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Research Article

Groundwater quality assessment for drinking and irrigation purposes in Boumerdes Region, Algeria

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Abstract: In Algeria, water is a critically limited resource. Rapid demographic, urban and economic development has significantly increased water demand, the particularly for drinking water supply and agriculture. Groundwater serves as the primary source of water in the Boumerdes Region, located in northern Algeria, Therefore evaluating groundwater quality for water supply and irrigation purposes is very crucial. In this study, 49 groundwater samples were collected in 2021 and analyzed based on 17 physicochemical parameters. These results were processed using multivariate analysis and compared against the standards established by both the World Health Organization and Algerian Standards. The findings revealed that the concentrations of Sodium, Calcium, Magnesium, and Nitrate of some samples exceeded acceptable limits, indicating that physicochemical treatment is necessary before use for drinking water supply. For irrigation suitability, several indices were employed, including Sodium Adsorption Rate (SAR), Wilcox diagram, Magnesium Absorption Ratio (MAR), Residual Sodium Bicarbonate (RSB), Permeability Index (PI) and Stuyfzand Index. The results of these indices show that groundwater in the region generally meets irrigation standards with a low risk. However, the groundwater should still be managed carefully to prevent salinity-related issues. This study highlights the current status of groundwater quality the Boumerdes region and offers important insights for the sustainable management of water resources in the area.

Keywords: Groundwater quality; Multivariate statistical analysis; Hydrochemical diagram; Water supply; Quality indices; Algeria

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Introduction

Groundwater is considered as a vital resource for both water supply and irrigation purposes (Abdennour et al. 2020; Musaab et al. 2022). The northern region of Algeria, characterized by a semi-arid climate, has recently experienced a severe shortage of surface water leading to an increased reliance in groundwater. This growing demand of groundwater has introduced several challenges, such as inefficient pumping, seawater intrusion, reduced reliable production, and deterioration in water quality. These issues have broader implications, such as increased healthcare costs, negative impacts on irrigation, and adverse effects on the agricultural economy (Rahal et al. 2021; Ferhati et al. 2022; Metaiche et al. 2023).

Recent studies have focused on the physicochemical analysis of groundwater (Adimalla et al. 2020; Li et al. 2019; Ruiz-Pico et al. 2019; Hossam Singh et al. 2020; Dimple et al. 2022; Olusola et al. 2022; Docheshmeh Gorgij et al. 2023; Li et al. 2023; Rehman et al. 2023), which has significantly contributed to the development of ground-

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water quality assessment, tools. These tools have become reliable for monitoring and predicting water quality. Additionally, multivariate statistical approaches are frequently used to analyze and evaluate the physicochemical properties of groundwater (Bencer et al. 2016; Blake et al. 2016; Chen et al. 2022; Djafer Khodja et al. 2022; Ferhati et al. 2023). In arid and semi-arid regions, both natural conditions and human activities impact soil quality and the sustainability of natural resources, including water. Expanding our knowledge of the geochemical evolution of water in these areas can lead to a deeper understanding of their hydrogeochemical systems, ultimately supporting sustainable water resource management and more effective soil conservation practices (Rahal et al. 2021).

The Boumerdes region holds a significant groundwater and surface water reserves, yet no prior studies have been conducted to evaluate the suitability of groundwater for drinking water supply and irrigation purposes. In this context, our study compares the groundwater quality with Algerian and World Health Organization standards (WHO) for water supply. We also calculate various quality indices to assess its suitability for irrigation, and present the findings through cartographic representations. Identifying the factors influencing water quality through appropriate evaluation methods is essential for accurately characterizing the region's hydro-geochemistry. This involves the application of multivariate statistical analyses, chemical facies assessments, and irrigation quality indices.

Commonly used irrigation indices, such as the Sodium Adsorption Ratio (SAR), Wilcox Index, Permeability Index (PI), Magnesium Absorption Ratio (MAR), Residual Sodium Bicarbonate (RSB), and Stuyfz Index have been widely used to assess groundwater quality for irrigation purposes (Al-Mashreki et al. 2023; Sinduja et al. 2023). The Boumerdes region has substantial reserves of groundwater and surface water. In the present study, 49 groundwater samples were collected to analyze 17 physicochemical parameters. Following the calculation of the ionic balance, 31 boreholes were selected for further evaluation of these parameters. This study aims to provide insights into groundwater characteristics of the Boumerdes region, with a focus on its cartographic representation and its suitability for water supply and irrigation purposes.

1 Study area

The Boumerdes region is a coastal area in central Algeria, located in northern Africa. It covers an area of 1,456.16 km^2 and features 100 km-long coastline (Fig. 1). The region is bordered to the north by the Mediterranean Sea, to the south by the state of Bouira, to the east by Tizi Ouzou and to the west by Algeria's capital, Algiers and the state of Blida.

The geology of the Boumerdes region, as presented in Fig. 2, is primarily characterized by formations ranging from the Jurassic to the Quaternary periods, including clay, sandstone, limestone. Additionally, there are some base indentations composed of marmorized limestone, marbles, quartzites, phylliths, which are associated with magmatic bodies such as granite, rhyolite,

