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Characterization of the salinity of the alluvial aquifer in the upper valley of Wadi Rhumel (eastern Algeria)

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ABSTRACT

The region explored is part of the western area of the large watershed, Kebir Rhumel, located in eastern Algeria. It characterizes the plain of Tadjenanet–Chelghoum Laid. From a geological point of view, the study area is characterized by the formation of sedimentary outcrops which predominantly corresponds to Mio-Plio-Quaternary formations. The present study aims at the study of the hydrodynamic behavior of the alluvial aquifer and determines the impact of natural and anthropogenic pollution on the physico-chemical water quality of the shallow aquifer in the area of Tadjenanet–Chelghoum Laid. The study of the chemistry of the alluvial aquifer concluded that the hydrochemical behavior is characterized by a large variability in space. Mineralization increases gradually from west to east coinciding with the main direction of groundwater flow. Very high concentration of nitrates in irrigated areas located on the outskirts of Oued Rhumel concentration reflects the agricultural vocation of the region, marked by a wide variety of cultures, which uses an irrational way, especially nitrogen fertilizers.

Keywords: Salinity; Alluvial; Aquifer; Wadi; Rhumel

1. Introduction

The diversification of crops and growth of orchards on the plain of study, as well as increasing populations have led to an increase in water needs for irrigation and domestic purposes. Therefore, the number of wells has increased steadily from one year to another with increasing demand due to the implantation of medium-depth drilling and uncontrolled implantation wells for individual use. This has led to the mismanagement of the water potential of the region. This situation can result in a risk of pollution of various natural, agricultural, industrial, and domestic groundwater as well as surface water (dam Oued el Athmania located downstream of the plain) which undermined the effect of agriculture, as well as the installation of various industrial units in both cities of Tadjenanet and Chelghoum Laid. This situation is aggravated by the lack of wastewater treatment plants (WWTP) in the region and that all discharges of wastewater that are dumped into the river of Rhumel are untreated. This requires a thorough study of the hydraulic potential of the aquifer system of the plain of Tadjenanet–Chelghoum Laid. Our task is limited to explore the ground surface aquifer area to acquire the necessary data. For this purpose, we will try statistical

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and cartographic processing to give a better view on the spatial evolution of hydrodynamic and chemical characteristics of groundwater in the region, as well as their degree of vulnerability to different types of natural and anthropogenic pollution.

2. Materials and methods

2.1. Geological and hydrogeological settings

The explored region is part of the western area of the large watershed, Kebir Rhumel, located in eastern Algeria (Fig. 1). The review of the work of Vila 1980, Durozoy 1960, and stratigraphic logs of holes drilled in the field of study, helped visualize the different stratigraphic series [1,2]. The Mio-Pliocene formations covering large areas have good potential hydrogeological point of view, whose thickness varies from 100 to 150 m. They are formed by fluvial-lacustrine deposits of silt, sand, marl, and clay [3–5] (Fig. 2). The establishment of water balance according to Thornthwaite formula over a period of 16 years (1988 to 1989-2003/2004) in the station of Hammam Grouz shows that this region is in deficit with an annual average rainfall and temperature about 372.25 mm and 15.43˚C, respectively. Actual evapotranspiration represents 92% of the precipitation, while infiltration is very low, representing only 1.5% of precipitation (5.58 mm). This suggests that groundwater recharge is done not only by effective infiltration, but much of the water supply comes from carbonate formations bordering the water [6].

Piezometric levels measured on 33 water points distributed over the region during the study period of May 2007 have enabled us to establish the piezometric morphology of the aquifer. Analysis of the piezometric map (Fig. 3) shows that the aquifer has: A limitation of inflow from carbonate massifs which surround the plain to the north, southwest, and north; a tight limit on the southeastern land characterized by the presence of impermeable marl and evaporite formations. The bedrock is formed by clays and marls; a piezometric depression confused with cup of dam in extreme east of the study area. The studied aquifer is characterized by a flow converging towards the closed piezometric curves in westbound—this coincides with the morphology of the substrate. Power is supplied largely by carbonate formations of Cretaceous of Jebel Tnoutit and Jebel Grouz as Eocene formations of Draa Mestaoua and Jebel ed Dess [7].

