

Application of Water Quality Index to Assess the Potability of the Phreatic Aquifer in Ouargla (Algeria)

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ABSTRACT

Groundwater is essential for sustainable development and drinking water supply in the Saharan regions. This work aims to assess the quality of water for domestic use and the hydrogeochemical characteristics of the phreatic aquifer of the Ouargla. Forty-two (42) wells capturing the phreatic aquifer are sampled and analyzed. The parameters analyzed are pH, EC, TDS, cations and anions. The water's potability was evaluated using the Water Quality Index (WQI) method, using the main physicochemical parameters that have potential adverse effects on human health. The results obtained show three classes: the poor class (14.29%), the very poor class (19.04%), and the non-potable class (66.67%). The analysis of the Piper and the Gibbs diagrams, the Pearson correlation matrix and the diagrams of relationship between the major elements, as well as the indices of saturation of the main minerals, shows that the groundwater samples were arranged into two groups; Ca-Mg-SO₄-Cl (38.5%) and Na-Cl (61.5%), the geochemical processes occurring in the aquifer mainly include the dissolution of halite, gypsum, the cation exchange between water and clay minerals and anthropogenic inputs.

Keywords: Ouargla, WQI, phreatic groundwater, mineralization, Gibbs.

INTRODUCTION

The people of the Ouargla basin have traditionally relied on the water table for drinking water and irrigation of palm trees. This aquifer is tapped by traditional wells, which provide enough water for a population of only a few thousand people. Nonetheless, the basin's water needs have increased due to the huge growth in population, necessitating a reliance on the basin's highly abundant deep water reserves, represented by the terminal complex aquifer and the intercalary continent aquifer. During the 1980s, significant flows have been drawn from the CT and CI aquifers, contributing to groundwater recharge and the region's sparse rainfall. Because there is no natural outlet, the piezometric level at the surface has risen throughout the years of deep aquifer mining. The rising phenomena has had major

environmental implications, such as oases degrading and groundwater quality changing (Boussaada et al., 2023; Satouh et al., 2021; Bouselsal et al., 2015). This phenomena has harmed most lower Saharan regions' water tables (Kharroubi et al., 2022) (the Ouargla basin, the valley of Oued Souf, and the valley of Oued Righ), resulting in major economic losses for the rehabilitation of degraded areas. The current study intends to examine the consumption quality of phreatic groundwater in the Ouargla basin as well as to present the mechanisms of salinization of the waters of this aquifer.

DESCRIPTION OF THE STUDY AREA

The Ouargla basin is located in northeastern Algeria (Fig. 1). It occupies the bottom of a basin

