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Evaluation Of The Hydrochemistry And The Quality Of The Groundwater Of The Plain Of Sidi-Bel-Abbès And Tenira (North-West Algeria)

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Abstract
In arid regions, groundwater is the main water resource but faces pressure from increasing demand, which affects its quality and itssustainability. This study compared the hydrochemical characteristics of the Sidi Bel Abbès and Tenira plains in Algeria. The Sidi Bel Abbès groundwater is dominated by sodium, chloride or sodium, sulfate facies, while Tenira shows calcium, magnesium chloride facies. Irrigation assessment indicated a high salinity risk in both plains, with Sidi Bel Abbès having a poorer quality. The base exchange indices revealed preferential calcium release, and Sidi Bel Abbès showed higher mineralization (EC and TDS). Most Tenira waters met the JORA drinking standards, whereas Sidi Bel Abbès waters generally exceeded them. Both aquifers had good bacteriological qualitiesty.
Key words: *Groundwater, Hydrochemistry, quality, plain, Sidi-Bel-Abbès, Tenira*

1. INTRODUCTION

Water is essential for human life. It is used by humans in various activities (agricultural and industrial) and in daily life (domestic use and leisure). Generally, the origin of water used for human food comes from groundwater and fresh surface water and, in some cases, by softening seawater [1] (75% to 90% of the world's population use water of underground origin [2]. The growing demand for water has forced people to rely heavily on groundwater [3]. Some studies on groundwater quality have concluded that the pollution of these waters is of geological and anthropogenic origin, in particular from the infiltration of wastewater and the use of chemical fertilizers in agriculture [4].Good groundwater quality is important for future planning and management [5]. In arid and semi-arid regions, population growth, expansion of irrigated areas, and climate change are leading to an increasing demand for groundwater, which is the main resource for drinking water, irrigation, and industrial use. In Algeria, most of the northern groundwater has reached its exploitation limit [6]. Studies [7] have shown a decrease in precipitation in northwestern Algeria. [8] have also reported amplified warming. In a semi-arid context, drought is considered an obvious reality in the Mediterranean regions, especially in the north-west of Algeria [9]. The wilaya of Sidi Bel Abbès, located in the northwest of Algeria, includes two important plains, Sidi Bel Abbès and Tenira, which represent strategic reservoirs of groundwater in the region. According to data from the Wilaya Department of Hydraulics, the two main aquifers in this region are the Tenira-Telagh nappe and the Plio-Quaternary nappe of the Sidi Bel Abbès plain [10], which evolve in a semi-arid context. The need for this research is explained by the major problems facing the region, in particular, drought, overexploitation of groundwater resources, and unavailability of surface water. These water constraints necessitate a comparative hydrochemical and qualitative study of the groundwater in the two plains. The purpose of this study was to identify the mineralization processes that influence the chemical composition of the waters, highlight the factors of spatial variation, and evaluate the suitability of the waters for drinking water supply and irrigation. Finally, to guarantee its sustainable use in appropriate sanitary and environmental conditions

2. MATERIALS AND METHODS STUDY

Area The province of Sidi-Bel-Abbès is located in northwest Algeria. It shelters of the most fertile plains of Algeria [9], including the Sidi-Bel-Abbès plain in the center, the Belarbi plain in the east, the Hassi-Zahana plain in the southwest, and the Tenira plain in the south (Figure1)

