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# Groundwater Geochemical and Quality of the Continental Intercalary Aquifer in Béni Ounif (Southwest Algeria)

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**ABSTRACT**

The main objective of this work was to study the status of groundwater quality for drinking and irrigation uses in the locality of Beni Ounif. A total of 16 samples were taken at different locations in the study area from boreholes to capture the continental intercalary (CI) aquifer for physicochemical analysis. This work used the groundwater quality index (GWQI) method to evaluate water potability. The irrigation water quality was assessed by studying EC, SAR, Na%, KR, PI, and MR parameters. In addition, the mechanisms of mineralization of these waters were highlighted by the study of Piper, Gibbs, bivariate diagrams, and the calculation of saturation indices. The results show that the CI waters would have chemical constituents in accordance with the WHO guide values and the Algerian guide values for drinking water. The GWQI method showed a good quality of CI waters for consumption in the study area. On based the irrigation water parameters, the IC water samples are acceptable for irrigation provided that drainage techniques are applied to the cultivated land for tipsy soil salinization. In addition, the study of Piper, Gibbs, bivariate, and mineral saturation diagrams shows that the CI waters of the study area are of Ca-Mg-$SO_4$-Cl type, and the hydrogeochemical processes that control their mineralization are complex, namely, the alteration of silicate and carbonate minerals, the dissolution of gypsum and exchange ion.

**Keywords:** Béni Ounif, continental intercalary, potability, irrigation, mineralization.

## INTRODUCTION

The groundwater resources in North Africa's arid and semi-arid regions are small and have a lot of spatiotemporal variability (Hamlat et al., 2018; Bouselsal, 2017). However, these resources, which are not very renewable, are largely exploited to meet the inhabitant's needs for agriculture, industry, and drinking water supply. During the last decades, the water resources of Bechar (SW Algeria) region have been subjected to increasing exploitation to overcome the quantitative deficit related to extreme climatic conditions. The dam of Djorf Torba, which ensured the water needs in the region of Bechar, becomes insufficient to satisfy the increasing demands, especially with the creation of newly irrigated areas.

Faced with the future situation of water not optimistic and to meet the growing demand for water in the region of Bechar, officials have launched a large-scale hydraulic project to transfer water from the continental intercalary (CI) aquifer of Beni-Ounif to five municipalities in the wilaya namely Bechar, Kenadsa, Abadla, Mechraa Houari-Boumediene, and Erg Farradj. The project was commissioned in April 2019. The 1st part of the project aims to ensure a regular supply of drinking water by the daily transfer of 30000 $m^3$/d of water from ten (10) boreholes of a depth varying between 400 and 500 meters.

Given the above background, the main objectives of the present study were (1) to assess the physicochemical characteristics of groundwater of CI of Beni Ounif and compare the standards of the World

Health Organization (WHO, 2017) and the Algerian standards, (2) to classify the waters by applying the groundwater quality index (GWQI) method, (3) to categorize and evaluate the water quality parameters for agricultural use, (4) and to understand the mineralization mechanism of CI waters. The results of this study are intended to achieve better management of groundwater sources in the study area to prevent possible future water quality degradation.

## STUDY AREA

### Geographical context and climatology

The study area (Fig. 1) is part of the municipality of Beni Ounif, located in southwestern Algeria (Fig. 1). It occupies an area of 42,730 km$^2$, with a population reaching 13,000 inhabitants. The study area lies between longitude 4° West and 3° East and latitude 30° and 33° North. A Saharan-type climate characterizes the study area. The dry period is extended over the twelve months of the year. The annual rainfall does not exceed 32 mm. The relative humidity is low (< 40%). In July, the average annual temperature is about 27.37 °C, with a maximum of 38.83 °C (in July). The annual evaporation is about 1336.6 mm (MNO, 2021).

### Hydrogeological context

The study area is a syncline belonging to the Saharan platform (Merzougui et al., 2019). It is located at the foothills of the Saharan atlas. The outcropping geological formations belong to the Paleozoic, Mesozoic, and Cenozoic. The litho-stratigraphy of the study area (Fig. 2) is represented in the west by the outcrop of formations of primary age (Cambrian, Carboniferous, and Devonian) and overlain by the Jurassic, which outcrops to the north of the study area. Deposits of sand, clay, limestone, and dolomite are of Cretaceous age overlying the Jurassic. At the top, alluvial deposits and sand dunes cover the depressions of the study area.

From the hydrogeological point of view, the study area's subsoil comprises three aquifers (ARNH, 2012; Merzougui et al., 2019**.** At the surface, the superficial free aquifer constituted by alluvium of plio-quaternary age, the average depth of the substratum is about 10 m. This aquifer develops in the areas of depression. It is fed by the winter floods of Oued Sidi Aissa and Oued Lakhdar. Under the superficial aquifer, the Turonian aquifer is found made up of limestone and dolomite. This aquifer outcrops in the southwestern part of the study area. At the base, we find the continental intercalary aquifer of the lower Cretaceous age, consisting of an alternating layer of sandy clay with passages of sandstone limestone. Its thickness in the study area varies between 100 and 250 m. The boreholes tapping this aquifer give a flow rate of about 36 l/s.