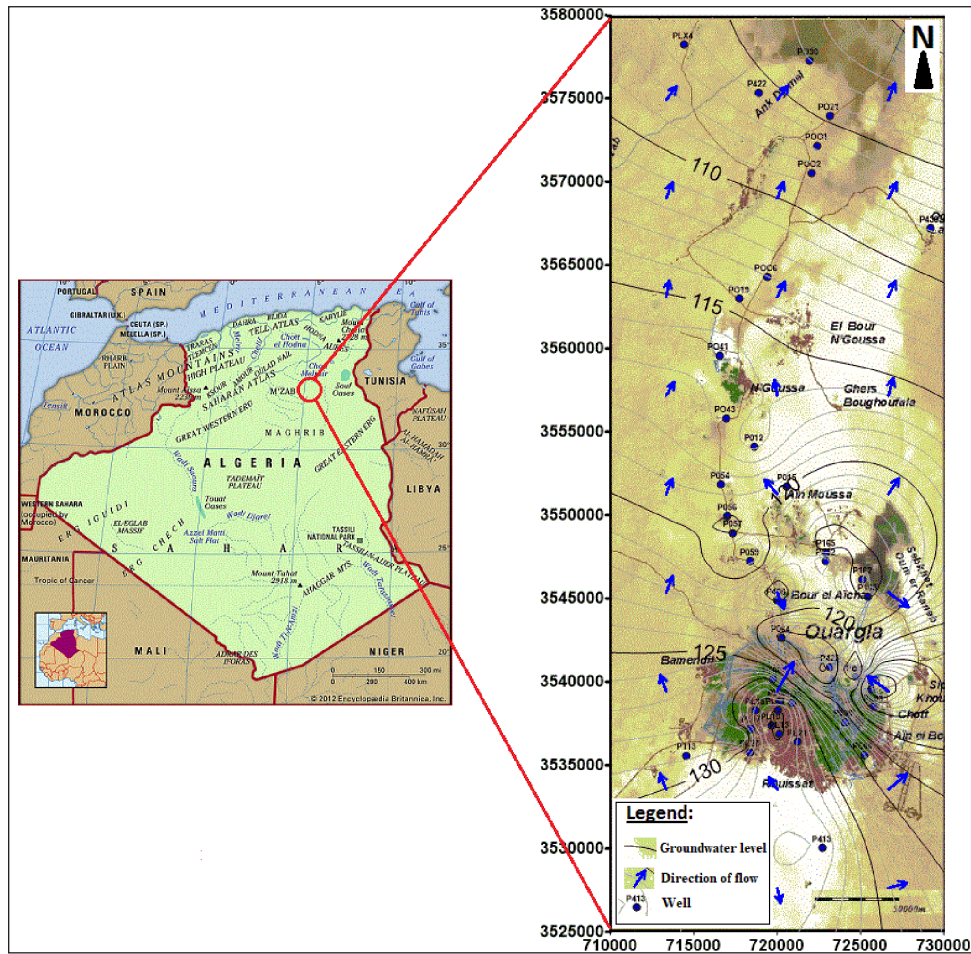


Figure 1. Positioning and piezometry of the phreatic aquifer in the study area

in the lower valley of the Mya wadi (Satouh et al., 2021; Hadj-kouider, 2019). It extends over an area of about 1100 km². This depression extends between the UTM coordinates: longitude 710000 E/730000 E and latitude 3530000N/360000N. The region's climate is hyper-arid; the annual precipitation does not exceed 70 mm, the average monthly temperature is about 24.74 °C, and the annual evaporation is about 2758.8 mm (NOM, 2020). The study area is a basin cut into the continental formations of red sands and soft sandstones with crisscrossing stratification, with calcareous nodules interspersed with calcareous or gypseous levels Mio-Pliocene age (Hamdi-Aïssa, 2001; Medjani et al., 2021).

The Ouargla basin is part of the sedimentary basin of the northern Sahara extending over approximately one million km², of which 60% is in Algeria (Zeddouri et al., 2010; Castany, 1982). This basin is a depression of SSW-NNE direction (Chellat, 2014; Busson, 1970; Cornet, 1964) filled with a sedimentary series of the Paleozoic and Mesozoic, with a thickness exceeding 5000 m.

In the study area, the interpretation of logs of water and oil drilling shows that the basement contains three aquifers (Boussaada et al., 2023; Kharroubi et al., 2022; ANRH, 2004; OSS, 2003; UNESCO, 1972) these are from top to bottom, phreatic aquifer, the aquifer of the terminal complex (CT), and the aquifer of the intercalary continental (CI). The phreatic aquifer is unconfined, Quaternary and Mio-Pliocene age, represented by sands, sandstones, and gravels with gypsum and tuff levels (calcareous concretion) in chotts and sebkhas (Satouh et al., 2021; Bouselsal et al., 2015). The piezometric map (Fig. 1) shows a general flow direction from south to north. The high point of the water table is south of Ruisset (136 m), and the lowest point is at Sebkhet Safioune (100 m). The hydraulic slope oscillates between 0.08% and 0.10%. The sources of recharge of the phreatic aquifer are the leaking urban wastewater and the irrigation water abstracted from confined aquifers of the Terminal Complex and the Continental Intercalary (Satouh et al., 2021).

MATERIAL AND METHODS

A groundwater sample campaign was carried out in 42 wells to gather phreatic groundwater from Ouargla. The GPS locations of the sampled water sites were validated on the field. After sampling, the physicochemical parameters (pH, temperature, and conductivity) were determined on-site using a portable multi-parameter. Water samples were collected in plastic bottles according to Rodier (1996) sampling methodology for laboratory examination. The data was statistically analyzed using the SPSS version 19.0 software. To create the statistical research, the Pearson correlation matrix, and to compare the numerous factors evaluated with potability norms. The saturation indices for the major evaporite minerals may be calculated using software such as PHREEQC (Sracek et al., 2004; Mukherjee et al., 2008; Parkhurst and Appelo, 1999). DIAGRAMMES software (Simler, 2014) was used to display the samples on Piper diagrams and determine the chemical facies. Water potability was measured by comparing it to Algerian drinking water standards (JORADP, 2011) (Table 1) as well as utilizing the water quality index (WQI) technique (Bouselsal and Saibi, 2022; Ouarekh et al., 2021).

