

Assessing the Drinking Water Quality Index in Arid Areas: An Analysis of the El Hadjeb Region in Biskra, Southeastern Algeria.

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Received: 05 August 2025

Received in revised form: 20 September 2025

Accepted: 09 October 2025

Available online: 01 October 2026

Abstract

Investigating the hydrogeochemical processes and regional variations in groundwater quality within the Lower Eocene aquifer of the El Hadjeb region in southeastern Algeria is the aim of this study. The groundwater samples are tested for electrical conductivity (EC), pH, temperature (T), total dissolved solids (TDS), and major ionic elements like Na^+ , K^+ , Ca^{2+} , Mg^{2+} , CO_3^{2-} , HCO_3^- , Cl^- , and SO_4^{2-} . In semi-arid and arid regions, the aquifer is a very important source of water. The findings indicate that sodium chloride (Na-Cl) is the predominant hydrochemical facies of the groundwater with evaporite mineral undersaturation and a small amount of dolomite precipitation. The modal Gibbs diagrams suggest that the main geochemical regulators are evaporation and rock-water interactions. The samples examined had Water Quality Index (WQI) values between 87.26 and 153. 33.33% of the samples fall into the "good" category and 66.66% into the "poor" category. High WQI values, which indicate declining water quality, are associated with increases in SO_4^{2-} , K^+ , Na^+ , Ca^{2+} , Mg^{2+} , HCO_3^- , Cl^- , and TDS. These results demonstrate how important effective groundwater management is to maintaining the sustainability of this fragile aquifer.

Keywords:

Groundwater, Lower Eocene aquifer, Water Quality Index (WQI), El Hadjeb.

DOI: [10.33899/injes.v26i4.61113](https://doi.org/10.33899/injes.v26i4.61113), ©Authors, 2026, College of Science, University of Mosul.

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1. Introduction

Having access to safe, potable water is very important for keeping people healthy, and it is still a big subject of interest (Kada and Demdoun, 2020). Groundwater represents the leading source of both drinking water and irrigation worldwide (Aragaw and Gnanachandrasamy, 2021; Li et al., 2021). In dry and semi-arid climates, access to freshwater plays a pivotal role in supporting regional development. Uncontrolled extraction of groundwater could lead to severe repercussions in the future, impacting both the aquifer and crop sustainability (e.g., depletion of deep-water resources). Algerian Saharan groundwater, an important supply for drinking, industrial, and

agricultural water, is the second most significant source (Lezzaik et al., 2018). El Hadjeb region, located in Biskra in the northeastern Algerian Sahara, experiences a hot and arid climate, low rainfall, and high temperatures with rapid evaporation rates. Within this region, there are considerable water reserves in the subsurface, comprising overlapping aquifers ranging from the uppermost free surface water aquifer to the deepest Albian aquifer. Notably, the groundwater resources within these aquifers meet the water demands of "El Hadjeb," catering to both the shallower terminal aquifer and the deeper confined continental intercalaire. The Lower Eocene formation, which is the main focus of this investigation, emerges as the most promising water reservoir in the study area due to its cracked

limestone composition. Water quality is closely linked to the physical and chemical variables that define its composition in a specific environment. Geological formations and human activities play a key role in determining these water quality parameters (Subramani et al., 2005). Groundwater is the dominant water provision for almost all uses in arid and semi-arid regions (Al-Shaibani, 2008). Numerous studies have demonstrated that anthropogenic activities exert a considerable influence on groundwater quality in arid and semi-arid areas across the globe (He et al., 2020; Li et al., 2019). To effectively manage and evaluate these water resources, it is important to have a deep understanding of the hydrogeological and hydrogeochemical properties of these aquifers (Umar et al., 2001). The main processes affecting the hydrochemical quality of groundwater are sorption, desorption, ion exchange, and mineral dissolution and precipitation within the groundwater flow (Apodaca et al., 2002). Several investigations have examined groundwater geochemistry. In the Tongchuan area of China, Li et al. (2018) used geochemical data to trace key hydrochemical mechanisms and evaluated how geological structures have an effect on the chemistry of groundwater. In Tunisia, Houatmia et al. (2016) employed various water quality parameters for hydrochemical characterization and assessment of water geochemistry in aquifer systems. Previous Algerian studies, such as Ziani et al. (2017), utilized graphical tools to study the geochemical processes that happen in the shallow aquifer of Djacer spring in Quaternary alluvial formations. In their study of the El Guettar Oasis aquifer system, Mokadem et al. (2015) combined hydrogeological, hydrochemical, and isotopic data to find the principal processes and controlling factors influencing groundwater composition and flow dynamics in southwestern Tunisia.

