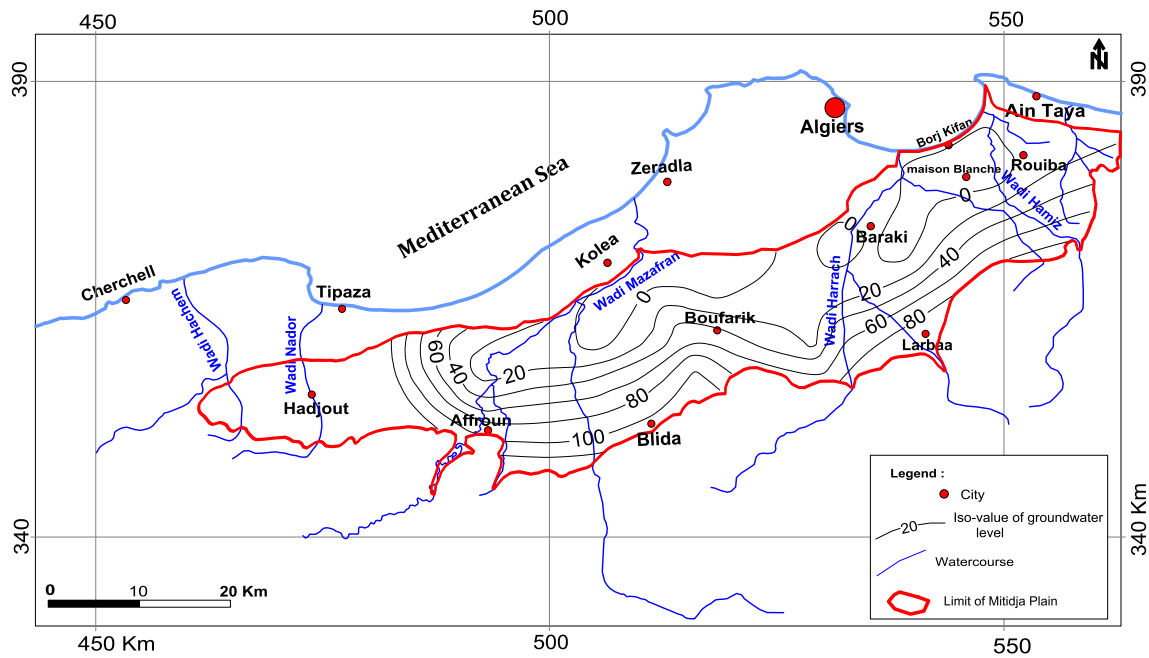


Fig. 6 Piezometric map of Mitidja plain in the dry period 2010

center of the plain are due to the aquifer thickness and the excellent permeability of alluvial formations.

The map indicates also a reverse flow direction, from the sea to the continent, it is the seawater intrusion which has been observed for 3 decades.

The map of reducing the groundwater levels in the alluvial plain of Mitidja from 1974 to 2010 shows a clear

decrease in water levels in this aquifer (Fig. 7). In the coastal sector, near to the cities of “Maison Blanche” and “Rouiba”, the wells in this area have a high salinity due to seawater intrusion after an overexploitation of groundwater in this catchment field, which induced a reverse groundwater flow from the sea toward the aquifer.