2.2. Sample collection

The sampling campaign was carried out during the end of the period of high water (May 2007). Thirty-three (33) samples were taken at water points (wells and drilling). (Fig. 4). Chemical analysis was performed in the laboratory of the WWTP of Batna and a private laboratory analysis of soil and irrigation water was also performed. The chemical elements

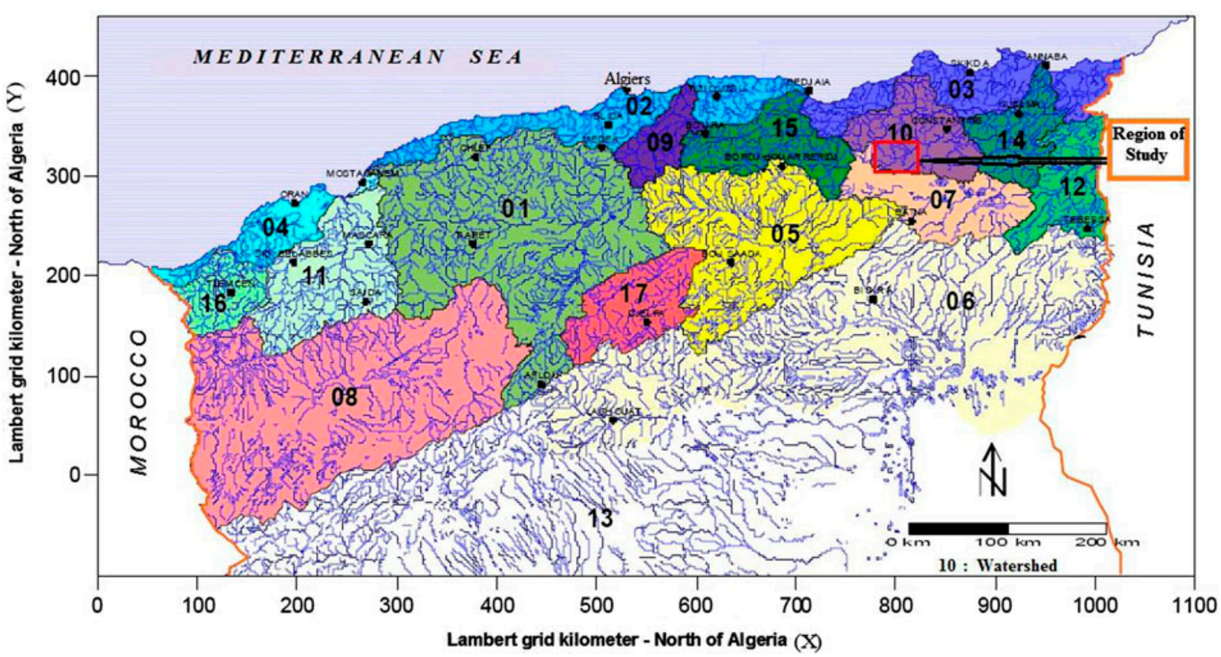

Fig. 1. Location of the study area.