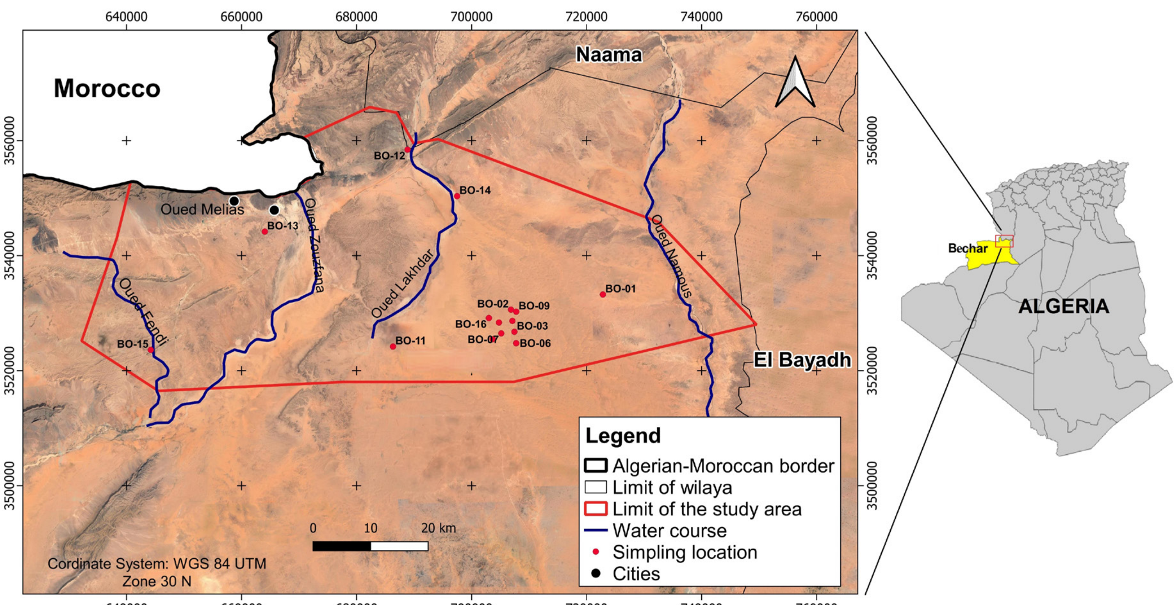


**Figure 1.** Location map of the study area

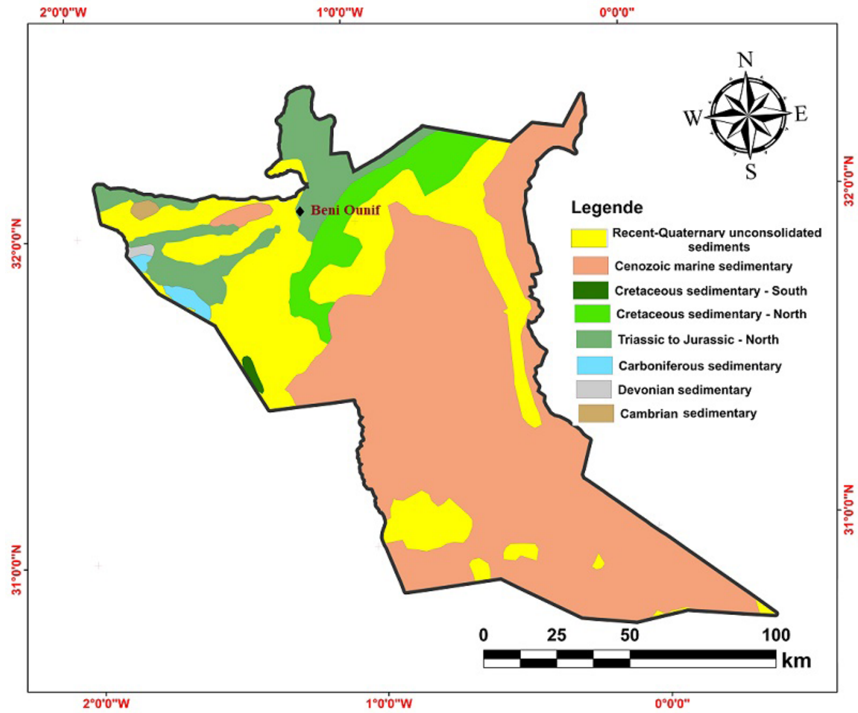


**Figure 2.** Geological map of Beni Ounif

## MATERIALS AND METHODS

### Chemical sampling and analysis

A sampling and hydro-chemical measurement campaign was conducted in the study area in March 2019 in the boreholes to capture the CI aquifer of Beni Ounif. Sixteen (16) water samples were collected and analyzed: 10 sampling points are located in the catchment area (Fig. 1), intended to supply the city of Bechar, and six (6) boreholes are distributed in the study area. The electrical conductivity, pH and temperature were determined at the sampling site using a portable multiparameter. The samples for laboratory analysis were filtered and transported in polyethylene bottles. Transportation of the sample bottles to the laboratory was done in a cooler at a low temperature (4 °C). The analyses were carried out at the ANRH laboratory in Adrar. Nitrates, sulfates, chlorides, and fluorine were determined using a spectrophotometer, while a flame spectrophotometer was used to determined calcium, sodium, and potassium. Magnesium, carbonate, and bicarbonate were analyzed by titrimetry.

### Statistical analysis and assessment of water quality

Chemical data analysis was performed using the SPSS version 19.0 software. The assessment of the chemical quality of water intended for consumption was determined using the GWQI method. The suitability of water for agricultural use was determined by studying the potential parameters related to irrigation water quality. These are electrical conductivity (EC), sodium percentage (Na%), sodium, adsorption ratio (SAR), permeability index (PI), Kelly ratio (KR), and magnesium ratio (MR). These irrigation factors are estimated using the following formulas (Kebili et al., 2021; Kharroubi et al., 2022):

$$Na\,\% = \frac{(Na + K)}{(Na + K + Ca + Mg)} \times 100 \quad (1)$$

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

$$KR = \frac{Na}{Ca + Mg} \quad (3)$$

$$PI = \frac{Na + K + \sqrt{HCO3}}{Ca + Mg + Na + K} \times 100 \quad (4)$$

$$MR = \frac{Mg}{Ca + Mg} \times 100 \quad (5)$$

## RESULTS AND DISCUSSION

### Water chemistry

The evaluation of physicochemical parameters (Table 1) shows that the CI waters are alkaline, with the pH values ranging from 7.10 to 7.60. Therefore, they are within the range of pH values recommended by the World Health Organization and Algerian standards (6.5 to 8.5). The electrical conductivity is the measure of the ability of a body or solution to transmit electrical current. The EC values in the study area vary between 550 µS/cm (Beni Ounif city) and 922 µS/cm (Oued Lakhdar and Fendi). The measured values are in conformity with the standards (EC <1500 µS/cm). Total dissolved solids of the analyzed samples varied between 352 and 590 mg/l, with an average of 498.72 mg/l.