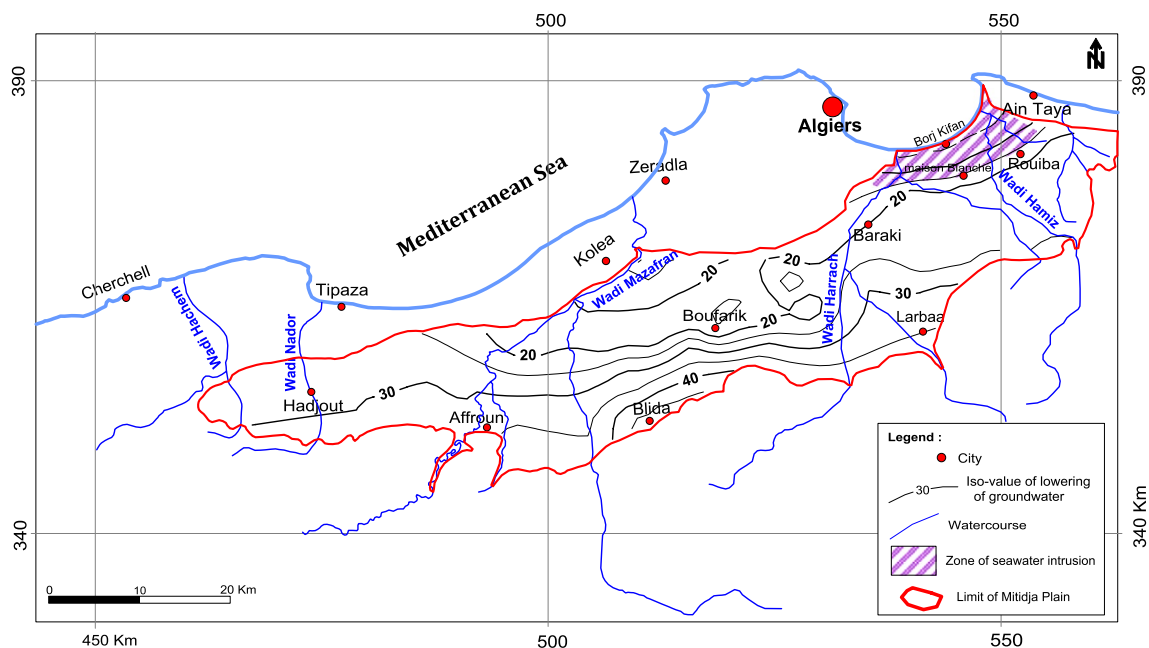


Fig. 7 Reducing the groundwater level in the alluvial plain of Mitidja from 1974 to 2010

The consequence of the piezometric Drawdown levels in this aquifer is due mainly by the long period of drought (since the 1980s), the significance of Discharging wells (more than 5000 wells, according to ANRH), the large number of illegal wells that are never inventoried, as well as the continuous and intensive pumping of wells in the catchment fields in this plain.

Evaluation of groundwater quality

The geochemistry allows us to appreciate the chemical process which formed in the aquifer, and the interaction between groundwater and rocks. The groundwater chemistry depends generally on the geological formations of saturated and non-saturated areas, the residence time in the aquifer, and in the flow direction of groundwater. The groundwater quality is influenced also by climatic conditions and by the anthropogenic activities (Table 4).

The analysis of the annual average of physicochemical parameters of groundwater over the period of 6 years (2005–2010), shows concentrations in the limit of the Algerian standard of drinking water, except the nitrate concentrations, which are moderately higher than the standard value of nitrate (50 mg/l). The possible origin of nitrate is due to the anthropogenic activities in Mitidja plain, such as the agricultural origin, where the rate of fertilization has exceeded the norms and it reaches the value 400 kg of nitrogen/hectare. The urban origin, because the discharges of sewerage networks are not completely connected to the wastewater treatment plant for purification, but they go to the wadis which can pollute groundwater

and surface water. The discharge of sewage comes from different industrial units without treatment which can also pollute the groundwater in this plain, and it can increase the concentrations of nitrate.

The physicochemical analyses of groundwater of 36 samples (Fig. 8) for the wet period 2010 (the period with an important number of samples compared to the dry period 2010, and the samples are more distributed over the plain) are given in the Table 5.

Table 5 gives the descriptive statistical analysis of the physicochemical parameters collected from the Mitidja plain in the wet period 2010.

The pH parameter determines the acidity or alkalinity of water, which corresponds to the activity of the H^+ ions that exist in water. The pH values of the wet period 2010 show that all samples are in the range of drinking water (between 6.8 and 8.8), indicating groundwater is slightly alkaline in this alluvial aquifer. It can be explained by the impact of anthropogenic activities on groundwater quality.

On the Mitidja Plain (Fig. 9), the majority of samples has $EC > 1500 \mu S/cm$ (71% of samples), but based on the Algerian norm of EC, there are only 20% of samples that exceed the norm (2800 $\mu S/cm$). The highest values of EC ($EC > 5000 \mu S/cm$) are observed mainly in the coastal area; in close proximity to Rouiba-Maison Blanche and Borj Kifan. They are due to the problem of seawater intrusion, after the overexploitation of groundwater. However, the high values of EC in the upstream and in the centre of the plain are due to the anthropological pollution of groundwater or due to the water–rock interaction (the geology of the aquifer).