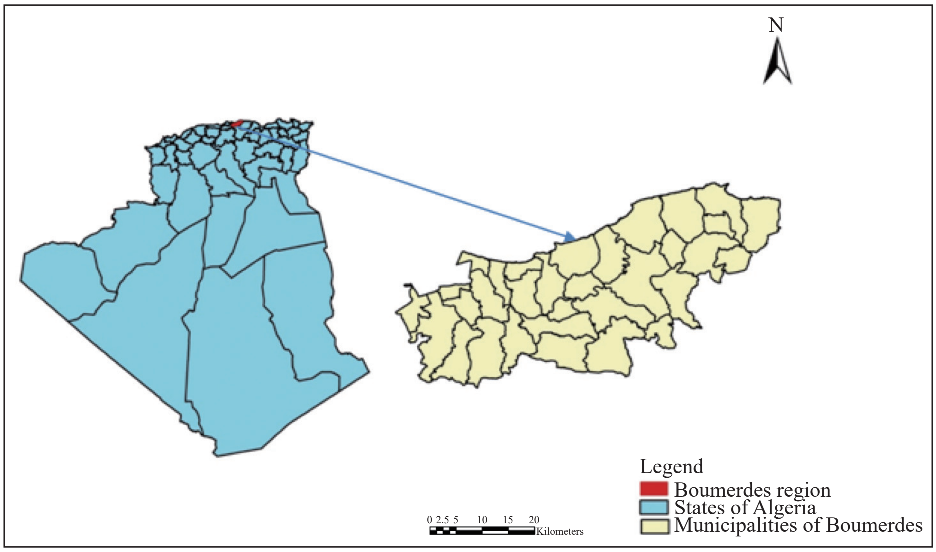


Fig. 1 Geographic location of Boumerdes region

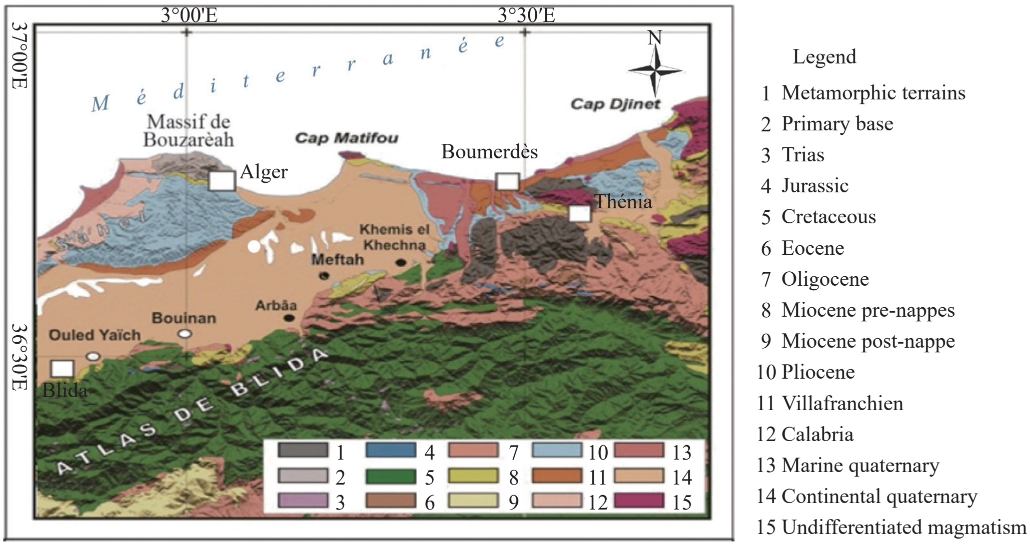


Fig. 2 Lithological map of Boumerdes region

andesite, basalt and dacite (Djafer Khodja, 2020).

The region consists of 43.15% of marly formations, sandstones, and conglomerates, belonging to the marine Oligocene period. Marine formations from the Lower Miocene, primarily composed of sandstones and marls, account for 14.91%. Crystalline and micaceous schists, which include chlorite and sericine schists, as well as biotite quartz, make up 19.84% of the region. Lower Cretaceous formations occupy 2.11% of the basin, consisting of clayey schists, gray marls and sandstones. Continental Quaternary alluviums cover 18.6% of the region.

2 Material and methods

A sampling campaign was carried out in 2021 by the Algerian water of Boumerdes laboratory team in Boumerdes. Groundwater samples were collected from 49 boreholes, as depicted in Fig. 3, obtain representative data on the spatial variability of groundwater quality.

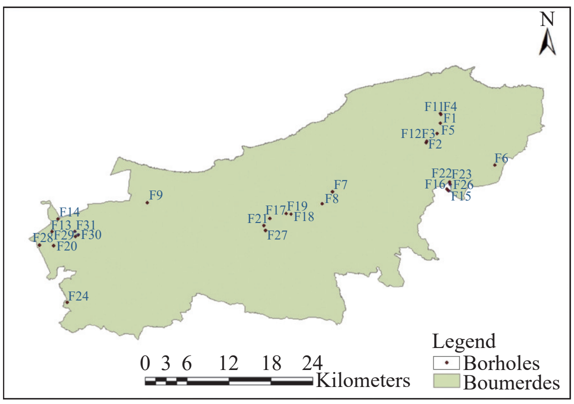


Fig. 3 Cartographic of 49 boreholes of the study area

The study area comprises boreholes with depths ranging from 30 m to 120 m depth. Groundwater e samples were collected after 10 min of pumping and stored in polyethylene bottles. In situ measurements were conducted for pH, temperature and conductivity. The analysis focused on determining the contents of major ions, including (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-}, NO_3^{-}). Samples from the 49 boreholes were analyzed to assess groundwater quality in the region.

To validate the sampling results, the ionic balance (IB in%) was calculated usin the following Equation 1 (Barbaroux et al. 2014).

$$IB = \frac{\sum Cations - \sum Anions}{\sum Cations + \sum Anions} 100 \qquad (1)$$

The contents of actions and anions are expressed in meq/L.

Where: $-10\% < IB < 10\%$: Generally poor but usable; $IB < -10\%$ or $IB > 10\%$: Poor.

The Ionic balance results for the 49 boreholes indicated that 31 of them had IB values not exceeding 10%, suggesting that the results are acceptable. Therefore, this study is based on the data from these 31 boreholes. The physicochemical characteristics of these 31 boreholes are presented in Table 1. The remaining 18 boreholes exceeded 10% for the ionic balance, resulting in poor analysis results, which precludes their use in this study.