According to the World Health Organization (WHO, 2017) and Algerian standard (JORADP, 2011), the permissible limit of TDS for drinking water is 1000 and 1500 mg/l, respectively. The amount of calcium and magnesium determines the total hardness (TH) of water. The TH values range from 173 mg/l to 342 $CaCO_3$ measured in boreholes BO-03 and BO-15, respectively. According to the classification of Sewyer and McMcartly (1967), the waters of the CI aquifer are classified as hard (56.25%) and very hard (43.75%). These measured contents remain within the recommended values for drinking water.

The descriptive statistical report in Table 1 shows that nitrate has a min, mean, and max of 0.52 mg/l, 21.42 mg/l, and 135.54 mg/l, respectively. The evaluation of the major constituents of groundwater shows that all elements are within the WHO (2017) recommended potability standards and Algerian standards. $SO_4^{2-}$ levels in CI groundwater oscillate from 50 to 183 mg/1. The $Cl^-$ concentration varies from 50 to 115 mg/l with an average of 98.13 mg/l. The concentrations of $HCO_3^-$ vary between 148 and 183 mg/l. $K^+$ varies from 4 to 7 mg/l with an average of 5.27 mg/l.

$Ca^{2+}$ concentrations have a min, mean and max of 39 mg/l, 54.38 mg/l and 67 mg/l, respectively. The $Na^+$ content of the intercalary continental waters of the study area ranges from 45 to 80 mg/l with an average of 62.51 mg/l. $Mg^{2+}$ concentration in CI groundwater ranges from 15 to 43 mg/l with an average of 32.83 mg/l. The nitrate levels vary from 19.60 to 43.05 mg/l, with an average value of 26.17 mg/l. These values do not exceed the potability standard, but they indicate the effect of surface pollution on CI waters. It can be seen that the infiltration of urban water and irrigation water (Bouselsal and Saibi., 2022) in the southwest of the study area is responsible for this contamination.

### Assessment of the potability of CI waters

Water quality monitoring is aimed at inform the public, government institutions, and decision-makers about the status of water resources and identify the most favorable action to protect human health and the aquatic ecosystem. The assessment of CI water quality for potability was determined with reference to the WHO standards (2017) and Algerian standards (JORADP, 2011; Bouselsal, 2017) for drinking water (Table 1). The result reveals that the intercalary continental waters of the study area are potable. The concentrations of chemical constituents are in accordance with the recommended national and international standards.

In addition, the GWQI method (Bouselsal and Saibi., 2022; Shah et al., 2021; Ouarekh et al., 2021) has been used to better assess the water quality of the continental intercalary of Beni Ounif. Since its inception in 1965 (Banda and Muthukrishna, 2020), many WQI indices have been developed and formulated by scientists (Kachroud et al., 2019). The method is widely used by various researchers and environmentalists worldwide to

**Table 1.** Portability standards and variations of hydrochemical parameters in CI groundwater

| Parameter | Ca | Mg | Na | K | Cl | $SO_4$ | $HCO_3$ | $NO_3$ | TDS | TH | pH | EC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | The concentration of anion and cation expressed in mg/L and TH in mg/l $CaCO_3$ | | | | | | | | | | | (µS/cm) |
| Mean | 54.38 | 32.83 | 62.51 | 5.27 | 98.13 | 113.81 | 161.09 | 26.17 | 498.72 | 273 | 7.31 | 779.25 |
| Max | 67.00 | 43.00 | 80.00 | 7.0 | 115.00 | 183.00 | 183.00 | 43.05 | 590.08 | 342 | 7.60 | 922.00 |
| Min | 39.00 | 15.00 | 45.00 | 4.00 | 50.00 | 50.00 | 148.00 | 19.60 | 352.00 | 173 | 7.10 | 550.00 |
| Std–Dev | 10.17 | 9.21 | 8.42 | 0.82 | 16.03 | 53.37 | 14.05 | 8.89 | 87.74 | 63 | 0.15 | 137.10 |
| Alg–Std2011) | 100–200 | 50–150 | 200 | 12 | 250–500 | 250–400 | – | 50 | 500–1500 | 100–500 | 6.5–8.5 | 1500–2800 |
| WHO (2017) | 75–200 | 50–150 | 200 | 12 | 200–500 | 200–600 | 300–500 | 45 | 500–1000 | 100–500 | 6.5–8.5 | 500–1500 |

describe the state of water quality. The advantage of this method is that it numerically summarizes a set of water quality parameters into a single value. This facilitates their communication with the different operators in the water field.

In this work, the Algerian standards of potability were taken into account for the calculation of GWQI (Table 2). The calculation of GWQI summarized in Eq. (6) goes through 3 steps (Bouselsal and Saibi., 2022); in step 1, each of the 11 parameters is assigned a weight ($w_p$) according to its significance in the global drinking water quality. Table 2 lists the parameters. In the step 2, the relative weight ($Wp$) is determined by division over the sum of the weights ($w_p$). In the step 3, the rating ($q_i$) for each parameter is calculated by dividing its concentration in the chemical parameter ($C_i$) by its respective value in the Algerian standard ($S_c$); then, the result is multiplied by 100.

**Table 2.** Weight of water quality index parameters

| Parameter | $w_p$ | $S_c$ | $W_p$ |
|---|---|---|---|
| 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 |

$$GWQI = \sum \left[ \left( \frac{w_p}{\sum_{n}^{i=1} w_p} \right) * \left( \frac{C_i}{S_c} * 100 \right) \right] \quad (6)$$

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;
$qi$ – quality notation ($qi = C_i/S_c$);
$W_p$ – the relative weight ($W_p = q_i/\sum q_i$).