The goal of this study is to make important contributions to science by looking at the hydrochemical properties of the aquifer system, identifying the main factors and mechanisms governing its chemical composition, applying water quality indices to determine if groundwater

is safe for people to drink, and improving understanding of the geochemical transformations responsible for mineral accumulation within the Lower Eocene aquifer in the investigated region.

2. Geology and hydrogeology

The area of study is located about 14 kilometres southwest of Biskra's centre in southeast Algeria. It is situated between Tolga and El Outaya to the north, Oumache and M'lili to the south, Biskra to the east and Bouchagroune to the west; its area spans 208.75 km². This area is known for its extremely dry climate, with an average of 137.16 mm of precipitation per year, most of which falls between October and January. Temperatures average 34.64 °C annually, ranging from 7.10 °C during the colder months to peaks of around 41.28 °C in summer. Estimated annual evapotranspiration reaches approximately 1175.13 mm. Geographically, the Ziban area reflects contrasting structural features between the northern Atlas formations and the southern Saharan zones. From a geological perspective, Biskra serves as a transitional zone, where structural and sedimentary characteristics intersect. Mountainous terrain dominates the northern sector, while the southern part corresponds to a subsiding basin within the northern fringe of the Sahara. Hydrogeologically, the Biskra region hosts four principal aquifer systems: 1. The Quaternary aquifer, 2. The integrated Lower Eocene–Senonian limestone aquifer, 3. The sand aquifer of the Mio-Pliocene, 4. Sandstone aquifer of the Continental Intercalaire.

The most widely used groundwater source in the area is the limestone aquifer, which was created by the Lower Eocene and Senonian. This is the subject of the current study.

This aquifer is particularly accessible in the western part of the study zone, where its depth is relatively shallow—reaching up to 200 meters—compared to depths exceeding 400 meters further east. Groundwater extraction yields vary, with flow rates ranging from 10 liters per second via pumping to 30 liters per second through artesian discharge.

The upper boundary of this aquifer comprises clayey-sandy deposits from the Mio-Pliocene in the northern areas, and Eocene marls with gypsum layers in the south. The main reservoir consists predominantly of fractured white limestone from the Lower Eocene, along with dolomitic marl-limestone formations from the Upper Senonian. The base of the aquifer is underlain by carbonate rocks assigned to the Lower Senonian. In the study zone, the aquifer depth ranges between 120 and 350 meters.

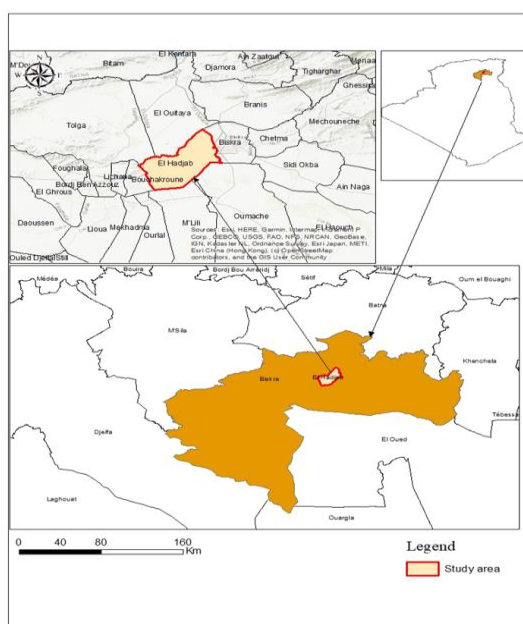


Fig. 1: Study area location.

