

Hydrochemical and microbiological quality of groundwater in the Merdja area, Tébessa, North-East of Algeria

Chemseddine Fehdi · Abdelkader Rouabhia ·
Abdelbasset Mechai · Manel Debabza ·
Khalida Abla · Kostas Voudouris

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Abstract The aim of this study was to perform a preliminary assessment of the hydrochemical and microbial groundwater quality of the Merdja plain (Tébessa area). Twenty samples of groundwater collected from Bekkaria (Site 1) to Ain Chabro (Site 2) were assessed for their suitability for human consumption. Groundwater from the aquifer in the Merdja area can be divided into two major groups according to geographical locations and chemical compositions. Water in the center part of the study area is characterized by the dominance of chloride, sulfate, sodium, and potassium; whereas waters in the limestone aquifers in the west are dominated by the same cations but have higher concentrations of bicarbonate. Microbiological parameters were determined in 13 groundwater samples collected from the study area. Total coliforms, thermotolerant coliforms, *E. coli*, *Enterococcus* spp., *Salmonella* sp., *Staphylococcus* spp., and *P. aeruginosa* were detected in 96.36, 88.18, 100, 47.5, 97.27, 96.7, and 75 % of the groundwater samples, respectively. The pollution of groundwater comes from a variety of sources, Ouadi El Kebir River, including land application of agricultural chemicals and organic wastes, infiltration of irrigation

water, septic tanks, and infiltration of effluent from sewage treatment plants, pits, lagoons, and ponds used for storage.

Keywords Groundwater · Pollution · Hydrochemistry · Microbiology · Algeria

Introduction

Water dissolves minerals present in soil and rock portions during its flow, which deteriorates groundwater quality by natural processes of geogenic origin. In the Merdja area, local population largely depends on water from shallow aquifer. Agricultural activity and untreated domestic wastewaters cause a degradation of a quality of groundwater (Rouabhia et al. 2008). Contaminants can easily reach the groundwater through soils and are rapidly transported over large distances (Vu Thi Minh et al. 2006; Masoud Eid Al-Ahmadi 2013). On the other hand, because of the recent globalization, a number of industries are coming up to establish their activities in the country. As most of the industries are not adhering to the strict environmental norms, the industrial activities can overtake the impacts of agricultural practices and municipal waste waters on groundwater quality, leading to severe groundwater pollution. Pollution not only affects water quality but also threatens human health and socioeconomic development. Assessment of groundwater pollution is, thus, an important aspect for proper civilization and also for development of database for future planning of water resources developmental strategies (Subba Rao 2012). In view of this, tracer tests, hydrochemical and microbiological investigations are suitable methods for providing a scientific basis for the development of sustainable groundwater protection schemes (Babyl Prasad et al. 2014; Bakalowicz 2005).

C. Fehdi (✉) · A. Rouabhia
Department of Geology, Tébessa University, Route de Annaba
villa N° 71, 12000 Tébessa, Algeria
e-mail: fehdi@yahoo.fr

A. Mechai · M. Debabza · K. Abla
Department of Biology, Tébessa University, 12002 Tébessa,
Algeria

K. Voudouris
Department of Geology, Aristotle University of Thessaloniki,
Thessaloniki, Greece

The application of these techniques requires considerable financial, logistic and technical efforts including wells monitoring and sampling, cooling and transport of the samples, and sophisticated analyses in microbiological and hydrochemical laboratories. In rich countries, these facilities are usually available. In developing countries and remote areas, however, such investigations are a challenge and require special methodological adaptations.

The study area is near the city of Tebessa in eastern Algeria, is among the poorest and remotest regions in the country (Fig. 1). This area lies in the semiarid region of Algeria and is susceptible to the various threats which surround both growing urban areas as well as developing agricultural areas. The city of Tebessa and the -surrounding villages (Bekkaria, Hammamet) have seen a great deal of growth in the past decade, with the establishment of new industries and farms.

The purpose of this study is twofold. The first is to study the hydrogeological regime in this area -with the help of chemical and isotopic data. Such studies can help constrain hydrogeological regimes which are poorly covered by water-level data. The second purpose is to evaluate the present status of water quality in the area. This will help both in present water resource planning in the area as well as provide a baseline for future water quality evolution studies. The Tebessa area straddles two groundwater level aquifers; the limestone aquifer, and the alluvial aquifer. In general, the shallow groundwater in Merdja area is found in the alluvial fan deposits from plio-quaternary age (Fig. 2). This aquifer is overlying geologic formations consist of cenomanien marly layers and form aquicludes. The recharge to the aquifer takes place in the highlands of Dyr, Bouroumane from east, and Doukkane from the west.

Climate and precipitation

Annual precipitation in the study area ranges between 200 and 350 mm, and thus the area is considered to be a semi-desert area. Temperatures can rise in the summer to 45 °C. This situation of dryness accentuates the drawdown of water resource especially during the last decade because the renewal of this resource is very weak.

The dry climate, the atmospheric dust, and low intensity of precipitation can also affect the groundwater quality generally causing increased salt content.

Geological and hydrological setting

The geology of study area was studied by several authors Blés and Fleury (1970), Vila (1980). The micropaleontologic and biostratigraphic analysis has showed that from the stratigraphic point of view, the study area covers the plio-quaternary tectonic depression of Tebessa. This depression separates the highlands of Dyr situated in the North from the one of Doukkane and Mestrie highlands in the South.