RESULTS AND DISCUSSION

Chemical facies and salinity

We were able to determine the water types using hydro-chemical data from phreatic groundwater. These chemical data are shown on the Piper diagram (Piper, 1944) (Fig. 5). The graphic distinguishes four kinds of groundwater (Peiyue et al., 2019): (1) Ca-Mg-HCO₃, (2) Ca-Mg-SO₄-Cl, (3) Na-Cl, and (4) Na-HCO₃. According to the Piper diagram, the measured waters are classified as Ca-Mg-SO₄-Cl (38.5%) and Na-Cl (61.5%). This classification emphasizes the dominance of the evaporitic facies and the hydrogeochemical processes that regulate the high mineralization of phreatic aquifer of Ouargla, which varies from 2.3 g/l (P162) to 281.6 g/l (P059).

Assessment of the potability of water

The purpose of water potability evaluation is to educate the general public, government agencies, and decision-makers about the status of water resources and to determine the most advantageous action to safeguard human health. Water quality was assessed for potability using Algerian drinking water standards (JORADP, 2011) (Table 1). According to the results, the phreatic aquifer in

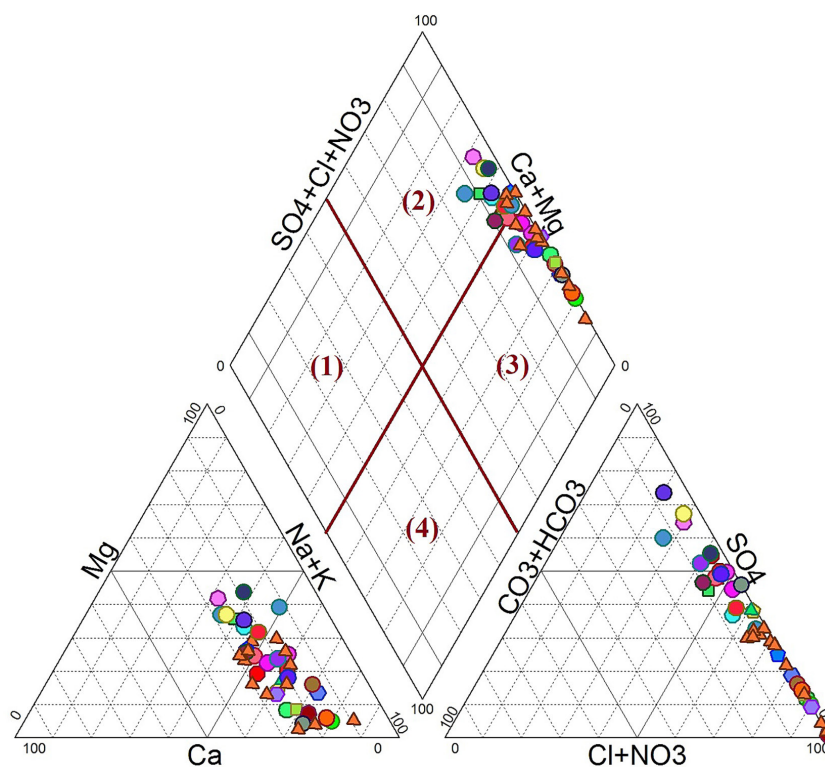


Figure 2. Piper diagram showing the chemical facies of Phreatic aquifer

Ouargla is not drinkable. Chemical ingredient concentrations do not satisfy Algerian norms. The groundwater under investigation is salty, and key element concentrations (Table 1) are typically greater than acceptable levels. The electrical conductivity ranges from 2790 $\mu\text{S}/\text{cm}$ (P059) to 169600 $\mu\text{S}/\text{cm}$ (P064), with a mean of 48380 $\mu\text{S}/\text{cm}$. These values are much higher than the Algerian norm for potability (2800 $\mu\text{S}/\text{cm}$).

