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Management and monitoring of mixed groundwater and surface water quality in Bechar, southwestern Algeria

Gestione e monitoraggio della qualità delle acque sotterranee e superficiali nella città di Bechar, Algeria sud-occidentale

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Abstract

Bechar, in southwestern Algeria, depends on two main water sources: groundwater accounts for 80%, while surface water accounts for 20%. The aim of the study is to assess the suitability of water in the Bechar region for drinking and irrigation purposes by analyzing physical and chemical parameters. The results revealed distinct differences in the composition of groundwater and surface water. Surface water was characterized by SO_4^{2-}, Cl^-, Ca^{2+} *and* Mg^{2+} *composition, whereas groundwater varied between* SO_4^{2-}, Cl^-, Ca^{2+}, *and* Mg^{2+} *and* HCO_3^-, Ca^{2+}, *and* Mg^{2+} *types. We classified most groundwater samples as good quality for drinking purposes, while the surface water requires careful quality monitoring. In addition, the quality of irrigation water has been assessed, with groundwater being more suitable and reliable than surface water sources. The study also highlighted significant changes in the chemical properties of water when groundwater is mixed with dam water, including increased pH, reduced concentration of dissolved salt and effects on mineral concentrations (such as calcium, magnesium) and anions (such as chlorides, sulfates and nitrates). All these findings highlight the need to improve water resource management and sustainability*

Riassunto

La città di Bechar, nell'Algeria sud-occidentale, dipende da due principali fonti idriche: l'80% proviene da acque sotterranee, mentre il 20% da acque superficiali. L'obiettivo dello studio è valutare la qualità delle acque utilizzate nella regione per scopi potabili e irrigui, analizzando i parametri fisici e chimici. I risultati hanno rivelato nette differenze nella composizione delle acque sotterranee e superficiali. La composizione delle acque superficiali è caratterizzata da SO_4^{2-}, Cl^-, Ca^{2+} e Mg^{2+}, mentre quella delle acque sotterranee è caratterizzata da SO_4^{2-}, Cl^-, Ca^{2+}, Mg^{2+} e da HCO_3^-, Ca^{2+}, Mg^{2+}. La maggior parte dei campioni di acqua sotterranea può essere classificata come di buona qualità per scopi potabili, mentre le acque superficiali richiedono un attento monitoraggio idrochimico. È stata inoltre valutata la qualità dell'acqua di irrigazione, dimostrando che le acque sotterranee sono più adatte e affidabili rispetto alle acque superficiali. Lo studio ha inoltre evidenziato cambiamenti significativi nelle proprietà chimiche delle acque sotterranee mescolate con le acque contenute nelle dighe, tra cui un aumento del pH, una ridotta concentrazione di sali disciolti ed effetti sulle concentrazioni di minerali (come calcio e magnesio) e anioni (come cloruri, solfati e nitrati). Tutti questi risultati evidenziano la necessità di migliorare la gestione e la sostenibilità delle risorse idriche.

Introduction

Water is the most crucial resource on the planet and it is considered essential for life, as it covers about 71% of the Earth's surface. Water exists in various forms and types, playing a vital role in providing drinking water, supporting ecosystems, and sustaining agriculture and industry.

Currently, competition for water resources has intensified, particularly in arid and semi-arid regions where water scarcity is prevalent. Unfortunately, water quality assessment often receives little attention in these areas (Aragaw & Gnanachandrasamy, 2021; Batarseh et al., 2021). According to Zubaidi et al. (2020), several interrelated factors, such as population growth, climate change, intensive agriculture, urbanization, and industrial activity, increase the demand for water. Hanjra & Qureshi (2010) and Oude Essink (2001) indicate that ensuring water quality and maintaining its availability are vital for future generations, necessitating the recognition of the importance of water and the implementation of sustainable practices.

Yousefi et al. (2018) emphasized the need for proper water quality assessment, especially with the increasing demand for clean water for drinking and irrigation purposes.

Such evaluations encompass hydrochemical analyses and the characterization of various physico-chemical parameters, including Electrical Conductivity (EC), Hydrogen power (pH), major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), major anions (SO_4^{2-}, HCO_3^{-}, Cl^{-}, NO_3^{-}), and other chemical compounds found in the water (Mester et al., 2023). The utilization of the Water Quality Index (WQI) method has been instrumental in assessing the quality of both surface and groundwater (Wu et al., 2018), condensing extensive data into a single value through a predefined set of criteria (Abbasi et al., 2012). This comprehensive approach enables a holistic evaluation of water quality, facilitating informed decision-making regarding its suitability for various uses and highlighting the importance of sustainable water management practices.

Aher & Gaikwad (2017), Bora & Goswami (2017), Goher et al., (2014) provided evidence that the WQI simplifies complex water data, making it a useful tool for decision-makers. Based on that, specific indicators such as the drinking water and irrigation water quality indices were developed to assess different water uses.

Bechar is located in a dry area in Algeria, facing significant water supply challenges, given the insufficient availability of surface water to meet drinking and irrigation needs, characterized by weak rain distributions and high evaporation rates. This makes groundwater the only option to meet the ever-increasing demand for water. This study aims to determine the physical and chemical characteristics of groundwater and surface water and assess its quality for drinking and irrigation purposes, to assist decision makers in improving the management of water resources and associated risks.

Kendouci et al. (2019) noted that drinking water storage tanks play a vital role in meeting the clean and safe water needs of communities, where they collect and store potable water, thus ensuring its continuous and stable availability, especially in areas with water shortages or during periods of drought. Water quality standards change as they move from treatment plants to user taps, as a result of increased residence time of water in the distribution network and reduced concentration of disinfectants, as chemical reactions that begin during treatment in bulk water and on pipe walls continue. In addition, mixing water from different sources in the tanks alters its quality, as indicated by Spencer (2012).

In the city of Bechar, south-west of Algeria, water sources include the Djorf Torba dam (surface water), the Turonian aquifer of Ouakda, the Jurassic aquifer of Moughel, and the Albian aquifer in Boussir.

In this study, we provided a comprehensive assessment of groundwater and surface water quality in Bechar using multiple indices, alongside chemical facies analysis to understand geochemical interactions. Geographic Information Systems were also applied using the inverse distance weighting technique to map water quality distribution. Meanwhile, the study focused on the impact of mixing groundwater and surface water within the reservoirs, an aspect that has not been deeply studied in previous research in the region, providing a comprehensive view of changes in water quality that contributes to improving water resource management.

Study Area

The city of Bechar is located in southwestern Algeria, at an elevation of about 750 meters above sea level, situated at latitudes 31°10'55" and 32°02'54" N and longitudes 1°21'07" and 2°24'18" E (Fig. 1). It spans an area of approximately 5,050 square kilometers, about 950 kilometers southwest of the Algerian capital and roughly 58 kilometers south of the Moroccan border. It is bordered administratively to the north by Moughel and Lahmar, to the west by Béni Ounif, to the east by Kenadsa, and the south by Taghit. Bechar is a significant regional hub, with approximately 63% of the province's population residing within its boundaries (Mebarki et al., 2024). As of 2023, its population numbered around 288,553 inhabitants.

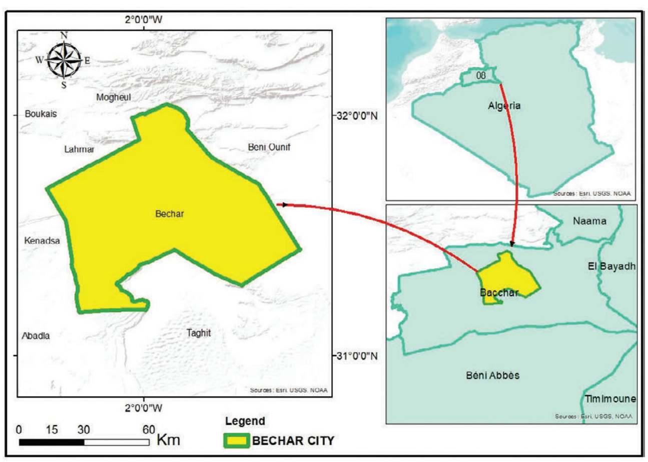

Fig. 1 - Map of the study area.

Fig. 1 - Carta dell'area di studio.