The study area is constituted in the major part by cretaceous formations (Fig. 2), forming a series of anticlines and synclines. The stratigraphic sequence is presented in the form of alternation of carbonated formations of limestones, marly limestones, and argillaceous marls.

The plio-quaternary and quaternary terrains occupy the central part; they are consisted by actual and recent alluvial deposits, conglomerates, gravels, sandstones.

The summary analysis of the stratigraphic column of the study area shows the presence of three aquiferous formations among them the formation of plio-quaternary one.

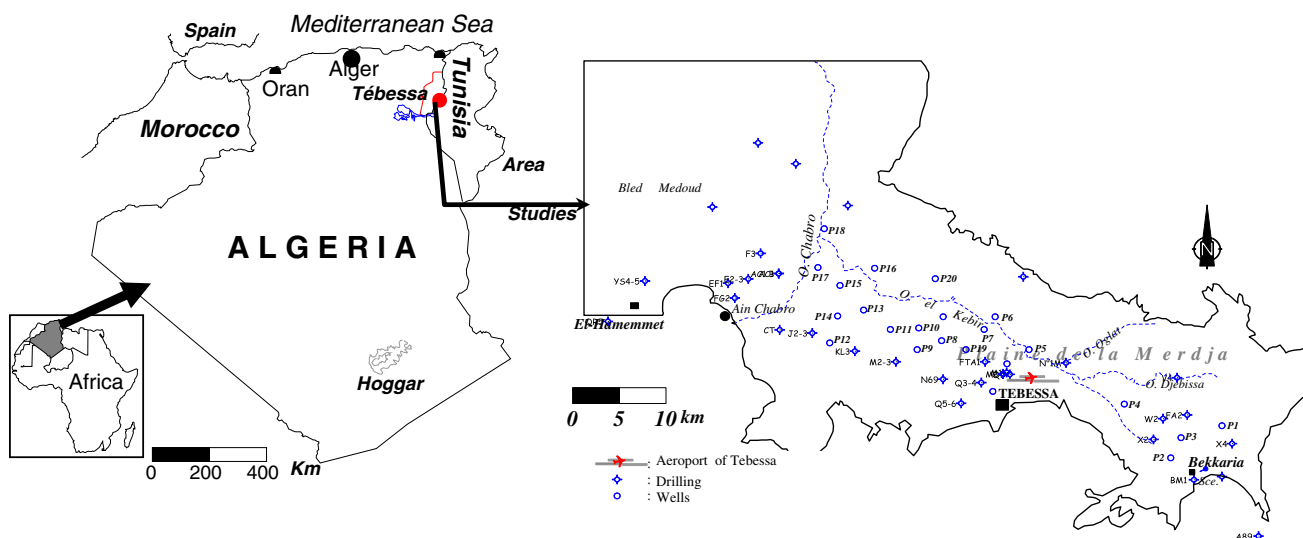
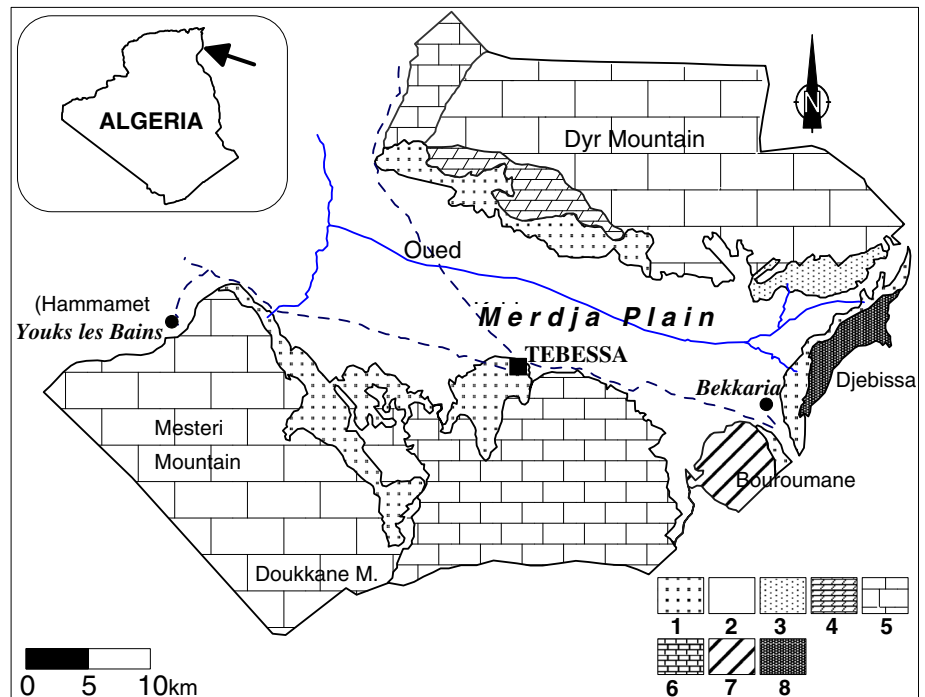


Fig. 1 Location of the study area in eastern part of Algeria

Fig. 2 Geological map of the study area. 1 conglomerates and gravels, 2 alluvial fans, 3 sand, 4 turonian limestone, 5 maestrichtian limestone, 6 eocen limestone, 7 cenomanian marl, 8 triassic formations



This aquifer of great extension occupies the major part of the tectonic depression, limited at the West and at the East by two great faults of NW–SE orientation. It is consisted very varied deposits such as, alluvial fans, silts, calcareous crust, conglomerates, and gravels. This aquifer plays an important role in the supply of drinking water for the inhabitants of this area (Fehdi et al. 2008).