Table 4 The annual average of chemical parameters of groundwater in Mitidja Plain from 2005 to 2010 (ANRH 2010; Djoudar 2014; Zamiche et al. 2018)

Year	EC ($\mu S/cm$)	pH	Na ⁺ (mg/l)	Mg ²⁺ (mg/l)	Ca ²⁺ (mg/l)	K ⁺ (mg/l)	Cl ⁻ (mg/l)	HCO ₃ ⁻ (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)
Wet period										
2005	1799	7.3	116	48	163	1	297	277	211	75
2006	1753	7.3	100	44	187	2	185	339	232	86
2007	1622	7.4	75	50	171	0	162	356	226	63
2008	1382	7.4	66	44	145	1	151	327	183	34
2009	1850	6.7	99	43	131	2	189	291	201	53
2010	1702	7.8	114	41	147	4	166	426	178	37
Dry period										
2005	1345	7.4	81	40	153	1	178	281	165	48
2006	1517	7.4	94	36	174	1	183	312	192	64
2007	1397	7.6	53	46	167	1	154	343	199	47
2008	1374	7.4	103	39	126	1	148	336	164	37
2009	1464	7.4	107	47	140	3	176	351	211	45
2010	1404	7.9	74	45	132	2	133	340	164	35
Algerian norm 2011	2800	6.5–9.5	200	150	200	12	500	–	400	50

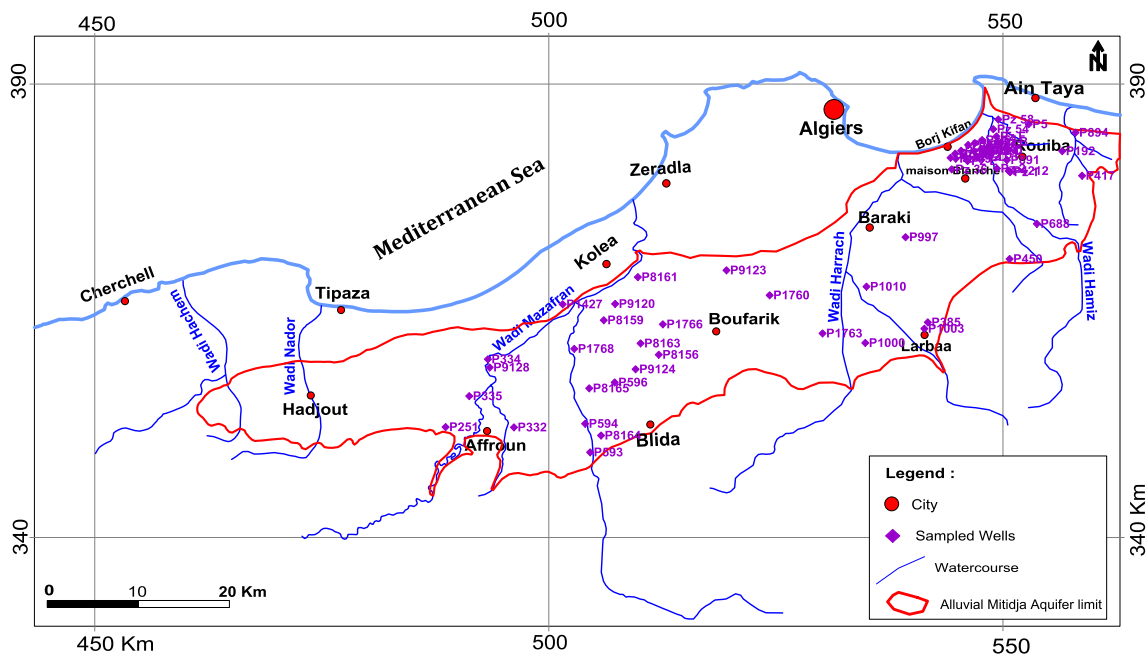


Fig. 8 Location map of sampled wells

The results show also that the electrical conductivity is powerfully dependent on the chemical composition of water and its temperature.