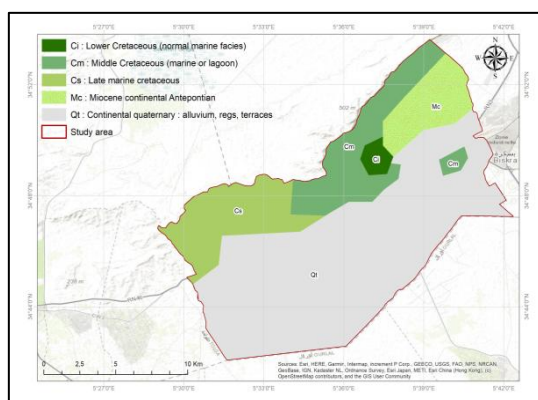


Fig. 2: Geological map of the research region based on the geological map of Algeria and modified using the GIS system.

(Table 1). The groundwater in the El Hadjeb region was tested in May 2017 during a field work carried out to investigate the Lower Eocene aquifer. All analyses were conducted at the Laboratory of the Scientific and Technical Research Centre for Arid Regions (CRSTRA), Biskra. Analytical precision was ± 0.01 for pH, $\pm 2\%$ for EC, and $\pm 5\%$ for the major cations and anions. Temperature, pH, and electrical conductivity are important physicochemical parameters. To ensure consistent and accurate data collection during sampling, field measurements of these parameters were made using a WTW multiparameter probe (Weilheim, Germany) in situ. Samples of water were analyzed to determine the presence of main and trace dissolved elements. The amounts of calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), and bicarbonate (HCO_3^-) were measured using a titration technique. The concentration of sulfate ions (SO_4^{2-}) was measured using a UV- visible spectrophotometer. Potassium (K^+) and sodium (Na^+) were detected using flame photometry at the same laboratory. Mineral saturation indices for a range of common minerals that could be present in the investigated sites were calculated at the measured discharge temperatures. Analysis was performed using PHREEQC version 2.7 software following the procedures outlined by Parkhurst and Appelo (1999) and interfaced with Diagrams version 6.59. The Piper diagram is then generated using the AqQA RockWare version 1.5 demo software package.

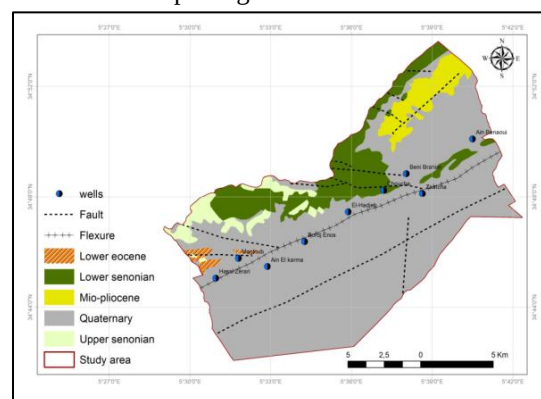


Fig. 3: Map of the study area's hydrogeology and the distribution of wells located in agricultural areas.

3. Materials and methods

A. Sampling and Physicochemical Characterization

From wells located in the Lower Eocene aquifer, nine different water samples were taken

Table 1: Geographic coordinates and details of the sampled wells in the El Hadjeb region

Well ID	Longitude (E)	Latitude (N)	Depth (m)
El-Hadjeb	5°35' 52,80"	34°47'27,6"	160
Beni Brahim	5°38' 2,4"	34°48'50,4"	130
Ain Benaoui	5°40' 30"	34°50'6"	150
Bordj Enos	5°34' 15,6"	34°46'22,8"	96
Choucha	5°37' 12"	34°48'14,4"	104
Magloub	5°31' 48"	34°45'46,8"	---
Hassi Zerari	5°30' 57,6"	34°45'3,6"	210
Ain El Karma	5°32' 52,80"	34°45'28,8"	250
Zaatcha	5°38' 38,4"	34°48'7,2"	260

B. Water Quality Evaluation

B.1. Assessment of Groundwater Quality for Drinking purposes

The Water Quality Index (WQI) method examines various factors to determine the safety of water for multiple purposes, including supporting aquatic life, irrigating crops, enhancing landscape aesthetics, offering recreational and aesthetic benefits, and ensuring potability (Bouslah et al., 2017). WQI is a rating that reflects the combined impact of various water suitability parameters (Ramakrishnaiah et al., 2009). This process consists of generating a single index value that encapsulates the combined influence of various water quality parameters on the suitability of water for human consumption (Chung et al., 2015; Tiwari and Mishra, 1985). The original WQI was developed by Brown et al. (1970), and its calculation requires several consecutive steps.