Hydrochemical data

Sampling and analysis

Water samples from 20 c aquifers were collected (Table 1). The temperature, conductivity, and pH were measured in the field. Bicarbonate was measured by titration to the methyl orange endpoint. Chloride was determined by titration and precipitation of AgCl until silver chromate appears. Sulfate was determined by precipitation of BaSO₄ and then measuring the absorbency with spectrophotometer. Cations were determined using atomic absorption spectrophotometry. Microbiological parameters were determined in 13 groundwater samples collected from the study area. Microbiological analyses usually require sterile water sampling, cooling of the samples, and rapid transport to a microbiological laboratory (Hurst et al. 2002). In a poor and remote area like Merdja area, such procedure is nearly impossible. Therefore, the portable water testing kit OXFAM-DELAGUA (2004) was used. This equipment is designed to test for the critical

parameters specified in the WHO guidelines (2004). The testing kit can be used to analyse for different types of indicator bacteria by varying the cultivation conditions, i.e., the growth medium, incubation temperature, and time. In the study area, the samples were analyzed for thermotolerant coliforms (TTC), as these are considered to be of high sanitary significance (WHO 2004). According to the WHO standards, thermotolerant coliforms must be absent in a 100-ml water sample.

The first step of the analysis is to pass a defined water volume through a sterile filter, which is then placed on a paper pad soaked in liquid growth medium. After 16–18 h of incubation at 44 °C, the colonies are counted. The result is given in TTC/ml, sampling volumes between 1 and 100 ml can be chosen dependent on the bacteria content.

To minimize counting errors, each water sample was analyzed at least in two different volumes. The sampling strategy for the microbiological investigations was the same as described for the hydrochemical sampling.

Analysis of the groundwater regime is done using three approaches. The various chemical characteristics were mapped and the spatial distributions of these characteristics were compared with a piezometric map. Thermodynamic equilibrium models were carried out using PHREEQE (version 2.10) and saturation index was calculated with respect to several minerals such as calcite, aragonite, dolomite, halite, and gypsum. Finally, the waters were evaluated based on various drinking and agricultural water criteria including total hardness, salinity hazard, and sodium absorption hazards. The following discussion will

Table 1 EC values ($\mu\text{S}/\text{cm}$) and ion concentrations (mg/l) in groundwater samples of the Merdja area, North-East of Algeria

Well name	EC	Na	K	Ca	Mg	Sr	HCO ₃	SO ₄	NO ₃	Cl	PO ₄
P5	1,630	195.7	11.3	144.6	79.3	0.70	343.4	204.4	44.0	320.7	2.80
P7	4,781	391.2	19.2	179.7	88.3	0.50	385.5	236.2	20.0	710.0	2.00
J2–3	1,490	129.2	14.7	163.7	70.4	0.60	255.7	250.8	64.0	281.7	2.80
M2–3	866	72.0	17.8	93.5	51.7	1.04	294.8	209.3	70.0	288.2	3.10
P6	1,540	118.8	10.3	173.6	70.6	3.12	284.0	246.8	40.0	270.8	1.00
P13	890	66.7	09.1	134.8	40.6	0.63	231.1	220.8	36.0	240.3	4.50
PE69	1,985	82.6	20.1	154.8	49.2	0.91	207.2	301.4	86.2	37.8	1.80
P20	1,620	115.0	13.8	227.8	65.0	0.84	442.8	251.8	60.0	230.9	1.00
P10	986	38.4	10.8	124.7	53.7	2.5	335.5	185.1	72.4	21.8	1.00
P05	2,168	194.6	10.1	171.2	121.6	1.04	347.2	267.8	35.0	387.9	1.90
P04	1,571	136.1	14.8	148.7	54.7	0.78	188.7	260.1	48.0	281.5	2.60
P18	1,565	122.8	19.1	169.9	46.3	1.29	174.8	230.4	120.1	280.6	1.00
Q5–6	894	61.4	14.1	116.2	44.1	1.52	189.1	250.8	56.3	156.6	2.80
P11	2,579	315.1	5.8	216.4	80.7	0.62	445.3	302.4	18.0	525.4	1.00
M2	2,789	189.4	27.0	445.8	83.6	0.77	248.1	284.9	72.3	644.7	2.30
Q3–4	1,176	73.1	21.8	171.5	50.1	1.47	351.0	145.6	70.0	40.8	2.00
P09	1,066	102.8	14.3	134.4	47.3	0.90	231.8	138.7	42.0	270.8	3.90

illustrate the significance of these results in the context of water types, movement, and pollution.

Results and discussion

Water type

The water types in the area of study were determined based on their chemical composition. Chemical analyses were plotted on a trilinear diagram (Fig. 3). Waters in the western part of the study area are characterized by the dominance of chloride, sulfate, sodium, and potassium, whereas water in the eastern part of the study area is dominated by the same cations but have relatively higher concentrations of bicarbonate. Several maps were drawn for each chemical constituent that were analyzed in the water taken from production wells. Figure 4 shows the distribution of the chloride, in the study area. The highest concentrations of this anion seem to show local pollution with large distances from any obvious pollution sources such as waste dumps or waste-water treatment plants. Hydrochemistry analysis indicates a high nitrate concentrations (discussed in the following), indicating that agricultural seepage is responsible for water quality degradation.

