

Geochemistry and Water Quality Assessment of Continental Intercalary Aquifer in Ouargla Region (Sahara, Algeria)

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ABSTRACT

Groundwater is vital for all living beings and the socio-economic development of arid regions. The present study evaluated the pertinence of groundwater of the continental intercalary (CI) aquifer in the Ouargla region for domestic and agricultural purposes. Sixteen (16) water samples were collected and analyzed for physical parameters, major cations and anions. The appreciation of groundwater potability was compared with the WHO (2017) standards. Agricultural water quality was evaluated using the Irrigation Water Quality Index (IWQI) method and the study of irrigation parameters: EC, SAR, SSP, PI, KR, PS and MAR. The results show that the CI waters are dominated by mixed Ca-Mg-Cl type (56.3%) and Ca-Cl type (43.7%). Natural rock-water interactions, including silicate weathering, evaporite dissolution and cation exchange, were the dominant processes controlling the mineralization of CI waters. According to WHO (2017), EC (100%), T (100%), TDS (100%), Na⁺ (87.5%), K⁺ (100%), Ca²⁺ (12.5%), Mg²⁺ (18.75%), SO₄²⁻ (100%), and TH (100%), samples exceed the permissible limit, indicating that most of the groundwater samples do not have good quality for drinking purposes. The calculated IWQI showed that 31.25% of the water samples were in the good category and 68.75% in the doubtful category.

Keywords: Ouargla, CI, WHO, potability, irrigation, mineralization.

INTRODUCTION

In the region of Ouargla, the lack of surface water resources and the severe climatic factors, namely, low precipitation, high temperatures and high evaporation, make the underground water reserves the main source for drinking water supply, as well as agricultural uses and industrial use. For a long time, the population of the Ouargla basin has been using the waters of the surface aquifer for drinking water supply, irrigation of palm groves, and market gardening (Fontaine, 1996). This aquifer is exploited by traditional wells, giving sufficient water for the population that does not exceed a few thousand inhabitants. However, the significant population growth has increased the water

needs in the region of Ouargla, which requires the use of very abundant deepwater reserves, represented by the complex terminal and continental intercalary aquifer (Nezli, 2009; OSS, 2003).

After the strong exploitation of the complex terminal (CT) aquifer in the last 30 years, signs of degradation of the CT aquifer are noticed, presenting themselves mainly in the low piezometric level and the increase of its salinity (Kharroubi et al., 2022; Bouselsal and Belksier, 2018). The flow rates of the boreholes are insufficient to meet the water demand, especially after the creation of new irrigation perimeters. The recent drillings are oriented towards exploiting continental intercalary aquifer (CI) to answer the strong demand for water for drinking water supply, agricultural use

and industrial use. The boreholes capturing the CI are very solicited because their very large flow exceeds 160 l/s, and the water pressure is about 15 bar. The objectives of the present study were (i) to determine the physico-chemical properties of the groundwater of Ouargla CI, (ii) to determine the mechanisms of mineralization of the CI water, (iii) to evaluate the quality of the CI water for human consumption and irrigation based on the study of chemical data collected from water boreholes capturing the CI aquifer.

STUDY AREA

Location, geomorphology and climate

The area investigated is localized in the Ouargla region, in the northeastern part of the northern Algerian Sahara (Fig. 1). It covers an area of 20,000 km², with a population reaching 297,000 in 2018. The geographical coordinates of the study area are 05°00'00"/5°45'00"E and 31°47'33"/32°30'00"N. Agriculture is the main activity in the region of Ouargla. A total of 8,000 farmers share 9,000 ha of irrigated land, of which 6,800 are dedicated to date palm groves that produce 30,000 tons per year. The study area presents the most important city of the Algerian Eastern

Sahara. It includes the most important industrial and commercial fabric in the region. These favorable conditions are the causes of the demographic development of the region of Ouargla.

The topography of the study area shows altitudes vary between 268 m and 42 m, with relatively low slopes oscillating between 0.6 ‰ and 1.8 ‰. The study area presents the following geomorphological forms (Hamdi-Aïssa, 2001; Medjani et al., 2021): (i) The hamada, which forms a rocky plateau at an altitude of about 200 m, of quaternary to Mio-Pliocene age, (ii) The existing alluvial stretches as fossil alluvial terrace (iii) The Sebkhass formed stretches of water bodies. They were Sebkhass Safionne, Sabkhet Oum Rneb and chott Ain Beidha and (iv) The glacis on the slopes constituted by sandstone formations of the Mio-Pliocene. The land use map in the region of Ouargla shows the following distribution: (i) the sands and bare soil, which covers 70% of the area studied, (ii) an agricultural area consisting of palm groves and cultivated areas, (iii) an area of open water occupied by chotts and sebkhass and (iv) urban areas include the city of Ouargla and chief towns of communes.

The climate of the region of Ouargla is of Saharan type, characterized by a hot, dry summer and a mild winter; the average monthly temperature is about 24.59 °C, the maximum temperature

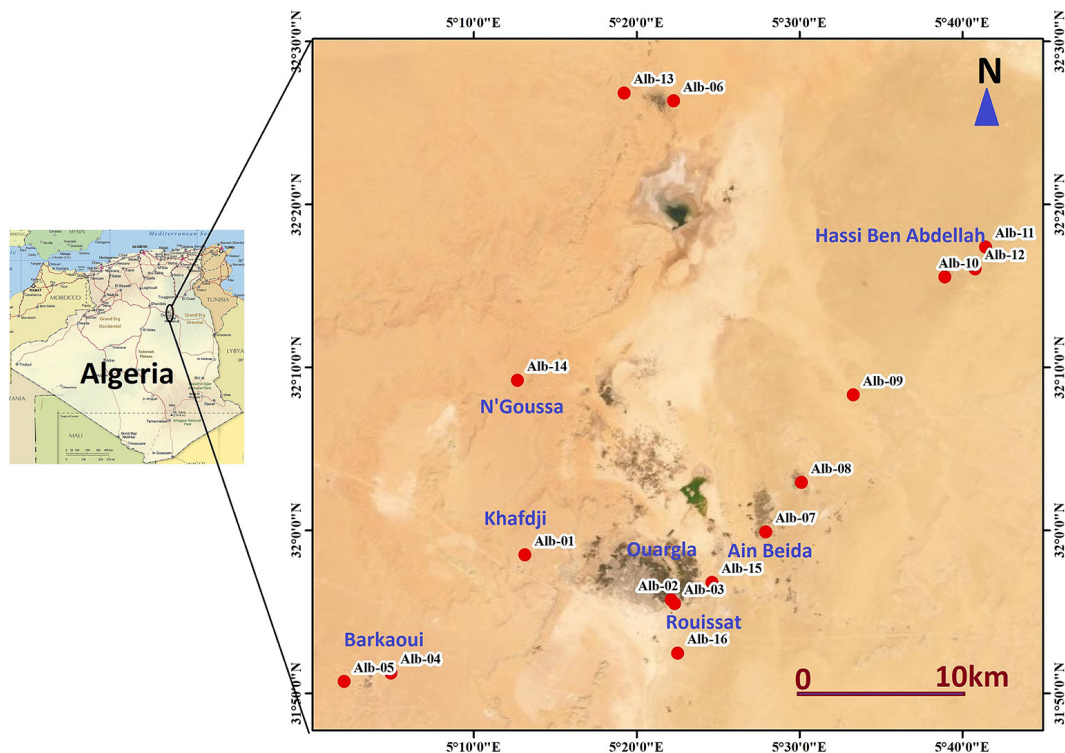


Figure 1. Map showing the location of the study area and position of boreholes sampled

is reached in July (37.9 °C), and its minimum is observed in January (12.3 °C). The interannual average rainfall is about 40.44 mm, November is the rainiest month (7.7 mm), and July is the driest (0.2 mm) (NOM, 2020). The water balance is deficient because of the low rainfall and high evapotranspiration, indicating that the surface aquifer's recharge from the effective precipitation is zero.