3 Results and discussions

The result of study are divided into two parts: The first examines the suitability of groundwater in the

Table 1 Physico-chemical data of Boumerdes groundwaters (2021)

Variables	Minimum	Maximum	Moyenne	Ecart type	Variance
T	9.00	25.00	20.16	5.30	28.07
pH	6.62	7.84	7.11	0.32	0.10
Cond	114.00	2,050.00	1,167.32	425.55	181,091.96
Turbid	0.30	62.00	5.29	12.69	161.07
Na^+	21.00	80.00	43.74	12.49	155.93
K^+	1.00	7.00	3.58	1.77	3.13
Ca^{2+}	52.00	216.00	128.39	40.12	1,609.98
Mg^{2+}	11.00	110.00	42.42	23.45	550.05
NH_4^+	0.00	0.77	0.05	0.15	0.02
Fe^{2+}	0.00	0.37	0.06	0.11	0.01
Mn^{2+}	0.00	0.24	0.02	0.05	0.00
HCO_3^-	186.00	689.00	429.06	110.21	12,146.66
Cl^-	22.00	184.00	89.74	46.83	2,192.93
SO_4^{2-}	11.00	312.00	83.65	55.78	3,111.37
NO_2^-	0.00	0.55	0.05	0.12	0.01
NO_3^-	0.00	103.00	18.83	21.82	476.19
PO_4^{3-}	0.00	0.36	0.01	0.06	0.00

Notes: All Data in (mg/L) except (Turbid (NTU), Cond (μS/cm), pH and T (°C)).

Boumerdes region for water supply, and the second assesses its suitability for irrigation.

3.1 Suitability for water supply

The groundwater quality in the Boumerdes Region was evaluated using multivariate statistical analysis (Seikhy Narany et al. 2014). This analysis involved comparing the physicochemical properties of the groundwater against Algerian and World Health Organization standards to determine its suitability for drinking water supply. The conformity of the physicochemical analysis for water supply was validated by comparing our results with the relvant Algerian and World Health Organization standards, as presented in Table 2(Bengherbia et al. 2014).

In comparison of the maximum value of Table 2 with the standards outlined in Table 1, it was found that the pH, conductivity, temperature, K^+, Cl^-, SO_4^{2-}, are within standards, but Turbidity, Na^+, Ca^{2+}, Mg^{2+}, NH_4^+, NO_3^-, exceed the established norms. For the elements that exceed the norms, it is necessary to ensure physicochemical treatment of the groundwater is necessary before it can be released for water supply. This result is supported by the studies of Khous et al. (2019) and Yahiaoui et al. (2023) who conducted geochemical evaluation of groundwater quality in the Mitidja Plain, which is in proximity to our study region; The geographic information forthe sampling points and the physico-chemical parameters that exceed the norms are illustrated and discussed in the cartographic maps presented in Fig. 4.

Table 2 Physicochemical analysis for water supply according to Algerian and World Health Organization Standards (World Health Organization, 2006; Official Journal of the Algerian Republic, 2011)

Parameters	Algerian Standards	WHO Standards
pH	6.5–9	6.5–9.5
Conductivity (μS⁄cm)	2,800	no guide value
Temperature (°C)	25	no guide value
SO_4^{2-}(mg/L)	400	500
HCO_3^-	no guide value	no guide value
NO_3^-(mg/L)	50	50
Ca^{2+}(mg/L en $CaCO_3$)	200	30
Mg^{2+}(mg/L)	no guide value	100
Na^+(mg/L)	200	no guide value
K^+(mg/L)	12	12
Cl^-(mg/L)	500	250
Turbid (NTU)	5	5

3.1.1 Multivariate statistical analysis

Data processing from the physicochemical analysis of groundwater in the Boumerdes region was

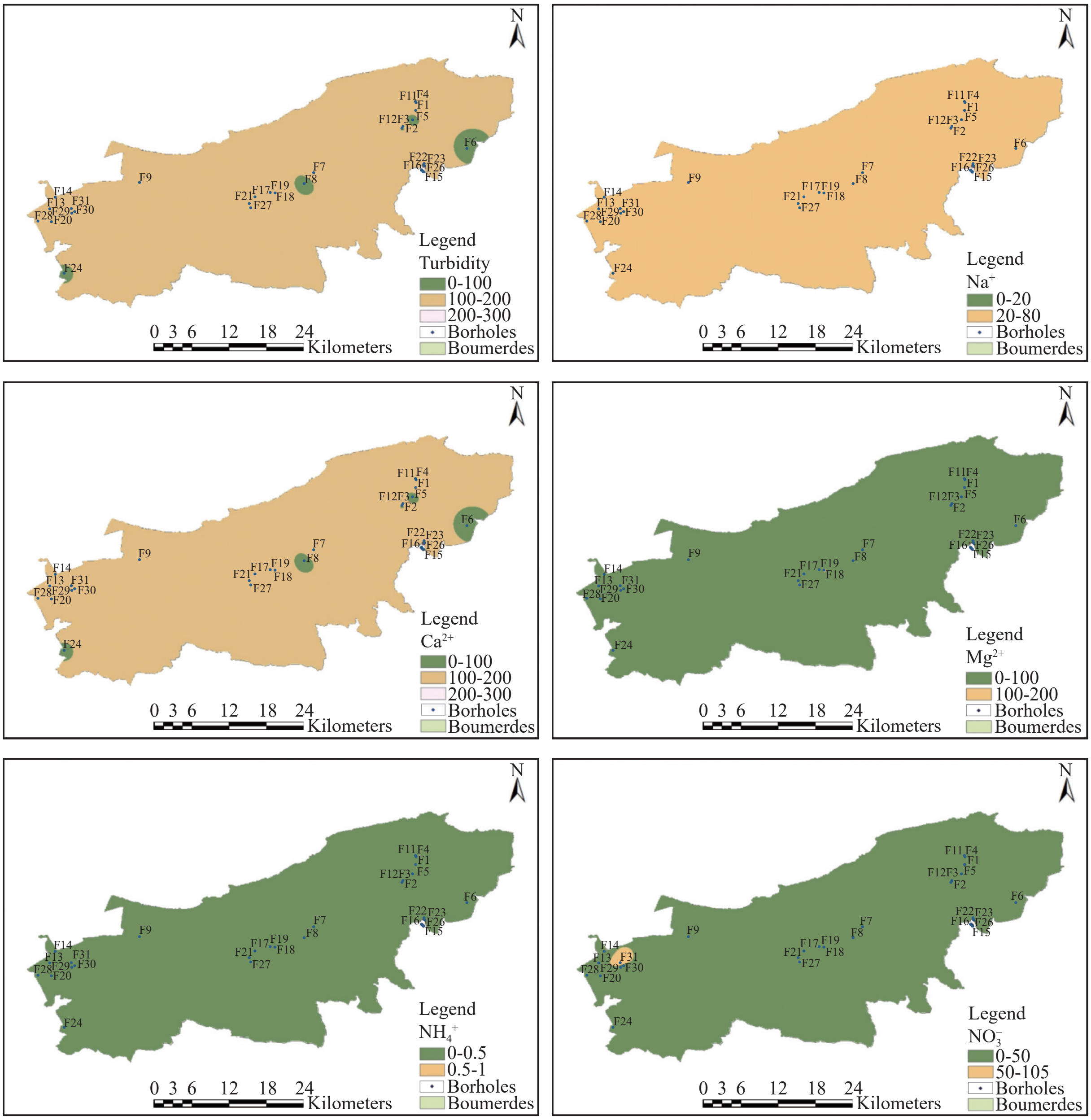


Fig. 4 Cartography of the physic-chemical parameters of the study area

carried out using SPSS version 29.01.0 (171) software.