Groundwater movement and evolution

Two piezometric highs are recognized in the study area (Fig. 5). One has a static water level of 861 m and is located near Bekkaria. The second is in the west of the

study area and has a static water level of 831 m at the El Hammamet. The piezometric map suggests that the direction of groundwater movement must be moving as shown in Fig. 4 from the east towards the center in one path and the other path is from the western part towards the center part.

Groundwater movement shows that the Merdja plain is subsidized in two hydrogeologic aquifer systems; at the east, this system is recharged through carbonate outcropping from Bouromane highlands and in the west part, this aquifer system has a direct alimentation from Meastrichtian fractured limestone.

Water quality

The purpose of this section is to characterize the waters for both domestic as well as for irrigation purposes. Water was classified in Table 3 based on total hardness according to the classification of Sawyer and McCarty (1967).

Hardness is indicated from the presence of divalent metallic cations of which calcium and magnesium are the most abundant in groundwater. These ions react with soap to form precipitates. Hard water is unsatisfactory for household cleaning purposes, hence, water-softening processes for removal of hardness are needed (Todd 1980).

Total hardness is calculated through the following equation (Todd 1980)

$$\text{TH} = 2.5 \text{ Ca (mg/l)} + 4.1 \text{ Mg (mg/l)}$$

It was observed that the examined water samples collected from wells were found to be hard, except the well

Fig. 3 Piper trilinear diagram of water chemistry in the study area

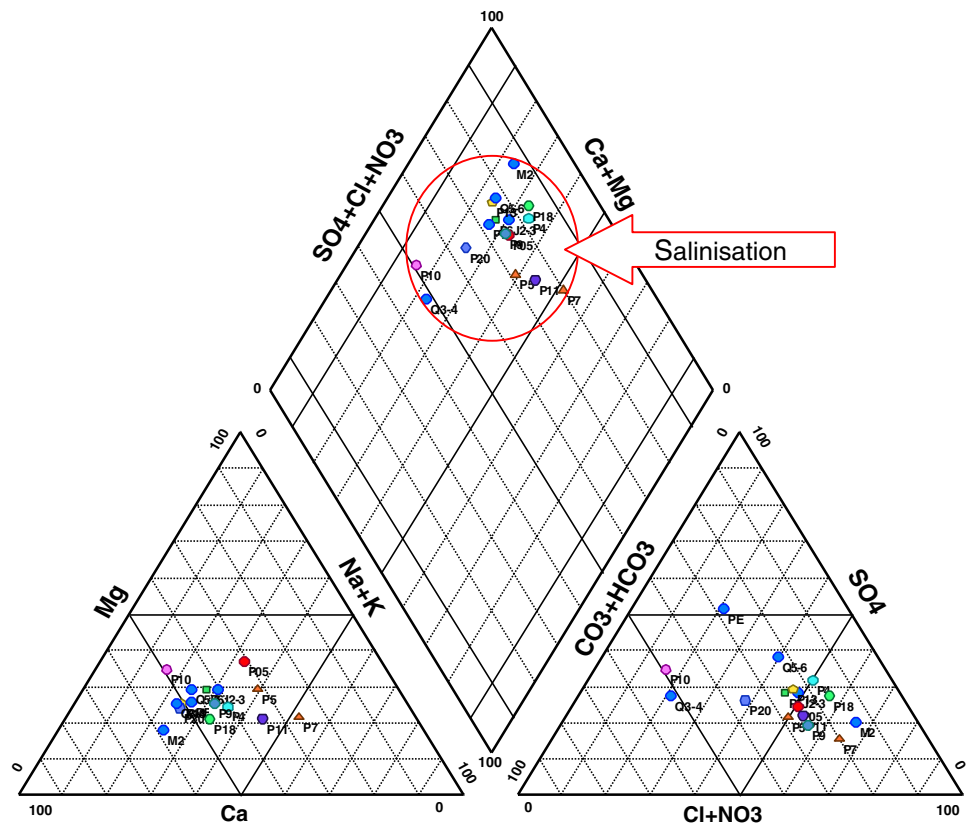
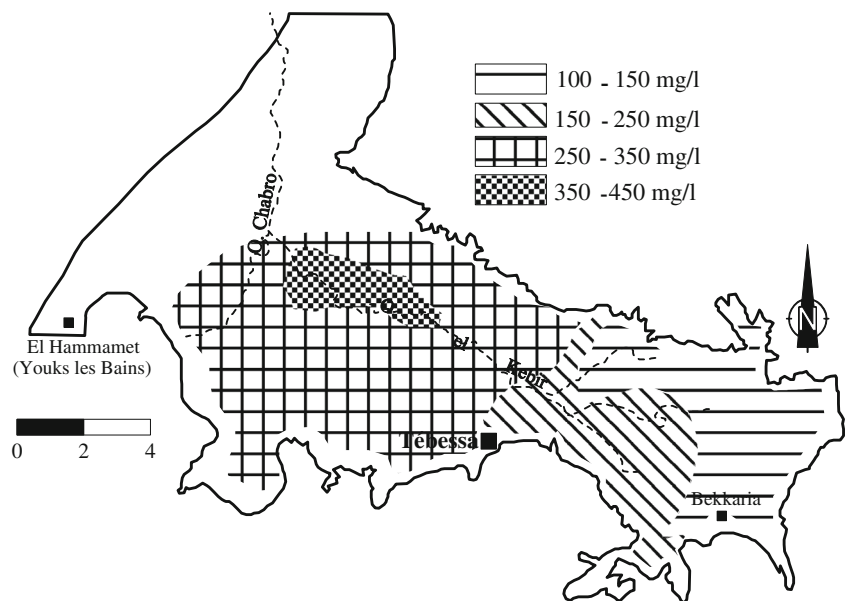


Fig. 4 Chloride distribution in the water of the area



M2 which is located in the eastern part of the area studied. This water sample is classified as very hard water.