The sodium and chloride concentrations show that the high values (more than 27% for Na^+ , and 18% for Cl^- exceeds the standards of drinking water), which are observed near the coastal area in the northeast of the plain are due to the phenomenon of seawater intrusion in this coastal sector of the aquifer (Table 5).

The concentrations of calcium in this area indicate that more than 35% of samples have contents more than the international standard drinking water. The highest values can be due to the groundwater flow directions and the dissolution of the carbonate formations. However, the rest of the wells located mainly in the centre and upstream of the plain have values lower than 200 mg/l. While, the presence of bicarbonates in groundwater is due to the dissolution of the carbonated formations which border the plain.

The analysis results reveal potassium values exceed 12 mg/l in some wells in this plain, they come from the alteration of potassium clays and the dissolution of chemical fertilizers (NPK) which were used massively by farmers in the agriculture. The presence of this ion may also be linked to wastewater effluents discharge, and the several traditional septic tanks existing in the rural areas.

The highest values of sulfates concentrations of groundwater are located in the North East of Reghaïa city and in the coastal area of the plain, which can be explained by effect of the pollution comes from the Lake of Reghaïa (natural reserve of surface water located in the East of Mitidja plain),

the industries existing in the south-west of the study area, the discharge of wastewater into the nearby watercourses of the plain without prior treatment, the use of fertilizers in agriculture, the effect of evaporation, and also the salt water intrusion in the coastal sector.

The nitrate values show more than 45% of wells have concentrations from 50 to 231 mg/l (Fig. 10), higher than the standard limit of 50 mg/l (WHO 2008). They were due to the excessive use of fertilizers in agricultural activities. The farmers use a quantity of 400 kg per hectare for the most cultures which occupy this plain. It was due also to the influence of wastewater discharge without treatment in many places in Mitidja plain. The geology of Mitidja in the shape of basin associated with an aquifer made up with permeable formations (gravels and sands), supported the immigration of the nitrate toward the saturated zone and the contamination of the groundwater.

We can say that spatial distribution of sodium, chlorides, calcium, magnesium, and nitrates shows that the zones with higher concentrations are observed in northeast of the plain near the coastal area, which can have been attributed to anthropogenic pollution after overexploitation of groundwater in this aquifer process (seawater intrusion). This infiltration of seawater has been as a consequence the increase of contents of chloride and sodium ions.

The spatial distribution map of the WQI shows that the western and eastern of the study area have a poor groundwater quality. In general, WQI decreases from the center to the periphery of the Mitidja aquifer, under the effects of the direction of groundwater flow, especially toward the coastal

Table 5 Physico-chemical parameters in the Mitidja Plain (wet period 2010)

Parameter	EC ($\mu\text{S}/\text{cm}$)	pH	Na ⁺ (mg/l)	Mg ²⁺ (mg/l)	Ca ²⁺ (mg/l)	K ⁺ (mg/l)	Cl ⁻ (mg/l)	HCO ₃ ⁻ (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)
Wet period										
Min	370	6.8	21	6	13	0	30	1	14	0
Max	7800	8.8	1800	148	521	40	2754	669	696	231
Average	2202	7.52	218	50.1	183	5.5	386.4	260.2	223.2	57.7
SD	1627.5	0.44	322.5	29.2	106.9	6.8	579.3	227.7	154	54
Algerian norm 2011	2800	6.5–9.0	200	150	200	12	500	–	400	50
> Exceed norm Algerian	20.3	0	27.1	0	35.6	8.5	18.6	–	10.2	45.8

area in Bordj Kifan and Rouiba (Fig. 11). These results indicate that the salinity by seawater intrusion is the principal factor which degrades the chemical quality of the aquifer of Mitidja in the east part of the plain. However, the anthropogenic pollution and the natural processes are responsible for the degradation of groundwater quality in the center and west parts of the plain.