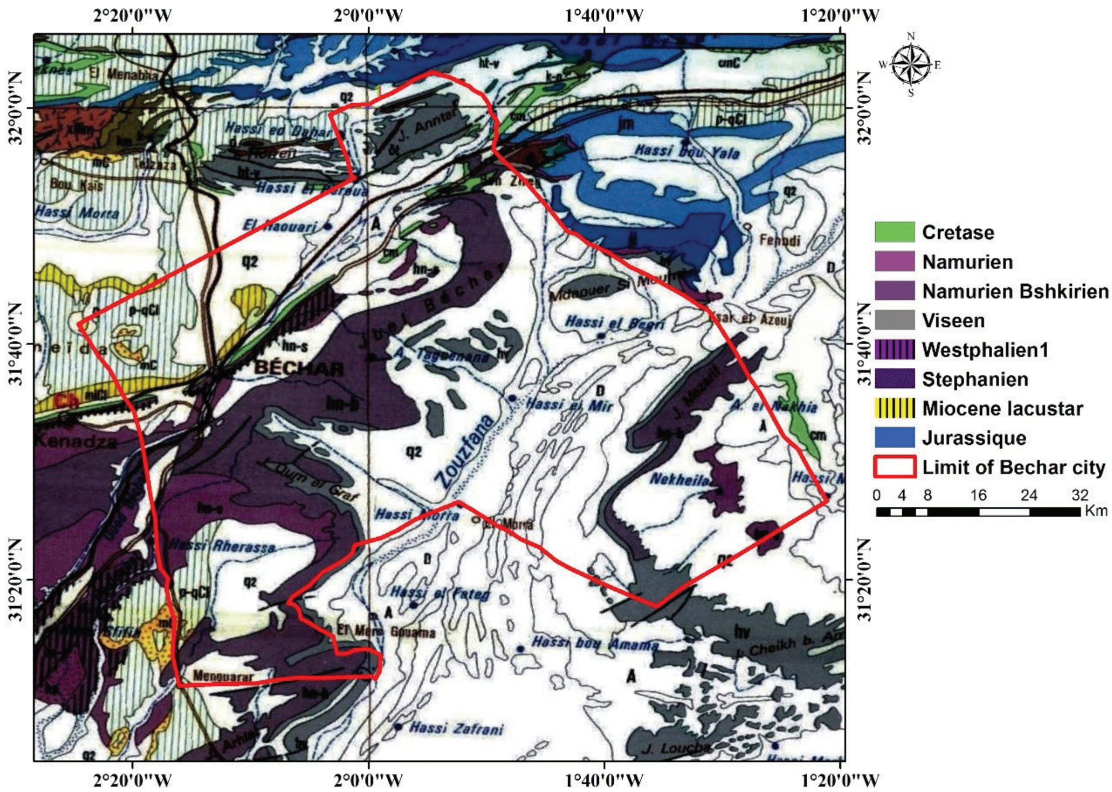

Fig. 2 - The geological map of the city of Bechar (Bekhira et al., 2019).

Fig. 2 - Carta geologica della città di Bechar (Bekhira et al., 2019).

From a climatic perspective, Bechar is located into an arid region, with cold winters and hot summers. Temperatures range from a minimum of 9.8 °C in January to a maximum of 34.8 °C in July, with an average annual precipitation of about 72.97 mm and a maximum monthly evaporation average of 496.8 mm in July and August. Regarding water resources, the area heavily relies on groundwater, primarily used as a source of drinking water and for irrigating purposes. Groundwater serves as the sole source for the residents of the Bechar region, particularly during periods of drought. Geologically, the region lies in a transitional zone between the Saharan Atlas Mountains and the desert, characterized by diverse geological formations spanning the Jurassic, Cretaceous, Triassic, and Quaternary periods (Fig. 2) (Menchikoff, 1936). The Lower Cretaceous sandstone is predominantly utilized as a primary water source, covering nearly every basin with a thickness exceeding 100 m (Mebarki et al., 2024).

The Ouakda hydrogeological system is made up of two aquifers: Turonian and Quaternary. Mebarki et al. (2024) mentioned that the flow rate is approximately 6,700 m^3/day, based on estimates from the National Agency for Water Resources Distribution. In addition, the Moughel aquifer, located north of Bechar, near the Moroccan border (Kendouci et al., 2023), is a semi-captive aquifer with dolomitic limestone fissures from the Lower Jurassic epoch that provided around 2,600 m^3/d in 2023 for drinking water supply (Mebarki et al., 2021; Mebarki et al., 2024). Furthermore, the Boussir aquifer is part of the Alpine water pipeline network owned by the municipality of Beni-Ounif and dates back to the Lower Cretaceous era. This is mostly composed of sand, gravel, and clay rocks, and is distinguished by its capacity to deliver water at a daily production rate ranging from 25,000 to 30,000 m^3/d.

Materials and Methods

This section of the research pertains to the materials used and the methodology (Fig. 3) we adopted in this study.

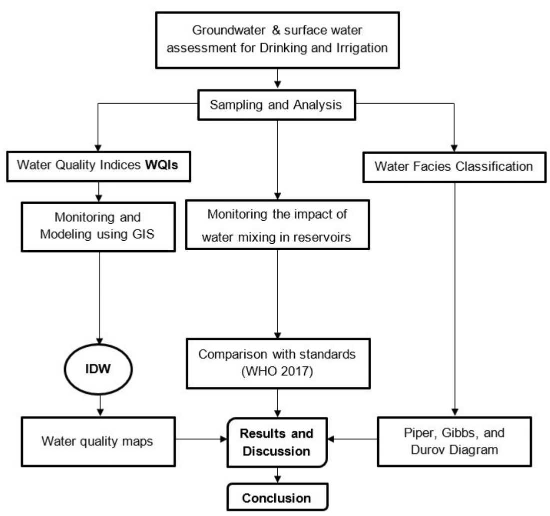

Fig. 3 - A flowchart illustrating the methodology adopted in this study.

Fig. 3 - Diagramma di flusso che illustra la metodologia adottata in questo studio.

Sampling and Analysis

A total of 154 samples divided among three groundwater sources (Ouakda, Moughel, and Boussir aquifer) and Djorf Torba dam (surface water) were collected for a period of 4 years from January 2020 to December 2023, to analyze eleven elements, Electrical conductivity (EC), mineralization, and pH to assess water quality for consumption and irrigation (Fig. 4). Subsequently, a flame photometer was used to measure sodium (Na^+) and potassium (K^+). The UV-visible spectrophotometer quantified sulfate (SO_4^{2-}) and nitrate (NO_3^-), and the complex titration method was used to identify calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), and bicarbonate (HCO_3^-).

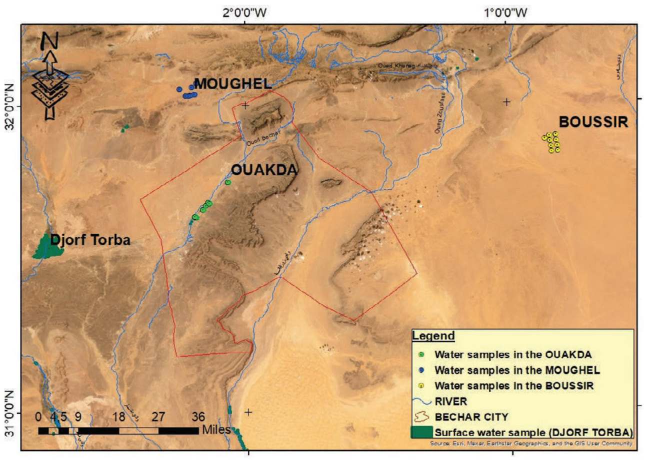

Fig. 4 - Water sampling location in the study area.

Fig. 4 - Ubicazione dei punti di campionamento nell'area di studio.

These values were then used to classify water samples according to several water quality index (Bora & Goswami, 2017; Varol & Davraz, 2015). Location maps and spatial distribution maps of different parameters were created using the Geographic Information System. Graphical representations including Piper plot, Durov diagram, Gibbs diagram, USSL diagram, and Wilcox diagram were also created.

Water Quality Indices (WQI)

The relevance of surface/ground water for drinking and irrigation purposes was assessed using the WQIs, which included DWQI, IWQI, Na%, SAR, SSP, PI, KI, and PS values. The WQI is a computational tool that summarizes water quality, aiming to convert a set of physical and chemical parameters into a single value that reflects the overall state of water quality. This allows for the evaluation and comparison of water quality at different locations and time periods, thereby facilitating the interpretation of data and decision-making related to water resource management (Horton, 1965; Brown et al., 1972):

- DWQI (Drinking Water Quality Index) is used to assess the suitability of water for human consumption based on various physical and chemical standards;
- IWQI (Irrigation Water Quality Index) is used to assess water quality for irrigation purposes by combining 5 criteria into one value;
- Na% (Sodium percentage) is used to assess the suitability of water for irrigation purposes due to the effect of Na^+ concentrations on soil permeability;
- SAR (Sodium Adsorption Ratio) is used to assess the suitability of water for irrigation based on Sodium hazards;
- SSP (Soluble Sodium Percentage) is used to assess salinity levels by comparing Na^+ concentrations to Ca^{2+} and Mg^{2+} concentrations;
- PI (Permeability Index) is used to estimate the impact of water salinity and alkalinity on soil permeability, which affects agricultural land productivity;
- KI (Kelly's Index) is used to measure the suitability of water for irrigation by comparing the concentration of sodium to calcium and magnesium;
- PS (Potential Salinity) is used to assess the suitability of water for use in irrigation, based on the concentrations of Chloride and Sulfate ions.