Geological and hydrogeological context

The Ouargla basin is part of the Saharan platform. It is located in the synclinal of the Saharan basin. The sedimentary series is several thousand meters thick (Fabre, 1976; Chellat, 2014; Kharroubi et al., 2022; Satouh et al., 2021). At the surface, only the quaternary and mio-Pliocene terrains outcrop. The description of the sedimentary formations was established by interpreting water and oil drilling logs (ANRH 2004). The lithostratigraphy is distinguished from top to bottom by the following geological formations (Fig. 2): (i) the Quaternary, consisting of eolian sands, sometimes gypsum and reworking products of the Mio-Pliocene terrains, (ii) the Mio-Pliocene, consisting of a powerful set of sands and clays that rest unconformably on the senonian, (iii) the Eocene consisting of limestone sometimes marly, it constitutes a lithological continuity with carbonated senonian. (iv) The Senonian is divided into two different lithological units. Namely, the carbonate Senonian at the top, constituted by limestone with dolomitic marl layers and the lagoonal Senonian at the base, constituted by an irregular alternation of anhydrite, dolomite, clay and salt banks, and by a more or less uniform composition

of the Senonian, (v) the Turonian is essentially limestone sometimes dolomitic, (vi) the Cenomanian consists at the top of an alternation of clay and dolomitic marl, sometimes salt clay, anhydrite and some dolomitic intercalations. At the base, it consists of dolomitic clay and marl, with occasional clays, (vii) the Vraconian formed by clays, dolomitic marls, dolomites and sometimes dolomitic and clayey limestones, (viii) sands, sandstones and clays represent the Albian. The roof of the Albian is found at a depth between 900 and 1200 m, its average thickness is about 450 m, (ix) the Aptian consisting of dolomites alternating with anhydrite, clays and lignites, its average thickness is 50 m, and (x) Barremian consisting of sands with intercalations of clay and sandstone dolomite, its average thickness is 100 m.

The Ouargla region belongs to the Northern Sahara Aquifer System (SASS), which is shared by three countries: Algeria, Tunisia and Libya. It covers an area of more than one million km², of which 70% is in Algeria (Edmund et al., 2003; OSS, 2003 Cornet, 1964). The SASS is the superposition of two main aquifers. They are the continental intercalary aquifer (CI), the deepest and the complex terminal aquifer (CT). The subsoil of Ouargla contains (Zeddouri et al., 2010; Bouselsal et al., 2015; Satouh et al., 2021; Kharroubi et al., 2022)(i) a superficial aquifer with a thickness ranging from 1 to 8 m, which occupies the entire floor of the valley of Ouargla. Sands, sandstones and gravels represent the lithology of the aquifer with the presence of gypsum and tuff levels (calcareous concretion) in the chotts and sebkhas. (ii) the complex terminal aquifer is constituted by two aquifer horizons, namely the mio-pliocene

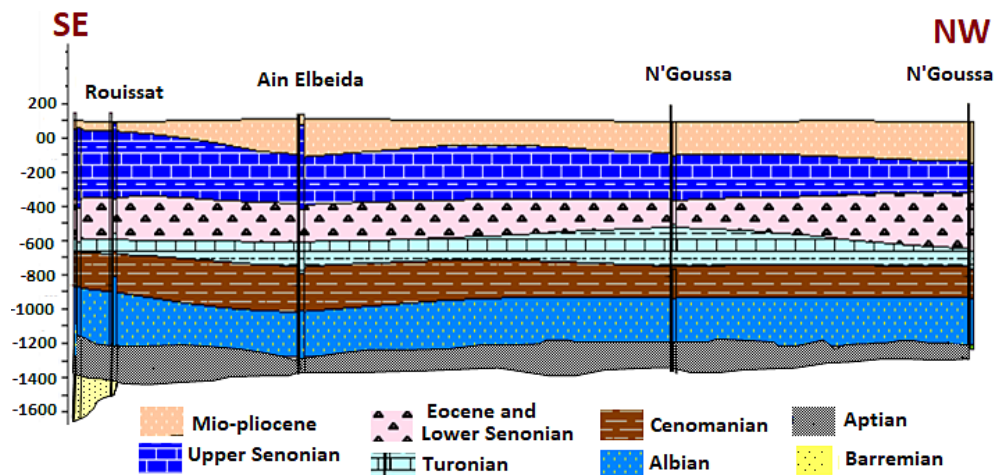


Figure 2. Geological sections in the study area

aquifer, by gravels and sands in a clay matrix, and the Senonian aquifer, constituted by limestone, the thickness of which varies from 50 to 250 meters. (iii) the continental Intercalary aquifer (CI), consisting of sandy and sandstone formations, with intercalations of clay and sandstone dolomite, of Albian and Barrimian age, with a total thickness of about 550 m, the top of the aquifer is between 850 and 1200m depth. The CI is artesian gushing, the pressure at the head of the drillings is about 15 bar (Touahri et al., 2022), and the water temperature is high (50 °C to 55 °C), influenced by the great depth of the aquifer (ANRH, 2004).

MATERIALS AND METHODS

The data from the intercalary continental boreholes were provided by the National Agency of Hydraulic Resources (ANRH) of Ouargla. Sixteen water boreholes among the 18 boreholes tapping the intercalary continental aquifer in the study area are examined in this study. The data are coordinates, flow rates, technical sections of the boreholes, hydrochemical data, physical parameters, major cations and anions. The XL-STAT software (2014) for Windows was used to interpret the hydrochemical data. The software diagram was used to determine the chemical facies of water, calculate the saturation index of the main minerals and realize bivariate diagrams, which determine the origin of mineralization of the waters of the intercalary continental aquifer.

The statistical analysis results were used to evaluate the potability of the groundwater regarding the drinking water standards of the World Health Organization (WHO, 2017). The assessment of water quality for agricultural use was done by applying the irrigation water quality index (IWQI). IWQI uses seven (7) irrigation parameters

to estimate the suitability of groundwater for agricultural use. These parameters are electrical conductivity (EC), sodium adsorption ratio (SAR), soluble sodium percentage (SSP), permeability index (PI), Kelly ratio (KR), Potential Salinity (PS) and Magnesium Adsorption Ratio (MAR).

RESULTS AND DISCUSSION

Water chemistry

Temperature is an important abiotic factor. It is necessary because it plays a role in the solubility of gases, the dissociation of dissolved salts and determining pH. It depends on the geological nature and the depth of the aquifer in relation to the surface of the Earth. The temperature increases gradually with a geothermal gradient of about 1 °C every 30 m. The interbedded continental aquifer in the study area extends to depths between 900 and 1600m (Fig. 3). The considerable depth of the CI aquifer leads to a strong increase in water temperature under the effect of a geothermal gradient (Nezli, 2009; Bouselsal et al., 2014). The water temperature varies between 50 and 55 °C, with an average of 52.68 °C. These values largely exceed the norm recommended by WHO (18 to 25 °C).