Nitrates in drinking water are a major contaminant (Rouabhia et al. 2008). They are nowadays frequently found in aquifers. In arid and semiarid regions, sources of nitrates in groundwaters have either been linked with direct anthropogenic pollution in towns or with leaching

of fertilizers in agricultural areas. Nitrate (NO_3^-) concentrations of the phreatic waters (Table 1) were found far above the World Health Organization (WHO 2004) recommended limit (45 mg l^{-1}) especially for those samples occurring in rural areas. Almost 65 % of sampled dug wells showed concentrations greater than 45 mg l^{-1} .

Fig. 5 Piezometric map of Merdja aquifer

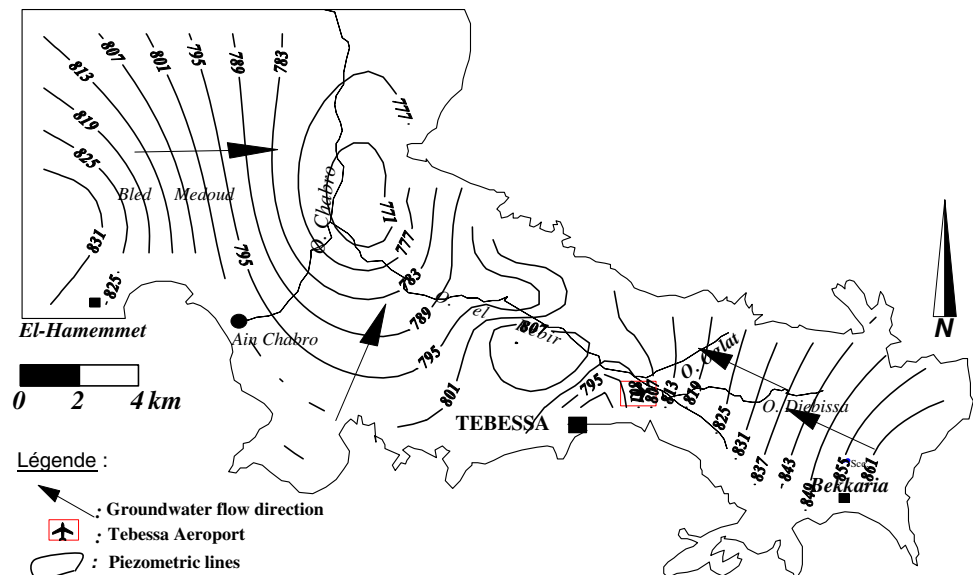


Table 2 Water classes according to sodium absorption ratio and salinity hazard

Well	SAR	EC	Salinity hazard	Sodium hazard	Water class
P5	4.29	1,630	High	Medium	C3–S2
P7	4.63	4,781	High	Medium	C3–S2
J2–3	8.26	1,490	High	Medium	C3–S2
M2–3	5.44	866	Medium	Low	C3–S2
P6	5.89	1,540	High	Medium	C3–S2
P13	9.74	890	High	Medium	C2–S1
PE69	8.62	1,985	High	Medium	C2–S1
P20	12.79	1,620	V. high	Low	C2–S1
P10	8.74	986	High	Low	C2–S1
P05	13.46	2,168	V. high	Medium	C2–S1
P04	8.99	1,571	V. high	Medium	C2–S1
P18	14.71	1,565	V. high	Medium	C3–S1
Q5–6	5.41	894	Medium	Low	C2–S1
P11	6.89	2,579	High	Medium	C3–S1
M2	5.07	2,789	High	Medium	C3–S1
Q3–4	6.86	1,176	V. high	Medium	C3–S1
P09	7.61	1,066	V. high	Low	C2–S1
P5	9.06	1,630	V. high	Low	C2–S1
P17	4.29	4,781	High	Low	C4–S2
J2–3	5.21	1,490	V. high	Medium	C4–S2

The presence of high nitrate concentrations in the phreatic waters is not only the direct consequence of a massive usage of artificial fertilizers, but is also a consequence of contamination by domestic septic tanks. The latter is unfortunately favored by the absence of a sanitation network in the whole region and where more than 800 septic tanks are in use. This fact contributes

to the nitrification of groundwaters according to the process.

Nitrate concentrations vary between 18 (sample P11) and 120.1 mg/l (sample P18). The highest concentrations were found in the middle and the west part of the study area (Fig. 6); however, lowest concentrations are located in the eastern part (Bakkaria zone).

Irrigation in the area uses groundwater exclusively, which explains the high nitrate concentrations. In the center part, wadi El Kebir is probably responsible for elevated nitrate concentrations in its immediate vicinity.