3.1.1.1 Principal Component Analysis (PCA)

Principal Component Analysis (PCA) proved to a reliable method for determining the physicochemical characteristics of groundwater (Anazawa et al. 2005; Belkhiri et al. 2010; Tiri et al. 2014; Ferhati et al. 2022).

In this study, PCA was performed on 31 boreholes and 17 physicochemical parameters. The first step involved checking the Kaiser-Meyer-Olkin (KMO) index to assess the adequacy of the sampling. The second step consisted of calculating the correlation matrix of parameters, as show in Table 3 and Table 4. The final step included the representation of individual diagrams, which are

Table 3 Kaiser-Meyer-Olkin measure of sampling adequacy

Sampling adequacy tests		Value
Kaiser-Meyer-Olkin index for measuring sampling quality		0.593
Bartlett's test of sphericity	Khi- square approx	249.871
	ddl	136
	Meaning	<0.001

Table 4 Correlation matrix of the physicochemical parameters of Boumerdes groundwater

Variables	T	pH	Cond	Turbid	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	NH_4^{+}	Fe^{2+}	Mn^{2+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	NO_2^{-}	NO_3^{-}	PO_4^{3-}
T	**1.00**																
pH	0.00	**1.00**															
Cond	−0.17	−0.21	**1.00**														
Turbid	−0.01	−0.18	−0.22	**1.00**													
Ca^{2+}	−0.25	−0.21	**0.53**	0.34	**1.00**												
Mg^{2+}	−0.25	−0.06	**0.58**	0.09	0.39	**1.00**											
Na^{+}	0.08	−0.36	0.37	0.27	0.47	0.34	**1.00**										
K^{+}	−0.03	0.16	−0.22	0.07	0.16	−0.30	0.17	**1.00**									
NH_4^{+}	−0.41	−0.07	0.11	−0.04	0.09	0.21	−0.06	0.13	**1.00**								
Fe^{2+}	−0.06	0.13	0.45	0.36	0.46	0.40	0.25	0.04	0.08	**1.00**							
Mn^{2+}	−0.02	0.10	−0.20	0.79	0.38	0.18	0.35	0.32	−0.10	0.38	**1.00**						
Cl^{-}	−0.31	−0.18	0.32	0.37	**0.65**	0.48	0.20	−0.05	0.17	0.34	0.46	**1.00**					
SO_4^{2-}	−0.06	−0.08	0.50	0.03	**0.54**	**0.61**	0.39	0.02	0.08	0.46	0.24	0.44	**1.00**				
HCO_3^{-}	0.04	−0.30	0.42	0.48	**0.61**	**0.58**	**0.62**	0.10	−0.01	0.42	**0.52**	0.50	0.49	**1.00**			
NO_2^{-}	0.27	−0.02	−0.25	−0.15	−0.16	−0.29	0.02	0.31	−0.07	−0.17	−0.17	−0.34	−0.21	−0.08	**1.00**		
NO_3^{-}	−0.23	−0.03	−0.03	0.08	−0.10	0.08	−0.02	−0.40	0.08	0.06	−0.11	−0.04	−0.04	−0.33	−0.11	**1.00**	
PO_4^{3-}	0.17	−0.24	0.26	0.01	0.18	0.20	0.18	−0.27	−0.06	0.20	0.14	0.37	0.18	0.32	−0.07	−0.16	**1.00**

presented in Fig. 5.

Table 3 presents the Kaiser-Meyer-Olkin index and the Bartlett's test of Sphericity. The Kaiser-Meyer-Olkin index value was found to be 0.593, indicating a meritorious sampling adequacy. Bartlett's test of Sphericity yielded a value of less than 0.0005, demonstrating a significant rejection of the null hypothesis, confirming that the correlation matrix is not an identity matrix.

Table 4 presents the correlation matrix of the physicochemical parameters of Boumerdes groundwater. It represents their variability. The ion Ca^{2+} exhibits an average positive correlation of 0.53, 0.65, 0.54, and 0.61 with electrical conductivity, Cl^{-}, SO_4^{2-}, and HCO_3^{-}, respectively. Similarly, Mg^{2+} shows an average positive correlation of 0.58, 0.61, and 0.58 with electrical conductivity, SO_4^{2-}, and HCO_3^{-}, respectively. Additionally, HCO_3^{-} demonstrates an average positive correlation of 0.52 and 0.62 with Mn^{2+} and Na^{+}, respectively.

Fig. 5 illustrates the individual diagrams of Boumerdes groundwater, demonstrating that over 71.491% in the parameters is accounted for. The figure reveals strong correlations with high loadings for conductivity, Ca^{2+}, Mg^{2+}, Fe^{2+}, Na^{+}, HCO_3^{-}, SO_4^{2-} and Cl^{-}. The analysis indicates Factor 1 (F1) accounts for approximately 42.534% of the variance, it give good correlation with conductivity, Ca^{2+}, Mg^{2+}, Fe^{2+}, Na^{+}, HCO_3^{-}, SO_4^{2-} and Cl^{-}. This suggests that F1 can be classified as a salinization factor due to the mineral reactions occurring in the area. Factor 2 (F2) accounts for 28.957% of variance, primarily, explaining the HCO_3^{-} parameter,