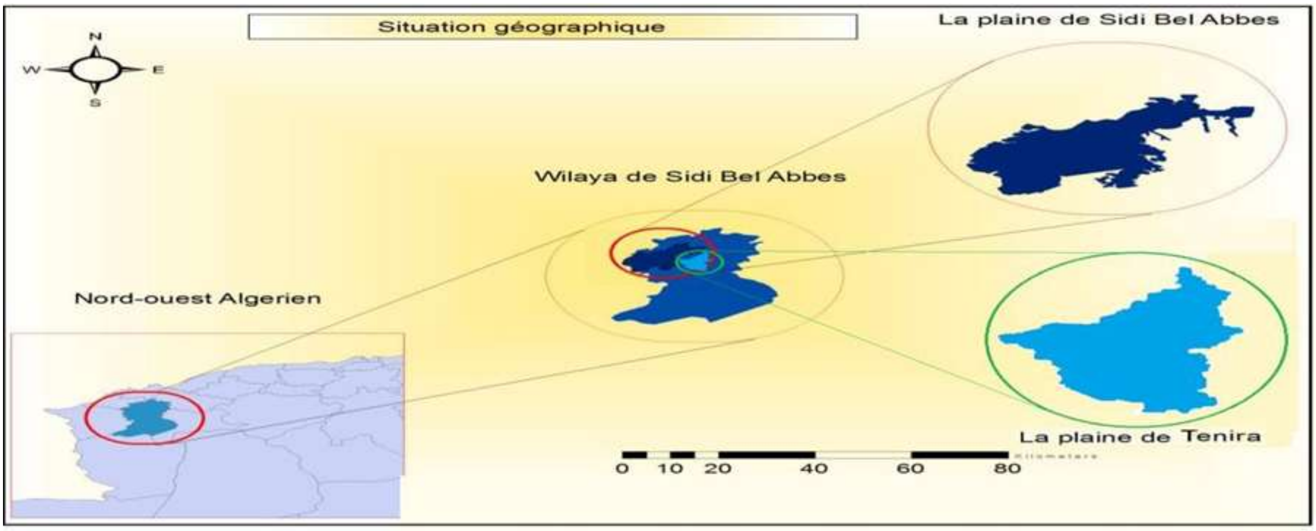

Figure 1: Location map of the study area

Geology of the study area

The Sidi Bel Abbés plain is an elongated depression, oriented WSW-ENE, covering an area of 1180.5 km^2, located between the northern altitudes 34°86' and 35°22' and the western longitudes 0°94' and 0°32'. It is part of the downstream sub-watershed of the Mekerra [10]. It is a vast basin with an impermeable clay-marl substratum of Miocene or lower Pliocene age, filled with Quaternary detrital formations, essentially conglomerate and sandy and sandstone deposits alternating with silts, coming from the disintegration of the reliefs that surround it [11]. The plain is limited to the north and east by post-Cretaceous terrain and to the south by Jurassic and Cretaceous terrain (Figure 2). This area, defined by its semi-arid climate, is largely focused on agricultural activity. The plain comprises a Plio-Quaternary alluvial sheet, which constitutes the main aquifer of the region, with an area of 730 km^2. It is supplied according to three processes: direct supply by precipitation water, supply by adjacent aquifers either by direct lateral infiltration or via sources, and finally, a supply by wadis. The average depth of the nappe is 15 to 20 m with shallow areas (less than 10 m) along the Lamtar and Tissaf wadis [12]. In contrast, the Tenira region is integrated into the vast region of Orania. It is located in the southeast of the Sidi Bel Abbés plain and is mainly based on secondary Jurassic terrain, composed of stacks of limestone, sandstone, and dolomite layers. These formations give the soil a superficial, stony, and sandy appearance. In the valley of the Wadi Melghir, the Tenira basin (approximately 10 km/10 km) is used for agricultural and pastoral purposes, constituting one of the 16 units of the large Macta basin located in the western part of Algeria, and is integrated into the large Telagh-Tenira complex [13]. The Tenira region, owing to its pivotal position (Figure 3), belongs to a complex tectonic province where the NE-SW (Atlasic) and WSW-ENE (Tellian) directions intersect, to which the NW-SE secondary directions are added [14].

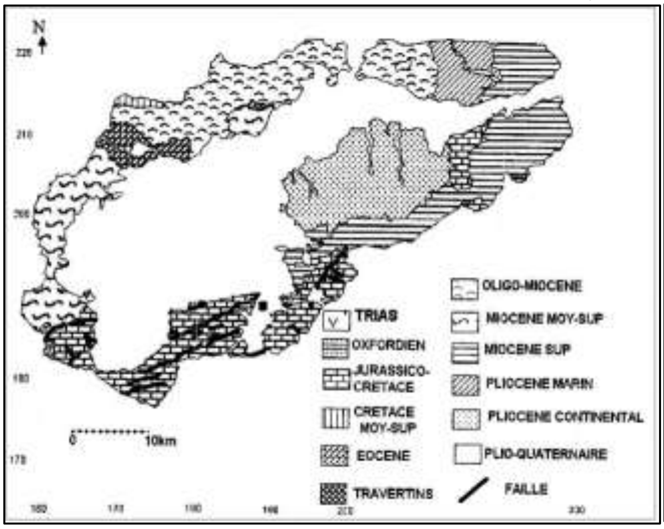

Figure2: Simplified geological map of the plain of Sidi-Bel-Abbès

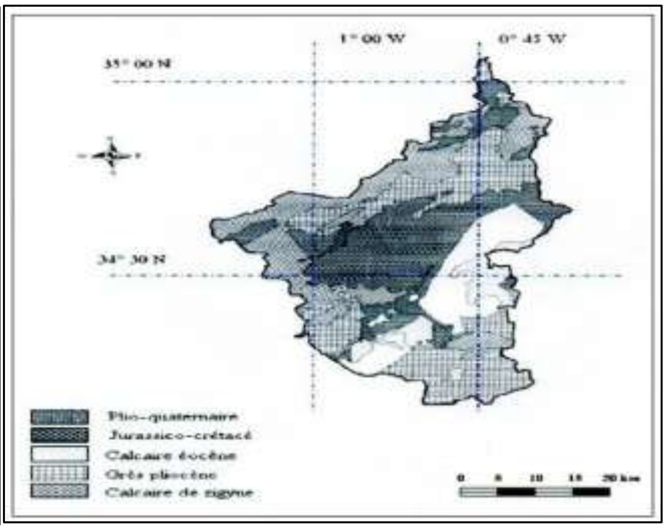

Figure3: The main layers of the plain of Tenira

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The hydrogeology of The Sidi Bel Abbés plain is poorly documented. The only relatively complete study identified in the bibliography was conducted in 1970. Currently, the plain benefits only from non-periodic monitoring carried out by the ANRH of Oran (National Agency for Hydraulic Resources) concerning the water table and the salinity of the Plio-Quaternary Aquifer (PQA). The Sidi Bel Abbés plain shelters five aquifers: the plio-quaternary alluvium, the zigyne limestones, the dolomites and limestones of Sidi Ali Benyoub, the Eocene limestones of Sidi Ali Boussidi and the Pliocene sandstones of Tenira. The latter is composed of conglomerates from the continental Pliocene at the base, surmounted by sandy sandstone. This training is essential because it strongly contributes to PQA recharge. The main outlet of the PQA is located in the Rocher district, north of the city of Sidi Bel Abbès, where the Mekerra Wadi drains most of the waters of the aquifer [15]. The Tenira plain is entirely included in the Telagh sub-watershed, coded 11-05 by the ANRH of Oran, and extends over an area of 763 km^2. The tablecloth of the Tenira plain is part of the large Tenira-Telagh tablecloth located in Upper Melghir. The renewal of the waters of the nappe is largely, linked to the prevailing climatic situation. This nappe rests in discordance on the limestone formation of Remailia and more precisely on its first two terms (dated from the Kimmeridjian-Hauterivian), namely the member of zegla B composed of calcareous-marly layers presenting a rather notable crack permeability and karstification and the zegla a member formed of highly cracked compact limestones. These two members constitute an excellent aquifer reservoir and seem to be in hydraulic continuity with the plio-quaternary formations of the surface layer [16]. The eastern and western borders are limestone and sandstone-limestone reliefs [17]. Sampling and analysis method Monitoring and conservation of surface and groundwater resources are essential for a sustainable environment and to meet the demand for fresh water. As it passes underground, the water acquires a mineral charge characteristic of the nature of the rocks it crosses. The study region is characterized by a semi-arid regime in which groundwater is an essential resource. In our case, this study aims to compare the hydro-chemical characteristics and quality of the groundwater taken from two distinct plains, the Sidi Bel Abbés plain and that of Tenira, which belong to the same region, to evaluate their current state and potential as strategic groundwater resources. A measurement and sampling campaign was conducted in April 2024 to achieve this. Water points were selected and distributed equitably between , the two plains (Figure 4), that is, 10 sampling points for each plain, to achieve good spatial distribution. The Lambert coordinates (x, y, z) of the water points studied and the maps were provided by the Directorate of Hydraulics of the Wilaya of Sidi Bel Abbés (Table 1). The temperature, electrical conductivity, and pH were measured in situ using a multiparameter P3 PH / SET LF). Chemical analyses were carried out at the laboratory of the ADE (Algerian Water) in the Wilaya of Sidi-Bel-Abbès. Calcium and magnesium were determined by complexometric titration with EDTA, chlorides by the Mohr method, nitrites, nitrates, and sulfates by colorimetry on a UV-visible spectrophotometer, bicarbonates and carbonates by a volumetric method with. And finally the sodium and potassium were determined by flame spectrometer. During this work, we carried out the search for pollution indicator germs, which are:total coliforms, fecal coliforms and sulfito-reducing clostridia. These bacteriological parameters were analyzed in the laboratory according to the Rodier analysis protocol .