The calculated GWQI indices divide the groundwater into five categories (Derdour et al., 2020): excellent (<51), good (51 and 100), poor (101 to 200), very poor (201 to 300), and unsuitable for drinking (>301). The GWQI values calculated for the 16 continental intercalary water samples in the study area are very close, ranging from 55 to 74. The results show that all the samples collected belong to the good quality category. The spatial distribution of GWQI was generated (Fig. 3). The highest GWQI indices are due to the higher electrical conductivity values,

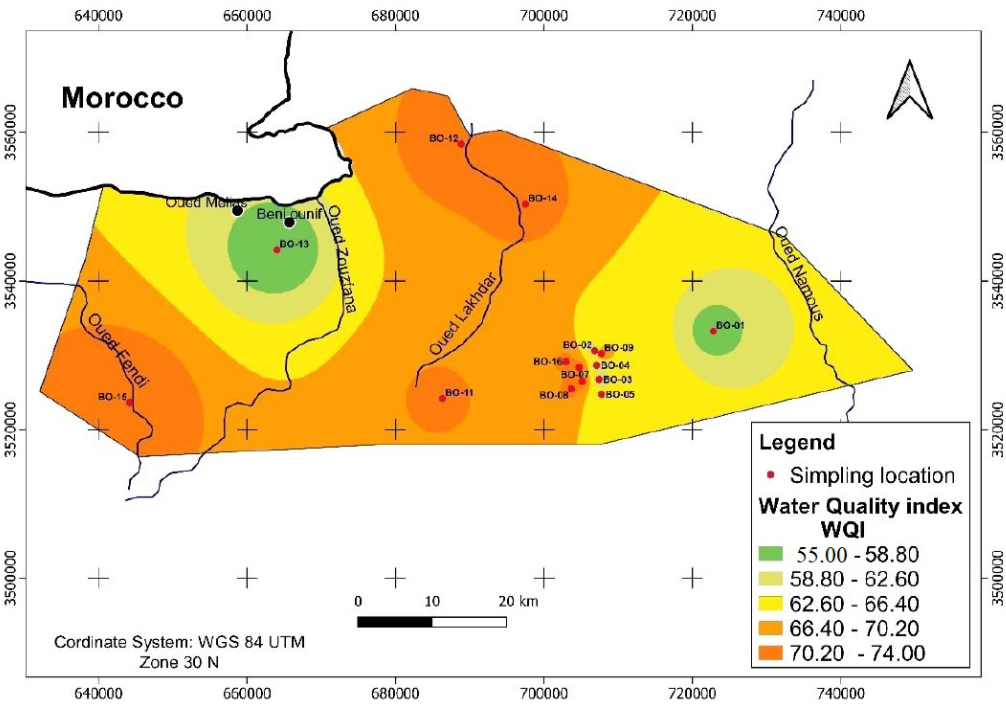


**Figure 3.** Groundwater quality index (GWQI) of CI groundwater in Beni Ounif

total dissolved solids, calcium, magnesium, and sulfate in the CI groundwater. The high values are found in the boreholes (BO-12 and BO-14) located in the northern part. However, the lowest value is found in boreholes (BO-01 and BO-13), located in the southeast and northwest of the study area, respectively.

## Assessment of water for agricultural use

The quality of irrigation water depends on the salinity of the water. The waters with high salt concentration decrease water absorption, which leads to delayed plant growth and reduced agricultural production. To evaluate quality and suitability for agricultural use of CI waters, identification of potential factors affecting plants and soil after crop irrigation was carried out. The parameters of irrigation water that seem to be the most important (Kebili et al., 2021) in determining the quality of irrigation water are EC, Na%, SAR, PI, KR, and MR.

EC is a crucial parameter for determining the suitability of groundwater for irrigation. EC expresses the salinity of the water. It allows for evaluating the risk of salinity for crops during irrigation. EC encountered in the study area ranges from 550 µS/cm to 922 µS/cm. The Wilcox (1955) classification (Table 3) shows that 62.50% of the CI waters were of high salinity (750 to 2250 µS/cm), and 37.50% of the CI waters were of medium salinity (250 to 750 µS/cm). In the twelfth case, moderate leaching is necessary to decrease the accumulation of salts.

$Na^+$% refers to the percentage of sodium and potassium by port all cations (Eq. 1). It is a factor that affects the characteristics of the soil. It plays a very important role in soil permeability and water infiltration. Very high $Na^+$% leads to reducing water leakage and soil aeration. The CI waters of Beni Ounif have values of $Na^+$% between (28.65) and (46.19). Wilcox (1955) show that 25% and 75% of the sample were in the permissible (40 to 60%) and good (20 to 40%) class, respectively (Table 3).

$Na^+$ risk is also estimated by the sodium adsorption ratio (SAR). It is a measure of the content of $Na^+$ in relation to $Mg^{2+}$ and $Ca^{2+}$. It is calculated according to formula 2. SAR was first studied by Richards (1954), and it is used to estimate the tendency of $Na^+$ absorption by the soil. Groundwater with high SAR accumulates sodium concentrations in the soil over time, which reduces the infiltration rate of water into the soil due to soil dispersion. The SAR values calculated in the investigation area range from 1.34 to 2.49 and therefore classify the CI waters in the excellent category (0 to 10 meq/l). The SAR and electrical conductivity data are plotted on the US Salinity Laboratory diagram (1954), in which electrical conductivity is considered a salinity hazard and