The electrical conductivity (EC) expresses the overall degree of mineralization of the groundwater and reflects the water's ionic charge. WHO recommends 1500 $\mu\text{S}/\text{Cm}$ as a limit value. The waters of the CI aquifer show electrical conductivity values ranging from 2165 to 3240 $\mu\text{S}/\text{Cm}$ with an average of 2684 $\mu\text{S}/\text{Cm}$ (Fig. 3). Thus, the values measured in the study area are not consistent with the standards set by the world health organization. In addition, measurements of the dry residue, which corresponds to the total dissolved salts (TDS) contained in the water after evaporation at

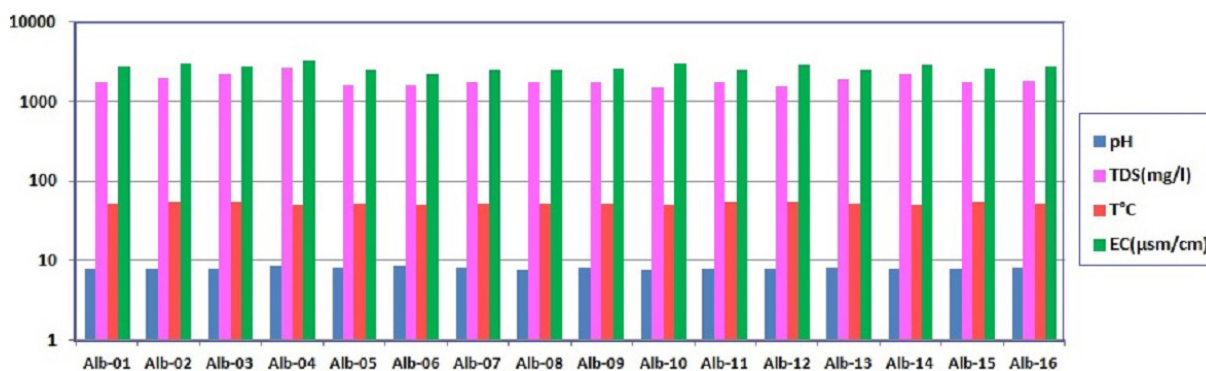


Figure 3. Variation of physicochemical parameters in the CI aquifer of Ouargla

110 °C, give values ranging from 1502 to 2658 mg/l, with an average of 1842 mg/l. These groundwaters are slightly saline (APHA, 2005).

The pH measures the concentration of the hydrogen ion in a given solution. It summarizes the stability of the equilibrium between the different forms of carbonic acid. In deep groundwater, pH is influenced by the buffer system developed by carbonates and bicarbonates, the geological nature of the aquifer and temperature. The pH values found in the study area are all alkaline. They vary from 7.6 (Alb-04) to 8.4 (Alb-06) (Fig. 3). These measured values are within the standard for potability (WHO, 2017).

Calcium (Ca^{2+}) is an alkaline earth element. It can come from gypsiferous formations ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and the dissolution of limestone (CaCO_3). Thus, the calcium concentration is directly related to the geological nature of the land through which the water flows. The CI aquifer's water contains between 83 mg/l to 207 mg/l of calcium (Fig. 4). It does not exceed the WHO drinking water standard (200 mg/l), except at boreholes Alb-10 and Alb-11. The presence of magnesium (Mg^{2+}) in groundwater is related to the dissolution of dolomite and limestone. Magnesium is a good indicator of the extended residence time in the aquifer. Mg content⁺² ranges from 73 mg/l to 240 mg/l, with an average of 124.67 mg/l. It should be noted that the magnesium values in the water are within the WHO standard for drinking water (150 mg/l) except in boreholes Alb-1, Alb-4 and Alb-12.

Sodium (Na^+) is very abundant on Earth. It is found in crystalline and sedimentary rocks (sands, clays, and evaporites). It can also come from the exchange of cations with clay minerals in the aquifer. The Na^+ ion further enriches the water due to the high solvent power of evaporites, such as Halite (NaCl). According to the analytical

results (Fig. 4), the sodium content in the studied aquifer varies between 175 mg/l and 320 mg/l with an average of 242 mg/l. 87.5% of the analyzed samples exceed the WHO recommended standard (200 mg/l). Potassium (K^+) is a chemical element, and its reaction with water is much stronger than that of sodium. The origin of K^+ in the CI aquifer results from the alteration of silicates such as feldspar or the dissolution of evaporites such as sylvite. Potassium plays a key role in muscle contraction, the heart, and the transmission of nerve impulses. The investigated area's (Fig. 4) range between 18 and 54 mg/l. They thus exceed the WHO standard for potassium. They thus exceed the WHO standard for drinking water (12 mg/l).

The chloride ion (Cl^-) always exists at highly variable concentrations in natural waters. It is a conservative tracer in natural environments because it does not participate in redox reactions and does not form insoluble precipitates. Its probable origin in the studied aquifer is mainly related to the dissolution of salt formations (NaCl and KCl). Chlorides give an unpleasant taste and pose the problem of corrosion in pipes and tanks from 50 mg/l. According to the WHO standard for drinking water, the chloride value should not exceed 600 mg/l. The concentrations recorded in the study area (Fig. 5) vary between 375 mg/l and 565 mg/l, with an average of 439.78 mg/l. Thus, all measured values are within the standard recommended by WHO (2017).

Sulfates (SO_4^{2-}) are naturally present in water. They are bound to major cations (calcium, magnesium and sodium). Calcium sulfate is the most common form found in groundwater, and the highest concentrations in the CI aquifer are naturally occurring. The variation of sulfates comes from the dissolution of evaporite salts (gypsum, anhydrite) and the oxidation of sulfides (pyrite)