The high calcium and magnesium contents in the water lead to an increase in overall hardness (TH). In the region investigated, the TH varies between 789 and 7953.6 mg/L CaCO_3 , in wells P422 and P12, respectively, suggesting extremely hard water (Freeze and Cherry, 1979). These findings greatly outperform the Algerian norm of 500 mg/L CaCO_3 . The nitrate levels in groundwater samples varied from 1 to 133 milligrams per liter, with an average of 28 milligrams per liter. Anthropogenic causes such as nitrogen-rich fertilizer application (Jamshidi et al., 2021) to plants and agricultural operations that result in nitrate leaching through permeable soil into groundwater in agricultural regions and human waste from septic tanks underneath urban areas contribute to the increased NO_3^- content (Lapworth et al., 2017; Foster et al., 2002).

Additionally, the groundwater quality index (GWQI) approach (Bouselsal and Saibi, 2022; Singh et al. 2021; Arachchige et al., 2021) has been applied to improve the water quality of the phreatic aquifer in Ouargla region. Since its debut in 1965 (Banda et al., 2020; Brown et al., 1970), several WQI indices have been discovered and defined by scientists (Galal Uddin et al., 2021). The approach is frequently utilized by numerous academics and environmentalists worldwide to characterize the level of water quality. This approach has the benefit of quantitatively combining a number of water quality factors into a single value (Kebili et al., 2021). What facilitates communication with the different water field operators. In this research, the Algerian potability requirements were employed to calculate the GWQI (Table 2). The GWQI computation is broken down into three phases, as shown in equation 1 (Touahri et al., 2022; Sadeghi et al., 2021). The first step is to give each of the eleven characteristics a weight (wp) depending on their value in terms of total drinking water quality. These parameters are shown in Table 2. The relative weight (Wp) of each parameter is derived in the second step by dividing the total of the weights

Table 1. Hydrochemical parameter variations and portability standards

Parameter	pH	CE	TDS	HCO_3^-	Cl^-	NO_3^-	SO_4^{2-}	Na^+	K^+	Mg^{2+}	Ca^{2+}
	-	($\mu\text{S}/\text{cm}$)	(mg/L)								
Median	7.9	48380	58707	237	27786	28	7870	14705	1386	1156	4201
Max	8.4	169600	281630	619	135000	133	87000	81500	10700	8600	20000
Min	6.9	2790	2364	52	335	01	688	313	19	95	160
SD	0.3	55884	79090	130	41656	32	14083	22754	2535	1449	5941
JORADP (2011)	6.5–8.5	1500–2800	1500	-	250–500	50	250–400	200	12	50–150	100–200

Table 2. Water Quality Index Parameter weights

Parameter	qi	S_c	Wp
pH	4	8.5	0.114
EC	4	1500	0.114
TDS	5	500	0.114
Ca	2	75	0.057
Mg	1	50	0.028
Na	2	200	0.057
K	2	12	0.057
Cl	3	250	0.085
HCO_3	3	300 (WHO 2017)	0.085
SO_4	4	250	0.114
NO_3	5	50	0.114
Total	35	-	1

(wp). In the third phase, the rating (qi) of each parameter is derived by dividing its concentration in the chemical parameter by the Algerian standard concentration. The resulting number is then multiplied by 100.

$$GWQI = \sum \left[\left(\frac{w_p}{\sum_{i=1}^n w_p} \right) * \left(\frac{C_i}{S_c} * 100 \right) \right] \quad (1)$$

where: C_i – concentration of each parameter;
 S_c – guide value fixed by the Algerian standard (Table 2);
 w_p – the weight of each parameter;
 q_i – quality notation ($q_i = C_i/S_c$);
 W_p – the relative weight, ($W_p = q_i/\sum q_i$).

Groundwater may be divided into five groups using the estimated GWQI indices (Touahri et al., 2022; Arfa et al., 2022; Sadeghi et al., 2021).

namely excellent (50), acceptable (50 and 100), bad (100 to 200), extremely poor (200 to 300), and unsuitable for drinking (>300). The WQI indices for 42 water samples from the Ouargla shallow aquifer varied from 116 to 12271, with an average of 2432. Three types of water quality were found (Fig. 3). Six (6) boreholes are in the poor category (PL31, PLX4, PL15, PL22, P54, and P59), eight (8) are in the extremely poor category (P416, PL32, PL10, PL13, P408, P56, P57, and P566), and twenty-eight (28) are in the non-drinkable category.