Details about how the above WQIs are calculated and the suitability of water based on their values are reported in the Appendix.

Results and Discussion

Physico-chemical parameters

Table 1 reports the physico-chemical characteristics of the groundwater and surface water samples collected from January 2020 to December 2023.

This study included 159 samples from both groundwater and surface water sources. The values of Electrical Conductivity (EC), Hydrogen power (pH), and major ions (Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, HCO_3^-, SO_4^{2-}, and NO_3^-) were recorded for all samples. Table 1 includes minimum, maximum, mean, and standard deviation values. Most of the samples in the study area, whether surface water or groundwater, showed that the mean pH values ranged from 7.25 to 7.56, indicating alkaline water properties as they did not exceed the recommended values by the World Health Organization (WHO, 2017).

The EC values in surface water associated with the Djorf Torba dam ranged from 897 to 12,042 µS/cm. According to the WHO (2017) guidelines, 93.54% of the EC values fall within the acceptable range of 1,000 µS/cm.

Conversely, the EC values for groundwater in Ouakda accounted for 52.46% of samples that did not exceed the WHO recommended limit. In Boussir, this was 79.31%, while in Moughel it was 82.35%. These results indicate that part of the samples remain within accepted criteria, while the remainder exceed the recommended limit.

The cation found in the highest concentration in the surface water of the study area (Djorf Torba dam) was calcium (Ca^{2+}), followed by sodium (Na^+), magnesium (Mg^{2+}), and potassium (K^+), with average mass concentrations of 222 mg/L, 165 mg/L, 78 mg/L, and 12.7 mg/L, respectively. The anion found in the highest concentration was chloride (Cl^-), followed by bicarbonate (HCO_3^-) and then sulfate (SO_4^{2-}), with average mass concentrations of 1471 mg/L, 427 mg/L, and 343.5 mg/L,

Tab. 1 - Descriptive statistical analysis of the physico-chemical parameters.
Tab. 1 - Analisi statistica dei parametri chimico-fisici.

Parameter	T	pH	EC	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl–	SO_4^{2-}	NO_3^-
Djorf Torba dam (surface water) Number of samples = 31												
Max	31.8	8.27	12042	6640	222	78	165	12.7	427	1471	343.5	35
Min	11.2	7	897	440	60	9.36	34	3	61	194.97	77.05	0
MEAN	21.85	7.56	2030	1045	97.9	38.39	73	7.9	170	436.64	158.87	4.73
SD	6.40	0.30	2004	1100	38.6	15.73	23	2.2	75.8	238.22	55.47	6.58
Ouakda aquifer (groundwater) Number of samples = 60												
Max	29.5	7.9	2115	1096	88	68.4	66	9.6	518.5	531.75	117.4	45.62
Min	13.3	6.94	580	282	32	15.6	1	0.2	183	141.6	0.98	1.77
MEAN	23.1	7.29	980	491	63.1	39.8	36	2.2	382.3	240.08	35.50	15.98
SD	5.1	0.23	243	126	14.9	13.2	18	1.9	101.1	76.49	26.94	8.75
Boussir aquifer (groundwater) Number of samples = 29												
Max	25.8	8.02	1840	925	100	76	86	11.1	427	354	107.6	70.5
Min	18.2	7.23	587	285	28	7.2	15	1.5	152	53	20.8	1.07
MEAN	21.6	7.56	874	430	52	43.1	27	4.9	272.7	150	56.4	36.02
SD	2.4	0.19	345	176	18	14	17	2.7	77.9	84.5	26.7	14.00
Moughel aquifer (groundwater) Number of samples= 34												
Max	27.7	7.7	1927	970	86	68.64	55	6.5	488	288	78.2	85
Min	13.3	6.69	418	202	17.6	12	5	0.6	262.3	35.45	21.12	4.43
MEAN	16.83	7.25	804.53	435.79	55.71	40.93	14.69	1.93	374.85	114.25	41.79	33.57
SD	3.08	0.28	358	159.54	17.40	15.18	11.38	1.35	74.37	55.43	15.35	20.57
Note: With the exception of pH, temperature (°C), and EC (µs/cm), all parameters are stated in mg/L.												

respectively. The cation found in the highest concentration in the groundwater for Ouakda was calcium (Ca^{2+}), while the anion found in the highest concentration was chloride (Cl^-). Calcium (Ca^{2+}) and bicarbonate (HCO_3^-) were the cation and anion, respectively, with the highest concentrations in the groundwater for Boussir and Moughel. The concentration of the other ions was relatively low.

Groundwater facies and control of geochemical processes

The main ionic constituents of the water samples analyzed in this study were traced on the Piper diagram to analyze hydrochemical facies (Piper, 1944). Each facies type indicates the predominant cations and anions that influence the hydrochemistry of a sample (Singh et al., 2020).

The four main facies types represented in the Piper diagram are Ca^{2+}, Mg^{2+}, SO_4^{2-}, and Cl^- (Type I); Na^+, Cl^-, and SO_4^{2-} (Type II); Na^+, K^+, and HCO_3^- (Type III); and Ca^{2+}, Mg^{2+}, and HCO_3^- (Type IV). The results revealed that in the cationic triangle, 20% of all samples collected at the Djorf Torba dam belonged to the calcium type, while the others belonged to the non-dominant class, and in the anionic triangle, chloride type was the dominant class in all samples (Fig. 5). The chemical composition characteristics of groundwater using the Piper diagram in the Ouakda aquifer showed that the predominant cations in the interstitial water were Mg^{2+} and Ca^{2+}, the others belonged to the non-dominant class, whereas the predominant anion was bicarbonate (HCO_3^-) and chloride (Cl^-). From the Boussir aquifer, the major cations in the interstitial water were Mg^{2+}, and the anions were bicarbonate (HCO_3^-) and chloride (Cl^-), while in the Moughel aquifer, the principal cations in the water were Mg^{2+} and Ca^{2+}, and the primary anions were HCO_3^-. In the rhomboid shape of the Piper diagram, surface water samples from the Bechar region fell into the SO_4^{2-} Cl^- Ca^{2+} Mg^{2+} type, while groundwater samples were divided into two main hydrochemical facies: some fell into the SO_4^{2-} Cl^- Ca^{2+} Mg^{2+} class, while others fell within the HCO_3^- Ca^{2+} Mg^{2+} range.

The ion content characteristics of groundwater are jointly affected by factors such as atmospheric precipitation, temperature, and subsurface lithology, which are also linked to the regional hydrogeological environment (Fan et al., 2014).

The diagram was classified into three fundamental zones by applying the Gibbs plot to understand the effects of various mechanisms controlling water chemistry (Fig. 6a). The first zone consists mainly of precipitation with low TDS and high $Na^+/(Na^+ + Ca^{2+})$ and $Cl^-/(Cl^- + HCO_3^-)$ ratios. The second domain is characterized by moderate levels of TDS and aforementioned cation/anion ratios, representing rock alteration. The final mechanism is the third evaporative domain in the upper half of the Gibbs diagram with extremely high TDS (Gibbs, 1970).

By analyzing groundwater samples from Bechar using Gibbs diagrams, it was found that samples from the Bechar groundwater fell within the TDS range of 200 to 10,000 mg/L. Furthermore, most of the water samples in the Ouakda aquifer fell within the evaporative concentration control zone

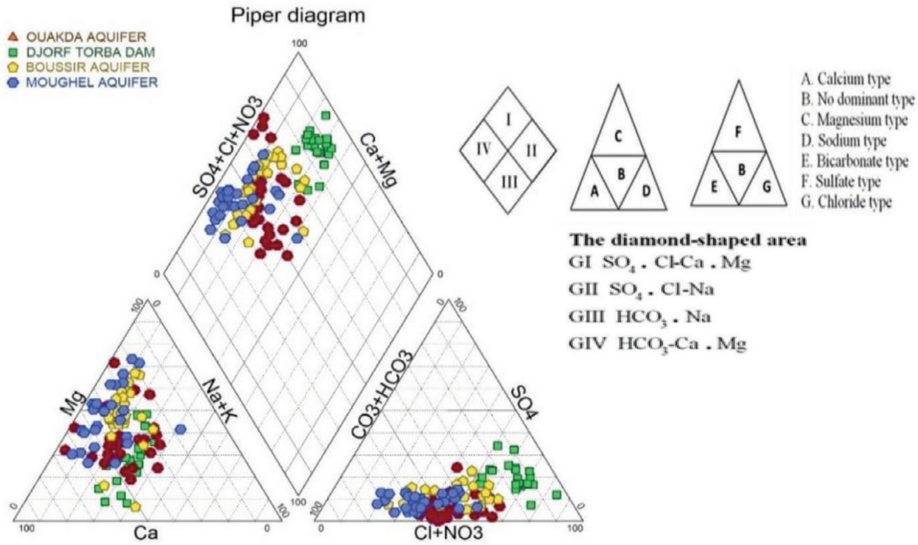

Fig. 5 - Piper diagram of samples collected in the study area.