Our investigation of socio-economic activities in the plain helped us to explain the origin of nitrate pollution in this area. In fact, the industrial wastewater discharged in Wadi El-Harrach and wadi Hamiz and in their tributaries, added to this the urban discharges, agricultural effluents, chemical fertilizers, intensive livestock farming and the several wild dumps concentrated in this area are responsible for the anthropogenic pollutants and the degradation of groundwater quality. Wastewater is discharged into the receiving environment without a serious control and treatment. The quantity of nitrate resulting from these discharges continues to increase each year. The annual quantity is estimated at more than 75,000 tonnes of nitrates per year (Djouadar 2014), which is a real problem of groundwater contamination in this alluvial aquifer.

Hydrogeochemical facies

Usually, the hydrogeochemical processes of groundwater are studied by plotting the ion concentrations of water samples on Chadha's diagram (1999). This diagram has been effectively useful in several studies worldwide to establish the various hydrogeochemical processes (Karmegam et al. 2011; Thilagavathi et al. 2012, Bouderbala 2017b).

Chadha's suggested diagram can classify water into four types:

- *Group 1* characterize recharge water type, Ca–HCO₃.
- *Group 2* indicate an excess of Ca–Mg–Cl, with ion exchanged reverse.
- *Group 3* describe saline water rich in Na–Cl,
- *Group 4* water ion-exchange Na–HCO₃.

Plotting the samples of groundwater on this diagram (Fig. 12), we observe the majority of samples fall in the group 2 (around 60%), and the rest fall into group 1 (30%) and the group 3 (10% of samples).

Group 1 includes water samples situated in the upstream of the area, it characterizes the recharge area. These samples are far from anthropogenic source of pollution, or located near watercourses where there is the effect of the dilution process. Water classified as a calcium–bicarbonate water type.

Group 2 is characterized by high calcium and magnesium levels versus sodium and potassium. It is explained by the alteration of minerals like calcium and

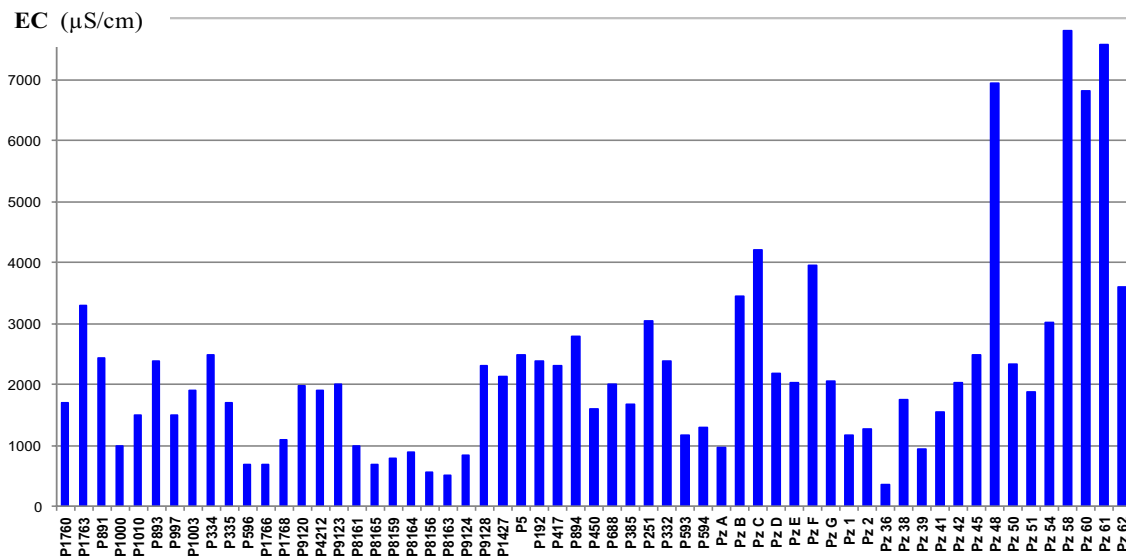


Fig. 9 Variation of EC in the groundwater of Mitidja alluvial aquifer (wet period 2010)