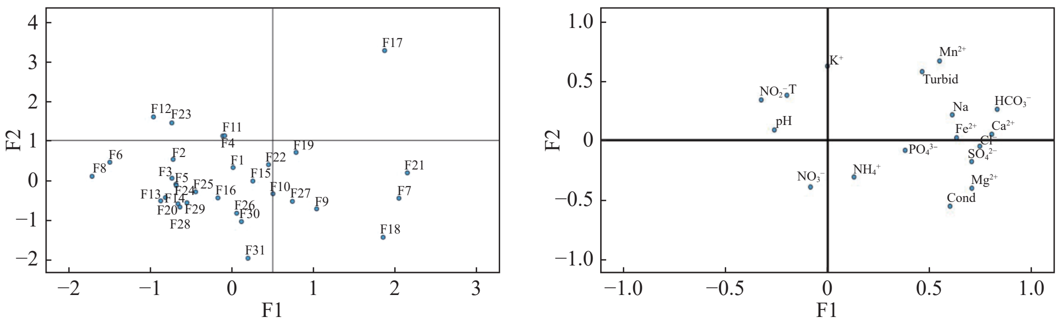


Fig. 5 Individual's diagrams of Boumerdes groundwater

while displaying an inverse correlation with K^+ and turbidity. The subdivision of the measurement points into three groups is observed from the projection analysis of boreholes in the factorial plan F1-F2. The first group, characterized by strong mineralization, included boreholes F6, F7, F8, F17, F18, F21. The second group, including borehole F2, F3, F5, F9, F13, F14, F16, F20, F23, F24, F25, F28, F29, represents the least mineralized waters compared to the first group. The third group, which consists of the weakly mineralized waters, includes boreholes F1, F4, F10, F11, F15, F19, F22, F26, F27, F30, and F31.

3.1.1.2 Hierarchical Cluster Analysis (HCA)

Hierarchical Cluster Analysis was used to classify the physicochemical parameters and boreholes of Boumerdes groundwater (Athamena et al. 2023). The representation of Cluster Dendrogram for the physicochemical parameters and boreholes is show in Fig. 6.

The Cluster Dendrogram for the physicochemical parameters reveals three distinct groups:

The first group consists of HCO_3^-;

The second group includes conductivity (Cond);

The third group encompasses turbidity, pH, temperature (T), Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, NH_4^+, Mn^{2+}, HCO_3^-, Cl^-, SO_4^{2-}, NO_2^-, NO_3^-, and PO_4^{3-}.

The Cluster Dendrogram for the boreholes also reveals three groups:

The first group contains boreholes F7, F9, F10, F18, F21, and F27.

The second group comprises boreholes F6, F8, F12, and F17.

The third group contains F1, F2, F3, F4, F5, F11, F13, F14, F15, F16, F19, F21, F22, F23, F24, F25, F26, F28, F29, F30, and F31.

These results confirm those found by the Principal Component Analysis.

3.1.2 Diagram

3.1.2.1 Piper diagram

The Piper Diagram is used to regroup the chemical facies of the groundwater (Khelif et al. 2018, Lan et al. 2024). The results of the Piper Diagram are given in Fig. 7.

The analysis of the Piper Diagram shows the presence of two chemical facies:

1- Chloride, Nitrate, Bicarbonate facies;

2- Calcium, Magnesium, Bicarbonate facies.

Nitrate, Calcium and Magnesium are the dominant cations, while Bicarbonates, Carbonates and Chloride are the dominant anions across all studied samples.

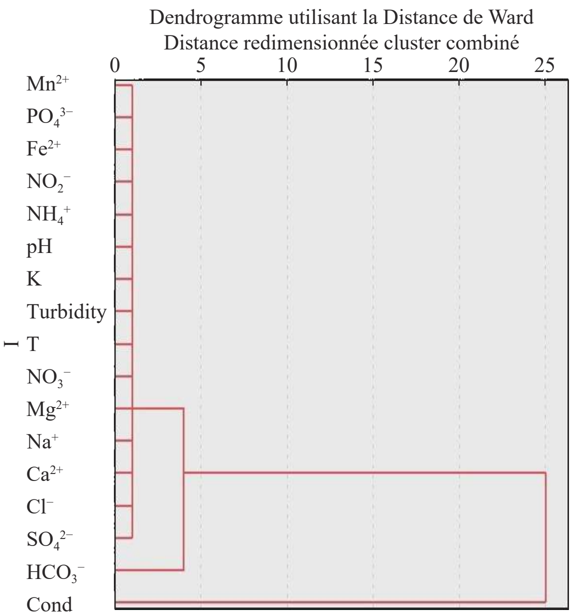
Different facies were observed within two depth intervals: The first layer exhibits a chloride, calcium and magnesium facies, attributed to the dissolution of carbonate rocks.

More soluble rocks such as anhydrite, gypsum and halite, serve the primary sources of Ca^{2+}, Mg^{2+}, Na^+, K^+, CO_3^{2-}, and Cl^- in the soil. However, the distribution of these key elements is influenced by factors such as the distance from landforms, lithology, groundwater flow direction, and other sources of contamination.

3.1.2.2 Schoeller-Berkaloff Diagram

The Schoeller-Berkaloff Diagram presents the dominant facies from all the physico-chemical parameters. The results of the Schoeller-Berkaloff Diagram are show in Fig. 8.