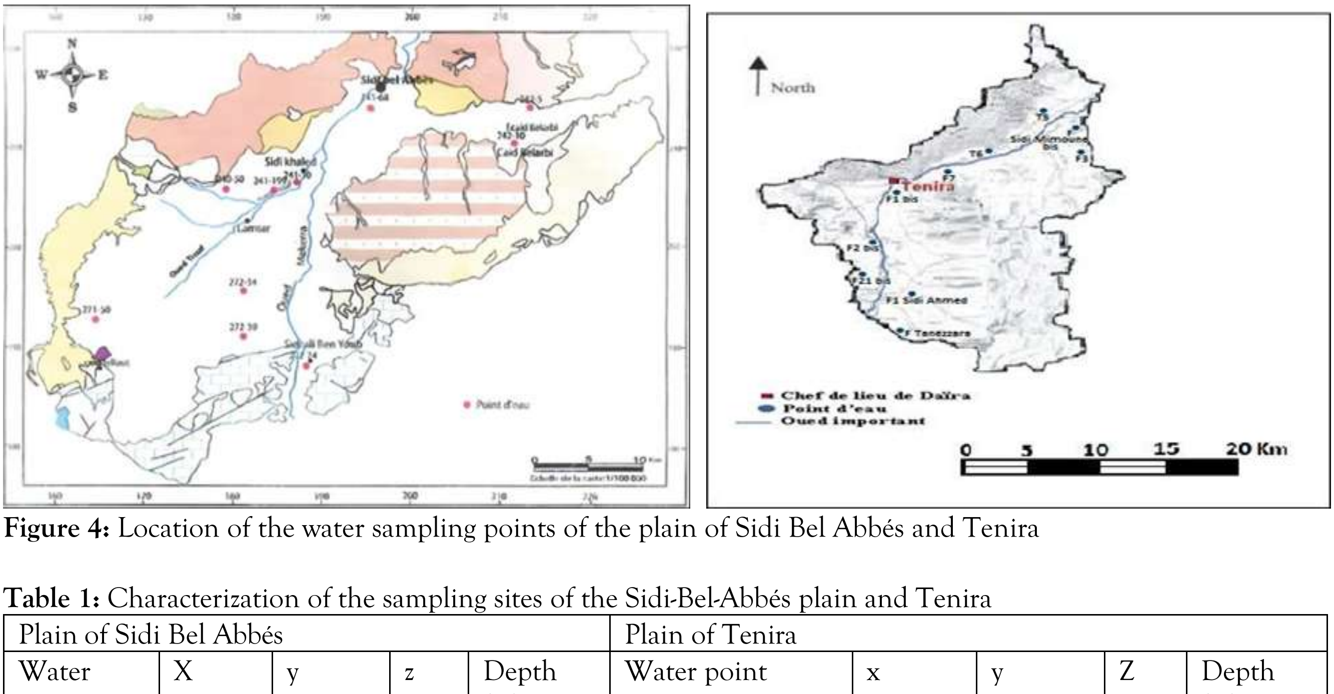

Figure 4: Location of the water sampling points of the plain of Sidi Bel Abbés and Tenira

Table 1: Characterization of the sampling sites of the Sidi-Bel-Abbés plain and Tenira

Plain of Sidi Bel Abbés					Plain of Tenira				
Water point	X	y	z	Depth (m)	Water point	x	y	Z	Depth (m)

W240-50	179300	205600	584	30	F7	206890	196840	610	160
W241-10	187300	206100	524	120	F21 bis	202191	193670	640	180
W241-68	195600	213650	458	50	F Sidi Mimoune bis	211911	198350	540	300
W241-199	184800	205400	530	11	T6	208739	197670	601	160
W242-50	213500	213650	490	30	F1 bis	205538	196260	616	70
W242-10	211750	210000	538	20	F2 bis	202983	194095	620	190
W271-50	164400	192850	622	15	F Sidi Ahmed	203942	191290	653	135
W272-34	181800	195150	675	40	F Tenezzara	197352	188250	650	120
W272-39	181850	190850	658	25	T5	210679	198510	577	130
W272-74	188750	187780	669	75	F3	213039	198160	580	210

3. RESULTS AND DISCUSSION

The chemical facies of groundwater are determined using three classifications: Stabler representation, Piper diamond diagram, and semi-logarithmic Schöeller-Berkaloff. These diagrams were created using the Diagrams software of the Avignon Hydrology Laboratory version 5.9. Establishment of characteristic formulas according to Stabler To better study the chemical facies, the classification of Stabler was used. The characteristic formulas of the analyzed waters were obtained from the percentages of the amounts in reaction (r %) of the various ions and are reported in Tables 2 and 3.