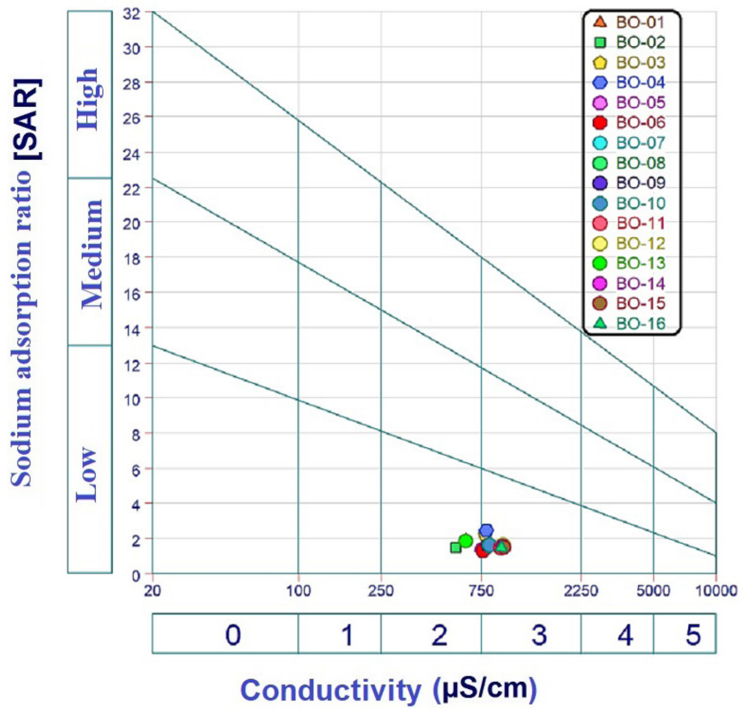


**Figure 4.** The US Salinity Laboratory diagram for CI groundwater of Beni Ounif

sodium absorption ratio (SAR) a sodium hazard. The diagram (Fig. 4) reveals CI waters fall in the class $C_2S_1$ and $C_3S_1$, indicating water with medium to high salinity and low sodium hazard.

The Kelly ratio (1963) is another important factor to calculate to obtain further details on groundwater quality, evaluating the sodium concentration in relation to calcium and magnesium. The KR is calculated by formula 3. KR with values exceeding 2 is considered unfavorable for irrigation. When KR is limited between 1 and 2, the water is of poor quality for agricultural use, while irrigation water with a Kelly index not exceeding 1 is considered favorable for irrigation. The Kelly ratio values found in the study area (Table 3) show that the CI waters in the study area are of good quality for irrigation.

The infiltration of water into the soil after irrigation depends on the permeability of the soil. This infiltration can be modified with time if the chemical quality of the irrigation water is unfavorable. The soil permeability is determined by the parameter permeability index (PI). It is strongly influenced by the concentration of $Na^+$, $Ca^{2+}$, $Mg^{2+}$, and $HCO_3$. The PI is calculated by the application of Eq. (4). Doneen (1964) determines three categories of irrigation water according to the PI values; class 1 excellent (max permeability of 100%), class 2 good (max permeability of 75%), and class 3 (max permeability of 25%). The calculated PI values in the study area (Table 3) range from 45.8 to 68%, indicating that the CI groundwater in the study area is slightly suitable for irrigation.

The magnesium ratio is another essential factor in evaluating irrigation water quality. It is calculated by using Eq. (5). The high MR in water negatively affects the quality of the soil, which becomes more alkaline and lowers the yield of plants. The MR values exceeding 50% are considered unsuitable for irrigation, while MR values below 50% are considered suitable for irrigation (Raghunath, 1987). The MR values calculated for CI waters (Table 3) range from 36 to 53%. These ratios indicate that 96.43% of CI waters are suitable for irrigation.

## Chemical facies and mechanisms of water mineralization

The analytical data obtained from CI groundwater samples are plotted on a Piper diagram (Piper, 1944) (Fig. 5). From the diagram, groundwater can be classified into four types of water (Adimalla, 2019; Peiyue et al., 2019): (1) Ca-Mg-$HCO_3$, (2) Ca-Mg-$SO_4$ -Cl, (3) Na-Cl, and (4) Na-$HCO_3$. All the CI water samples from Beni

**Table 3.** Parameters of water for agricultural use

| Sample | CE | % Na | SAR | KR | PI | MR |
|---|---|---|---|---|---|---|
| BO-01 | 620 | 40.96 | 1.94 | 0.72 | 67.05 | 45.21 |
| BO-02 | 550 | 35.49 | 1.50 | 0.57 | 65.84 | 36.00 |
| BO-03 | 612 | 42.59 | 2.22 | 0.77 | 64.51 | 48.96 |
| BO-04 | 608 | 46.19 | 2.49 | 0.89 | 68.07 | 50.38 |
| BO-05 | 798 | 29.93 | 1.42 | 0.44 | 52.93 | 50.77 |
| BO-06 | 700 | 28.75 | 1.34 | 0.41 | 52.54 | 46.92 |
| BO-07 | 830 | 31.05 | 1.60 | 0.46 | 50.96 | 50.77 |
| BO-08 | 910 | 29.22 | 1.52 | 0.42 | 46.85 | 50.77 |
| BO-09 | 832 | 32.28 | 1.64 | 0.49 | 52.94 | 53.07 |
| BO-10 | 830 | 32.09 | 1.64 | 0.48 | 52.52 | 52.61 |
| BO-11 | 905 | 28.98 | 1.51 | 0.42 | 46.47 | 51.39 |
| BO-12 | 900 | 30.36 | 1.62 | 0.45 | 47.38 | 49.63 |
| BO-13 | 617 | 40.40 | 1.90 | 0.70 | 66.26 | 45.58 |
| BO-14 | 914 | 29.51 | 1.57 | 0.43 | 46.64 | 52.97 |
| BO-15 | 922 | 28.65 | 1.51 | 0.41 | 45.83 | 52.19 |
| BO-16 | 920 | 29.34 | 1.53 | 0.42 | 46.82 | 50.77 |
| Min | 550 | 28.65 | 1.34 | 0.41 | 45.83 | 36.00 |
| Max | 922 | 46.19 | 2.49 | 0.89 | 68.07 | 53.07 |
| Mean | 779,25 | 33.49 | 1.68 | 0.53 | 54.60 | 49.25 |
| Std-Dev | 137,10 | 5.78 | 0.31 | 0.15 | 8.58 | 4.28 |