Fig. 5 - Diagramma di Piper dei campioni prelevati nell'area di studio.

and the rock alteration control zone (Fig. 6a). However, most of the groundwater samples from the Boussir and Moughel aquifers fell within the evaporative concentration control zone.

When water becomes enriched in minerals until it reaches a high saturation level, leading to an increase in TDS, reverse ion exchange can play a crucial role in regulating the chemical composition of groundwater. The Durov diagram, which correlates pH, TDS, and major ions, has been adopted as a visualization tool in hydrogeology by various researchers (Durov, 1948). This diagram illustrates three essential processes: mixing/dissolution, ion exchange, and reverse ion exchange (Fig. 6b). When the TDS exceeds 200 mg/L, all samples were found in the ion exchange zone, confirming the previous statistical explanation.

Water Quality Indices

In this study, the groundwater and surface water quality in the Bechar region was assessed using parameters introduced in the previous sections (DWQI, IWQI, Na%, SAR, SSP, KI, PS, and PI). These parameters were statistically analyzed and categorized to better understand the overall water quality. Additionally, GIS zoning maps for each parameter were used to display and examine water quality in the study area for various purposes, such as drinking water and agricultural irrigation. This integrated approach provides a comprehensive understanding of groundwater and surface water quality, which is vital for sustainable water resource management and informed decision-making regarding environmental policies.

Table 2 shows the statistical analyses on Djorf Torba dam, Ouakda aquifer, Boussir aquifer and Moughel aquifer.

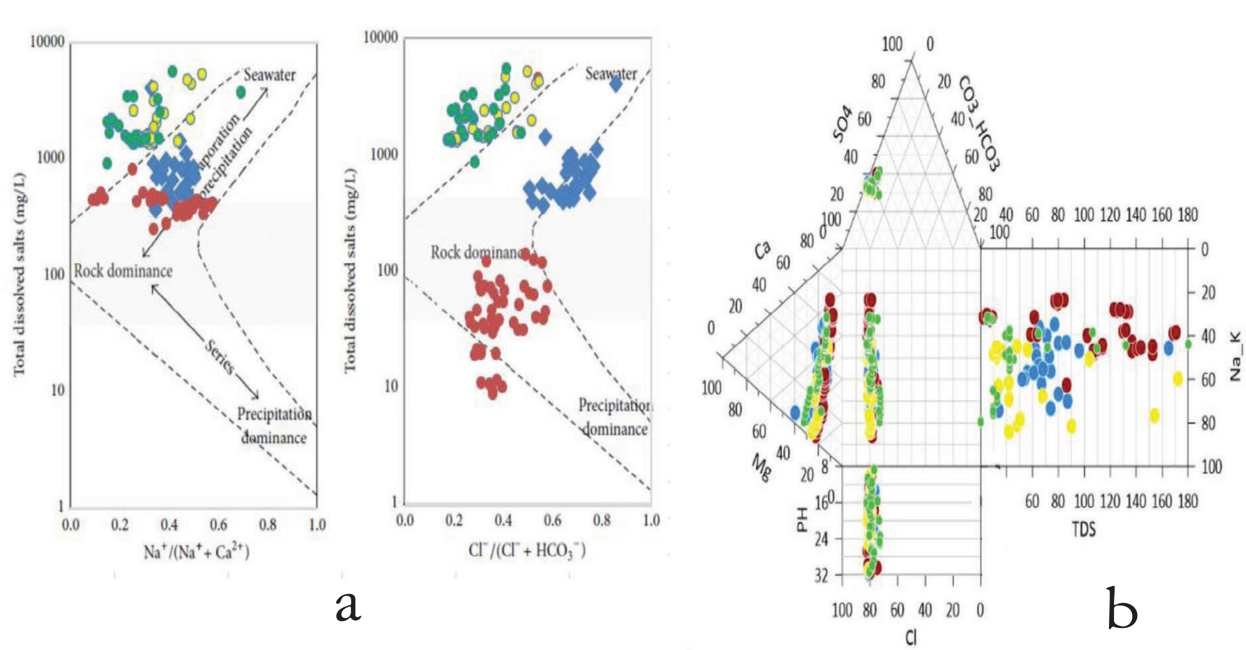

Fig. 6 - The geochemical mechanism controlling water chemistry: (a) Gibbs plot; (b) Durov diagram.

Fig. 6 - Meccanismo geochimico che governa la chimica dell'acqua: (a) Diagramma di Gibbs; (b) Diagramma di Durov.

Tab. 2 - Statistical analysis and classes of WQIs (Djorf Torba dam (surface water) Number of samples = 31.
Tab. 2 - Analisi statistica e classi di WQIs (Diga di Djorf Torba (acque superficiali) Numero di campioni = 31) .

Water Quality Indices (WQIs)	Sample Range			Range	Water Category	Number of Samples (%)
	Min	Max	Mean			
Djorf Torba dam (surface water) Number of samples = 31						
DWQI	50.94	110.35	75.29	<50	Excellent water	0 (0%)
				50-100	Good water	29 (93.55%)
				100-200	Poor water	2 (6.45%)
				200-300	Very poor water	0 (0%)
				>300	Unsuitable for drinking	0 (0%)
IWQI	10.33	73.50	56.42	85–100	No restriction	0 (0%)
				70–85	Low restriction	3 (9.68%)
				55–70	Moderate restriction	15 (48.39%)
				40–55	High restriction	4 (12.90%)
				0–40	Severe restriction	2 (6.45%)
Na%	51.78	71.18	61.56	<20	Excellent	0 (0%)
				20–40	Good	0 (0%)
				40–60	Permissible	8 (33.33%)
				60–80	Doubtful	16 (66.67%)
SAR	5.37	18.49	9.83	<10	Excellent	0 (0%)
				10–18	Good	0 (0%)
				18–26	Doubtful or fairly poor	8 (33.33%)
				>26	Unsuitable	16 (66.67%)
SSP	49.39	70.42	60.00	<60	Safe	11 (45.83%)
				>60	Unsafe	13 (54.17%)
KI	0.98	2.38	1.55	>1	Unsuitable	23 (95.83%)
				<1	Good	1 (4.17%)
PS	2.18	15.64	5.58	>5	Injurious to unsatisfactory	18 (60%)
				3–5	Good to injurious	10 (33.33%)
				<3	Excellent to good	2 (6.67%)
PI	30.38	51.16	40.21	<25%	Unsuitable—Class III	0 (0%)
				25–75%	Good—Class II	24 (100%)
				>75%	Good—Class I	0 (0%)

Drinking Water Quality Index (DWQI)

The results of the analysis showed variations in water quality among different water sources (Tab. 2). The classification of water quality using the DWQI indicated that approximately 93.55% of surface water samples were classified as good, while the remaining 6.45% were classified as poor quality. All groundwater samples were within the good quality category, with values ranging from 50 to 100, using the inverse distance weighting technique to analyze and distribute drinking water quality indicators in the study area. This method allowed for an accurate spatial representation of water quality distribution, helping to identify the most suitable areas for drinking purposes (Fig. 7). This indicates that most surface water samples can be considered safe for drinking, while groundwater can consistently be relied upon as a safe source of drinking water.

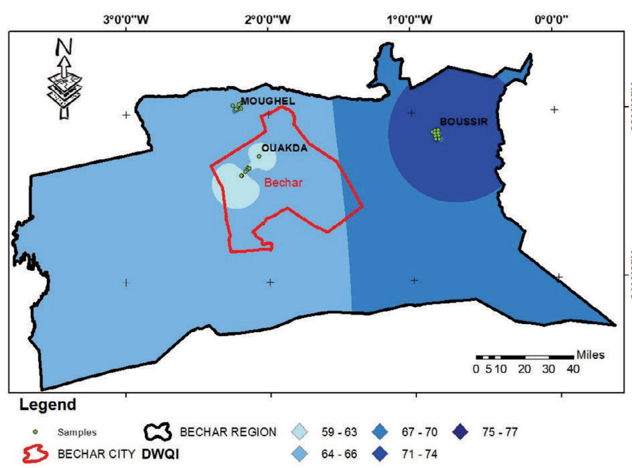

Fig. 7 - Spatial distribution map of DWQI in the study area.
Fig. 7 - Carta della distribuzione spaziale del DWQI.