B.2. Calculation of quality rating (qn)

The quality score (q_n) assigned to the n^{th} parameter is calculated by using the ratio of its measured concentration in the water sample to the corresponding permissible limit set by the WHO (2011), and multiplying the result by 100 (Table 2).

$$q_n = 100 \left[\frac{(V_n - V_{i0})}{(S_n - V_{i0})} \right] \quad (1)$$

Where: q_n denotes the quality score attributed to the n^{th} parameter; V_n corresponds to the observed concentration (mg/L) of the respective chemical constituent in the sample of water; S_n refers to the maximum allowable concentration of that parameter as defined by regulatory standards; V_{i0} indicates the theoretical or ideal concentration of the parameter in uncontaminated water.

All ideal (V_{i0}) values are assumed to be zero (0) for drinking water in all parameters except pH, where it is 7.0, and dissolved oxygen = 16.6 mg.dm⁻³ (Tripathy and Sahu, 2005).

B.3. Unit Weight Calculation (Wn)

The unit weight (W_n) for the n^{th} parameter is determined by applying the following formula:

$$W_n = K/S_n \quad (2)$$

Where: W_n refers to the unit weight assigned to the n^{th} water quality parameter, S_n represents the guideline or permissible concentration for the corresponding parameter, and K is the proportionality constant

B.4. WQI Calculation

The Water Quality Index (WQI) is computed utilizing the equation:

$$WQI = \frac{\sum q_n W_n}{\sum W_n} \quad (3)$$

See Table (3) for more details.

Table 2: WHO guideline values and corresponding relative weights used in water quality index calculation.

Water quality parameter	World Health Organization (WHO, 2011)	1/Sn	K	Relative weight Wn
pH	6.5–8.5	0,117	2,634	0,31
CE (µS/cm)	300a	0,00333		0,00878
TDS (mg/L)	600	0,00166		0,00439
TH (mg/L)	500	0,02		0,005268
Cl ⁻ (mg/L)	250	0,004		0,010536
SO ₄ ²⁻ (mg/L)	250	0,004		0,010536
HCO ³⁻ (mg/L)	120	0,0083		0,02195
Ca ⁺² (mg/L)	75b	0,0133		0,03512
Mg ⁺² (mg/L)	50b	0,02		0,05268
Na ⁺ (mg/L)	200	0,005		0,01317
K ⁺ (mg/L)	12	0,083		0,2195
NO ₃ (mg/L)	10	0,1		0,2634
a WHO (2006)				
b WHO (2004)				

Table 3: WQI classification system for groundwater quality (Ramakrishnalah et al. 2009; Ketata et al., 2011).

Classification of drinking water quality.		
WQI range	Class	Type of water
<50	I	Excellent water
50–100	II	Good water
100–200	III	Poor water
200–300	IV	Very Poor water
>300	V	Water unsuitable for drinking

4. Results and discussion

A. Water Chemistry

The chemical analyses of groundwater samples collected from the study area are presented in Table 4. Groundwater samples extracted from the Lower Eocene aquifer show pH values varying between 6.00 and 7.72. Electrical conductivity (EC) values in the Lower Eocene

aquifer vary from 2920 to 7010 $\mu\text{S}/\text{cm}$ with an average of approximately 4307 $\mu\text{S}/\text{cm}$. The electrical conductivity values demonstrate that most drillings surpass the recommended quality of water standards based on the World Health Organization Standards (WHO, 2002). Electrical conductivity indicates the concentration of total dissolved solids and major ions in the water body (Deshpande and Aher, 2012). The large changes in