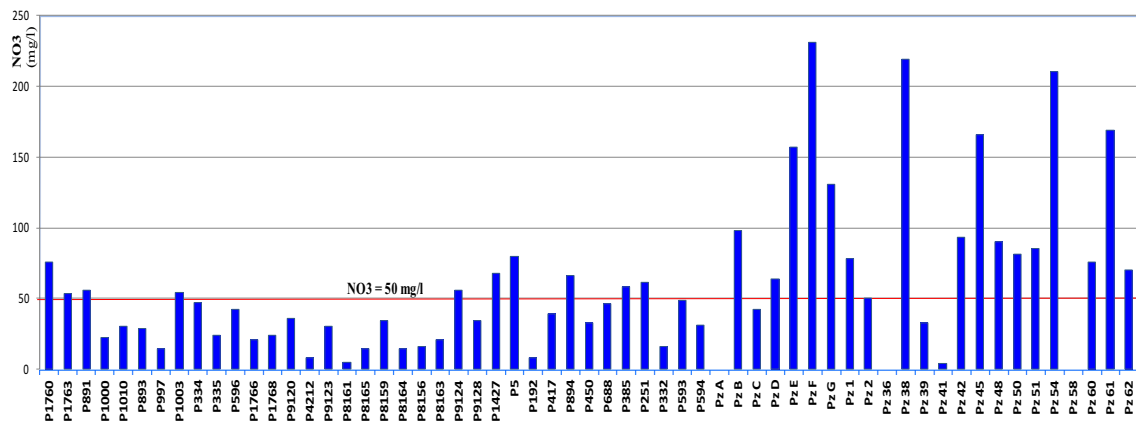


Fig. 10 Variation of nitrates (NO₃⁻) in the Mitidja alluvial aquifer (wet period 2010)

magnesium carbonate rocks or calcium carbonate rocks, and the exchange water–rock interaction, which has taken place during groundwater flows. It is also characterized by a surplus of Cl⁻ and SO₄²⁻ compared to HCO₃⁻; perhaps due to the effects of human activity, mainly wastewater discharge in the plain without prior treatment, the use of fertilizers and pesticides in agriculture. This group belongs to Ca²⁺–Mg²⁺–Cl⁻ water type.

The group 3 is characterized by high levels of Na⁺ and Cl⁻, which indicate the process of marine intrusion in this coastal part of the aquifer, and the wells are affected by seawater.

These water samples belong to Cl–SO₄–Na–Mg water type.

Conclusion

Water resources in Algeria, particularly in the Mitidja plain are limited, vulnerable and unequally distributed spatially. This sensitive situation inevitably requires new actions to exploit these resources, in a rational way.

The purpose of this work is to study the spatial variability of some chemical properties of groundwater in the Mitidja plain by a parametric approach of the quality index to evaluate the quality of water for drinking and irrigation purposes, in a relationship with climate change.