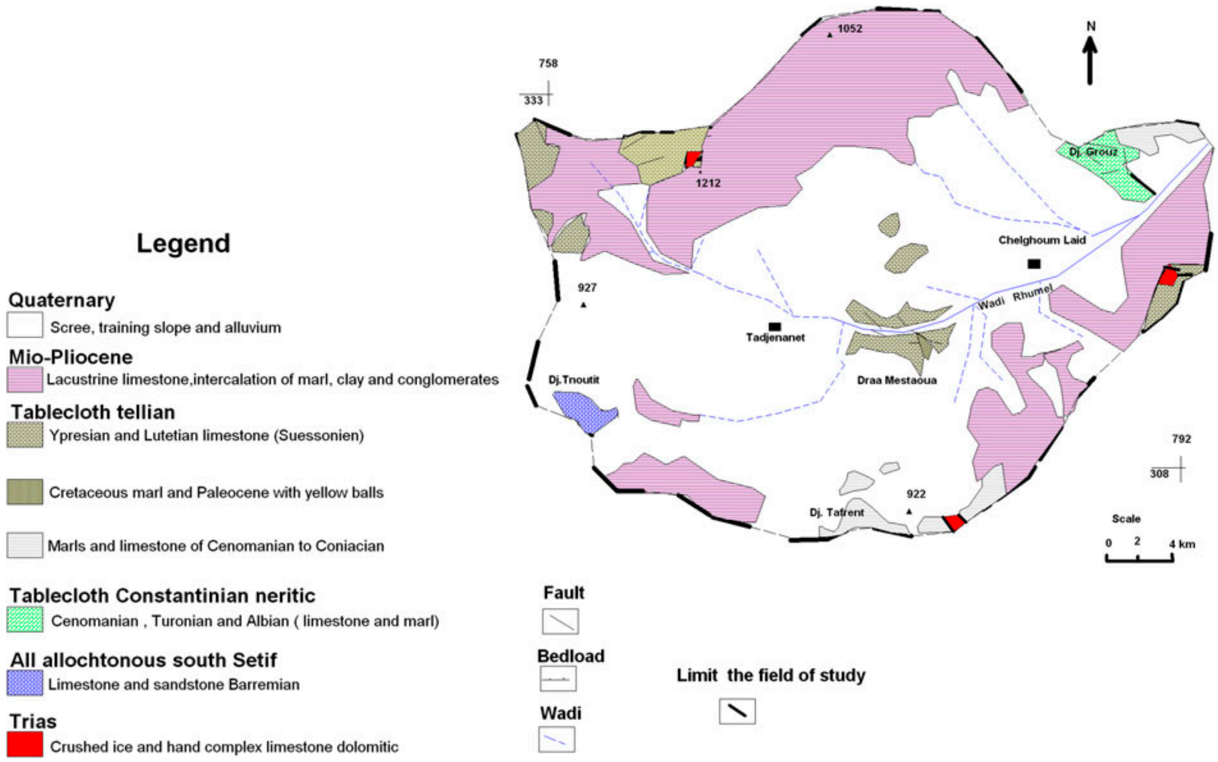

Fig. 2. Geological map of sub-basin of Tadjenanet–Chelghoum Laid.

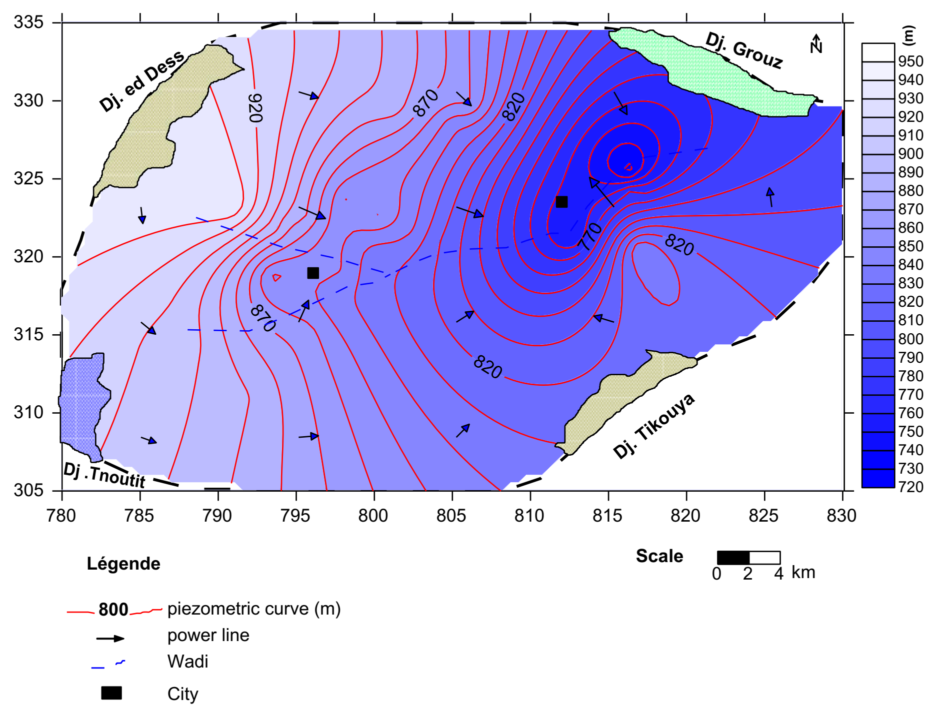

Fig. 3. Piezometric map. May 2007.