EC values are due to the long-term interaction of groundwater with rock and the effects of humans on the environment (Nazzal et al., 2014). Furthermore, the total dissolved solids (TDS) range from 2055 to 4590 mg/L with a mean value of 3087.44 mg/L. The main sources of total dissolved ions (TDS) in water are anions like carbonate, bicarbonate, chloride, and sulfate, as well as cations like calcium and magnesium (Houatmia et al., 2016). The calcium and magnesium concentrations range from 228 to 480 mg/L and 60 to 216 mg/L, respectively, with average values of 348.89 and 160.80 mg/L. Deposits of gypsum and carbonate break down to produce calcium and magnesium. Magnesium, in conjunction with calcium, is obtained from

magnesium-rich carbonate formations such as dolomite. Magnesium is commonly found in evaporite rocks like carnallite ($\text{KMgCl}_3 \cdot 6(\text{H}_2\text{O})$) and biotite. Potassium levels range from 11.30 to 22.82 mg/L, associated with the alteration of potassic clays. Potassium concentrations are higher in aquifers with thin clayey layers. Sodium concentrations range between 203.78 and 1246.14 mg/L, primarily attributed to evaporitic deposits and base exchange processes. The main source of chloride is the dissolution of natural ions dissolving, such as sylvite (KCl) and halite. Chloride levels range from 426 to 1420 mg/L. At levels between 425.86 and 1126.02 mg/L, sulphate ions (SO_4^{2-}) are linked to the production of evaporites, leaching, and the oxidation and dissolution of gypsum rocks.

Bicarbonate levels range from 200.08 to 275.72 mg/L because carbon dissolves in aquifers and carbonate weathering happens. Higher levels of Ca^{2+} and Mg^{2+} that come from calcite and dolomite buffering activities control the Total Hardness (TH) of groundwater.

Fig. 4 illustrates the total hardness (TH) of groundwater in the Lower Eocene aquifer. The values range from 122 to 203 °F. These results indicate that all examined wells exhibited "very hard water", a condition primarily influenced by the decomposition of carbonate and evaporite minerals.

Table 4: Statistical hydrogeochemical parameters

Wells	pH	TDS (mg/L)	EC (μS/cm)	TH (°F)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO ₄ (mg/L)	HCO ₃ (mg/L)	NO ₃ (mg/L)
El-Hadjeb	6,99	3283	4620	122	260	136,80	772,80	18,81	1065	772,33	251,32	4,73
Beni Brahim	6,95	3323	5470	130	228	175,20	844,10	14,31	1278	555,79	222,04	5,14
Ain Benaoui	7,24	3624	5550	125	244	153,60	874,46	17,81	1420	664,06	244,00	5,25
Bordj Enos	7,2	2476	3640	145	480	60,00	518,88	16,31	745,5	425,86	224,48	3,98
Choucha	7,72	4590	7010	186	392	211,20	1246,14	18,81	1349	1126,02	241,56	2,86
Magloub	7,17	2055	2920	147	360	136,80	203,78	22,82	426	700,15	200,08	3,42
Hassi Zerari	7,02	2322	3090	180	360	216,00	213,90	11,80	426	880,60	207,40	2,67
Ain El karma	6,768	2622	3470	203	452	216,00	224,02	11,30	426	1046,62	241,56	1,54
Zaatcha	6	3492	3000	150	364	141,60	884,81	15,31	1313,5	490,83	275,72	4,80
Max	7.72	4590	7010	203	480	216	1246.14	22.82	1420	1126.02	275.72	5.25
Min	6	2055	2920	122	228	60	203.78	11.30	426	425.86	200.08	1.54
Mean	7.0	3087.44	4307.7	154.2	348.89	160.80	642.54	16.36	938.78	740.25	234.24	3.82

TDS: Total dissolved solids, EC: Electrical conductivity, TH:

Hydrotimetric title, Min: Minimum, Max: Maximum

Sawyer and McCarty (1967) said that the overall hardness of the lower Eocene aquifer investigated at a temperature between 122 and 203°F, which suggests the water is exceptionally hard.