The suitability of groundwater for irrigation is contingent on the effects on the mineral constituents of the water on both the plant and the soil (Rouabhia et al. 2008) Salts may harm plant growth physically by limiting the uptake of water through modification of the osmotic processes, or chemically by metabolic reactions such as those caused by toxic constituents (Todd 1980). Sodium concentration is important in classifying irrigation water because sodium reacts with soil to reduce its permeability. Soils containing a large proportion of sodium with carbonate as the predominant anion are termed alkali soils; those with chloride or sulfate as the predominant anion are saline soils, ordinarily, either type of sodium-enriched soil will support little or no plant growth (Todd 1980). Sodium content is usually expressed in terms of percent sodium defined by the relationship:

$$\%Na = \frac{(Na + K) \cdot 100}{Ca + Mg + Na + K}$$

where the concentrations of the constituents are expressed in milliequivalents per liter. In Table 2, the analysis of waters was classified based on the divisions proposed by Wilcox (1948).

Fig. 6 Nitrate distribution in the water of the area

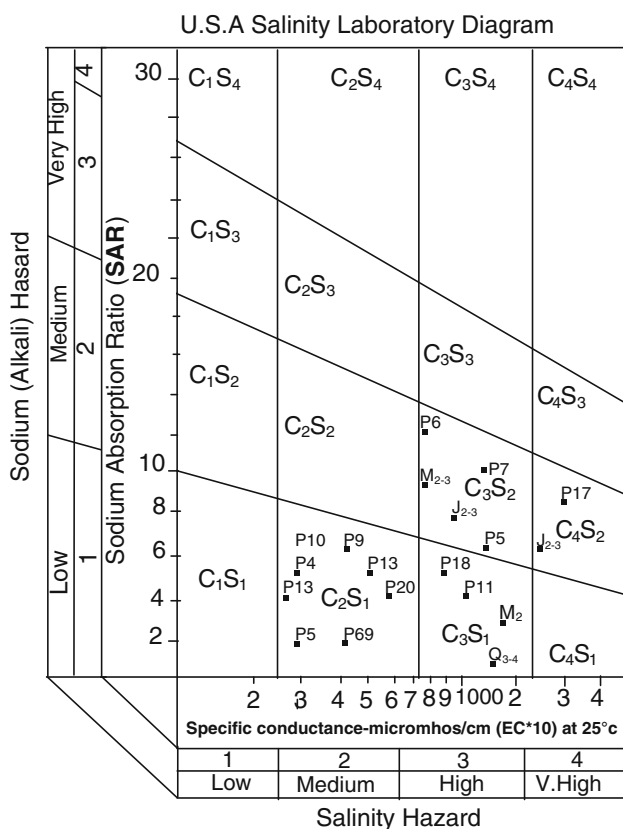
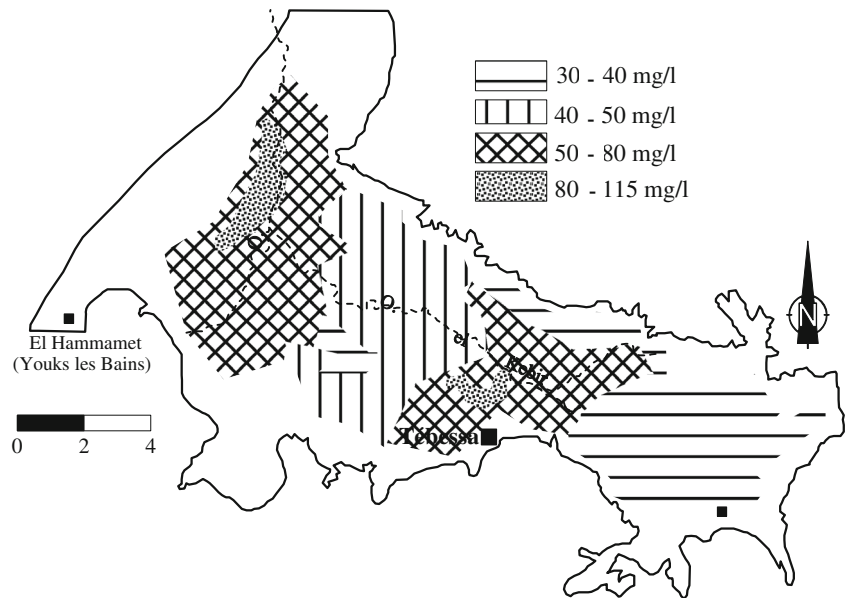


Fig. 7 Salinity hazard of the groundwater samples of the study area

The sodium adsorption ration (SAR) is also used here because of its direct relation to the adsorption of sodium by soil. It is defined by the following equation (Todd 1980):

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}}$$

where the concentration of the constituents is expressed in milliequivalent per liter. The sodium adsorption ratio was plotted on the U.S.A. salinity laboratory diagram (Fig. 7). Table 2 shows the water classes according to the SAR method. The waters were found mostly confined in four classes of water type; i.e., C3–S2, C2–S1 and C3–S1 and C4–S2 which has medium to very high salinity hazards and low to medium sodium alkalinity hazards.

Microbiology

Microbiological parameters were determined in 13 groundwater samples collected from the study area (Table 3). Total coliforms, thermotolerant coliforms, *E. coli*, *Enterococcus* spp., *Salmonella* sp., *Staphylococcus* spp., and *P. aeruginosa* were detected in 96.36, 88.18, 100, 47.5, 97.27, 96.7, and 75 % of the groundwater samples, respectively. The pollution of groundwater comes from a variety of sources, Ouadi El Kebir River, including land application of agricultural chemicals and organic wastes, infiltration of irrigation water, septic tanks, and infiltration of effluent from sewage treatment plants, pits, lagoons, and ponds used storage.