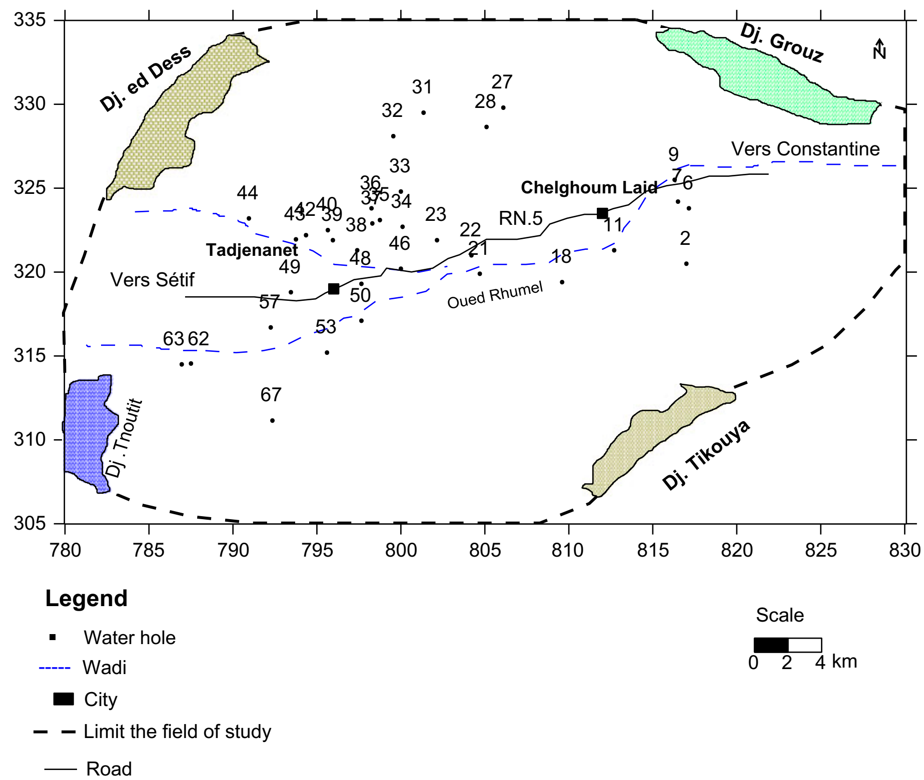

Fig. 4. Inventory map of water points.

which were assayed are: Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, SO_4^{-2}, Cl^-, NO_3^-, NO_2^-, NH_4^+, PO_4^{-3}; they were determined by atomic absorption spectrometer for cations, and by titration for chloride presence and alkalinity. Nitrogen elements were determined by spectrophotometry, nitrates in the presence of silicate give paranitosalicylate sodium, yellow in color (415 nm). The temperature (*T*), the electrical conductivity (EC), and pH were measured on the ground using a portable multi-parameter instrument [8].

3. Results and discussion

Salinity has a significant effect on water quality especially in arid and semi-arid areas, which have high salinity of groundwater particularly for shallow aquifers, resulting in the phenomenon of evaporation [9]. The analysis results are summarized in (Table 1). The dispersion around the mean (m) of these elements is done using the standard deviation (σ) and coefficient of variation ($CV = \sigma / m$), it is estimated that the series is homogeneous when CV < 50% [10].

According to the results of analyses of water chemistry, the alluvial aquifer is characterized by a wide variation in concentrations of chemical elements. It is noted that the deviation from the average is significant for certain elements such as magnesium, sulfate, and nutrients. (Fig. 5). The great variability of nitrogen compounds such as nitrates is probably due to the use of chemical and organic fertilizers in agriculture and the decomposition of organic matter [9], [11,12] (Group 1). Regarding sulfates originating from the dissolution of gypsum formations, high concentrations are limited in space and do not concern the plain (Group 2). The deflection of the rest of the parameters relative to the average is approximately 40%. This can be explained by a relatively uniform distribution of the concentration of these parameters in the space except for the magnesium concentrations which are related to sulfates (Group 3). Regarding the physical parameters, they have an identical distribution on the whole pitch (Group 4).

3.1. Chemical water facies

From the examination of the ionic form of the results of hydrochemical data of 33 water points collected in plain of Tadjenanet–Chelghoum Laid has shown that the calcium sulfate facies is the most

Table 1
Statistical characteristics of the physico-chemical parameters of water in the alluvial aquifer of Tadjenanet–Chelghoum.Laid. May 2007

Parameters Statistics	T (°C)	pH	EC (µs/cm)	Ca^{+2} (mg/l)	Mg^{+2} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	HCO_3^- (mg/l)	SO_4^{-2} (mg/l)	Cl^- (mg/l)	NO_3^- (mg/l)	NO_2^- (mg/l)	NH_4^+ (mg/l)	PO_4^{-3} (mg/l)
Max	19.2	8.63	3,611	304.6	172.44	143	11.3	512.4	1,100	339.15	486.4	0.05	0.56	2.2
Min	15.1	7.12	745	65.68	30.6	26.3	0.4	122	29	88.75	13	0.01	0.1	0.4
Average	17.3	7.62	1,465	148.39	70.67	76.95	6.71	256.43	272.63	191.58	102.6	0.02	0.25	0.95
SD	1.11	0.34	693	68.29	39.37	28.0	2.5	97.14	298.46	79.02	81.95	0.01	0.18	0.6
CV (%)	6.42	4.46	47.30	46.02	55.71	36.39	37.26	37.88	109.47	41.24	79.87	50	72	63.16
Standard WHO (2004)		6.5–8.5	2000	100	50	200	12		250	250	50	0.2	0 .4	

Note: CV: coefficient of variation; SD: standard deviation.

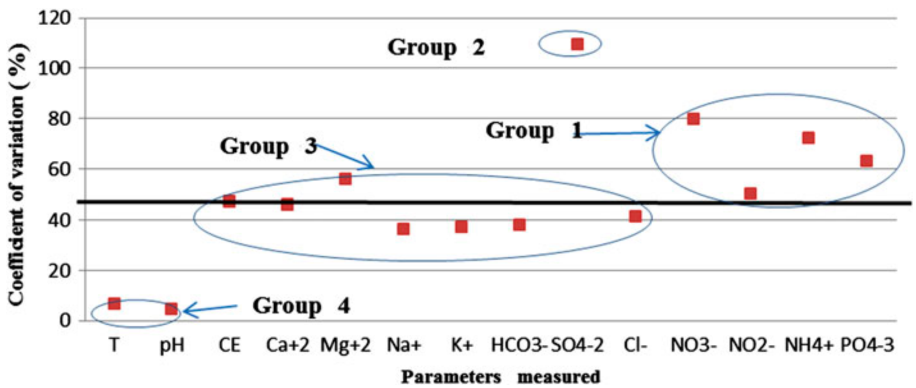

Fig. 5. The coefficient of variation of the physico-chemical variables measured in groundwater.