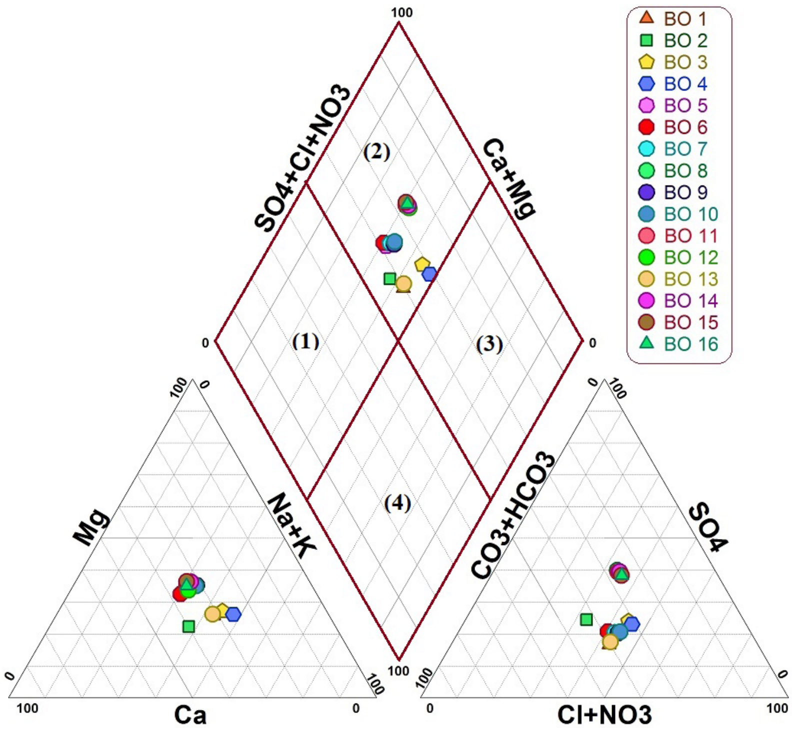


**Figure 5.** Piper diagram of CI water in Béni Ounif

Ounif fall to Ca-Mg-$SO_4$ -Cl. In the cations, it can be noticed that the alkaline earth exceeds the alkaline and that the strong acids exceed the weak acids. In the anions, it can be observed that the control of the strong acid over the weak acid and $SO_4$ and Cl have a greater influence than sodium (Venkatramanan et al., 2015). This type of water highlights the complexity of the hydrogeochemical processes that control the mineralization of CI waters in the study area.

The Gibbs diagram (1970) was drawn to define the mechanisms controlling the evolution of groundwater chemistry in the continental intercalary (CI) of Beni Ounif. The Gibbs diagram classifies the mechanisms governing the chemistry of waters into three types; (i) the first is that of waters influenced by water-rock interaction processes, (ii) the second represents waters influenced by the evaporation phenomenon, (iii) the third is that of the waters influenced by precipitation. The