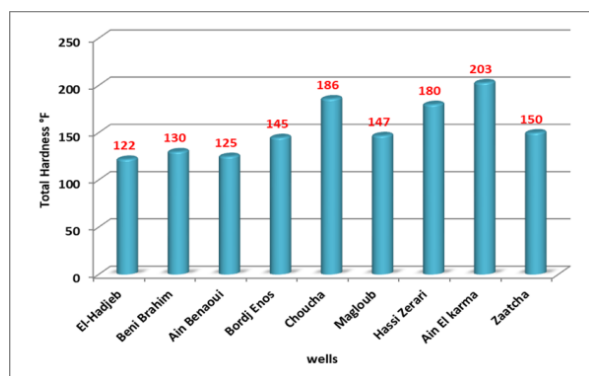


Fig. 4: Total Hardness (TH) of lower Eocene aquifer for the study area, May 2017.

B. Types of Water

The hydrochemical facies reveal the flow patterns of subterranean water and the influence of chemical processes within the geological environment (Bencer et al., 2016). Determined through the conversion of concentrations into meq/l and the classification of ions, these facies provide insights into flow and transport mechanisms in groundwater systems, offering valuable paleoenvironmental data (Hem, 1985; Glynn and Plummer, 2005; Ophori and Toth, 1989). The Piper diagram (Fig. 5) illustrates that

the majority of water samples in the lower Eocene aquifer exhibit a Na-Cl water type.

C. Saturation Index (SI)

The minerals that make up rocks interact with groundwater in two ways: Secondary minerals form when the conditions are either thermodynamically stable or too full, while primary minerals dissolve and release ionic species into solution (Houatmia et al., 2016). Saturation indices (SI) are assessed using the geochemical modeling software PHREEQ C for the groundwater concerning mineral phases (Fig. 6). In this study, carbonate minerals exhibit varying degrees of saturation: dolomite often remains saturated, with an index ranging from +0.02 to +0.48, followed by calcite ranging from -0.08 to +0.28, and aragonite ranging from -0.22 to +0.14. In contrast, evaporite minerals show lower saturation indices than carbonate minerals. Gypsum shows saturation indices between -0.88 and -0.36, anhydrite ranges from -1.1 to -0.58, and halite is largely undersaturated (between -5.73 and -4.49). Groundwater is undersaturated with respect to evaporite minerals (halite, gypsum, and anhydrite), while carbonate minerals tend to precipitate mainly in the form of dolomite.

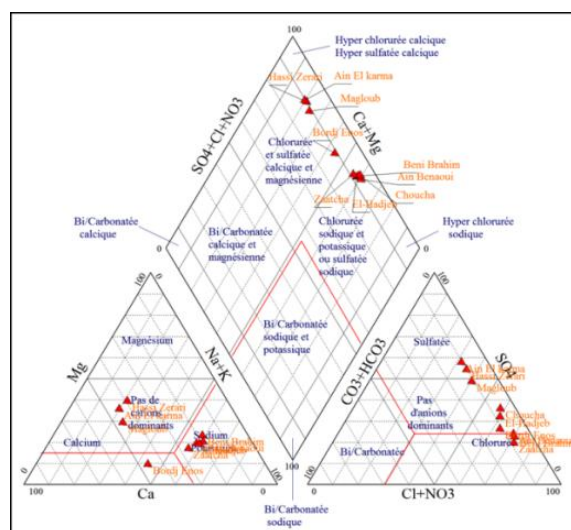


Fig.5: Piper diagram for groundwater samples from the study area, May 2017.

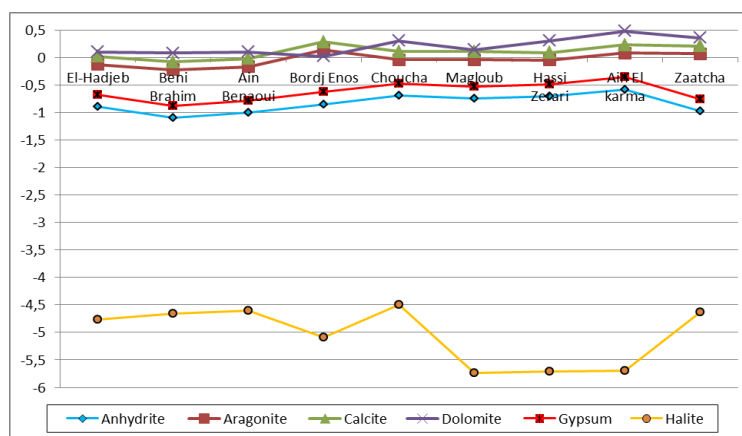


Fig.6: Mineral saturation indices for the Lower Eocene of the study area, May 2017.