The results of the Schoeller-Berkaloff Diagram



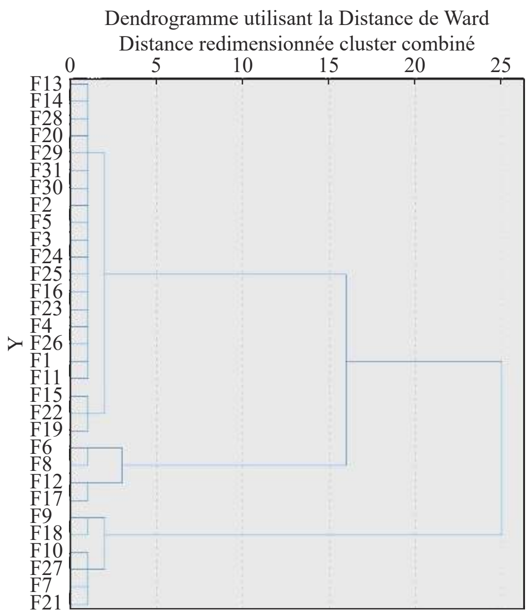


Fig. 6 Cluster Dendrogram for physicochemical and boreholes parameters

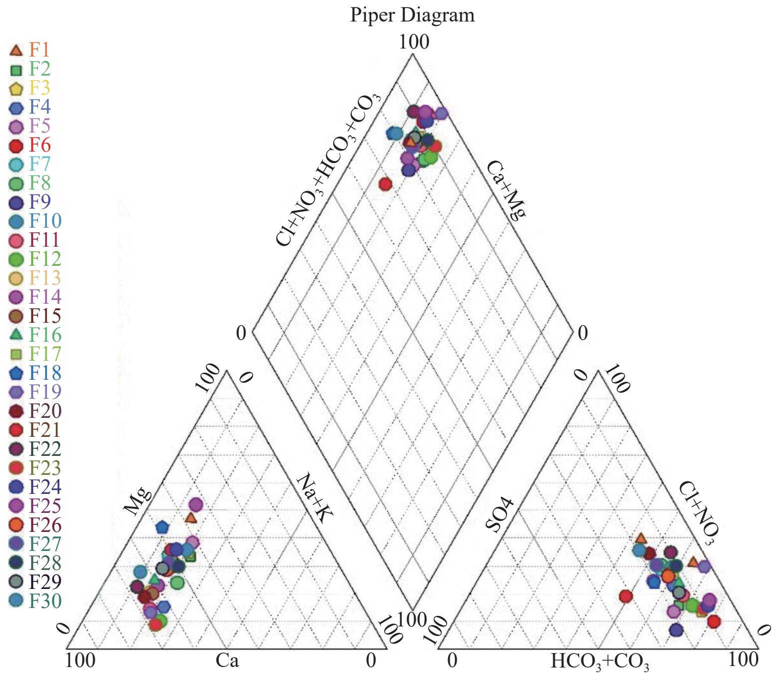


Fig. 7 Piper diagram of Boumerdes groundwater

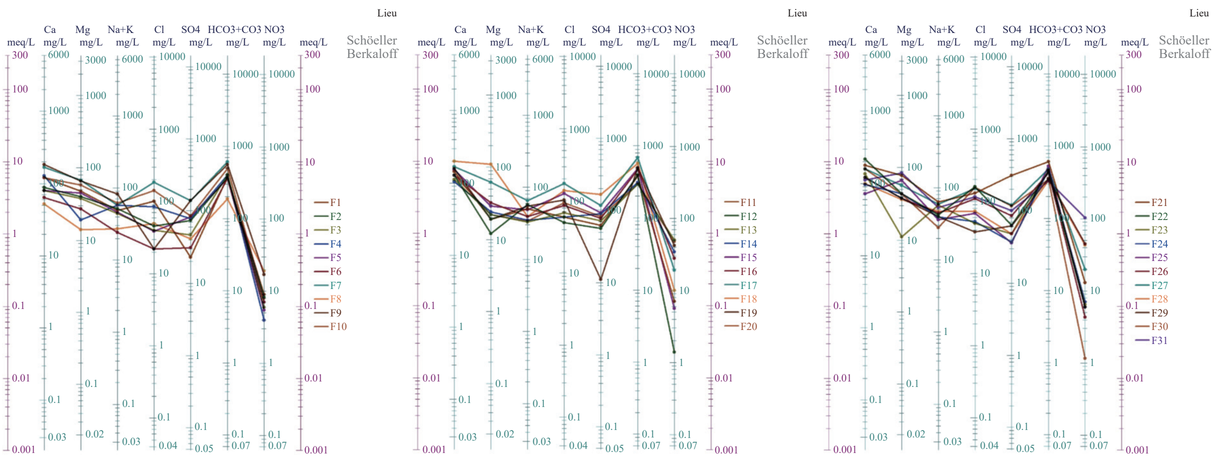


Fig. 8 Schoeller-Berkaloff diagram of Boumerdes groundwater diagram (F1-F10), (F11-F20) and (F20-F31)

confirm the predominance of two facies:

1- Chloride, Nitrate, Bicarbonate;

2- Bicarbonate, Calcium, Magnesium.

3.2 Suitability for irrigation

The suitability of Boumerdes groundwater quality for irrigation through the calculation of various indices, including Sodium Adsorption Ratio (SAR), Kelly's Ratio (KR), Sodium percentage (Na), Permeability Index (PI), Magnesium Absorption Ratio (MAR), Residual Sodium Bicarbonate (RSBC), Potential Salinity (PS) and Stuyfzand Index (SeikhyNarany et al. 2014, Nirdesh et al. 2023, Aly et al. 2024). The formulas and calculations for these indices are provided in Table 5 and Table 6, respectively.

According to Tables 5 and 6:

The Sodium Adsorption Ratio (SAR) provides insight into the abundance of sodium ions relative to calcium and magnesium ions (Bikundia et al. 2014). With SAR values exceeding 26, the water samples fall into sodium risk class S4, indicating a very high risk of alkalization (SAR>26) according to Richard's irrigation water classification (Chaibet et al. 2013; Tegegne et al. 2023).

Kelly's ratio is used to assess the suitability of water for irrigation (Kadyampakeni et al. 2017). All boreholes recorded a Kelly's ration of less than 1, indicating that the water is suitable for irrigation purposes.