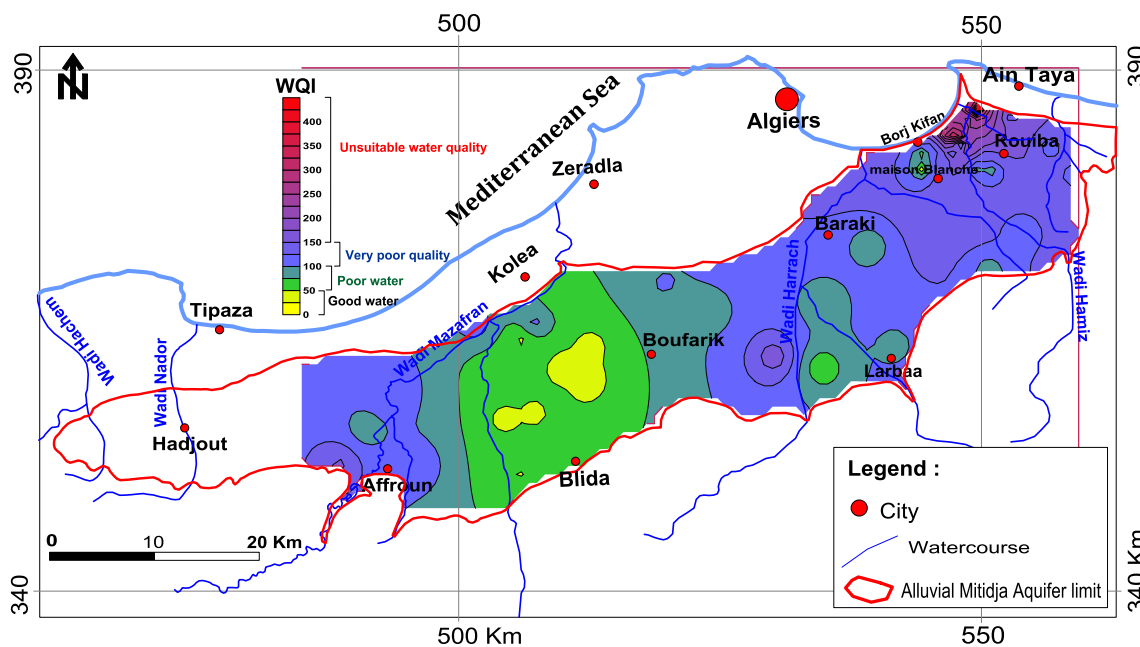


Fig. 11 The spatial distribution map of the WQI (wet period 2010)

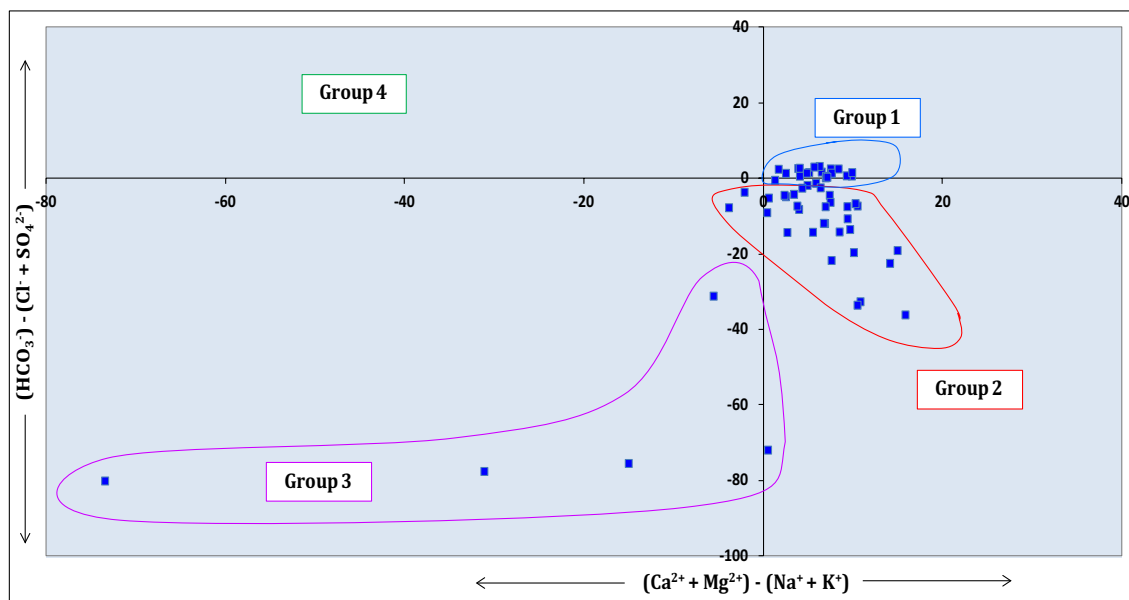


Fig. 12 Classification of hydrogeochemical water type for wet period 2010 (Chadha 1999)

Analysis of the chemical data showed the predominant of groundwater facies: Ca–HCO₃, Ca–Mg–Cl and Cl–SO₄–Na–Mg water type.

In addition, the salinity of the water in this plain varies from average to very high salinity.

It can be said that the groundwater in this aquifer is facing a huge risk of nitrate pollution and seawater intrusion, and becomes unfit for domestic and agricultural use.

It appears that the north-eastern part of Mitidja is the most vulnerable to the salinity because the contents of some elements greatly exceed the international standards set by WHO. It is the consequence of the very strong socio-economic pressure exerted on this part of Mitidja by industrial, agricultural and urban activities.

Thus, this work will be a statement of place and it can be a tool for decision-making regarding the exploitation of

this resource from the groundwater quality and the risk of contamination, for human health.

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