Water–rock interaction process

Interaction between groundwater and surrounding host rocks is believed to be the main process responsible for the observed chemical characteristics of groundwater in the Merdja plain. Evaluation of such process requires the description of the mineral assemblage of the rocks in which water is found, and the identification of chemical reaction responsible for the geochemical evolution of groundwater. From available studies in the literature (Drever 1997; Vu

Table 3 Microbiological parameters of some groundwater samples in the study area

Samples	M1	M2	M3	M4	M5	A1	A2	A3	A4	A5	A6	A7	A8
Total coliforms	+	+	+	+	+	–	–	+	+	+	+	+	+
Thermotolerant coliforms	+	+	+	+	+	–	+	+	+	+	+	+	+
<i>Staphylococcus</i> spp.	–	–	–	–	–	–	+	+	+	+	+	+	+
<i>Salmonella</i> sp.	+	+	+	+	+	–	+	+	+	+	+	+	+
<i>E. coli</i>	–	–	–	–	–	–	–	–	–	+	+	+	+

A1 sampled wells in Ain Chabro area, M1 sampled wells in Merdja area, – absence of microorganismes, + presence of microorganismes

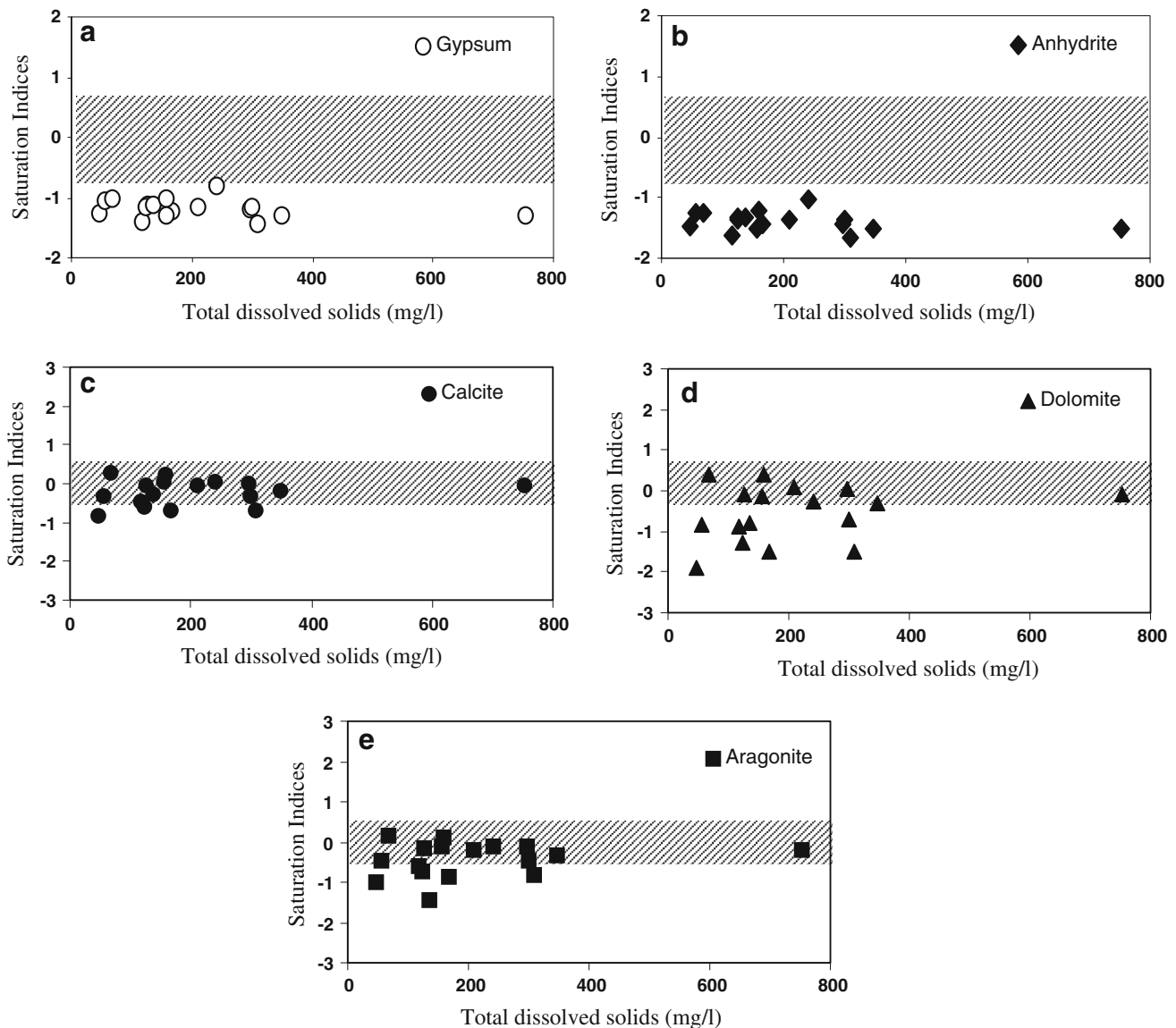


Fig. 8 Plots of saturation indices with respect to some carbonate and evaporite minerals, as computed with WATECF against total dissolved solids. Hatched zone indicates the saturation state

Thi Minh 2006), such reactions generally include chemical weathering of rock-forming minerals, dissolution–precipitation of secondary carbonates, and ion exchange between water and clay minerals.