Tab. 2 - Statistical analysis and classes of WQIs (Ouakda aquifer (groundwater) Number of samples = 60).
Tab. 2 - Analisi statistica e classi di WQIs (Acquifero di Ouakda (acque da falda) Numero di campioni = 60) .

Water Quality Indices (WQIs)	Sample Range			Range	Water Category	Number of Samples (%)
	Min	Max	Mean			
Ouakda aquifer (groundwater) Number of samples = 60						
DWQI	55.18	80.04	63.52	<50	Excellent water	0 (0%)
				50-100	Good water	60 (100%)
				100-200	Poor water	0 (0%)
				200-300	Very poor water	0 (0%)
				>300	Unsuitable for drinking	0 (0%)
IWQI	46.78	72.92	60.05	85–100	No restriction	0 (0%)
				70–85	Low restriction	5 (8.33%)
				55–70	Moderate restriction	19 (31.67%)
				40–55	High restriction	13 (21.67%)
				0–40	Severe restriction	0 (0%)
Na%	2.80	74.10	48.43	<20	Excellent	5 (13.51%)
				20–40	Good	3 (8.11%)
				40–60	Permissible	16 (43.24%)
				60–80	Doubtful	13 (35.14%)
SAR	0.15	12.69	5.96	<10	Excellent	0 (0%)
				10–18	Good	0 (0%)
				18–26	Doubtful or fairly poor	8 (33.33%)
				>26	Unsuitable	16 (66.67%)
SSP	2.51	73.72	47.52	<60	Safe	24 (64.86%)
				>60	Unsafe	13 (35.14%)
KI	0.03	2.81	1.14	>1	Unsuitable	19 (51.35%)
				<1	Good	18 (48.65%)
PS	2.42	347.27	27.01	>5	Injurious to unsatisfactory	52 (94.55%)
				3–5	Good to injurious	2 (3.64%)
				<3	Excellent to good	1 (1.82%)
PI	11.98	64.48	32.28	<25%	Unsuitable—Class III	29 (48.33%)
				25–75%	Good—Class II	31 (51.67%)
				>75%	Good—Class I	0 (0%)

Irrigation Water Quality Index (IWQI)

The results presented in Table 2 indicate that using surface water for irrigation in the study area negatively impacts both soil and crops at all levels. Moderate restriction was observed in most surface water samples (48.39%).

According to the IWQI classification results, approximately 57% of the groundwater samples were classified as having moderate irrigation restrictions, indicating their suitability for irrigating crops with moderate salt tolerance in areas with light soils. About 24% had low restrictions, indicating that crops may not tolerate salinity, and it is better to use sandy soil with medium permeability. The study revealed that 20% of the water in the area was classified as having high irrigation constraints, suitable only for highly permeable soils and crops with medium to high salt tolerance. The results of this study are valuable for assessing the suitability of groundwater for irrigation, as they illustrate how water suitability for irrigation is determined based on physical and chemical criteria. The Inverse Distance Weighting method was used to create interpretive maps of water quality (Fig. 8). According to IWQI values, this study revealed a deterioration in irrigation water quality from north to south within the study area, due to changes in its topography. This highlights the necessity of sustainable water management to enhance the overall effectiveness of irrigation practices in the region.

Sodium Percentage (Na%)

The analysis of sodium percentage (Na%) in groundwater samples, as presented in Table 2, reveals significant variation across the studied regions. In the Djorf Torba dam and Boussir

Tab. 2 - Statistical analysis and classes of WQIs (Boussir aquifer (groundwater) Number of samples = 29).
Tab. 2 - Analisi statistica e classi di WQIs (Acquifero di Boussir (acque di falda) Numero di campioni = 29) .

Water Quality Indices (WQIs)	Sample Range			Range	Water Category	Number of Samples (%)
	Min	Max	Mean			
Boussir aquifer (groundwater) Number of samples = 29						
DWQI	61.57	93.19	73.51	<50	Excellent water	0 (0%)
				50-100	Good water	29 (100%)
				100-200	Poor water	0 (0%)
				200-300	Very poor water	0 (0%)
				>300	Unsuitable for drinking	0 (0%)
IWQI	49.69	74.59	64.83	85–100	No restriction	0 (0%)
				70–85	Low restriction	3 (10.34%)
				55–70	Moderate restriction	23 (79.31%)
				40–55	High restriction	3 (10.34%)
				0–40	Severe restriction	0 (0%)
Na%	32.18	74.58	43.54	<20	Excellent	0 (0%)
				20–40	Good	13 (44.83%)
				40–60	Permissible	13 (44.83%)
				60–80	Doubtful	3 (10.34%)
SAR	2.41	14.42	4.28	<10	Excellent	27 (93.10%)
				10–18	Good	2 (6.90%)
				18–26	Doubtful or fairly poor	0 (0%)
				>26	Unsuitable	0 (0%)
SSP	29.62	73.54	41.03	<60	Safe	26 (89.66%)
				>60	Unsafe	3 (10.34%)
KI	0.42	2.78	0.78	>1	Unsuitable	5 (17.24%)
				<1	Good	24 (82.76%)
PS	2.19	13.59	5.92	>5	Injurious to unsatisfactory	16 (55.17%)
				3–5	Good to injurious	8 (27.59%)
				<3	Excellent to good	5 (17.24%)
PI	22.11	56.38	35.12	<25%	Unsuitable—Class III	1 (3.45%)
				25–75%	Good—Class II	28 (96.55%)
				>75%	Good—Class I	0 (0%)

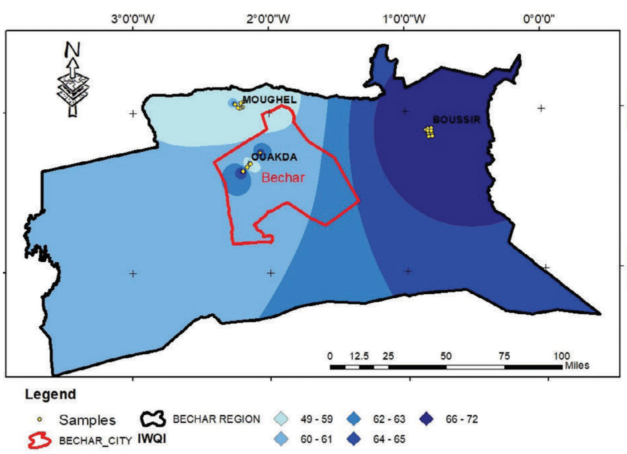

Fig. 8 - Spatial distribution map of IWQI in the study area.
Fig. 8 - Carta della distribuzione spaziale del IWQI.

aquifer, most samples fall within the doubtful and permissible categories for irrigation, indicating potential challenges in water suitability for agricultural use. In contrast, the Ouakda aquifer records a substantial proportion of samples in the permissible category, with limited representation in the excellent and good categories. Groundwater quality in the Moughel aquifer appears more favorable, with the majority of samples classified as excellent and good, suggesting better suitability for irrigation. These findings highlight the importance of continuous water quality assessment to ensure its sustainable use in agricultural activities.

An additional analysis was conducted to explore the relationship between EC and Na% for a more comprehensive evaluation of the suitability of irrigation water. The Wilcox diagram (Fig. 9) shows that the majority of surface and groundwater samples fall into the excellent and good

Tab. 2 - Statistical analysis and classes of WQIs (Moughel aquifer (groundwater) Number of samples = 34).
Tab. 2 - Analisi statistica e classi di WQIs (Acquifero di Moughel (acque di falda) Numero di campioni = 34) .