Table 5 Formula of Indices Values

Indices	Formula Values	Range	References
Sodium Absorption Ratio (SAR)	$SAR = \frac{[Na^+]}{\sqrt{\frac{[Mg^{2+}]+[Ca^{2+}]}{2}}}$	SAR value: <2=no harm, 2 to 12 =Low hazard, 12 to 22 = Medium hazard, 22 to 32 = High hazard	Bikundia et al. 2014; Chandra et al. 2017
Kelly's Ratio (KR)	$KR(\%) = \frac{[Na^+]}{[Ca^{2+}]+[Mg^{2+}]} \times 100$	KR >1, Unsuitable for irrigation KR <1, Suitable for irrigation	Kadyampakeni et al. 2017
Sodium percentage (%Na)	$Na(\%) = \frac{[Na^+]}{[Ca^{2+}]+[Mg^{2+}]+[Na^+]+[K^+]} \times 100$	Excellent (<20), Good (20–40), Permissible (40–60), Doubtful (60–80), and Unsuitable (>80)	Bouderbala et al. 2017 Yousuf Mia et al. 2023
Permeability Index (PI)	$PI = \frac{[Na^+]+\sqrt{[HCO_3^-]}}{[Ca^{2+}]+[Mg^{2+}]+[Na^+]} \times 100$	Class I with >75%, Class II lying between 25% and 75%, and Class III with <25%	Bouderbala et al. 2017 Johnbosco et al. 2021
Magnesium Absorption Ratio (MAR)	$MAR(\%) = \frac{[Mg^{2+}]}{[Ca^{2+}]+[Mg^{2+}]} \times 100$	MH >50% not suitable for irrigation	Adimalla et al. 2020
Residual Sodium Bicarbonate (RSBC)	$RSBC = [HCO_3^-] - [Ca^{2+}]$	RSBC index values of <5 meq/L indicates water suitable for irrigation	Mallick et al. 2021
Potential Salinity (PS)	$PS = [Cl^-] - \frac{1}{2}[SO_4^{2-}]$	<3 meq/L indicates water suitable for irrigation	Doneen, 1964
Stuyfzand Index	Presents the concentration of Chlorides in water	< 5 mg/L, Very Oligohaline between 5 mg/L and 30 mg/L, Oligohaline between 30 mg/L and 150 mg/L, Fresh between 150 mg/L and 300 mg/L, Fresh Saumater between 300 mg/L and 1,000 mg/L, Saumater between 1,000 mg/L and 10,000 mg/L, Saumate Salted between 10,000 mg/L and 20,000 mg/L, Salted >20,000 mg/L, Very Salty	Coetsiers et al. 2006

Sodium percentage is crucial for classifying water and assessing its suitability for irrigation based on sodium percentages (as function of sodium), calcium, magnesium, and potassium (Yousuf Mia et al. 2023). The sodium percentage (%Na) on the Wilcox Diagram indicates two water quality classes: Excellent (<20), represented by boreholes F6, F8, F12, and F17, and Good (20–40), represented by boreholes F1, F2, F3, F4, F5, F7, F9, F10, F11, F13, F14, F15, F16, F18, F19, F20, F21, F22, F23, F24, F25, F26, F27, F28, F29, F30, and F31.

Permeability Index measures the rate of water infiltration into and through the soil and is an important parameter for irrigation (Egbueri et al. 2021). The Permeability Index of Boumerdes groundwater ranges between 25% and 75%, indicating good quality and posing no issues related to soil permeability.

Magnesium Absorption Ratio is significant in evaluating irrigation water quality. High levels of magnesium can lead to soil infiltration problems and increased salinization in soil (Adimalla et al. 2020). The MAR (%) for almost all boreholes does not exceed 49%, indicating suitable quality for irrigation. However, boreholes F25 and F31 have MAR (%) values that exceed 49%, classify them as marginal quality. While these can be used for irrigation, caution is advised.

Residual Sodium Bicarbonate (RSBC) is critical in assessing irrigation water quality. Water with a high RSBC value typically has a high pH, which can lead to the deposition of sodium carbonate in the soil, ultimately rendering it infertile (Mallick et al. 2021). The variation of RSBC in Boumerdes groundwater shows values of less than 5 meq/L of RSBC for all boreholes, indicating satisfactory groundwater quality that does not pose problems related to bicarbonate and calcium in irrigated soils.

Potential Salinity assesses the suitability of water for irrigation without regard to dissolved salts (Doneen, 1964). The Potential Salinity of all boreholes is less than 3 meq/L indicating that Boumerdes groundwater is generally suitable for irrigation, with the exception of boreholes F7, F17, F22, and F30.

Stuyfzand Index indicates the concentration of

Table 6 Agricultural suitability Index for Boumerdes groundwater

Drilling	SAR(%)	KR	Na(%)	PI(%)	MAR(%)	RSBC	PS	Cl^-(mg/L)
F1	85.86	19.26	15.98	37.15	39.74	0.21	2.62	101
F2	104.31	26.61	20.75	46.4	42.84	1.71	0.54	46
F3	94.53	25.05	19.86	49.08	43.92	2.69	0.64	40
F4	109.08	27.36	21.11	46.86	19.66	0.22	1.6	85
F5	95.36	24.31	19.4	44.81	48.12	1.84	0.24	39
F6	55.51	16.87	14.26	52.76	41.02	2.69	0.3	22
F7	92.14	17.43	14.82	34.2	40.02	1.71	3.77	184
F8	73.09	26.7	20.63	57.85	30.74	0.45	0.96	49
F9	128.74	23.82	19.17	36.04	37.16	0.06	1.1	22
F10	110.64	23.85	19.15	40.61	44.35	2.11	3.11	141
F11	89.43	21.38	17.32	41.05	17.87	−0.99	1.06	60
F12	115.53	30.08	22.76	49.68	13.39	0.1	0.83	50
F13	70.11	18.22	15.33	40.59	24.46	−0.74	1.18	68
F14	75.84	20.04	16.59	42.82	27.56	−0.14	0.77	60
F15	83.77	18.76	15.59	39.56	23.93	0.33	2.58	125
F16	71.69	16.88	14.3	40.77	29.19	1.32	1.64	86
F17	100.51	19.35	16.09	37.1	37.83	2.91	3.69	173
F18	50.76	8.23	7.57	22.44	47.56	−0.64	2.21	139
F19	105.52	24.15	19.37	43.6	16.37	0.21	2.77	102
F20	68.75	16.98	14.44	37.48	22.08	−1.54	1.81	94
F21	92.24	16.58	14.12	31.74	41.98	1.01	0.42	129
F22	59.98	11.18	9.97	26.85	25.14	−3.55	3.82	158
F23	113.12	28.84	22.04	50.18	11.77	0.8	0.89	49
F24	78.48	19.14	15.98	43.55	43.04	2.8	1.09	52
F25	69.31	16.24	13.91	41.82	60.54	5.09	1.55	68
F26	81.5	19.09	15.84	40.29	34.3	0.94	2.18	108
F27	96.76	19.22	16.03	34.78	37	−0.04	2.97	149
F28	100.35	25.16	20.05	43.65	37.25	0.5	1.57	73
F29	75.39	17.66	14.9	37.47	34.3	−0.19	0.43	38
F30	48.93	10.19	9.23	27.98	30.7	−2.33	3.23	157
F31	88.74	17.75	15.02	30.87	55.29	−0.18	2.22	115

chlorides in water. Elevated chloride levels in irrigation water can adversely affect soil quality and, consequently, agricultural crop health (Coetsiers et al. 2006). Results from the Stuyfzand Index show that almost all boreholes in the aquifer have chloride concentrations between 30 mg/L and 150 mg/L, categorizing them as fresh water. However, boreholes F7, F22 and F30 exceed 150 mg/L, and are classified as brackish water.