Mechanism of salt charge acquisition

To establish the mechanisms regulating the mineralization of Ouargla phreatic groundwater, the Gibbs diagram (Gibbs, 1970; Venkatramanan

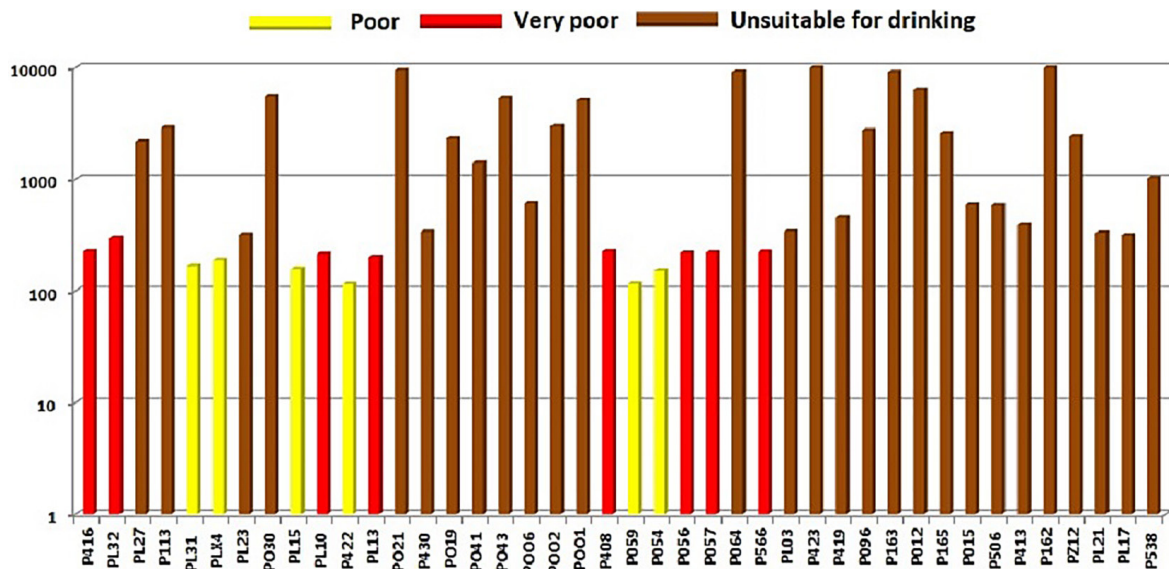


Figure 3. WQI variation in the Ouargla phreatic aquifer

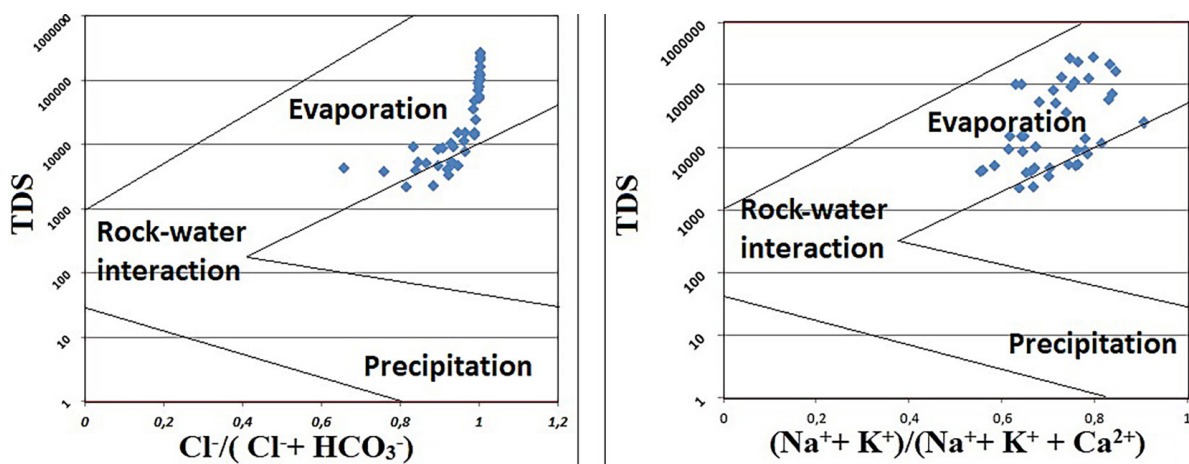


Figure 4. Gibbs diagram: (a) cations and (b) anions

Table 3. The Pearson correlation matrix of chemical parameters in groundwater

Variables	Mg ²⁺	Ca ²⁺	Na ⁺	K ⁺	Cl ⁻	SO ₄ ²⁻	HCO ₃ ⁻	NO ₃ ⁻	CE	TDS	pH
Mg ²⁺	1.00										
Ca ²⁺	0.72	1.00									
Na ⁺	0.56	0.93	1.00								
K ⁺	0.40	0.89	0.87	1.00							
Cl ⁻	0.69	0.95	0.95	0.82	1.00						
SO ₄ ²⁻	0.32	0.66	0.66	0.73	0.47	1.00					
HCO ₃ ⁻	-0.22	-0.35	-0.31	-0.33	-0.35	-0.14	1.00				
NO ₃ ⁻	-0.13	-0.31	-0.29	-0.30	-0.27	-0.25	-0.18	1.00			
CE	0.63	0.94	0.95	0.86	0.95	0.61	-0.31	-0.29	1.00		
TDS	0.54	0.95	0.94	0.94	0.93	0.65	-0.34	-0.30	0.97	1.00	
pH	-0.35	-0.78	-0.76	-0.78	-0.76	-0.50	0.35	0.07	-0.74	-0.81	1.00

et al., 2017) was developed. This graphic displays three realms to which different forms of water belong (Fig. 4). Water-rock interaction mechanisms have an impact on the first domain. The second region illustrates the evaporation-affected waterways. Precipitation-influenced water is the third domain. Evaporation dominates the waters of Ouargla phreatic groundwater, according