Two approaches, mathematical and graphical, are used for the resolution of hydrogeochemical problems. The mathematical approach is often used for the calculation of saturation indices of groundwater with respect to mineral

phases, thus providing some indication upon the equilibrium state between groundwater and the surrounding mineral rock assemblages. Several geochemical programs have been developed for such calculations. The graphical approach describes the stability fields of minerals in equilibrium with groundwater, in terms of the activity ratio (on a log scale) of ions in groundwater (Plummer et al. 1976) have been developed for such calculations.

In the present study, saturation indices (SI) with respect to carbonate (calcite, dolomite, and aragonite) and evaporite (gypsum, anhydrite) minerals, as well as activities of soluble species, were calculated using the computer chemical program WATEQF written by Plummer et al. (1976). Because all the investigated groundwaters were very low in total dissolved loads, the expression of Deby and Huckel (1923) was used for the computation of coefficient activities.

Figure 8 shows the poles of SI against total dissolved solids for all investigated groundwater. In the following discussion, we may assume that the SI values falling within the range of ± 0.5 units from zero indicate the equilibrium state. All of considered groundwaters are saturated with respect to calcite and most of them are undersaturated with respect to dolomite and aragonite (Fig. 8c, d, e) indicating a dissolution phase especially for dolomite ($\log K_s = -17.09$ in WATEQ).

On the other hand, groundwater samples found to be undersaturated with respect to evaporates minerals (gypsum and anhydrite), suggesting that these evaporite mineral phases are absent in the corresponding host rock.

Conclusions

This study has thrown light on both the hydrogeological regime of the Merdja area as well as on the status of the water quality in the study area.

Salinity and nitrate build-up at some locations seems to be related to the use of nitrate fertilizers in the farms of the area, although some pollution may be attributed to the effluent of the industrial zone. Microbiological contamination of groundwater probably results from agricultural activities and untreated domestic wastewaters.

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References

- Bakalowicz M (2005) Karst groundwater: a challenge for new resources. *Hydrogeol J* 13(1):148–160
- Blés JL, Fleury JJ (1970) Carte géologique de l'Algérie au 1/50000, feuille n°178, Morsott, avec notice explicative détaillée. Service de cartes Géologique et Sonatrach, Division d'hydrocarbure. Direction des explorations, Alger
- Deby, Huckel (1923) Zur Theorie der Elektrolyte. I. Gefrierpunktserniedrigung und verwandte Erscheinungen [The theory of electrolytes. I. Lowering of freezing point and related phenomena]. *Physikalische Zeitschrift* 24:185–206
- Prasad Bably, Kumari Puja, Bano Shamima, Kumari Shweta (2014) Ground water quality evaluation near mining area and development of heavy metal pollution index. *Appl Water Sci* 4:11–17
- Drever JF (1997) The geochemistry of natural waters, 3rd edn. Prentice-Hall INC, New York, p 379
- Fehdi Ch, Aek Rouabhia, Baali F (2008) The Hydrogeochemical characterization of Morsott-El Aouinet aquifer, Northeastern Algeria. *Environmental Geology*. Springer, Heidelberg. doi:10.1007/s00254-008-1667-4
- Hurst CJ, Crawford RL, Knudsen GR, McInerney MJ, Stetzenbach LD (2002) Manual of environmental microbiology, 2nd edn. ASM, Washington, DC 1158
- Al-Ahmadi ME (2013) Hydrochemical characterization of groundwater in wadi Sayyah, Western Saudi Arabia. *Appl Water Sci* 3:721–727
- OXFAM-DELAGUA (2004) Water testing Kit, users Manual, Version 4.1. Robbins, Surrey, p 58
- Plummer LN, Jones BF, Truesdall AH (1976) WATEQ-A FORTRAN IV version of WATEQ, a computer program for calculating chemical equilibrium of natural waters Revised 1978, 1984 Washington D.C. U.S Geol Surv Water Resour 76:13–61
- Rouabhia A, Fehdi Ch, Baali F, Djabri L, Rouabhi R (2008) Impact of human activities on quality and geochemistry of groundwater in the Merdja area, Tebessa, Algeria. *Environ Geol*. doi:10.1007/s00254-008-1225-0
- Sawyer C, MC Carty YP (1967) Chemistry and sanitary engineering. McGraw Hill, New York, p 518
- Subba Rao N (2012) PIG: a numerical index for dissemination of groundwater contamination zones. *Hydrol Process* 26: 3344–3350
- Vila JM (1980) La chaîne alpine de l'Algérie orientale et des confins Algéro-Tunisiens. Université Pierre et Marie curie, Paris VI, Thèse de Doctorat- es -sciences
- Nguyet VTM, Goldscheider N (2006) Tracer tests, hydrochemical and microbiological investigations as a basis for groundwater protection in a remote tropical mountainous karst area, Vietnam. *Hydrogeol J* 14:1147–1159
- WHO (2004) Guidelines for drinking-water quality, vol 1, Recommendations, 3rd edn. World Health Organisation, Geneva, p 515
- Wilcox L (1948) The quality of water for agricultural use. US Dept Agriculture Tech Bull 962, Washington
- Todd K (1980) Groundwater hydrology, 2nd edn. Wiley, New York, p 510