The various indices assessing irrigation water quality are presented and discussed in relation to each borehole, and are illustrated in different colors on the regional map shown in Fig. 9.

4 Conclusion

This paper evaluates the quality of Boumerdes groundwater and its suitability for water supply and irrigation using cartographic methods. The assessment was conducted through hydrochemical studies using multivariate statistical analysis, and diagram for water supply, as well as the calcula-

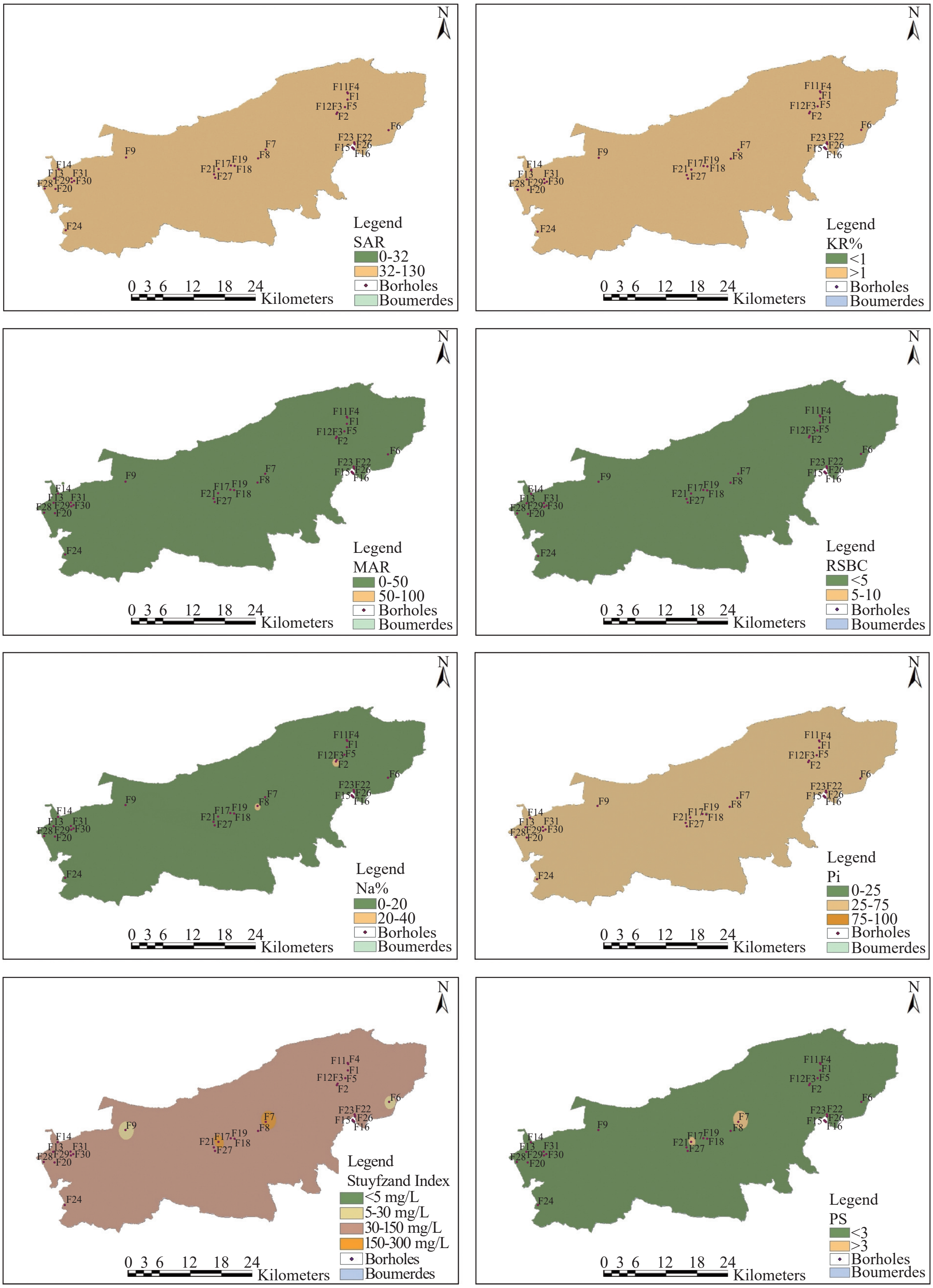


Fig. 9 Cartography of irrigation water quality indices

tion of several indices, including SAR, KR, PS, IP, MAR, RSBC, PS, and Stuyfzand Index for irrigation water.

The suitability of Boumerdes groundwater for water supply was assessed against Algerian and World Health Organization standards. The levels of sodium, calcium, magnesium, nitrate exceeded the established norms, indicating the need for physicochemical treatment prior to water supply. Results regarding irrigation suitability indicate that the SAR index suggests a low risk of salinization linked to groundwater, though salinization control measures should be implemented. The sodium percentage reflects permissible groundwater quality for irrigation, while the Permeability Index indicates good quality with no issues regarding soil permeability. The MAR (%) values prove the groundwater is suitable for irrigation, and RSBC results indicate satisfactory groundwater quality that does not pose issues with bicarbonate and calcium in irrigated soils. Additionally, Potential Salinity and Kelly's Ratio suggests the Boumerdes groundwater is generally suitable for irrigation, and the results from the Stuyfzand Index reveal that most groundwater is characterized by fresh water.

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