Water Quality Indices (WQIs)	Sample Range			Range	Water Category	Number of Samples (%)
	Min	Max	Mean			
Moughel aquifer (groundwater) Number of samples = 34						
DWQI	59.19	73.12	65.56	<50	Excellent water	0 (0%)
				50-100	Good water	34 (100%)
				100-200	Poor water	0 (0%)
				200-300	Very poor water	0 (0%)
				>300	Unsuitable for drinking	0 (0%)
IWQI	44.60	74.23	57.24	85–100	No restriction	0 (0%)
				70–85	Low restriction	14 (41.18%)
				55–70	Moderate restriction	12 (35.29%)
				40–55	High restriction	3 (8.82%)
				0–40	Severe restriction	0 (0%)
Na%	11.62	74.02	30.68	<20	Excellent	9 (31.03%)
				20–40	Good	13 (44.83%)
				40–60	Permissible	6 (20.69%)
				60–80	Doubtful	1 (3.45%)
SAR	0.72	11.49	2.54	<10	Excellent	28 (96.55%)
				10–18	Good	1 (3.45%)
				18–26	Doubtful or fairly poor	0 (0%)
				>26	Unsuitable	0 (0%)
SSP	10.72	73.41	29.17	<60	Safe	28 (96.55%)
				>60	Unsafe	1 (3.45%)
KI	0.12	2.76	0.51	>1	Unsuitable	4 (13.79%)
				<1	Good	25 (86.21%)
PS	1.57	13	5.91	>5	Injurious to unsatisfactory	17 (50%)
				3–5	Good to injurious	11 (32.35%)
				<3	Excellent to good	6 (17.65%)
PI	15.93	69.81	30.22	<25%	Unsuitable—Class III	13 (38.24%)
				25–75%	Good—Class II	21 (61.76%)
				>75%	Good—Class I	0 (0%)

categories, indicating a low to medium level of sodium and salinity, making the water safe to use for irrigation without adversely affecting soil and crops. These results enhance the usability of groundwater and surface water in irrigation, taking into account periodic monitoring to ensure continuity in quality.

Sodium Adsorption Ratio (SAR)

Table 2 indicates that the calculated SAR percentage belongs to the excellent category for over 90% of the groundwater samples, indicating their suitability for irrigation. The water samples were represented on a USSL diagram to explore the impact of water quality on crops. This diagram illustrates the relationship between EC and SAR, categorizing them into several classes (Fig. 10), with most of the samples classified as C3-S1 (high salinity–low SAR). This indicates that there is no effect on the water infiltration capacity in the soil due to the low value of the sodium adsorption ratio (SAR) compared to other ion ratios.

Soluble Sodium Percentage (SSP)

The results of SSP (Tab. 2) indicate that sodium levels in samples are balanced with calcium and magnesium, reducing the risk of affecting soil permeability, and therefore water can be used in irrigation without any adverse effects on soil and crops.

Kelly Index (KI)

We observed that the majority of the samples were unsuitable for irrigation. High values of KI (Tab. 2) indicate that there

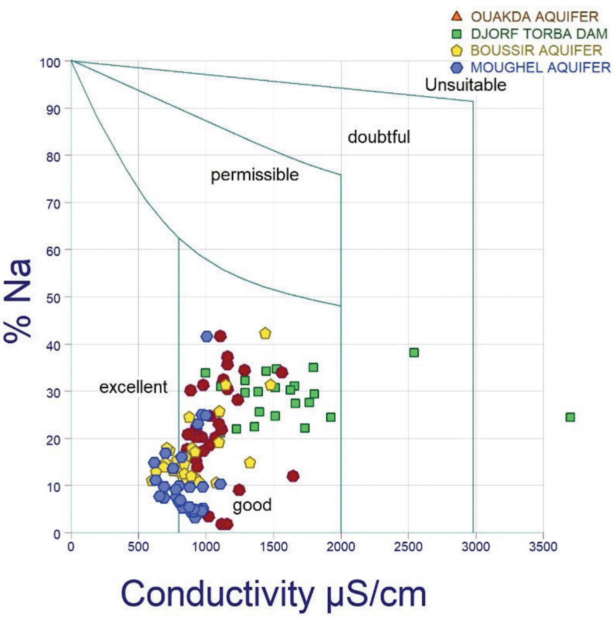

Fig. 9 - Wilcox diagram for irrigation purposes.

Fig. 9 - Diagramma di Wilcox per scopi irrigui.

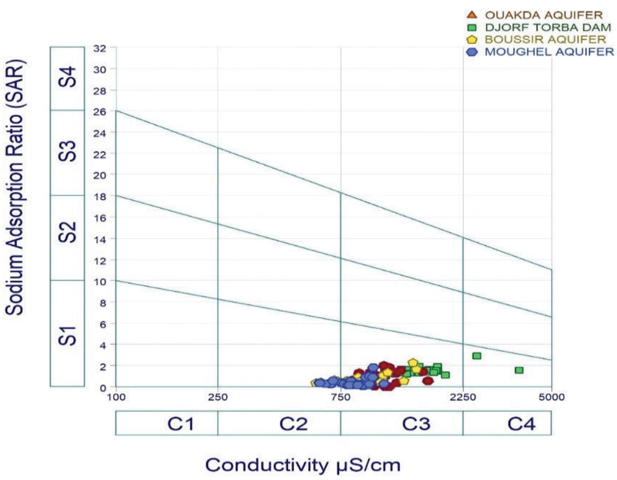

Fig. 10 - USSL diagram for irrigation purposes.

Fig. 10 - Diagramma USSL per scopi irrigui.

are potential risks to soil structure; this may negatively affect crop growth, so it requires remediation measures and the use of appropriate cultivation to reduce negative impacts.

Potential Salinity (PS)

PS index values are classified into three different categories (Tab. 2). The majority of groundwater and surface water samples are classified as Injurious to Unsatisfactory, especially the Djorf Torba dam and the Ouakda aquifer. In the Boussir and Moughel aquifer, while some samples fall into the Excellent and Good categories, a large proportion still indicate potential risks when used in irrigation. The results emphasize the need for continuous monitoring to ensure that water is suitable for agricultural use.

Permeability Index (PI)

PI values reflect variations in groundwater quality between different regions (Tab. 2). In the Ouakda and Moughel aquifers, samples are distributed between the Good and Unsuitable categories of irrigation, indicating a discrepancy in the impact of water quality on the soil. In contrast, most samples from the Boussir aquifer fall into the Good category, enhancing their irrigation potential without significant adverse effects. In the surface water (Djorf Torba dam), all samples fall within the Good category, indicating their high suitability for irrigation without the need for additional treatments. These findings underscore the importance of evaluating the PI when determining the suitability of water for agricultural use, as it plays a key role in determining the impact of water on soil permeability and the sustainability of agricultural production.

Monitoring the impact of water mixing in reservoirs

A comparison of the indicators of surface and groundwater quality is presented in Figure 11, where we used a logarithmic scale to illustrate the difference in concentrations. The results indicated that surface water has higher levels of electrical conductivity and major ions (Ca^{2+}, Mg^{2+}, Na^{+}, Cl^{-}, and SO_4^{2-}) compared to groundwater, reflecting the long-term effects of interactions between water and rocks and the process of mineralization. On the other hand, groundwater showed higher concentrations of magnesium and nitrates. As for the pH values, the results revealed slight differences between the two sources, indicating similar levels of alkalinity.

The water stored in the tank after mixing shows relative stability of pH, indicating that no significant chemical changes affecting the balance of acidity and alkalinity have occurred. As for the electrical conductivity, it decreases slightly, which reflects that the surface water has a higher concentration, and consequently, its impact on the stored water. Regarding the main ions, we observe that the concentrations of calcium, magnesium, and sodium decrease after mixing, which may be attributed to precipitation processes and chemical reactions within the reservoir. Regarding chloride, its concentration stabilizes at a level close to groundwater, indicating the

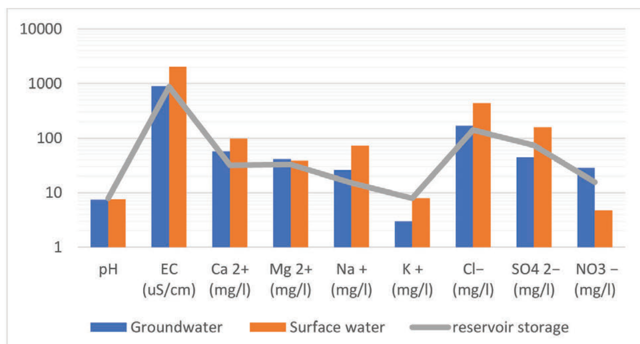

Fig. 11 - The effect of mixing groundwater and surface water on the physical and chemical properties in the reservoir.

Fig. 11 - L'effetto della miscelazione di acque sotterranee e superficiali sulle proprietà fisiche e chimiche del bacino idrico.

mixing effect on this element during storage. As for nitrate, the graph shows a clear decrease in stored water compared to groundwater, and the opposite for surface water, indicating biological consumption processes and interactions with other minerals within the reservoir. In contrast, sulfate maintains an average level between the two sources.

The city of Bechar has two major sources of water: groundwater and dam water. The dam water comes from storage in dams near the city.