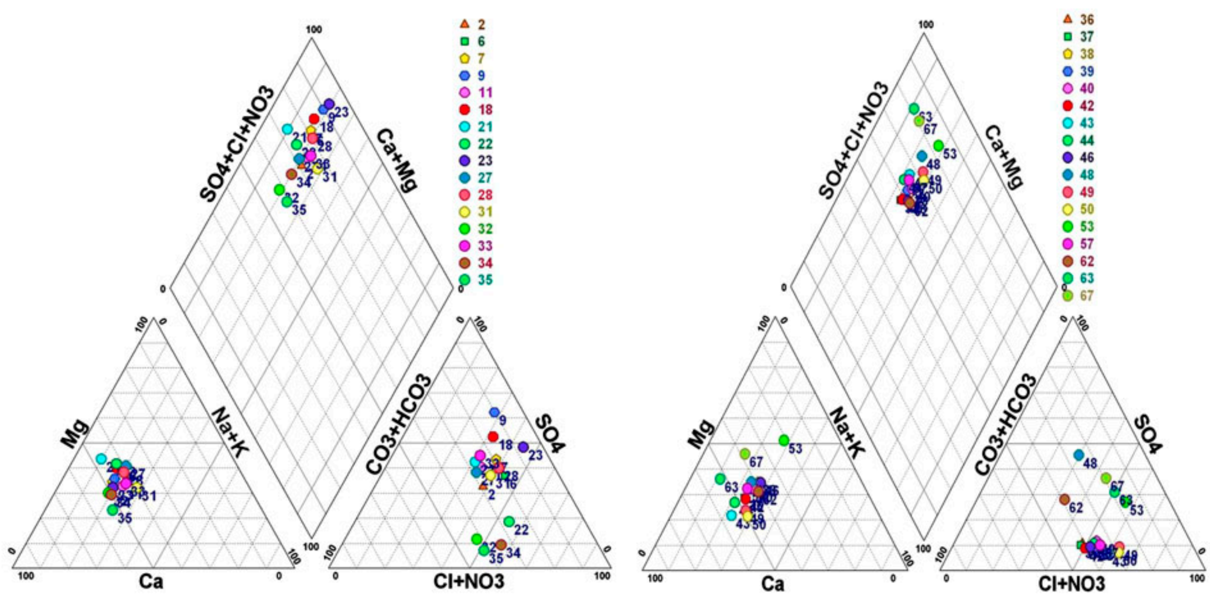

Fig. 6. Piper diagram. May 2007.

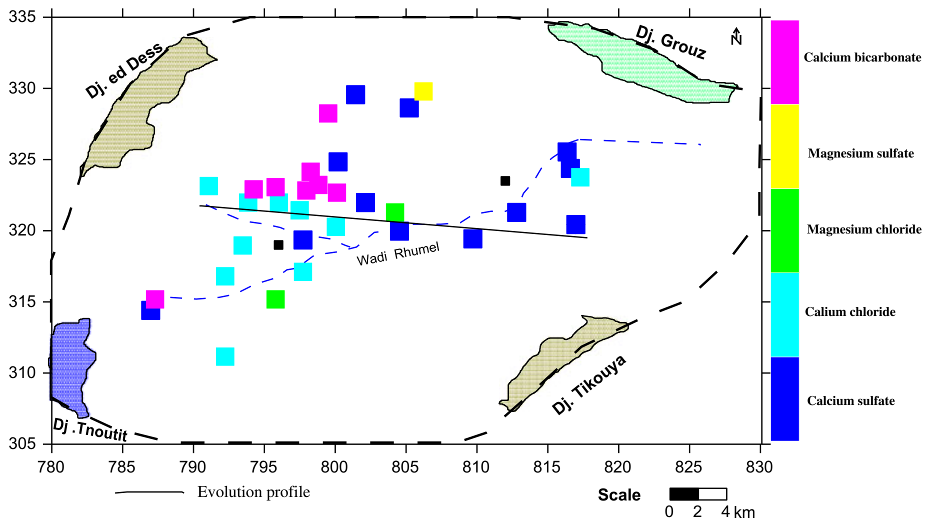

Fig. 7. Map of chemical facies. May 2007.