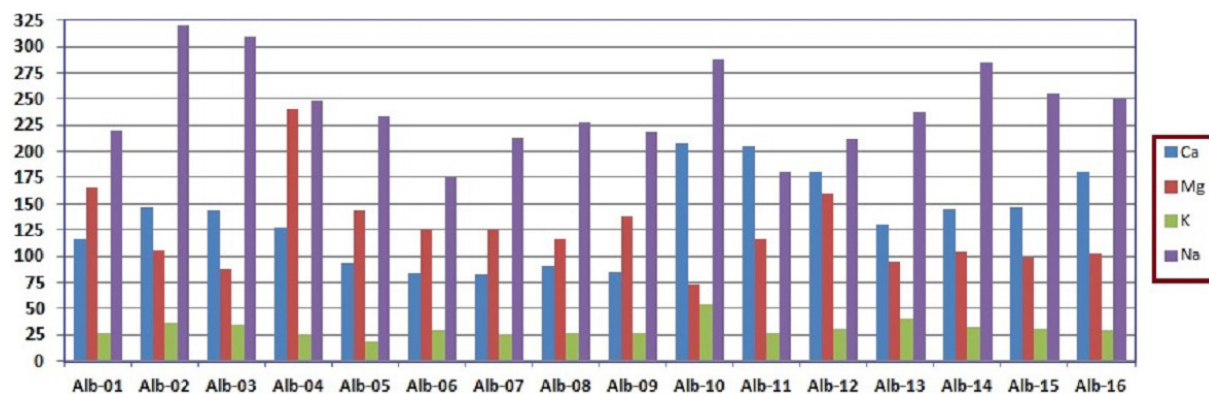


Figure 4. Variation of cation in CI aquifer of Ouargla

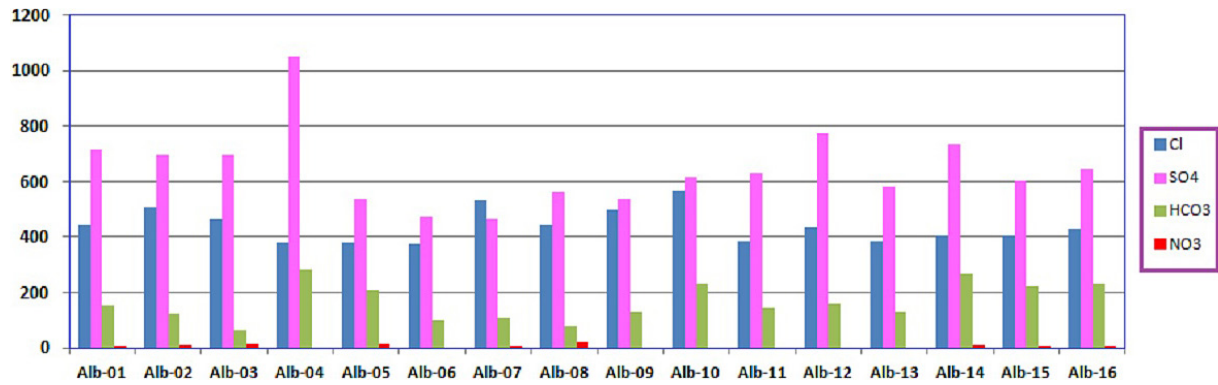


Figure 5. Variation of anion in CI aquifer of Ouargla

of sedimentary rocks. WHO sets the value 400 mg/l as the maximum admissible limit for drinking water. The sulfate values found in the study area (Fig. 5) vary from 463 mg/l to 1050 mg/l, averaging 644.37 mg/l. All recorded sulfate levels are above the WHO (2017) standard.

Most of the bicarbonate (HCO_3^-) content of natural waters comes from dissolved carbon dioxide (CO_2) in water. They also come from the dissolution of calcium or magnesium carbonates in the presence of carbon dioxide in water. The WHO recommended maximum bicarbonate concentration in drinking water is 600 mg/l (WHO, 2017). According to this study, the maximum value measured in the CI aquifer is about 281 mg/l. Therefore,

according to the results, this parameter is within the drinking water standard. Nitrates (NO_3^-) are the main forms of nitrogen in the water. It is in low concentration in captive aquifers, protected from surface pollution, as in the case of the CI aquifer. According to the analyses carried out on the waters of CI of Ouargla. The measured values oscillate between 0 and 15.3 mg/l (Fig. 4). This chemical parameter is within the potability standard.

Chemical facies

The Piper diagram is useful for understanding groundwater chemistry and its evolutionary processes. It allows determining the chemical facies

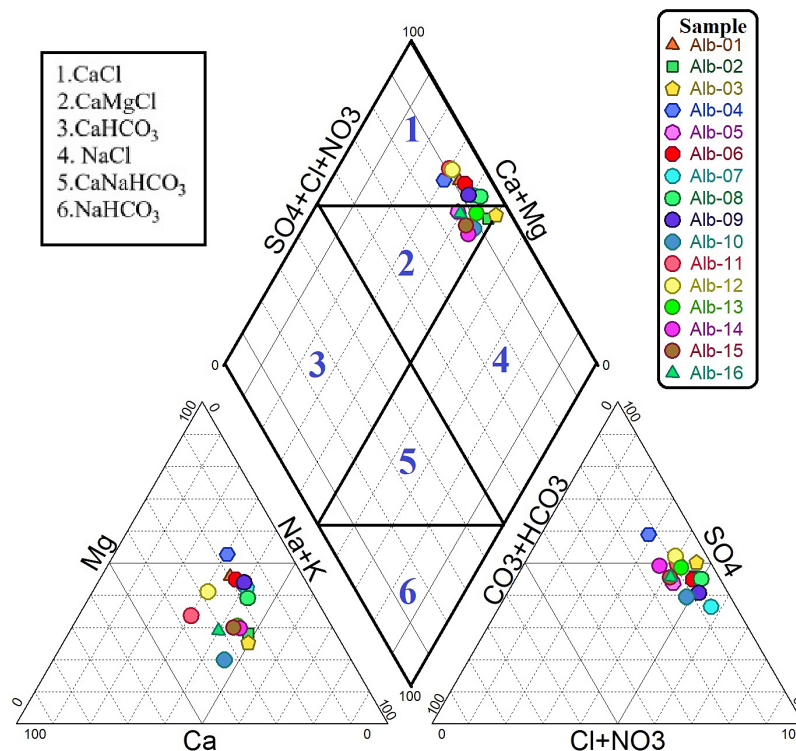


Figure 6. Piper diagram showing CI water types

of water (Piper, 1944). The diagram consists of a diamond-shaped field in the center and two triangular fields on both sides. The cations and anions are expressed as a percentage of the total cations (Ca, Mg and Na+K) and anions (Cl, SO₄ and HCO₃+CO₃) in meq/l. The cations are represented on the left triangle, while on the right triangle, the anions are represented. The points presented on the triangles are then projected into the central diamond-shaped field, which determines the facies of the water. From Figure 6, all samples show strong acids exceeding weak acids and alkaline earth metals (Ca+Mg) exceeding alkaline cations (Na+K). It can also be seen that the continental intercalary of mixed Ca-Mg-Cl type (56.3%) and Ca-Cl type (43.7%).

Origin of water mineralization

The main hydrogeochemical processes that control water mineralization in deep confined aquifers are ion exchange reactions between water and rock matrix, dissolution of dissolved salts, acid-base reactions and cation exchange phenomena. Bivariate diagrams are frequently employed to determine the source of groundwater geochemistry. The plots were constructed using groundwater concentration in milli-equivalents per liter (meq/l).

The Na-normalized Ca versus Mg and Na-normalized Ca versus HCO₃ scatterplots, proposed by Gaillardet et al. (in 1999) are effective and widely applied tools to determine the rocks contributing to groundwater mineralization. The diagrams show that the origin of chemical ions comes from

three types of rocks: evaporite dissolution, silicate alteration and carbonate rock alteration. As shown in Figure 7, most samples are located in the silicate weathering area and away from the evaporite dissolution field. Thus dissolution, precipitation, and cation exchange processes were actively occurring in the CI groundwater system.

Weathering of evaporites

The diagram of a variation of Na⁺ versus Cl⁻ shows that several points of water are aligned on the straight line of slope 1 (Fig. 8a). It testifies to the presence of a common source of sodium and chlorine due essentially to the dissolution of the halite (Bouselsal and Saibi, 2022; Kharroubi et al., 2022). However, other points show an excess of chlorine due to cation exchange and dissolution of other salts rich in Cl⁻. This result is confirmed by the calculation of saturation indices that show a state of undersaturation with respect to the mineral of halite (Fig. 9). The diagram of Ca²⁺ versus SO₄²⁻ shows an excess of sulfate over calcium (Fig. 8b). Calcium deficiency relative to sulfate characterizes the totality of the water points analyzed. In contrast, the most likely origin of sulfate in CI waters is the dissolution of gypsum in the CI reservoir rock. It is, therefore, possible that the dissolution of gypsum provides Ca²⁺ ions consumed by the precipitation of calcite or the fixation of calcium by clays (reverse cation exchange).