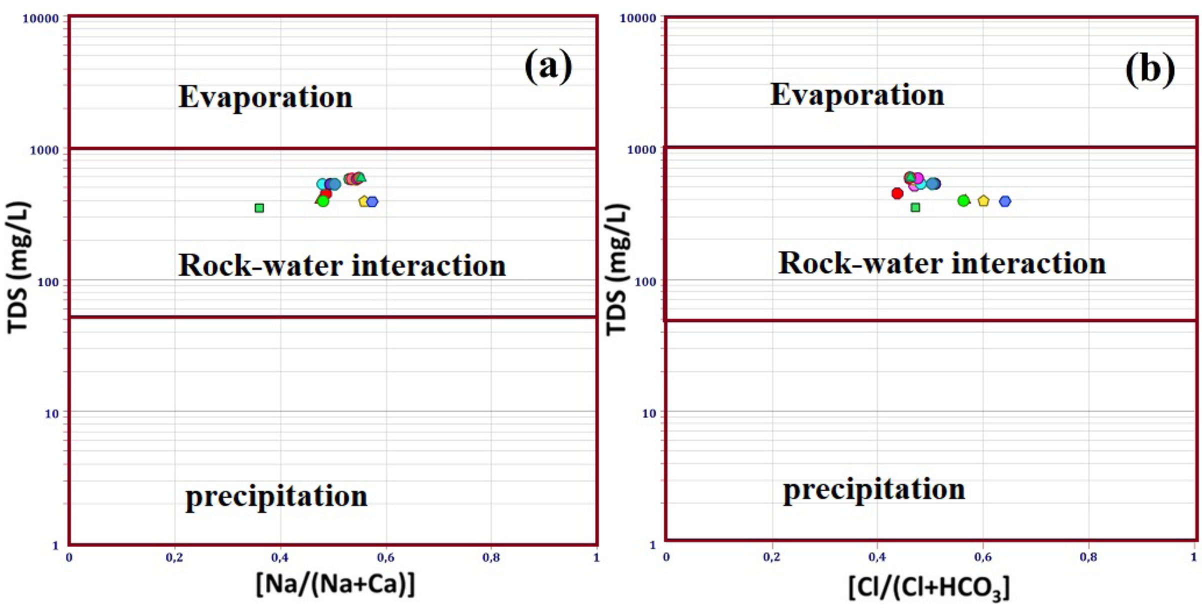


**Figure 6.** Mechanisms of water mineralization according to Gibbs diagram

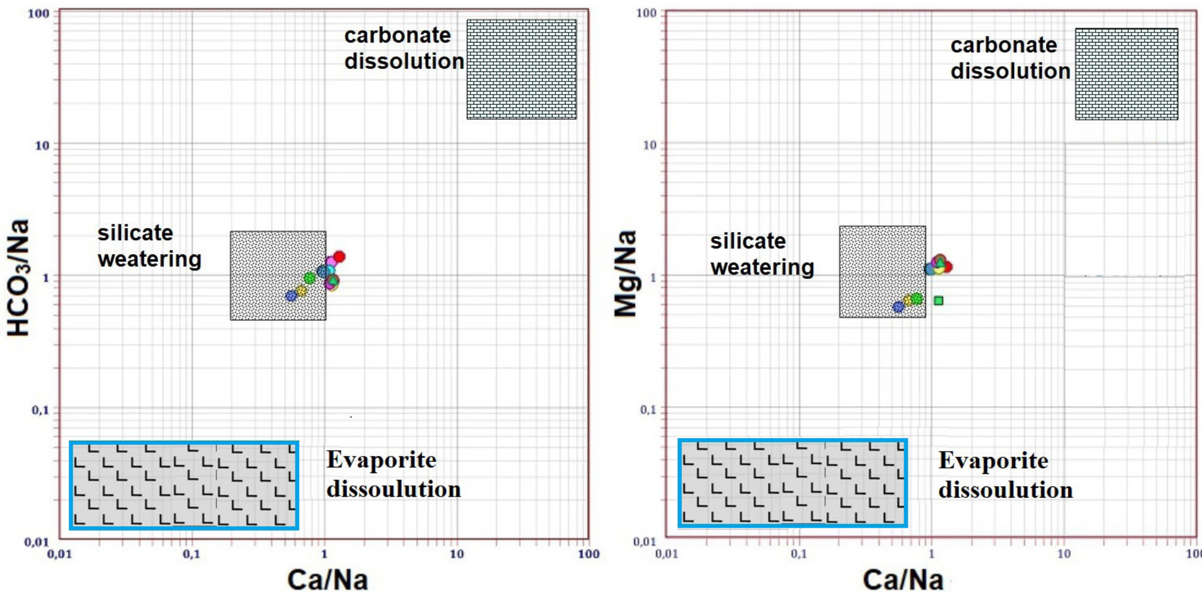


**Figure 7.** Identification of minerals weathering in CI groundwater

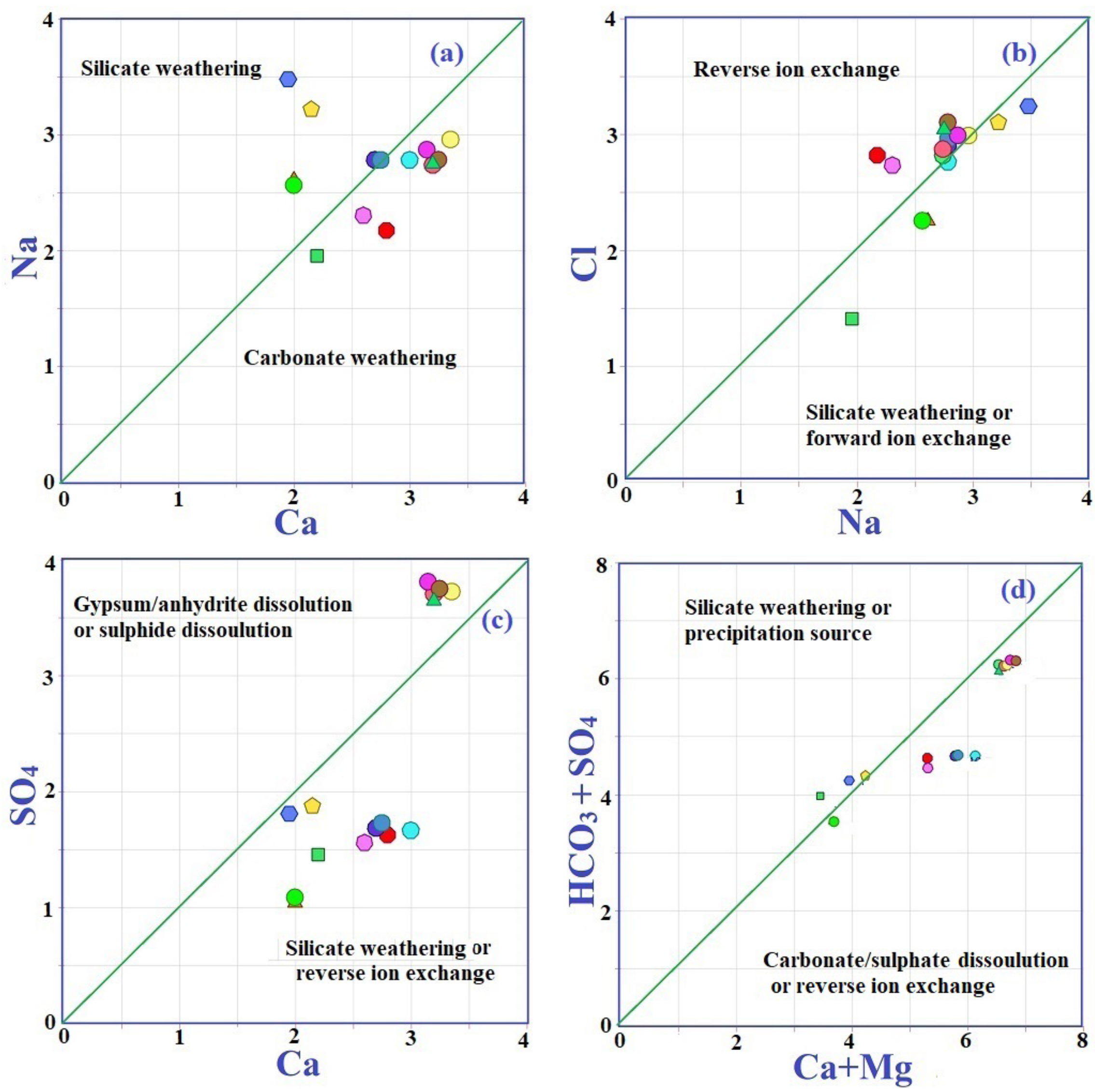


**Figure 8.** Binary diagrams between: (a) Na *vs.* Ca ; (b) Cl *vs.* Na ; (c) $SO_4$ *vs.* Ca; (d) $HCO_3+SO_4$ *vs.* Ca+Mg