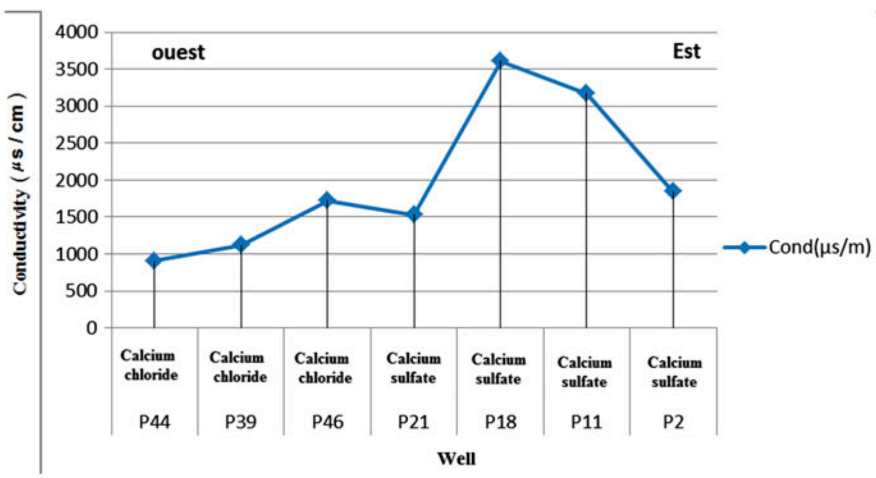

Fig. 8. Spatial distribution of chemical facies of the alluvial aquifer. May 2007.

dominant present in 36% of the all samples analyzed, followed by 30% calcium chloride facies. Calcium bicarbonate, magnesium sulfate, and magnesium chloride facies are contained in, respectively, 24, 6, and 3% of the samples analyzed. Based on this preliminary distribution of chemical water facies, it seems that the influence of evaporite and carbonate formations is marked by the dominance of sulfates, chlorides, and bicarbonates by the cationic center and calcium and magnesium by the anionic cluster. The analysis results carried on the Piper diagram [13] confirm the common origin of these waters. They are grouped into a single cluster influenced by the dissolution of evaporite formations (Fig. 6). This solution has generated several chemical elements, including sulfates, chlorides, calcium, and magnesium. By going from west to east the waters have a tendency to sulfated anionic pole. All water points shown on the triangle relating the cations put in the middle (mixed part) do have a tendency to calcium pole, except water points No. 53 and 67 located in west of the land of study.

3.2. *Spatial distribution of chemical facies*

The study of the spatial distribution of facies is in fact the study of the distribution of chemical parameters characterizing these facies across the plain. The prevailing settings of groundwater are sulfates, chlorides, and calcium. According to this map, we find that the water passes a calcium chloride and

Table 2
Saturation index of minerals in water

Water hole	Mineral					
	Carbonate minerals			Evaporite minerals		
	Calcite $CaCO_3$	Dolomite $CaMg(CO_3)_2$	Aragonite $CaCO_3$	Gypsum $CaSO_42H_2O$	Anhydrite $CaSO_4$	Halite NaCl
Average	−0.02788	−0.05030	−0.17121	−1.40939	−1.62970	−6.52667
Min	−0.56000	−0.74000	−0.70000	−2.02000	−2.24000	−6.98000
Max	0.45000	1.00000	0.31000	−0.41000	−0.63000	−6.00000
SD	0.221511	0.441415	0.220507	0.550284	0.549633	0.292486

Note: SD: standard deviation.