Alteration of silicates

The weathering of silicates plays a fundamental role in the mineralization of groundwater. However, the determination of silicate

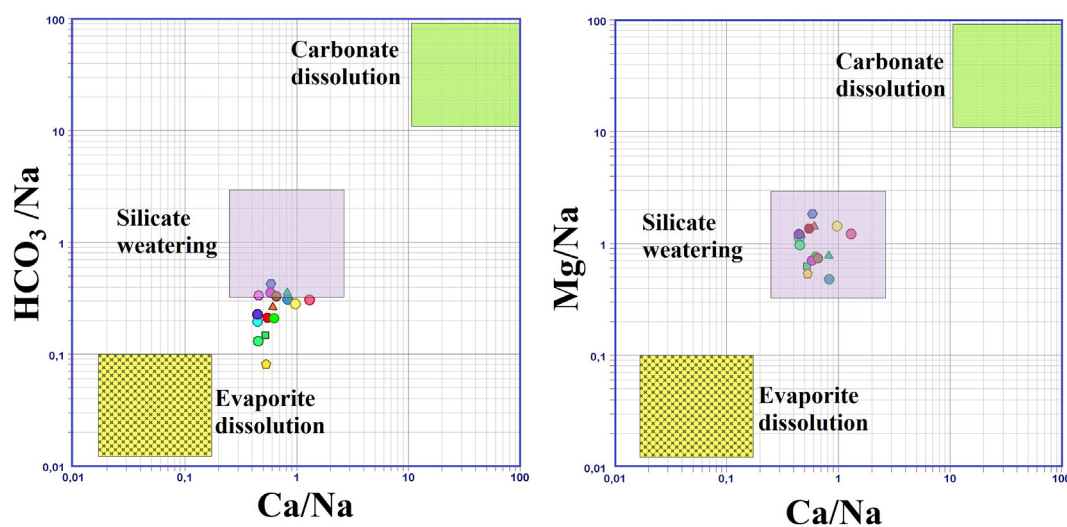


Figure 7. Bivariate plot Ca/Na vs HCO₃/Na and Ca/Na vs Mg/Na

weathering products is always very delicate because the weathering of silicates generates many solid species (Das and Kaur, 2001). The weathering process of silicates is commonly determined by studying the ratio of Na+K to total cations. All samples projected on the graph from Na+K to total cations lie above the 1:2 line, indicating weak silicate (alkali feldspar) weathering (Fig. 8c).

In the plot of Ca+Mg versus total cations (Fig. 8d), CI groundwater samples lie along the 1:0.6 equiline, indicating that silicate weathering at the same time as the dissolution of carbonate rocks (Roy et al., 2023; Kozłowski and Komisarek, 2017). The water samples below the 1:0.6 line indicate calcium and magnesium in CI waters originate from dissolved Ca- and Mg-rich rocks and minerals (limestone and gypsum), as previously indicated.

Cation exchange

The bivariate cation-anion plots of $Ca^{2+} + Mg^{2+}$ versus $HCO_3^- + SO_4^{2-}$ indicate the dominance of normal or reverse cation exchange along a 1:1 mixing line (Fig. 8e). Accordingly, the dominance of the reverse cation exchange phenomenon over the normal cation exchange is visible in the diagram, which shows the same trend in Fig. 8f. It can be seen that 62.5% of the samples are above the 1:1 straight line, indicating excess Ca^{2+} and Mg^{2+} . The remaining groundwater samples are positioned below the 1:1 line, indicating an excess of HCO_3^- and SO_4^{2-} by adding Ca^{2+} and Mg^{2+} . The excess of Ca, Mg, HCO_3^- and SO_4^{2-} could be derived from a common source of silicate alteration but also the dissolution of sulfates and carbonates existing in the intercalated continental reservoir.

The chloro-alkaline indices (CAI-1 and CAI-2), suggested by Schoeller (1965), supply comprehensive knowledge of cation exchange between groundwater and aquifer materials that majorly impact water geochemistry and assessment. The chloro-alkaline indices are calculated from the following (Roy et al., 2023):

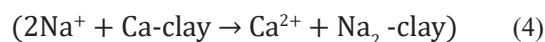
$$CAI - 1 = \frac{Cl^- + (Na^+ + K^+)}{Cl^-} \quad (1)$$

$$CAI - 2 = \frac{Cl^- + (Na^+ + K^+)}{HCO_3^- + SO_4^{2-} + CO_3^{2-} + NO_3^-} \quad (2)$$

where all concentrations are expressed in meq/l.

The CAI shows that the groundwater's calcium and magnesium negatively exchanged for

the reservoir rock's sodium and potassium. This process is called reverse cation exchange (Eq. 3). When CAI has a positive value, Na^+ and K^+ from the groundwater are replaced by calcium and magnesium from the aquifer. This is the normal ion exchange process (Eq. 4):



In a geochemical system, when CAI-1 and CAI-2 are negative, there is an exchange between calcium and/or magnesium in the water with sodium or potassium in the aquifer material. Conversely, when CAI-1 and CAI-2 are positive, there is an exchange between sodium and/or potassium in the water with calcium and/or magnesium in the aquifer material. The values of chloro-alkaline indices (CAI-1 and CAI-2) for the continental intercalary groundwater samples (Fig. 8f) show positive (62.5%) and sometimes negative (37.5%) values. These results highlight that 62.5% of the water samples exchange Na^+ and K^+ ions with Ca^{2+} and Mg^{2+} ions from the rock. In contrast, 37.5% of the water samples exchange calcium and magnesium ions with sodium and potassium ions of the rock.

Water saturation

PHREEQC software was used to calculate saturation indices (SI) with respect to evaporite and carbonate minerals as well as to explore mineral dissolution and precipitation patterns (Etteieb et al., 2015; Parkhurst and Appelo, 2005). The SI scatter plot shows that all water samples have positive SI values for carbonate minerals (calcite, aragonite, and dolomite), indicating supersaturation with carbonate minerals (Fig. 9). The negative SI values for gypsum, anhydrite, and halite indicate that the groundwater is undersaturated with these minerals (Fig. 9). More importantly, the SI values of gypsum, anhydrite, and halite are positively correlated with TDS values, indicating that dissolution of gypsum and halite is primarily responsible for the increase in TDS.

Assessment for drinking water

The suitability of CI water for human consumption was compared with the guide values of the World Health Organization (WHO, 2017). Researchers widely use this method of assessing water quality to define the suitability of water for