These sources are balanced by different chemical and physical structures, resulting in different concentrations of ions and chemicals in each. Although we noticed that groundwater and dam water seem to have somewhat similar properties, mixing them can lead to changes in water quality due to the influence of different geological and hydrological factors on each. The difference lies in the ionic composition, which can cause chemical reactions when mixed.

Controlling the mixing of these two sources requires advanced water resources management strategies, such as the use of modern water treatment techniques and periodic and accurate water quality control. This is aimed at preventing negative impacts on consumer health and the environment, ensuring safe and clean water for human use and long-term environmental sustainability.

The distribution network consists of 8 main pressure regions (Kendouci et al., 2019), connected to storage and production sites (Fig. 12).

To facilitate the identification and programming of measurements in the Bechar area, a special coding system has been adopted that includes 8 zones within the city of Bechar, with each zone having its own water distribution network:

Zone 1: The length of the distribution network, which represents the city center, is 93.57 km.
Network distributed by the 3rd military region tank (3 x 2,000 m^3) and the Niger Sea tank (2 x 3,000 m^3).

Zone 2: The length of the distribution network, which represents the Debdaba, is 79.89 km.
Network distributed by the Niger Sea reservoir (3 x 3,000 m^3).

Zone 3: The length of the distribution network, which represents the Debdaba North, is 11.55 km.
Network distributed by the Ouakda reservoir (4,000 m^3).

Zone 4: The length of the distribution network, which represents the Lahdeb, is 31.75 km.
Network distributed by the Ouakda reservoir (4,000 m^3).

Zone 5: The length of the distribution network, which represents the Ouakda, is 36.43 km.
Network distributed by the Ouakda drills N° 20, 14, 10, and 2 is connected to a reservoir with a tank capacity of 4,000 m^3.

Zone 6: The length of the distribution network, which represents the Zhun, is 84.53 km.
Network distributed by the tank of the Escadron (2 x 2,000 m^3 + 5,000 m^3)

Zone 7: The length of the distribution network, which represents the Industrial zone, is 40.20 km.
Network distributed by the tank of the 3rd military region (3 x 2,000 m^3).

Zone 8: The length of the distribution network, which represents the Bechar Djedid, is 100.56 km.
Network distributed by the tank of the 3rd military region (3 x 2,000 m^3), the tank Malah (3 x 250 m^3), and the tank of the Escadron (2 x 2,000 m^3).

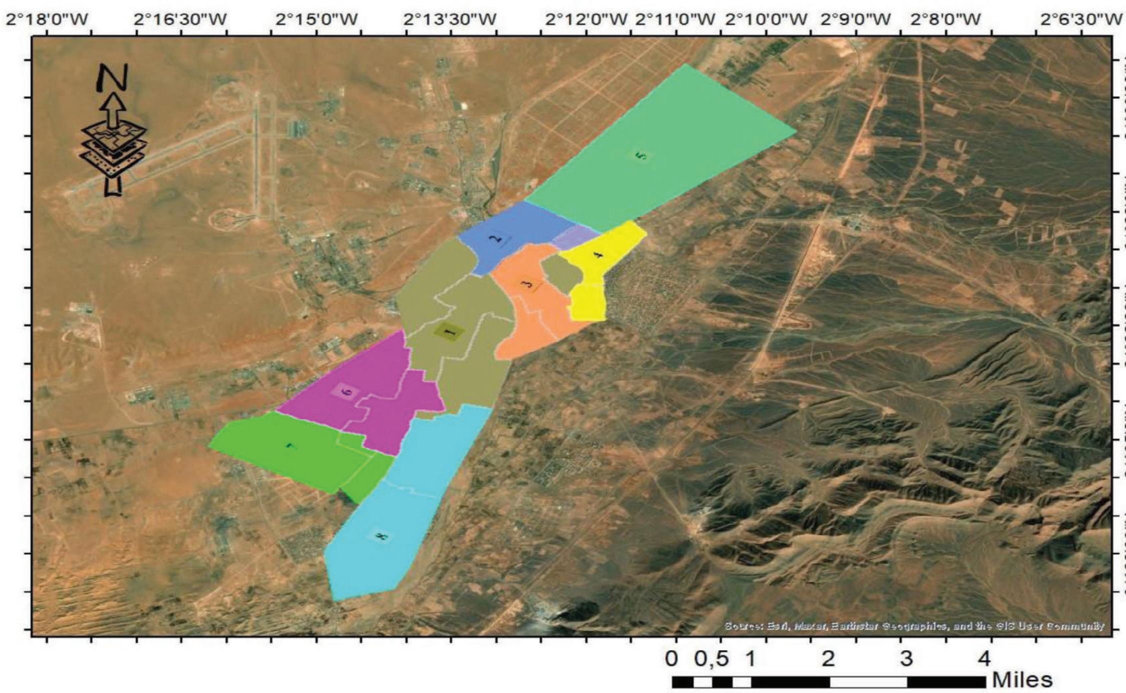

Fig. 12 - Distribution network regions of Bechar (ADE, 2024; Kendouci et al., 2019).

Fig. 12 - Reti di distribuzione della regione di Bechar (ADE, 2024; Kendouci et al., 2019).

Physico-chemical parameters

Hydrogen potential (pH)

pH values equal to 7.37 in groundwater, 7.87 in the tank, and 7.56 in the dam water. Although these values are among the criteria recommended by the World Health Organization (WHO), there is a discrepancy in the degree of acidity between groundwater and stored water for drinking supply, rising by about 6.78% when mixed with dam water (Fig. 13). This change is due to chemical interactions between various dissolved substances in groundwater and dam. The relationship between pH and hydrogen ion (H^+) concentration is logarithmic, where the decrease in pH increases H^+ concentration and vice versa. When mixing the bicarbonate (HCO_3^-) with hydrogen ion (H^+), H^+ concentration decreases and the pH value raises. The difference in CO_2 concentrations between the sources leads to its release from the mixture, reducing the formation of carbonic acid and resulting in an increase in pH. Additionally, the presence of highly buffering compounds (such as bicarbonates and carbonates) can enhance pH stability and affect their interactions within the aquatic system. On the other hand, the reservoir walls (cement concrete) affect the water alkalinity over time because of calcium degradation and calcium hydroxide (Kendouci et al., 2016).

Electrical Conductivity (EC)

Electrical Conductivity is one of the important parameters for assessing water quality, as changes in its value can refer to pollution, mixing or intrusion into water (Kendouci et al., 2019). The conductivity is also affected by the temperature of the water. It reflects the amount of soluble salts in water (Pescod, 1985; Rodier, 1996): high conductivity indicates a large amount of soluble salts and provides an idea of water mineralization (Rodier, 1996). The measurement of conductivity helps to assess total water mineralisation quickly and effectively (HCEFLCD, 2006).

Figure 13 shows a slight decrease in EC value in the reservoir estimated at 1.73% (EC value in groundwater was about 886 µS/cm and dropped to 871 µS/cm when mixed with soil shelf water, where EC value was 2.030 µS/cm). This combination leads to the dilution of dissolved substances in water, and since surface water is usually rich in dissolved substances such as salts and minerals, mixing them with groundwater reduces the concentration of these substances and thus reduces the value of the EC.

Calcium (Ca^{2+}) and Magnesium (Mg^{2+})

Calcium is the dominant element in drinking water, and its quantity varies according to the nature of the sediments, whether it is limestone or gypsum. This element is found in carbonate rocks and can also come from gypsum formations that are easily dissolved in water (BRGM, 2006).

Figure 13 shows a decrease in calcium and magnesium concentrations in the tank (43.79% and 20.04% respectively). Their concentrations in groundwater decreased from 56.93 to 32 mg/L and from 41.27 to 33 mg/L, respectively, when mixed with dam water containing 97.9 mg/L of Calcium and 38.39 mg/L of Magnesium (Fig. 11). Chemical interactions occur between mixed water and lead to the deposition of these elements. These interactions may be caused by ionostasis in mixed water and Calcium and Magnesium interaction with bicarbonate or sulfate, resulting in sediment formation that reduces the concentration of these dissolved elements in water (Bendida et al., 2024).

Sodium (Na^+) and Potassium (K^+)

Sodium is found in water at different concentrations, often influenced by human factors, but must not exceed 200 mg/L (WHO, 2017). Sodium comes from the rock air containing sodium silicate and aluminium and can also be released from soil after fertilizer use. It is known that potassium concentrations in water are low, and it is preferable that they do not exceed 12 mg/L (WHO, 2017).