D. Groundwater Geochemistry Regulation Mechanisms

Plotting Total Dissolved Solids (TDS) against the weight ratios of $\text{Na}/(\text{Na}+\text{Ca})$ and $\text{Cl}/(\text{Cl}+\text{HCO}_3)$ according to Gibbs (1970) can provide information about the main natural processes affecting water chemistry, including fractional crystallization, weathering of rocks, and atmospheric precipitation and evaporation. Most of the samples of groundwater are found in the evaporation-influenced zone, as shown in Figure (7), suggesting that water irrigation return is a significant factor in the evaporation process.

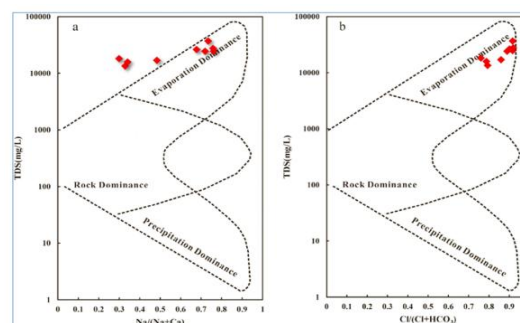


Fig.7: Gibbs plots explaining groundwater geochemical processes in the research area, May 2017.

E. Evaluation of the Potable Water Quality Index

According to the categorization by Ramakrishnaiah et al. (2009) and Ketata et al. (2011) as reported in Table (3), 33.33% of the samples are classified as belonging to the good water category (50-100), while 66.66% fall within the poor water category (100-200). The higher

levels of SO_4 , K, Na, Ca, Mg, HCO_3 , Cl, and TDS are linked to higher WQI values, which

demonstrate that the groundwater in the studied area is of not good quality (Table 5).

Table 5: Water quality index calculation for drinking purposes.

Samples/parameters	El-Hadje b	Beni Brahim	Ain Benaoui	Bordj Enos	Choucha	Magloub	Hassi Zerari	Ain El karma	Zaatcha
CE $\mu\text{S}/\text{cm}$	14,16	16,76	17	11,15	21,48	8,95	9,47	10,63	9,19
Ph	-0,22	-1,08	5,19	4,33	15,57	3,68	0,43	-5,02	-21,63
SO_4	3,41	2,45	2,93	1,88	4,97	3,09	3,89	4,62	2,17
NO_3	13,04	14,18	14,48	10,97	7,88	9,43	7,37	4,25	13,25
K	36,03	27,39	34,11	31,23	36,03	43,7	22,6	21,64	29,31
Na	5,33	5,82	6,03	3,58	8,59	1,4	1,47	1,54	6,1
Ca	12,75	11,18	11,96	23,53	19,22	17,65	17,65	22,16	17,84
Mg	15,09	19,32	16,94	6,62	23,3	15,09	23,82	23,82	15,62
HCO_3	4,81	4,25	4,67	4,3	4,63	3,83	3,97	4,63	5,28
Cl	4,70	5,64	6,27	3,29	5,95	1,88	1,88	1,88	5,8
TDS (mg/L)	2,51	2,55	2,78	1,9	3,52	1,57	1,78	2,01	2,67
TH (mg/L)	1,35	1,43	1,38	1,6	2,05	1,62	1,99	2,24	1,65
Overall WQI	112,95	109,9	123,74	104,37	153,17	111,89	96,32	94,41	87,26

5. Conclusion

To evaluate drinking water quality and identify hydrogeochemical processes, an investigation into the Lower Eocene aquifer in the El Hadje region was conducted. The groundwater from drinking wells is very hard, according to the total hardness (TH) analysis. Hydrochemical analysis indicated a Na-Cl water type, influenced by the study area's geology. The saturation index showed groundwater to be undersaturated with evaporite minerals like halite, gypsum, and anhydrite, with carbonate minerals primarily precipitating as dolomite. The Gibbs plot suggested that groundwater falls within the evaporation zone, likely due to irrigation return water causing evaporation. Overall, the calculated WQI values indicate that groundwater quality is generally unsuitable for drinking without treatment in the designated area.