to the projection of the studied water samples. Field data confirms the obtained conclusion, where the static level of the water table under the agglomerations (city of Ouargla) and agricultural lands is at minus 3 meters, encouraging water evaporation, especially in summer.

The Pearson correlation matrix of chemical parameters in groundwater of phreatic aquifer (Table 3) reveals the strong positive correlations between Ca²⁺ and SO₄²⁻, Na⁺ and Cl⁻, K⁺ and Cl⁻, Ca²⁺ and Cl⁻, K⁺ and SO₄²⁻, and Na⁺ and SO₄²⁻ all have strong positive correlations, according to the correlation matrix computation (Sivakumar et al., 2022). These linkages show how evaporation affects the chemistry of the waters. The ions Ca²⁺, SO₄²⁻, Na⁺, Cl⁻, and Mg²⁺ all have a positive relationship with TDS. This suggests that these ions aid in groundwater mineralization (Sail et al., 2019; Slimani et al., 2017; Nezli, 2009).

The connection between Na⁺ and Cl⁻ (Fig. 5a) is nicely aligned on the halite dissolution 1:1 line, demonstrating that groundwater is the consequence of halite dissolving (Bouselsal and Belksier., 2018). The Ca²⁺ and SO₄²⁻ association (Fig. 5b) reveals that sulfate and calcium develop in proportion. This connection shows the solubility of anhydrite and gypsum. The bulk of the locations, however, are below the gypsum dissolving line. The existence of SO₄²⁻ sources