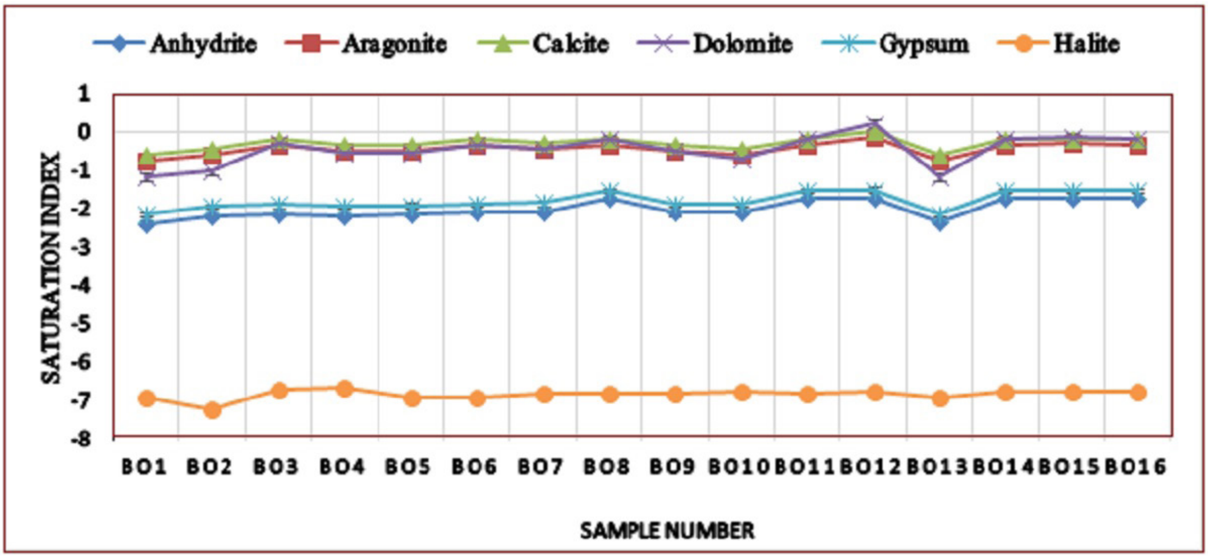


**Figure 9.** Saturation indices of some minerals

projection of the analyzed water samples on the Gibbs diagram (Fig. 6) shows that the chemistry of CI waters is mainly governed by rock weathering and water-rock interaction. As CI groundwater flows through the geological formations below ground, it is in permanent contact with the rocks. In this case, the influence of lithology on groundwater chemistry is very noticeable.

Weathering and water-rock interaction processes are also investigated by the graphs of Ca/Na compared to $HCO_3$/Na as well as Ca/Na compared to Mg/Na (Gaillardet et al., 1999). From the graph (Fig. 7), the groundwater in CI was largely influenced by silicate weathering. The result found is confirmed by the reservoir lithology of CI dominated by sandstones, sands, and clays.

The different mechanisms that contribute to the mineralization of the CI aquifer groundwater in the investigation area were also studied using binary diagrams between chemical elements (Fig. 8).

Fig. 8a indicates that carbonate and silicate alteration dominate the continental intercalary waters. In addition, when silicate alteration is involved in a geochemical process, sample chemistry data are plotted above the 1:1 line of $Na^+$, compared to $Cl^-$ graph (Apoorv et al., 2021). From Figure 8b, data are plotted above the line that confirms that silicate mineral alteration contributes to groundwater chemistry. It can also be seen that the reverse cation exchange between groundwater and clay minerals is an additional contribution of alkaline earth elements ($Ca^{2+}$ and $Mg^{2+}$). However, the study of the ratio of $Ca^{2+}$ compared to $SO_4^{2-}$ (Fig. 8c) indicates that about 62.5% of the water samples are below the 1:1 line, revealing the existence of silicate alteration. The remaining 37.5% of samples suggest the incidence of gypsum or anhydrite dissolution processes. This result is confirmed by the existence of the sulfate chemical facies. The graph ($Ca^{2+}$ + $Mg^{2+}$) compared to ($HCO_3^-$ + $SO_4^{2-}$) (Fig. 8d) shows that about 81.25% of the CI water samples above the 1:1 line indicates the contribution of carbonate and/or sulfate dissolution in the salinization of CI groundwater. The sandstone limestone levels promote this enrichment with $Ca^{2+}$ and $HCO_3^-$. An excess of $Ca^{2+}$+$Mg^{2+}$ over $HCO_3^-$ + $SO_4^{2-}$ may also originate from the aquifer material through the reverse ion exchange process (Manikandan et al., 2020).

The calculation of the saturation of the minerals of calcite, dolomite, gypsum, anhydrite, and halite (Bouselsal and Zouari, 2022) by the FREEQC software (Fig. 9) reveals that these minerals are undersaturated. The saturation index of the minerals is negative (SI < 0), which emphasizes that all minerals appear in water with their total concentrations due to the lack of precipitation. From this effect, it can be seen that the influence of evaporation on the chemistry of the waters of Beni Ounif CI is negligible.

## CONCLUSIONS

The intercalary continental aquifer of Beni Ounif is of major interest in the Algerian Sahara because it is exploited to supply water to the entire Bechar region. The geochemical study of the waters allowed to evaluating the portability and suitability of the water for irrigation and highlight the different geochemical processes that contribute to the mineralization of these waters. The chemical analyses show the CI waters meet the potability standards. The conductivity of the waters ranges from 550 to 922 μS/cm, and TDS ranges from 352 to 590 mg/l, with an average of 498.72 mg/l. The CI waters are classified as hard (56.25%) and very hard (43.75%). The CI waters are of good quality in reference to the results given by the GWQI method. The GWQI values for the waters range from 55 to 74.

The water quality for agricultural use was studied using parameters related to irrigation water quality. These are electrical conductivity (EC), sodium percentage (Na%), sodium, adsorption ratio (SAR), permeability index (PI), Kelly ratio (KR), and magnesium ratio (MR). The continental intercalary waters of Beni Ounif are classified as EC (High salinity (37.5%) and medium salinity (62.5%)), Na% (good (75%) and permissible (25%)), SAR (Excellent 100%), PI (good 100%), Kelly ratio (good 100%) and MR (suitable (62.5%) and unsuitable (37.5%)) The results reveal that the CI waters are mostly of good quality for irrigation. However, the mineralization of the waters requires good drainage of the cultivated lands. In addition, the analysis of Piper, Gibbs, and bivariate mineral saturation diagrams concluded that the CI waters are of the Ca-Mg-$SO_4$-Cl type and that the mineralization of CI aquifer waters is related to the alteration of silicate and carbonate minerals, gypsum dissolution, and reverse cation exchange.

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