6. Acknowledgments

The authors express gratitude for the support of the General Directorate for Scientific Research and Technological Development (DGRSDT) and the anonymous reviewers, whose perceptive comments greatly improved the quality of this work.

7. Conflict of Interest

The authors declare that they have no conflict of interest.

8. Funding Statement

Research received no external funding.

9. Author Contributions

Warda Chaib: Contributed to the conceptualization, methodology, data collection and analysis, interpretation, preparation of figures and tables, manuscript writing and revision, and overall coordination of the study.

Farida Bettiche: Contributed to the development of the methodology.

Nora Salemkour: Contributed to field data collection and sampling.

Asma Rezeg: Contributed to data analysis and interpretation.

Halima Mancor: Contributed to field data collection and sampling.

Khadija Bouzid: Contributed to laboratory analyses.

Nora Bouchahm: Contributed to manuscript revision.

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تقييم مؤشر جودة مياه الشرب في المناطق الجافة: تحليل منطقة الحاجب بولاية بسكرة،

جنوب شرقي الجزائر

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تاريخ الاستلام: 05 آب 2025 تاريخ المراجعة: 20 أيلول 2025 تاريخ القبول: 09 تشرين الأول 2025

تاريخ النشر الإلكتروني: 01 تشرين الأول 2026

المخلص

تهدف هذه الدراسة إلى تحليل العمليات الهيدروجيوكيميائية والتباينات الإقليمية في جودة المياه الجوفية ضمن طبقة الأيوسين السفلى في منطقة الحاجب الواقعة جنوب شرقي الجزائر. ولتحقيق هذا الهدف، تم إجراء تحاليل مختبرية شملت قياس التوصيلية الكهربائية (EC)، ودرجة الحموضة (pH)، ودرجة الحرارة (T)، والمواد الصلبة الذائبة الكلية (TDS)، إلى جانب تحديد تراكيز الأيونات الرئيسية، وهي: الصوديوم (Na^+)، البوتاسيوم (K^+)، الكالسيوم (Ca^{2+})، المغنيسيوم (Mg^{2+})، البيكربونات (HCO_3^-)، الكلوريد (Cl^-)، والكبريتات (SO_4^{2-}). تُعد هذه الطبقة الجوفية مصدراً مائياً بالغ الأهمية في المناطق شبه الجافة والجافة، وقد أظهرت النتائج أن السحنة الهيدروجيوكيميائية السائدة للمياه الجوفية هي كلوريد الصوديوم (Na-Cl)، معادن المتبخرات كانت تحت الإشباع وجزء صغير من معدن الدولومايت كان في حالة ترسيب، وظهور محدود لترسيب معدن الدولومايت. كما أوضحت مخططات جيبس أن العمليات الجيوكيميائية الرئيسية المتحكم في جودة المياه هي التبخر وتفاعلات المياه مع الصخور. من خلال حساب مؤشر جودة المياه (WQI)، وُجد أن القيم تراوحت ما بين 87.26 و153، حيث تنتمي 33.33% من العينات إلى فئة "جيدة"، بينما تقع 66.66% منها ضمن فئة "رديئة". وتشير القيم المرتفعة للمؤشر إلى تدهور جودة المياه، ويرتبط ذلك بارتفاع تراكيز SO_4^{2-} ، K^+ ، Na^+ ، Ca^{2+} ، Mg^{2+} ، HCO_3^- ، Cl^- ، وTDS. تؤكد هذه النتائج على أهمية تطبيق سياسات فعالة لإدارة الخزانات الجوفية الهشة من أجل ضمان استدامة هذا المورد الحيوي في ظل الظروف المناخية القاسية التي تميز المنطقة.

الكلمات المفتاحية:

المياه الجوفية، طبقة الأيوسين السفلى، مؤشر جودة المياه، الحاجب.

DOI: [10.33899/injes.v26i4.61113](https://doi.org/10.33899/injes.v26i4.61113), ©Authors, 2026, College of Science, University of Mosul.

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