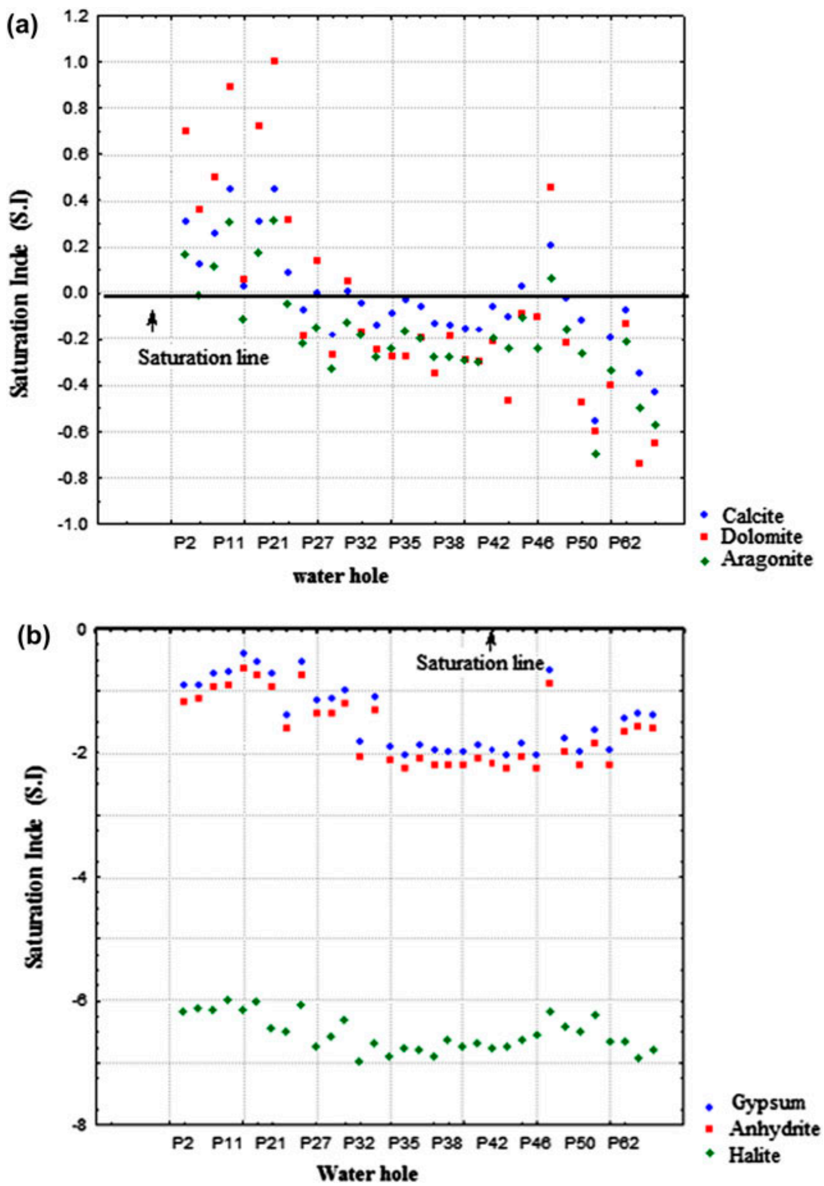

Fig. 9. Variations in the saturation index of carbonate and evaporites minerals in the alluvial aquifer. (a) Carbonate minerals. (b) Evaporite minerals.

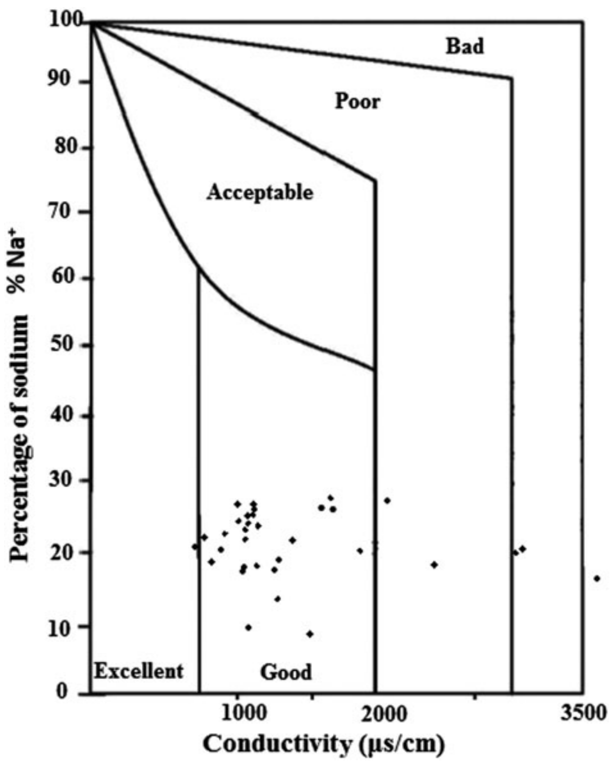

Fig. 10. Classification of water for irrigation according to the method of Wilcox.

bicarbonate to calcium sulfated facies (Fig. 7). The coexistence of these facies is in conjunction with the geological diversity of the land. The presence of carbonate formations and Triassic salt formations allows water to have a variable facies according to the terrain [14].

The study of the spatial evolution of chemical water facies of the water in conjunction with electrical conductivity (Fig. 8) allowed us to observe that according to the flow axis, the calcium chloride and calcium bicarbonate facies which appeared in the west area have become calcium sulfated at the center of the field of study, which is inferred from the quantities of electrical conductivity greater than 1,500 µS/cm, which reaches very high values of order 3,600 µS/cm and is explained by the phenomenon of acceleration of dissolution and the exchange effect between the basic alkali and alkaline earth metals.

3.3. State of dissolved minerals in water

In order to explain the acquisition of mineralization mechanisms, PHREEQC-2 program (version 2.10) was used for determining the saturation indices of some specific minerals (calcite, aragonite, dolomite, gypsum, anhydrite, and halite) (Table 2).