Table 2: The characteristic formulas according to STABLER of the groundwater of the Sidi-Bel-Abbès plain

Type de faciès	Groupe	Formulas of characteristic anions	Formulas of characteristic cations	High content	Water point
Calcium Chloride	1	r Cl^- > r SO_4^{-2} >rHCO_3^-	r Ca^{+2} >r (Na^++K^+) > r Mg^{+2}	SO_4^{-2} Na^+	W240-50
	2	r Cl^- > r SO_4^{-2} > r HCO_3^-	r Ca^{+2} > r Mg^{+2}>r (Na^++K^+)	SO_4^{-2} Mg^{+2}	W241-68
	3	r Cl^- > r HCO_3^- > r SO_4^{-2}	r Ca^{+2} > r Mg^{+2}>r (Na^++K^+)	HCO_3^- Mg^{+2}	W242-10; W272-34
Sodium Chloride	1	r Cl^- > r HCO_3^- > r SO_4^{-2}	r (Na^++K^+) > r Ca^{+2} >r Mg^{+2}	HCO_3^- Ca^{+2}	W241-10; W241-199 W272-39; W272-74
	2	r Cl^- > r HCO_3^- > r SO_4^{-2}	r (Na^++K^+) > r Mg^{+2} > r Ca^{+2}	HCO_3^- Mg^{+2}	W271-50
Magnesium Chloride	1	r Cl^- > r HCO_3^- > r SO_4^{-2}	r Mg^{+2} > r Ca^{+2} > r (Na^++K^+)	HCO_3^- Ca^{+2}	W242-50

Table 3: The characteristic formulas according to STABLER of the groundwater of the Tenira plain

Type of facies	Groupe	Formulas of characteristic anions	Formulas of characteristic cations	Strong content	Water point
	1	r Cl^- > r HCO_3^- > r SO_4^{-2}	r Ca^{+2} > r Mg^{+2}>r (Na^++K^+)	HCO_3^-	F1 bis;

Calcium Chloride				Mg^{+2}	F Sidi Ahmed; F Tenezzara; F3
	2	r Cl^- > r HCO_3^- > r SO_4^{-2}	r Ca^{+2} > r (Na^++K^+) > r Mg^{+2}	HCO_3^- Na^+	F7 ; T6 ; F2 bis; T5
Magnesium Chloride	1	r Cl^- > r SO_4^{-2} >r HCO_3^-	r Mg^{+2} > r Ca^{+2} > r (Na^++K^+)	SO_4^{-2} Ca^{+2}	F Sidi Mimoune bis
Calcium Bicarbonate	1	r HCO_3^-> r SO_4^{-2}>r Cl^-	r Ca^{+2} >r Mg^{+2}>r (Na^++K^+)	SO_4^{-2} Mg^{+2}	F21 bis

The classification of the groundwater, of the Sidi-Bel-Abbès plain, according to the Stabler ,diagram reveals a dominance ,of the chloride facies [9], comprising 50% of sodium chlorinated waters, characterized by two types of formulas, suggesting a dominant ion exchange process, 40% of calcium chlorinated waters, characterized by three types of formulas, and only 10% ,of magnesium chlorinated waters, characterized by a single type of formula. In the Tenira plain, the chloride facies are dominant, comprising 80% of the calcium-containing chlorinated waters, characterized by two types of formulas, indicating a predominant lithological control, 10% of magnesium-containing chlorinated waters characterized by one type of formula, and a relatively more frequent bicarbonate facies with 10% of calcium-containing bicarbonate waters, characterized by one type of formula.

3-1 Classification of waters according to the Piper diagram

The Piper diagram shows that the groundwater (Figure 5) in the Sidi Bel Abbès plain is dominated by chloride -sulfate and calcium–magnesium facies (80%), with some points (W241-10, W272-74) showing sodium-chloride or sodium–sulfate facies (20%). In the cation triangle, Na^+ and Ca^{2+} dominate over Mg^{2+}, whereas Cl $^-$prevailed among the anions. In Tenira, all samples exhibited a magnesium–calcium chloride facies, with no dominant cation and chloride as the main anion. These patterns reflect the hydrochemical evolution and mineralization processes in both plains.