other than anhydrite and gypsum causes this sulfate overload. The association between Na⁺ and SO₄²⁻ (Fig. 5c) reveals that thenardite (Na₂SO₄) dissolution causes a corresponding rise in sulfate and sodium (Kraiem et al., 2014; Garrett, 2001). The excess of sulfate over sodium, on the other hand, implies another source of sulfate, which has previously been mentioned (dissolution of anhydrite and gypsum). The association between Na⁺ and Ca²⁺ (Fig. 5d) distinguishes two groups of water locations. A group 1 in which the increase of Na⁺ and Ca²⁺ occurs simultaneously as a result of evaporite dissolution. The second group consists of places where we see a drop in Ca²⁺ but Na⁺ continues in evolution, which may be explained by cation exchange or precipitation of less soluble sulfates than halite. The graph SO₄²⁻ and Cl⁻ shows the link between these two components (Fig. 5e). The graph displays SO₄²⁻ proportionate with Cl⁻ signifying the common saliferous origin. Sulfates and chlorides are abundant in other regions. The lithological variety in the research region is reflected in this. The cation exchange between groundwater and the sandy-clay formations of the aquifer is calculated by evaluating the bivariate diagram in Figure 5f (Bouselsal and Zouari, 2022; Qichen et al., 2020) between [(Mg²⁺+Ca²⁺) - (SO₄²⁻ + HCO₃⁻)] and (Na⁺ +K⁺-Cl⁻). The graphic shows two groups of points: group (1) represents the lack of the cation exchange phenomena, and group (2) represents Ca²⁺ and Mg²⁺ enrichment relative to Na⁺ as a consequence of Na⁺ fixation and Ca²⁺ and Mg²⁺ release by the aquifer matrix. Consequently, the cation exchange phenomenon, when combined with the evaporite dissolving process, regulates the salinization of phreatic aquifer.