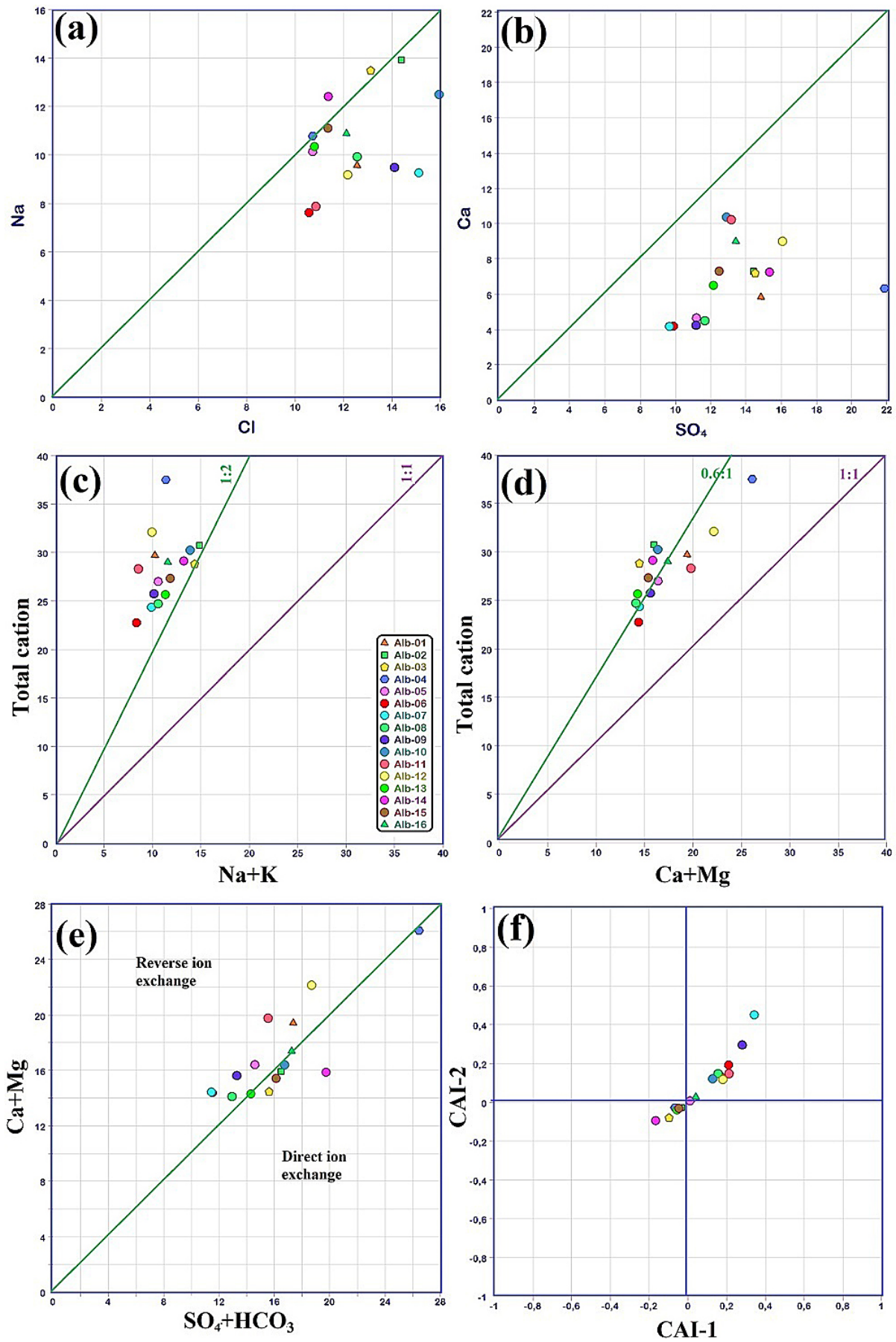


Figure 8. Plots indicating various mineralization processes in the study area: (a) Na vs. Cl ; (b) Ca vs. SO₄ ; (c) Total cation vs. Na +K (d) Total cation vs. Ca+Mg; (e) Ca+Mg vs. SO₄ +HCO₃ ; (d) CAI-1 vs. CAI-2

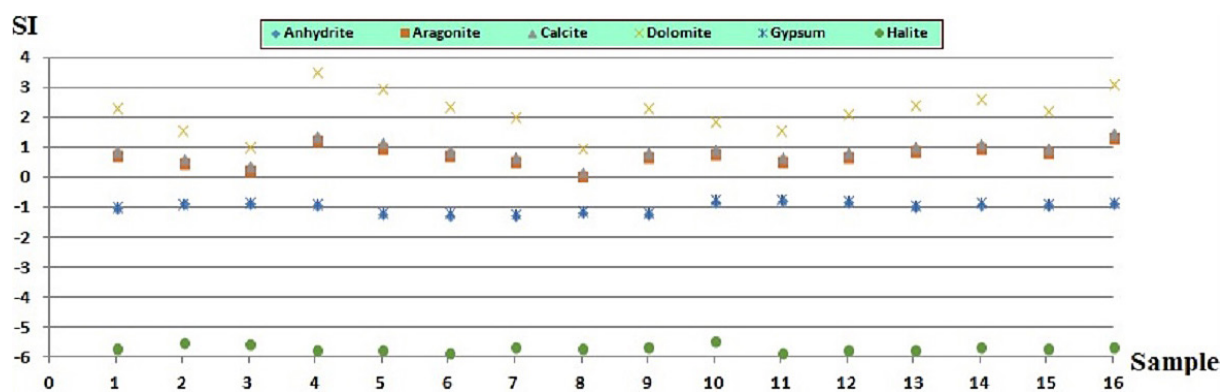


Figure 9. Variation of saturation indices in CI aquifer of Ouargla

human consumption. It also helps to determine the parameters targeted in the water treatment process before their distribution (Adimalla et al., 2020; Ismail et al., 2019; Rizwan et al., 2018). The minimum, maximum, mean and standard deviation statistical parameters allow understanding the various physicochemical parameters of water, such as pH, EC, T, TH, TDS and major ions (Table 1). The number and percentage of water samples that exceed the standards of potability given by the world health organization (WHO, 2017) is also indicated in Table 1.

TH is important in determining water quality for human consumption and domestic use. The TH values calculated in the studied aquifer vary between 713 and 1318 mg/l of CaCO₃. With reference to the classification established by Sawyer and McMcarty (1967), the groundwater of the continental intercalary of Ouargla is categorized as very hard. The TH values measured exceed the

potability standards (500 mg/l of CaCO₃). The parameters of EC, TDS and T indicate that the CI waters are mainly unsuitable for consumption, as the measured values exceed the permissible limits of the World Health Organization (WHO 2017) (Table 1). A similar trend was also observed for sulfate. In addition, Table 1 suggests that 87.5%, 18.75% and 12.5% of the boreholes exceeded the potability standards (WHO, 2017) for sodium, magnesium and calcium, respectively. These observations suggest that CI water is not potable without proper treatment.

Assessment for irrigation use

The suitability of water for agricultural use depends on the types and concentrations of ions dissolved in the water. Salty water reduces water uptake, negatively impacting crop growth and agricultural production. The Irrigation Water

Table 1. Suitability of groundwater for drinking purposes

Parameters	Unites	Min	Mean	Max	Standard deviation	WHO Standards 2017		Potability	
						Desirable limit (DL)	Permissible limit (PL)	No. of simple exceeded PL	% of simple exceeded PL
Ca	mg/l	83	135.18	207.5	42.14	75	200	02	12.5
Mg	mg/l	73	124.67	240	39.72	50	150	03	18.75
Na	mg/l	175	242	320	41.84	-	200	14	87.5
K	mg/l	18	30.63	54	8.17	-	12	16	100
Cl	mg/l	375	439.78	565	60.21	200	600	00	00
SO ₄	mg/l	463	644.72	1050	140.80	200	400	16	100
HCO ₃	mg/l	67	165.42	281	67.31	300	600	00	00
NO ₃	mg/l	0	7.45	42	11.64	-	45	00	00
pH	-	7.66	8.02	8.4	0.25	-	6.5 to 8.5	00	00
TDS	mg/l	1502	1842.37	2658	299.09	500	1500	16	100
T	°C	50	52.68	55	1.66	18	25	16	100
EC	µsm/cm	2165	2684.37	3240	270.55	500	1500	16	100
TH	mg/l (CaCO ₃)	713	857	1318	168	100	500	16	100