Figure 11 shows that the groundwater contains relatively low concentrations of Sodium (25.9 mg/L) and Potassium (3 mg/L) compared to the reservoir water, which contains 73 mg/L of Sodium and 7.9 mg/L of Potassium. After the mixing process, the Sodium concentration decreases

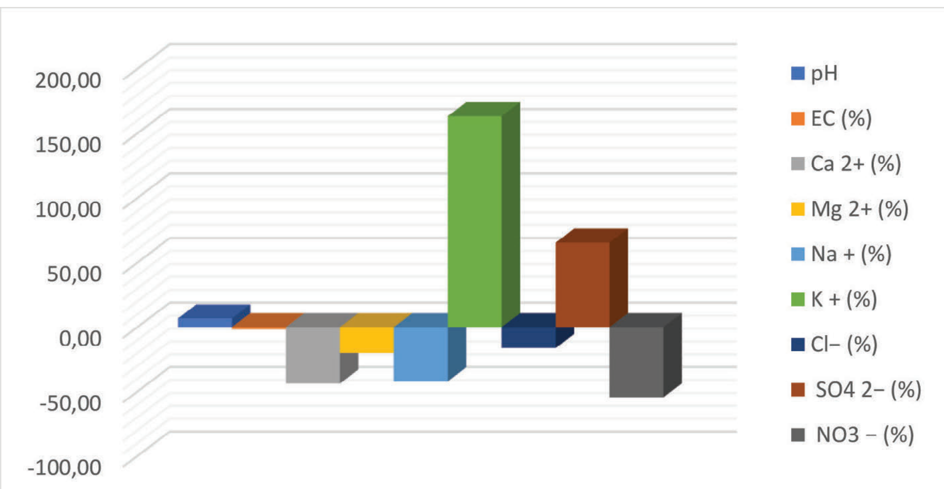

Fig. 13 - Relative changes in ion concentrations and physico-chemical parameters within a drinking water storage tank between groundwater and surface water.

Fig. 13 - Variazioni relative delle concentrazioni di ioni e dei parametri fisico-chimici tra acque sotterranee e acque superficiali all'interno di un serbatoio di stoccaggio di acqua potabile.

to 15 mg/L (-42.08%), while the Potassium concentration increases to 7.9 mg/L (+163.33%).

This is due to chemical reactions that occur when Sodium is absorbed by sediment or suspended solids, while reactions may result in the release of Potassium ion from additives or sediment in the tank. This change remains within the acceptable range of WHO standards, thus enhancing the safe use of mixed water (Bendida et al., 2024).

Chlorides (Cl^-) and Sulfates (SO_4^{2-})

Chloride and Sulfate affect water quality too. Chloride comes from natural sources and human activities, while Sulfate comes from rocks and industrial activities. Increasing the concentration of chlorates can damage aquatic life, while sulfur causes changes in the taste of water.

Chloride concentration decreased by 16.13% and sulfate concentration increased by 65.39% in the water supply tank (141 and 73.7 mg/L, respectively), remaining within acceptable limits according to WHO standards (Fig. 13). This change is due to several factors, such as the mitigation and mixing of groundwater (168.11 and 44.56 mg/L, respectively) with dam water (436.64 and 158.87 mg/L, respectively). In addition, there is interaction with other ions (e.g., Chloride interacts with Calcium and Sodium ions to form Sodium Chlorides and Calcium Chlorides, which are readily dissolved in water; Sulfate reacts with Calcium ions to form Calcium Sulfate, which may be deposited at water saturation, and with Barium ions to form no soluble Barium Sulfate).

Nitrates (NO_3^-)

Nitrate ion is the most oxidizing form of nitrogen. Natural sources of nitrate include rainfall and interactions between soil and vegetation cover. In addition, there are many human sources of nitrate, such as fertilizer leakage, livestock breeding, and domestic and industrial waste. Nitrate levels in groundwater depend largely on biogeochemical processes that control the nitrogen cycle.

Figure 13 shows a decrease in Nitrate concentration by more than 45.32% in the water supply storage tank. Nitrate concentration in groundwater was 28.53 mg/L (Fig. 11). This decrease refers to mixing groundwater with another water source, such as dam water. Furthermore, Nitrate interaction with other water-based ions can affect their ultimate concentration (e.g., Nitrates can interact with Ammonium (NH_4^+) to form Ammonium Nitrate (NH_4NO_3), a reduced substance that acts as a source of nitrogen and ammonium in soil; Nitrates can also interact with Calcium, Magnesium, and Sodium to form soluble compounds (such as $Ca(NO_3)_2$, $Mg(NO_3)_2$, and $NaNO_3$), which remain dissolved in water). In some cases, certain compounds may precipitate under specific conditions, such as changes in ion concentration or temperature.

Conclusions

This study evaluated the suitability of water from the Bechar region, in southwest Algeria, for drinking and irrigation purposes by analyzing 11 physico-chemical parameters. The results revealed a clear difference in the composition of groundwater and surface water. The main cationic components included Mg^{2+}, Ca^{2+}, Na^+, and K^+, while the anionic components were HCO_3^-, Cl^-, NO_3^-, and SO_4^{2-}. Surface water was primarily of the SO_4^{2-}-Cl^--Ca^{2+}-Mg^{2+} type, whereas groundwater was of the SO_4^{2-}-Cl^--Ca^{2+}-Mg^{2+} and HCO_3^--Ca^{2+}-Mg^{2+} types. The results showed variations in mineral concentrations in the groundwater, with noticeable effects from environmental factors, such as evaporation and changes in rock composition.

The results illustrate the difference in drinking water quality between various water sources. Despite the variability in the Drinking Water Quality Index (DWQI) values between surface and groundwater sources, all groundwater samples fell within the good quality category, with DWQI values ranging from 55.18 to 80.04. Also, most surface water samples can be considered safe for drinking, with DWQI values ranging from 50.94 to 110.35. Consequently, it is necessary to monitor the quality of these waters more closely and to continuously rely on groundwater as a safe source for drinking.

The study shows that evaluating irrigation water quality based on the Irrigation Water Quality Index (IWQI) revealed that a significant proportion of surface water samples had moderate to high restrictions, accounting for 48.39% and 12.90%, respectively. In contrast, groundwater samples predominantly exhibited moderate restrictions across all basins.

Irrigation water quality was assessed using multiple indices, including Na%, SAR, KI, PI, and PS. These results showed a variation in water quality between different surface and groundwater sources, with groundwater results being more favorable, making it a more reliable source for irrigation. The results indicated that groundwater samples generally complied with international irrigation standards, whereas surface water results were less consistent due to higher salt and sodium content in some indices.

Therefore, this study provides a comprehensive overview of water quality for irrigation and drinking purposes, highlighting areas that may require improvements to achieve sustainable water resource management in this region.

The study determined that groundwater lost quality when mixed with dam water, with changes in its physical and chemical properties. The pH increased by 6.78%, indicating a change in the balance of acids and alkalis. The Electrical Conductivity also decreased by 1.73%, reflecting a decrease in the concentration of dissolved salts. Calcium and Magnesium concentrations decreased by 43.79% and 20.04%, respectively, which is an indicator of the loss of basic metals. In addition, sodium concentration decreased by 42.08% and Potassium concentration increased by 163.33%, indicating unbalanced chemical reactions. Moreover, Chlorids have decreased by 16.33% in concentration, while Sulfates have increased by

65.39%, and Nitrate concentrations have decreased by more than 45%. These changes show that groundwater quality has been adversely affected by mixing with surface water, resulting in the loss of some of its important qualitative characteristics. At the conclusion of this study, the mixing of groundwater with dam water results in significant changes in the chemical properties of water, such as acidity, Electrical Conductivity, and concentrations of various elements such as Calcium, Magnesium, Sodium, and Potassium. These changes reflect the complex chemical interactions between dissolved ions and the effect of storage in tanks. It is necessary to adopt strict control measures and effective management techniques for filling ratios in tanks, in addition to cooperating with regulators to ensure that water quality is maintained. These actions contribute to ensuring safe and clean water, thereby promoting public health and ensuring environmental sustainability.

Recommendations include adjustment of tank filling ratios to mitigate the adverse effects of mixing water sources, thereby preserving the high quality of groundwater as a primary source for the inhabitants of Bechar city.

Competing interest
The authors declare no competing interest.

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Data collection and processing: ATBI Aymen, KENDOUCI Mohammed Amin, and MEBARKI Saliha; results interpretation: ATBI Aymen, KENDOUCI Mohammed Amin, and MEBARKI Saliha. Original draft: ATBI Aymen, KENDOUCI Mohammed Amin, and MEBARKI Saliha; writing-review and editing: ATBI Aymen, KENDOUCI Mohammed Amin, and MEBARKI Saliha.
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