Carbonate minerals have different degrees of saturation. Indeed, one of the ranges of calcite is −0.56 to

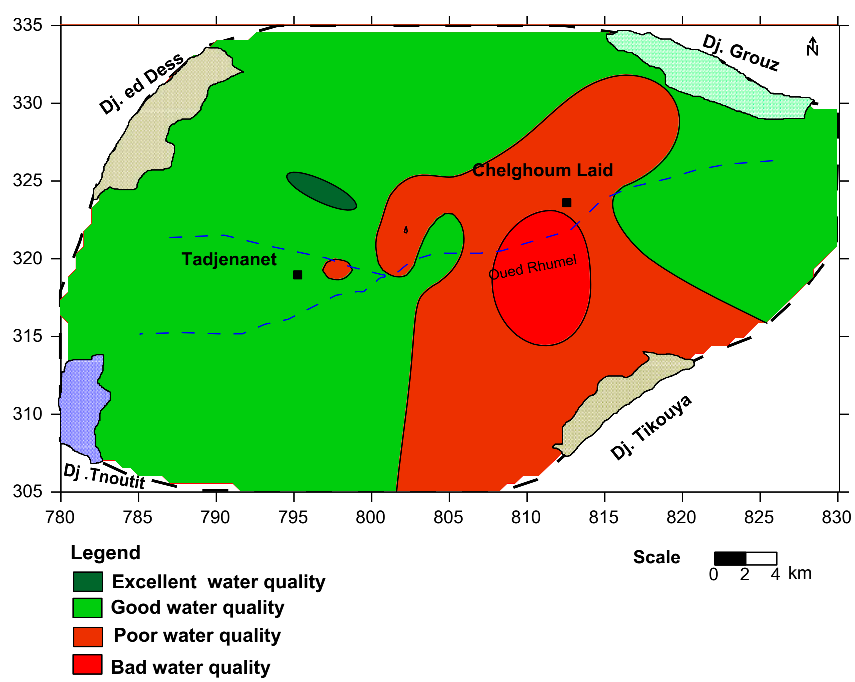

Fig. 11. Map of suitable irrigation water according to the method of Wilcox May 2007.

0.45, followed by that of the dolomite which ranges from −0.05 to 1, and finally the aragonite ranging from −0.70 to 0.31. If we assume that the steady state is in the range of −0.5 to +0.5, we can say that the three minerals are slightly under-saturated and close to equilibrium. The carbonate minerals tend to precipitate particularly in the form of calcite and dolomite (Fig. 9(a)). The evaporite minerals show degrees of saturation lower than the carbonate minerals for all analyzed samples (sub-saturated) (Fig. 9(b)). The gypsum receives indices that range from −2.02 to −0.41, followed by anhydrite whose index varies from −2.24 to −0.63 (83% of wells are under-saturated), and finally the halite whose indices vary from −6.98 to −6.00 (very under saturated), allowing these elements to be present in water at high concentrations. This simulation confirms the influence of evaporite rocks on the salinity of water and analyzed the importance of halite in chemistry.

3.4. *Classification of water based on the percentage of sodium absorbed by water (Method of Wilcox)*

Represention of the percentage of sodium as a function of conductivity on the Wilcox diagram [15] shows that 84.84% of water points have good to excellent quality for irrigation, 6% corresponds to poor quality, and 9% corresponds to bad quality (Fig. 10). We note that we have a progressive degradation of water quality by moving from west to east (Fig. 11).

4. Conclusion

The study of the chemistry of the alluvial aquifer of Tadjenanet–Chelghoum Laid allowed us to conclude that the hydrochemical behavior is characterized by a large variability in space. Mineralization increases gradually from west to east coinciding with the main direction of the groundwater flow. The waters are characterized by low salinity in the west near the mountains of Jebel ed Dess and Jebel Tnoutit, then they have the center and east, a relatively high mineralization near the city of Chelghoum Laid along Rhumel wadi. The spatial distribution of concentrations of chemical elements allowed for three main types of chemical facies, calcium sulfate, calcium chloride, and calcium bicarbonate facies with a small degree of the magnesium sulfate and magnesium chloride facies, where the waters have very high quantities of electrical conductivity field, which is explained by the acceleration of the phenomenon of dissolution of evaporite rocks and effect base exchange between the alkali and alkaline earth metals. Their distribution and lithology of aquifer recharge conditions. Calculating the saturation index of carbonate and evaporite minerals showed that former tend to rush before the latter, this has allowed chemical elements from the dissolution of gypsum to acquire significant levels. Concerning the suitability of these waters for irrigation, we find that the waters of the western zone of the study area can be used safely on the ground, with a risk of salinization in the center and east of the land of study, including water suitable for irrigation of salt-tolerant crops on well-drained soils.

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