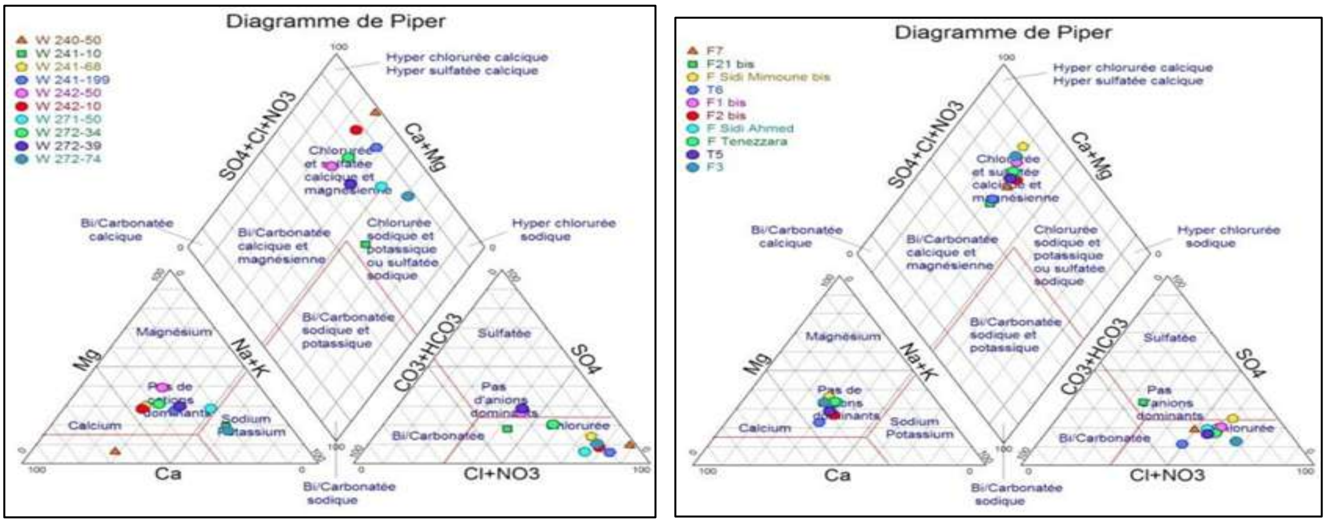

Figure 5: Piper diagram of water samples from the Sidi-Bel-Abbès and Tenira plains.

3-2 Classification of waters according to the semi-logarithmic Schöeller-Berkaloff diagram

The results of the chemical analyses are shown in the semi-logarithmic diagram designed by French hydrogeologists [13], where each chemical composition is represented by a figurative line (Figure 6). The application of this graphical method to the groundwater of the plains of Sidi Bel Abbès and Tenira showed practically the same type of chemical facies as those given by Stabler's formulas. The diversity of groundwater chemistry observed in two plains depends on the lithological composition of the layers crossed and the residence time of the waters in the aquifer.

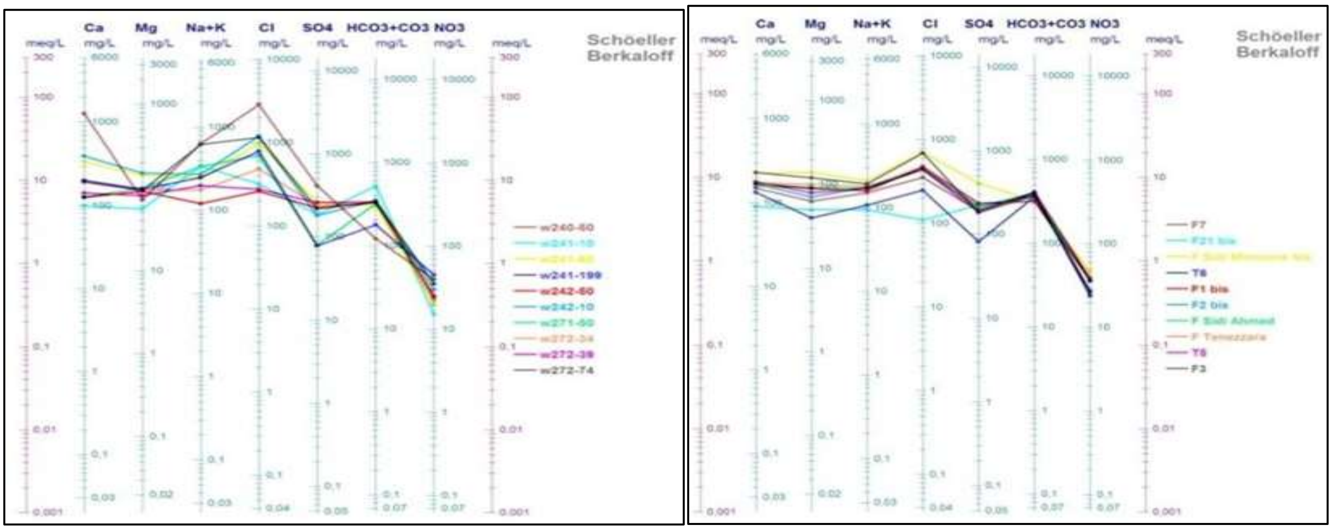

Figure 6: Classification of the groundwater of the Sidi Bel Abbès and Tenira

Groundwater is a major source for agriculture, and irrigation suitability is assessed using the Sodium Absorption Ratio (SAR), which evaluates Na^{+} exchange with Ca^{2+} and Mg^{2+} in soils. SAR values in the Sidi Bel Abbès Plain. SAR values in the Sidi Bel Abbès plain equation 1

$$SAR=\frac{rNa^{+2}}{\sqrt{rCa^{+2}+rMg^{+2}/2}} \quad (1)$$

range from 1.95 to 9.11, and in Tenira from 1.93 to 2.85, all below 10, indicating excellent irrigation quality. Irrigation suitability also depends on evapotranspiration and calcite precipitation. The conductivity and SAR (Table 4) values were visualized using Riverside diagram to evaluate salinity hazards. Overall, both plains provide groundwater suitable for sustainable irrigation (Figure. 7).

Table 4 The values of the SAR from the groundwater of the two plains

Plain of Sidi-Bel-Abbès		Plain of Tenira	
Point of water	**SAR**	Point of water	**SAR**
W240-50	4.6	F7	2.5
W241-10	5.5	F21 bis	1.93
W241-68	2.64	F Sidi Mimoune bis	2.58
W241-199	3.59	T6	2.05
W242-50	1.95	F1 bis	2.39
W242-10	2.85	F2 bis	2.85
W271-50	4.95	F Sidi Ahmed	2.67
W272-34	2.58	F Tenezzara	2.63
W272-39	3.24	T5	2.63
W272-74	9.11	F3	2.53

The groundwater of the Sidi-Bel-Abbès plain belongs to class (C3-S1) for the water points W242-50 and W272-39 and to class (C3-S2) for the water point W241-10, which are characterized by a high danger of salinization and a low to medium danger of alkalinity. Therefore, these waters are of acceptable quality for irrigation. The water points W241-68, W241-199, W242-10, and W272-34 belong to class (C4-S1), and W271-50 belongs to (C4-S2). These two classes are characterized by a very high danger of salinization and low to medium danger of alkalinity. These waters are of poor quality for irrigation purposes. The point W272-74 (C4-S3) shows a very high salinity combined with strong alkalinity, which classifies this water as poor quality for irrigation. Finally, very high salinity water with a medium risk of alkalinity (C5-S2) is found at the water point W240-50, this type of very poor quality water is generally not recommended for irrigation, but can be used in particular conditions (very permeable soils, good leaching and very soil tolerant plants) [9] .