Quality Index (IWQI) method (Salah Hassanién, 2018) provided a comprehensive picture of CI water quality for irrigation. To calculate the IWQI in the present study, 7 parameters were considered. They are electrical conductivity (EC), sodium adsorption ratio (SAR), soluble sodium percentage (SSP), permeability index (PI), Kelly ratio (KR), Potential Salinity (PS) and Magnesium Adsorption Ratio (MAR). The equations from 5 to 10 calculate these parameters (Singh et al., 2021; Kebili et al., 2021; Ouarekh et al., 2021; Arfa et al., 2022; Bahir et al., 2022):

$$\text{Sodium adsorption ratio} = \frac{\text{Na}}{\sqrt{\frac{\text{Ca} + \text{Mg}}{2}}} \quad (5)$$

$$\begin{aligned} \text{Percentage of sodium soluble} &= \\ &= \frac{\text{Na}^+ + \text{K}^+}{\text{Ca}^{+2} + \text{Mg}^{+2} + \text{Na}^+ + \text{K}^+} \times 100 \end{aligned} \quad (6)$$

$$\text{Kelly ratio} = \frac{\text{Na}^+}{\text{Ca}^{+2} + \text{Mg}^{+2}} \quad (7)$$

$$\begin{aligned} \text{Permeability index} &= \\ &= \frac{\text{Na} + \text{K} + \sqrt{\text{HCO}_3}}{\text{Ca} + \text{Mg} + \text{Na} + \text{K}} \times 100 \end{aligned} \quad (8)$$

$$\text{Potential Salinity} = \text{Cl}^- + \frac{1}{2}\text{SO}_4 \quad (9)$$

$$\begin{aligned} \text{Magnesium Adsorption Ratio} &= \\ &= \frac{\text{Mg}}{\text{Ca} + \text{Mg}} \times 100 \end{aligned} \quad (10)$$

The irrigation water quality index (IWQI) is calculated by applying the following Eq. 11:

$$IWQI = \sum \left[\left(\frac{w_i}{\sum_{i=1}^n w_i} \right) * (Qi * 100) \right] \quad (11)$$

where: W_i – the relative weight (Table 2);
 w_i – the weight of each parameter;
 n – the number of parameters;
 Qi – the quality rating of the individual parameter given by the relation

$Qi = (Ci/Si) \times 100$, Ci – the concentration of the individual parameter measured in the field (EC) and calculated by Eq.s 5 to 10, and Si is the standard value for the irrigation parameter (Table 2).

The irrigation water quality index classifies water into 5 categories, namely, excellent (<50), good (50 to 100), doubtful (100 to 200), permissible (200 to 300) and unsuitable (>300).

The electrical conductivity (EC) of water signifies its salinity potential. This factor is considered important in evaluating water for agriculture since high electrical conductivity leads to the creation of saline soil. The EC in the studied area oscillates between 2165 and 3240 $\mu\text{S}/\text{cm}$, with an average of 2684 $\mu\text{S}/\text{cm}$. Regarding the classification established by Wilcox (1948) in Table 3, all the CI samples analyzed are unsuitable for irrigation, except for sample Alb-06.

Richards (1954) was the first to use SAR to estimate the tendency for sodium adsorption by soil. High SAR values indicate a high potential for accumulation of sodium ions in the soil over time, which reduces water infiltration into the soil due to soil dispersion. The SAR values found in the study area range from 2.78 to 5.98. Therefore, CI groundwater is classified as excellent for irrigation. The EC and SAR data are plotted on the Richards (1954) diagram, in which electrical conductivity is used for salinity hazard, and the sodium adsorption ratio is used to determine alkalinity hazard. The Richards diagram (Fig.10) reveals that the CI waters fall into the C_4S_1 and C_4S_2 classes, indicating high salinity water and low to medium sodium risk.

The soluble sodium percentage (SSP) is also used to evaluate irrigation water quality as an important factor in studying the sodium risk. SSP is the ratio of monovalent cations to total cations multiplied by 100 (Eq. 5). A high percentage of Na^+ can decrease soil permeability and inhibit plant growth. This is an important factor when considering sodium risks. Sodium has the potential to react with the soil, reducing its permeability and supporting little or no plant growth.

Table 2. Parameters needed to calculate IWQI

Parameters	EC	SAR	SSP	KR	PI	PS	MAR
Weight	4	5	5	3	3	3	2
W_i	0.16	0.2	0.2	0.12	0.12	0.12	0.08
Standard S_i	2250	18	40	2	85	10	50

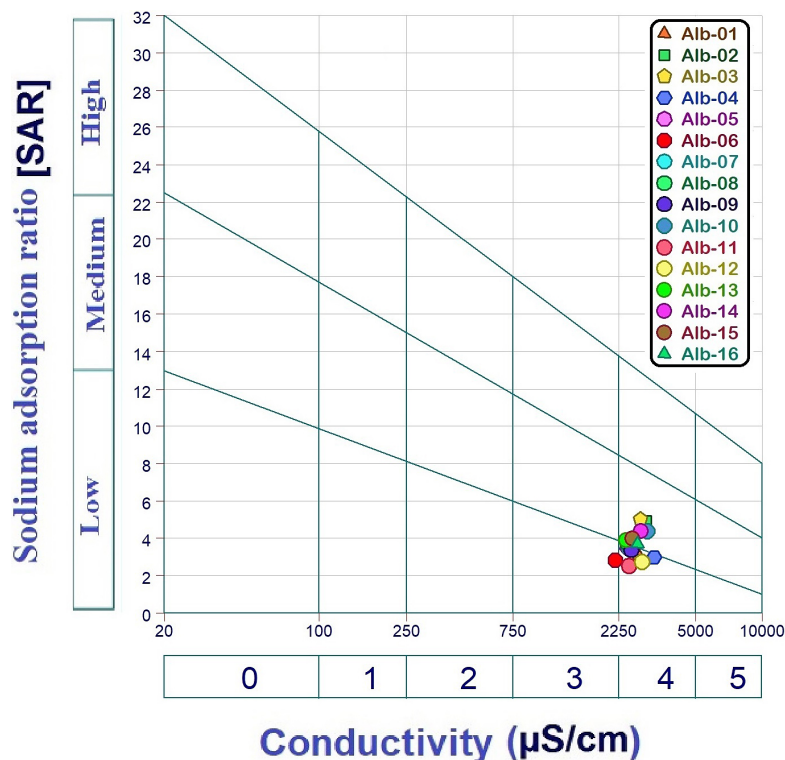


Figure 10. Richards diagram for CI water in Ouargla

According to SSP, water samples are classified into four classes (Hajji et al., 2018); excellent class (>20), good class (20 to 40), fair class (40 to 80) and poor class (<80). On the basis on the SSP values calculated for the CI waters of Ouargla (Table 3), 43.75% of the samples belong to the “Excellent” class, and 56.25% of the samples belong to “Good”.

The Kelly ratio (1963) is another important parameter that is practiced to obtain details on the quality of the groundwater, evaluating the concentration of sodium in relation to Ca^{2+} and Mg^{2+} . The KR is calculated by Eq. 3. If the KR is greater than 2, the groundwater is classified as unfavorable to irrigation. When KR is varied between 1 and 2, groundwater is qualified as poor quality for irrigation. At the same time, the water with a KR lower than 1 is suitable for irrigation (Ouarekh et al., 2021). Kelly ratio values in the study area (Table 3) ranged from 2.39 to 5.61. These values indicate that CI waters are unsuitable for irrigation.