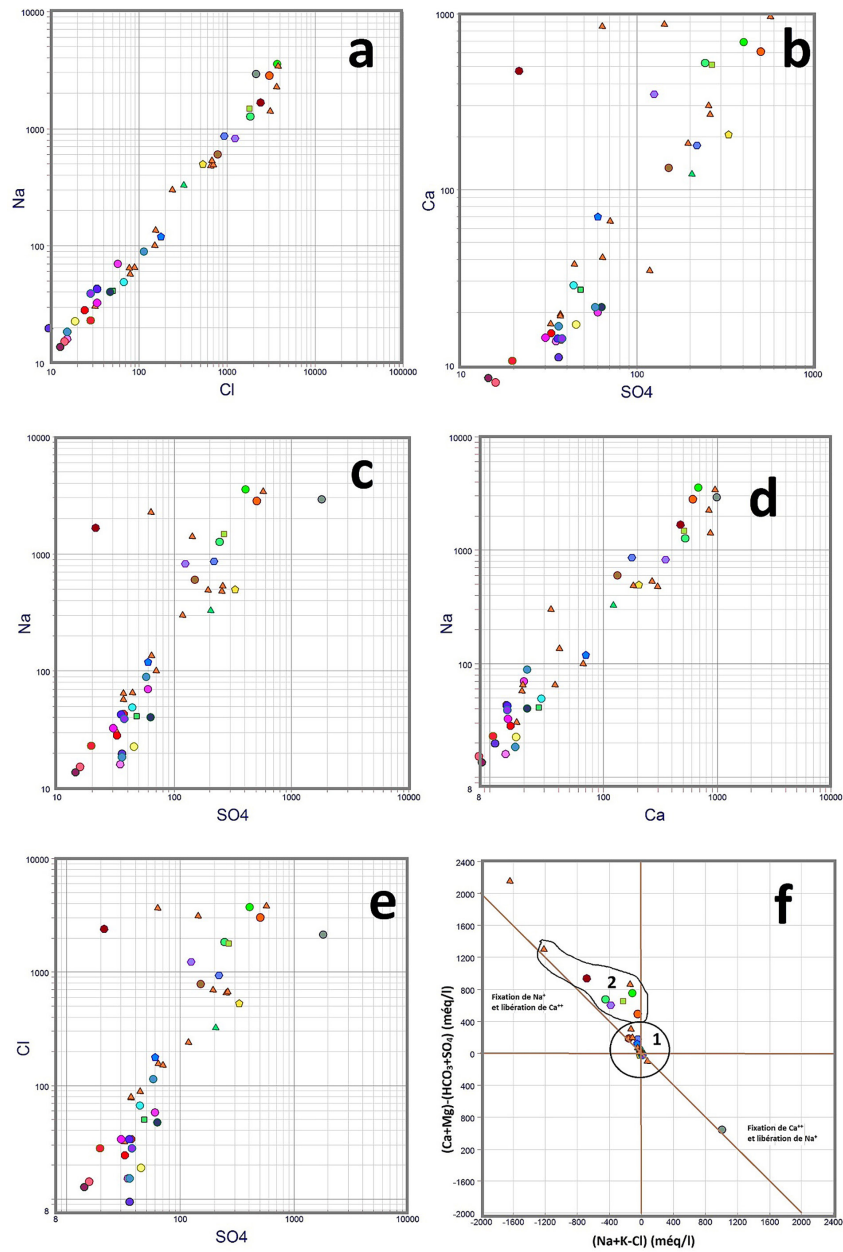


Figure 5. Binary diagrams between: (a) Na⁺/Cl⁻, (b) Ca²⁺/SO₄²⁻, (c) Na⁺/SO₄²⁻, (d) Na⁺/Ca²⁺, (e) SO₄²⁻/Cl⁻, (f) [(Mg²⁺+Ca²⁺) - (SO₄²⁻+HCO₃⁻)]/(Na⁺+K⁺-Cl)

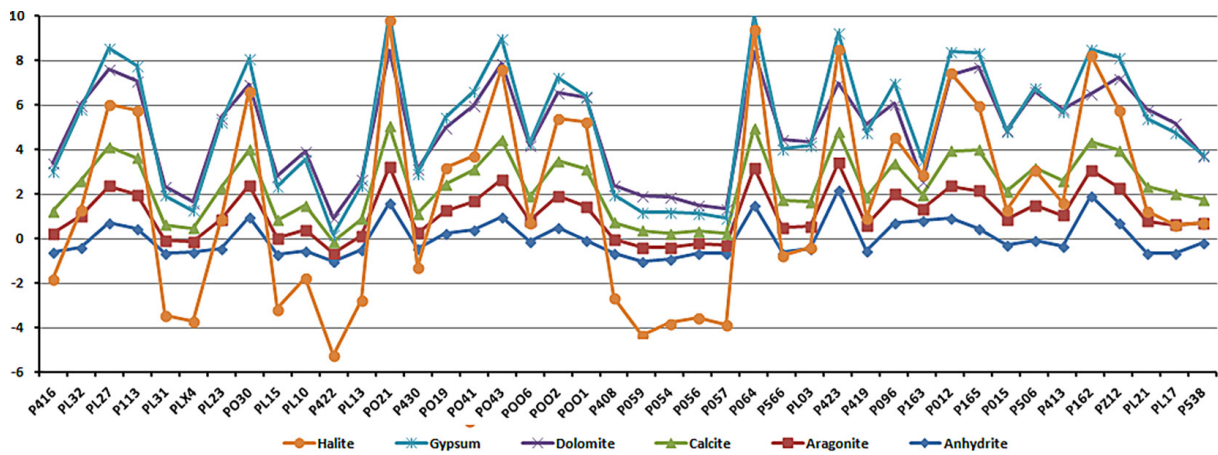


Figure 6. The primary mineral saturation indices

The saturation index findings obtained with the PHREEQC program (Appelo and Postma, 1994). are shown in Figure 6. Groundwater, on the other hand, is calcite, aragonite, and dolomite saturated. Sulfate minerals have a lower saturation level than carbonate minerals. Anhydrite's saturation index varies from +3.35 to +1.69. The saturation index of gypsum varies from -0.78 to +2.26 (45.23% of samples are saturated). Ultimately, halite's saturation index varies from -5.51 to -0.24. (so it is undersaturated).

CONCLUSION

The phreatic aquifer of Ouargla is composed of Quaternary sands, sandstones, and gravels. The water table flows south to north most of the time. The hydrogeochemical investigation finds that evaporitic facies (Ca-Mg-SO₄-Cl (38.5%) and Na-Cl (61.5%) predominate, with electrical conductivities of 2790 μS/cm (P059), 48380 μS/cm (P064), and 169600 μS/cm (P064), respectively. Salinity levels vary from 2.3 g/l (P162) to 281 g/l (P059). The groundwater analyzed is non-potable according to Algerian potability criteria. These groundwaters are saline and highly hard, with concentrations of most key elements above permissible values. The water quality index (WQI) approach finds that the WQI indices vary from 116 to 12271. Water quality was graded as bad (14.29%), extremely poor (19.04%), or non-potable (66.67%). The salinity of phreatic aquifer is connected to gypsum and halite dissolution, cation exchange, and pollution, according to a statistical and geochemical research.

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