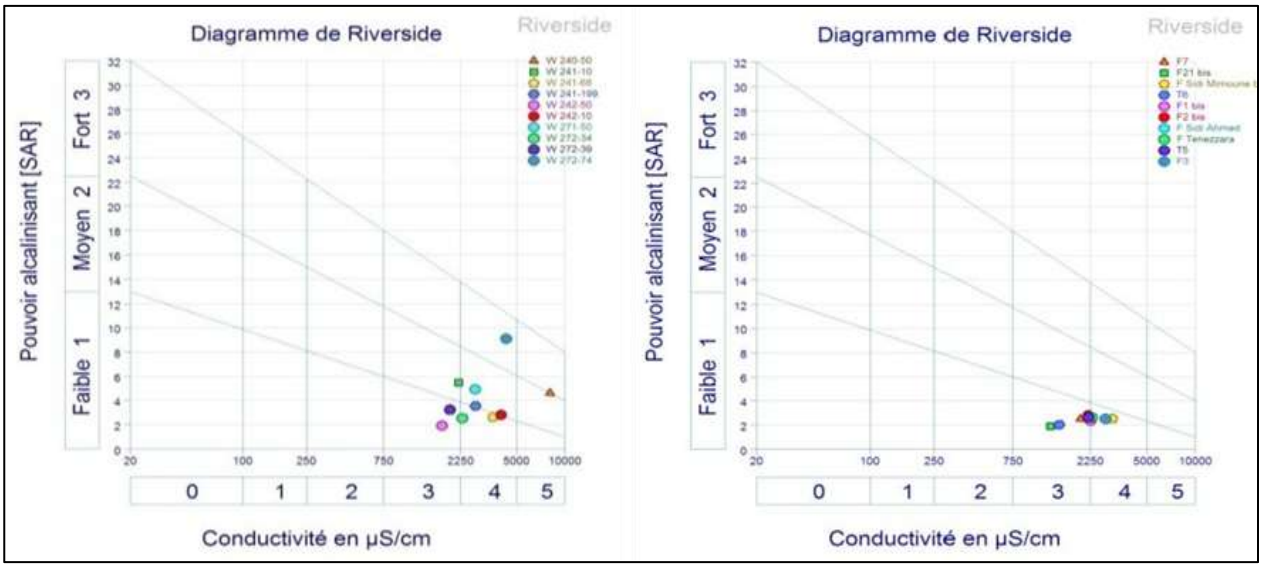

Figure 7: Classification of the groundwater of the Sidi-Bel-Abbèsand Tenira plains according to the Riverside diagram

In contrast, most of the water points studied in the Tenira Plain belong to class (C3-S1). This category of water is of acceptable quality for irrigation purposes. The second category corresponding to class (C4-S1) groups the water points (F Sidi Mimoune bis, F Tenezzara, and F3), which are of poor quality for irrigation. Classification of waters by the Wilcox method The Wilcox classification, based on the electrical conductivity and the sodium content in the water is expressed as a percentage. The representation of the different samples in this diagram allowed the characterization of the water for its suitability for irrigation

3-3 Classification of waters by the Wilcox method

The Wilcox classification [17],based on the electrical conductivity and sodium content of water, is expressed as a percentage. The representation of the different samples in this diagram allows the characterization of the waters for suitability for irrigation (Figure 8)

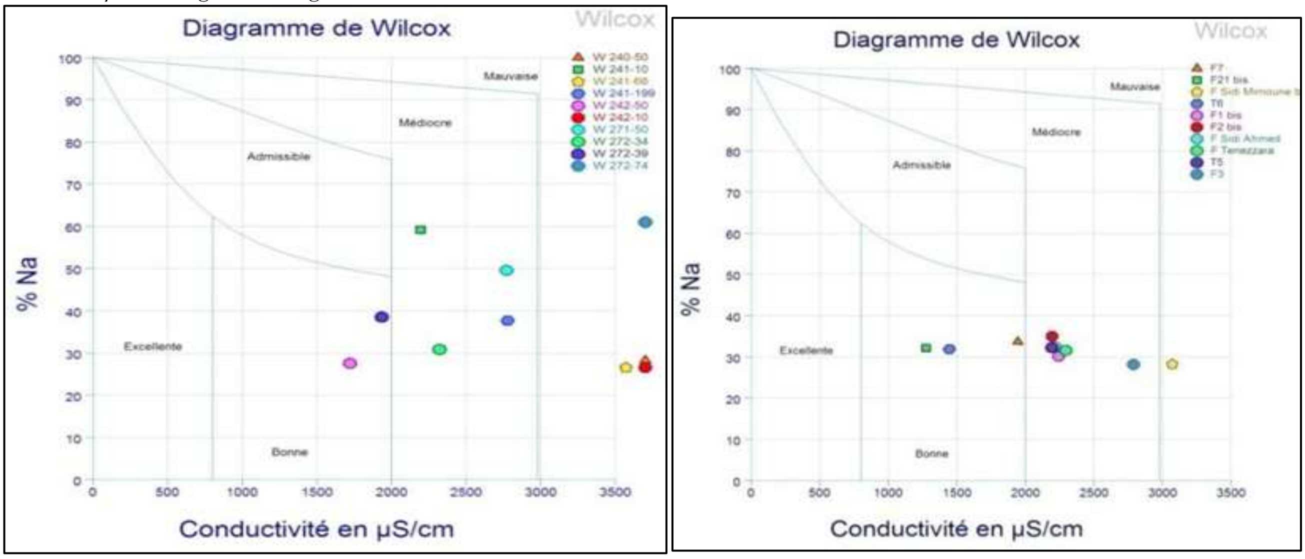

Figure 8 Classification of the waters of the plain of Sidi-Bel-Abbès and Tenira according to the diagram of Wilcox