The permeability of the soil is an important factor because it allows groundwater infiltration. The permeability index parameter (PI) calculated by Eq. 4 is used to evaluate the suitability of the groundwater for irrigation purposes. Water infiltration into the soil after irrigation is a function of soil permeability. The PI strongly correlates with Na^+ , Ca^{2+} , Mg^{2+} and HCO_3^- concentrations; Eq. 4

calculates the PI. Doneen (1964) classifies irrigation water into three categories namely (Bousel-sal and Saibi, 2022; Amrani et al., 2022); excellent class (>75%), good class (25–75%), and unsuitable for irrigation class (<25%). The PI values found in the investigated area (Table 3) oscillate between 19.59% and 29.93%, indicating that the waters of the continental intercalary in the Ouargla region are unsuitable for irrigation.

The Potential Salinity (PS) considers the concentration of sulfate and chloride when measuring water suitability for irrigation purposes (Eq. 9). Poorly soluble salts in irrigation water are precipitated and accumulated on the soil with each successive crop. The PS of groundwater samples is classified into three categories (Doneen, 1954; Kamaraj et al., 2021); Excellent to good (<5), good to detrimental (5-10) and detrimental to unsatisfactory (>10). The PS calculation of the CI water samples in the area investigated (Table 3) gives values ranging from 18.62 to 26.83 meq/l, with a calculated average of around 22.92 meq/l. Therefore, CI waters are classified as Injurious to Unsatisfactory for irrigation.

The magnesium adsorption ratio (MAR) is a parameter that measures the percentage of Mg^{2+} relative to the alkaline earth (Mg^{2+} and Ca^{2+}). MAR is calculated based on Eq. 5, where the Ca^{2+} and Mg^{2+} concentrations are in meq/l.

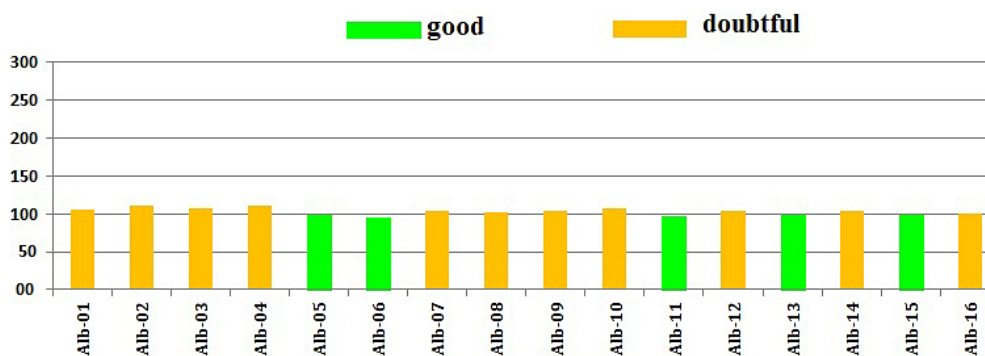


Figure 11. The irrigation water quality index (IWQI) of CI in Ouargla

Table 3. Parameters of water quality for irrigation purposes

Sample	EC	SAR	PS	SSP	PI	KR	MAR	IWQI
Alb-01	2762	3.41	23.95	17.29	26.50	2.96	11.19	104
Alb-02	2992	5.48	25.91	24.12	19.83	5.24	8.67	110
Alb-03	2800	5.58	24.43	24.94	19.59	5.61	8.05	108
Alb-04	3240	3.32	25.96	15.23	29.07	2.48	12.12	111
Alb-05	2464	3.93	19.57	19.62	22.60	3.71	11.48	98
Alb-06	2165	3.15	18.62	18.37	25.28	3.17	11.34	95
Alb-07	2503	3.83	23.87	20.36	22.78	3.85	11.41	103
Alb-08	2467	4.15	22.04	21.43	22.17	4.22	10.91	102
Alb-09	2566	3.77	23.60	19.71	23.36	3.65	11.65	104
Alb-10	3022	4.86	26.83	22.96	20.35	4.59	5.88	106
Alb-11	2508	2.78	20.91	15.08	29.93	2.39	7.73	96
Alb-12	2848	3.07	24.26	15.53	29.61	2.49	9.51	104
Alb-13	2445	4.30	20.24	22.18	21.28	4.34	8.73	98
Alb-14	2838	4.89	22.85	22.75	19.88	4.69	8.70	103
Alb-15	2597	4.44	21.12	21.76	20.79	4.32	8.42	99
Alb-16	2733	4.10	22.58	20.02	22.47	3.75	7.75	100

A magnesium adsorption rate (MAR) above 50% is considered unsuitable for agricultural use, as it negatively affects the soil and causes it to become alkaline. However, MAR below 50% is suitable for agricultural use (Raghunath 1987).

The IWQI values calculated for continental intercalary waters in the Ouargla region (Table 3 and Fig. 11) range from 95 to 111. 31.25% of the samples fall in the good category, and 68.75% of the samples analyzed fall in the doubtful category. The CI waters are marked by high salinity, which influences the irrigation parameters of Kelly ratio, permeability index and potential salinity.

CONCLUSIONS

Groundwater is an important water source for satisfying the domestic, agricultural and industrial needs. The present study focused on the

determination of the physico-chemical properties of the groundwater of Ouargla CI, the determination of the mechanisms of the mineralization of the CI water and the evaluation of the water quality for human consumption, irrigation and industry. On the basis on the interpretation of hydrochemical data collected from 16 boreholes capturing the CI aquifer. The results indicate that the waters of the intercalary continental aquifer (CI) present physicochemical parameters varying between; T (50 to 55 °C), EC (2165 to 3240 $\mu\text{S}/\text{Cm}$), TDS (1502 to 2658 mg/l), pH (7.66 to 8.4), Ca^{2+} (83 to 207 mg/l), Mg^{2+} (73 to 240 mg/l), Na^+ (175 to 320 mg/l), K^+ (18 to 54 mg/l), Cl^- (375 to 565 mg/l), SO_4^{2-} (463 to 1050 mg/l), HCO_3^- (67 to 281), NO_3^- (0 to 15.3 mg/l) and TH (713 to 1318 mg/l CaCO_3).

The representation of the samples on the Piper diagram shows that the groundwaters of continental intercalary are dominated by the Ca-Mg-Cl

(56.3%) and Ca-Cl (43.7%) facies. In addition, analysis of bivariate plots between chemical parameters and calculation of saturation indices of major minerals showed that mineralization of CI waters is controlled by rock-water interactions, including silicate alteration, evaporite dissolution and cation exchange. The suitability of CI water for human consumption was compared with the World Health Organization (2017) guideline values. According to WHO (2017), EC (100%), T (100%), TDS (100%), Na⁺ (87.5%), K⁺ (100%), Ca²⁺ (12.5%), Mg²⁺ (18.75%), SO₄²⁻ (100%), and TH (100%), samples exceed the permissible limit, indicating that most of the groundwater samples do not have good quality for drinking purposes. The irrigation water quality index (IWQI) method was used to estimate the water quality for agricultural use. Seven (7) parameters were taken into account to calculate IWQI. These are EC, SAR, SSP, PI, KR, PS and MAR. The calculated IWQI values range from 95 to 11. 31.25% of samples fall in the good category, and 68.75% of the analyzed samples fall in the doubtful category.

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