This classification is defined by the formula (Equation 2)

$$\%Na = \frac{Na^{+}+K^{+}}{Ca^{2+}+Mg^{2+}+Na^{+}+K^{+}} \times 100 \quad (2)$$

Where the concentrations of Na+, K+, Ca2+ and Mg2 are expressed in meq/l.The results of the Wilcox diagrams for the two plains studied have been reported in **Table 5.**

Table 5: Classification of groundwater according to Wilcox: Excellent (E), Good (B), Admissible (A),

Water point	E	B	A	M	M'	Water point	E	B	A	M	M'
W240-50	-	-	-	-	28.31	F7	-	33.77	-	-	-
W241-10	-	-	-	59.08	-	F21 bis	-	32.13	-	-	-
W241-68	-	-	-	-	26.62	F Sidi Mimoune bis	-	-	-	-	28.24
W241-199	-	-	-	37.76	-	T6	-	31.87	-	-	-
W242-50	-	27.57	-	-	-	F1 bis	-	-	-	30.2	-
W242-10	-	-	-	-	26.54	F2 bis	-	-	-	34.99	-
W271-50	-	-	-	49.54	-	F Sidi Ahmed	-	-	-	32.58	-
W272-34	-	-	-	30.9	-	F Tenezzara	-	-	-	31.55	-
W272-39	-	38.57	-	-	-	T5	-	-	-	32.33	-
W272-74	-	-	-	--	61.01	F3	-	-	-	28.16	-

The Wilcox diagram indicates that groundwater, in the Sidi Bel Abbès plain is mostly of mediocre to poor quality for irrigation, while Tenira groundwater is generally better, with several points classified as good Temperatures ranged, from 18.1–21 °C, in Sidi Bel Abbès and 19.9–23.6 °C in Tenira, reflecting aquifer depth differences, and all values complied with Algerian standards. The pH values indicate slightly alkaline waters in both plains (7.1–8.2 for Sidi Bel Abbès; 7.0–7.65 for Tenira) within the regulatory limits. Electrical conductivity and TDS (table 6) were higher in Sidi Bel Abbès (1580–7850 µS/cm; 1015–5470 mg/L) than in Tenira (Figure 9) (1055–3200 µS/cm; 690–2350 mg/L), indicating stronger mineralization linked to shallow aquifers, evaporitic formations, and anthropogenic inputs. A strong correlation exists between EC and TDS (R^2 = 0.99 in Sidi Bel Abbès; R^2 = 0.91 in Tenira), confirming these processes. Overall, the Tenira groundwater is more homogeneous and suitable for irrigation and domestic use than that of Sidi Bel Abbès. These results highlight the influence of geology, aquifer depth, and human activity on water quality Mediocre (M) and Bad (M')

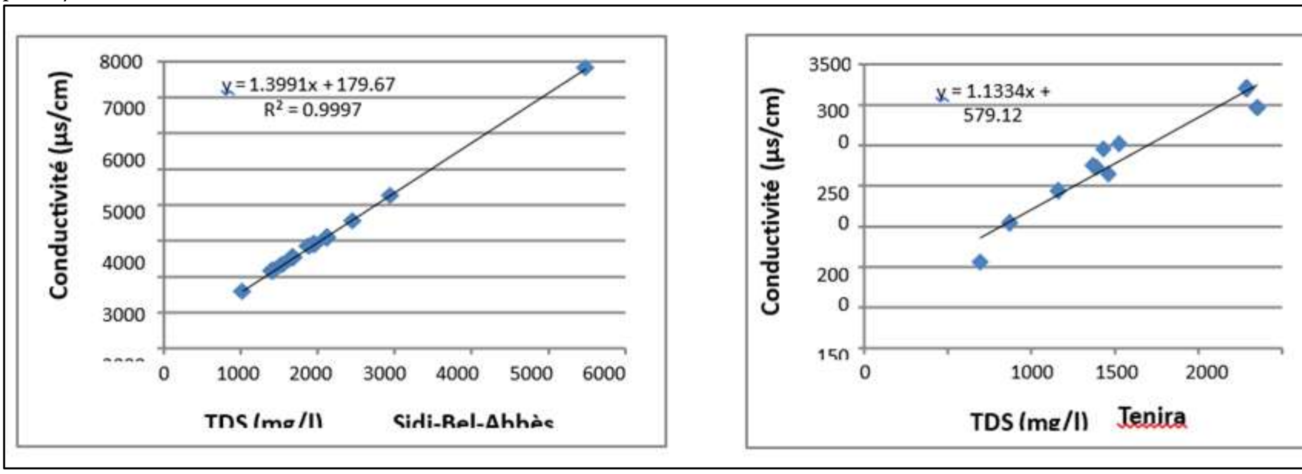

Figure 9 Evolution and correlation between the conductivity and dry residue across the plains of Sidi-Bel-Abbès and Tenira

Table 6: Values of the physical parameters and the TDS of the aquifers of the plains of Sidi-Bel-Abbès and Tenira.

Water point	pH	EC µs/cm	T °C	TDS mg/l	Water point	pH	EC µs/cm	T °C	TDS mg/l
W240-50	7.50	7 850	18.80	5 470	F7	7.65	1939	22.05	1 162
W241-10	8.20	1 580	21.00	1 015	F21 bis	7.52	1055	22.20	690
W241-68	7.80	3 560	19.20	2 450	F Sidi Mimoune	7.00	3200	23.60	2 287

					bis				
W241-199	7.10	2 910	18.10	1 949	T6	7.10	1542	22.00	870
W242-50	7.60	2 165	18.90	1 409	F1 bis	7.15	2450	19.90	1 432
W242-10	7.70	4 260	18.40	2 936	F2 bis	7.05	2220	22.50	1 390
W271-50	7.10	3 110	18.30	2 113	F Sidi Ahmed	7.02	2250	21.15	1 370
W272-34	7.90	2 550	19.00	1 675	F Tenezzara	7.55	2510	21.01	1 525
W272-39	7.15	2 320	18.60	1 522	T5	7.60	2140	21.10	1 460
W272-74	7.25	2 855	20.00	1 877	F3	7.31	2960	23.00	2 350

3-4 Chemical parameters, major cations Calcium and Magnesium

Calcium concentrations were higher in Sidi Bel Abbès (100–1265 mg/L) (Table 7) than in Tenira (90–230 mg/L), increasing downstream due to clay-limestone and alluvial deposits, wherea lower values near wadis indicated recharge. Magnesium levels were lower in both plains (Sidi Bel Abbès: 55–150 mg/L; Tenira: 40–140 mg/L), originating from marly and gypsum soils. Most samples meet the JORA standards, with Ca^{2+} and Mg^{2+} reflecting limestone and dolomite weathering

1- Potassium and Sodium

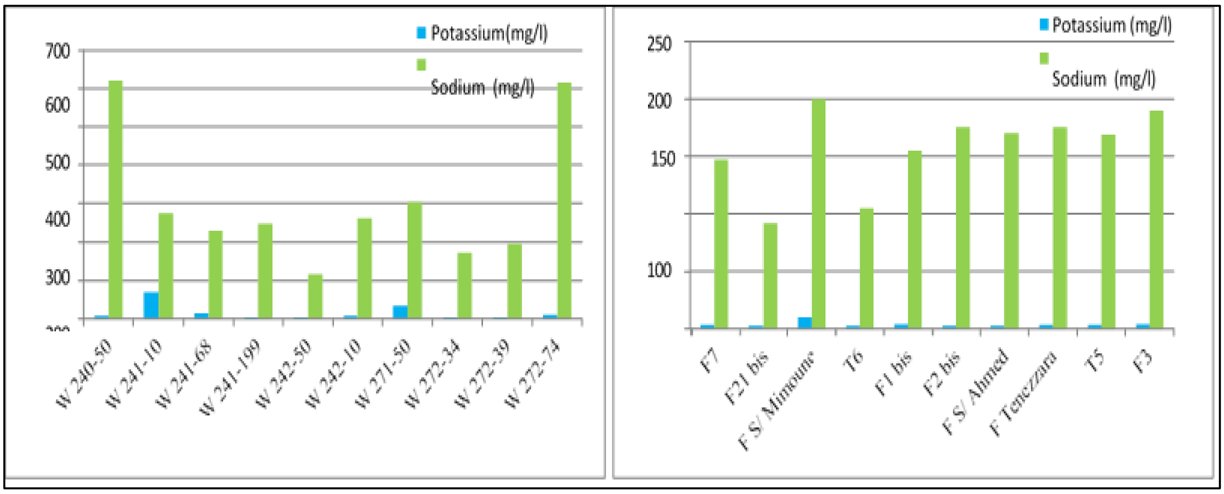

Figure 10 The Potassium and Sodium contents of the water samples from the plains of Sidi-Bel Abbès and Tenira.

Groundwater in the Sidi Bel Abbès plain shows high potassium and sodium concentrations (Figure10), often-exceeding JORA standards, due to irrigation recycling, alluvial leaching, and saline soil. In contrast, Tenira groundwater had lower and more uniform potassium and sodium levels within the permissible limitsof the Brazil Ianlégislation. These variations reflect differences in aquifer mineralization, clay and evaporite dissolution, and soil heterogeneity (Table 7)

Table 7: Concentrations of the major cations of the aquifers of the plains of Sidi-Bel-Abbès and Tenira

Water point	Ca^{2+} mg/l	Mg^{2+} mg/l	K^+ mg/l	Na^+ mg/l	Water point	Ca^{2+} mg/l	Mg^{2+} mg/l	K^+ mg/l	Na^+ mg/l
W240-50	1265	71	9	621	F7	151	63	3.55	147
W241-10	100	55	68	276	F21 bis	90	50	2.85	92
W241-68	338	142	14	230	F Sidi Mimoune bis	225	140	10	200
W241-199	200	95	4	246	T6	133	40	3	105
W242-50	125	90	4	117	F1 bis	170	89	3.9	155
W242-10	396	150	8	262	F2 bis	169	71	2.9	175
W271-50	126	98	34	304	F Sidi Ahmed	158	92	2.82	170
W272-34	190	92	4	173	F Tenezzara	170	100	3.55	175
W272-39	142	80	4	195	T5	180	80	3.5	169
W272-74	195	92	11	616	F3	230	120	4.15	190

2- Basic Exchange rate index (I.E.B)

The basic exchange index denoted IEB or chloro-alkaline imbalance index established by Schöeller (1934). This index is defined accordant to the formula (Equation 3)

$$IEB = \frac{rCl^{-} - r(Na^{+} + K^{+})}{Cl^{-}} \quad (3)$$

In both plains, the Ion Exchange Balance (IEB) indicates that groundwater generally exchanges Na^{+} and K^{+} from water for Ca^{2+} and Mg^{2+} from the soil (IEB > 0), with few exceptions at specific points (W241-10, W272-39 in Sidi Bel Abbès; F21 bis in Tenira) where the reverse occurs. This suggests that the aquifers release more in calcium than alkalis, and those waters are enriched in chloride faster than sodium and potassium, reflecting active ion exchange processes between water and the aquifer matrix.

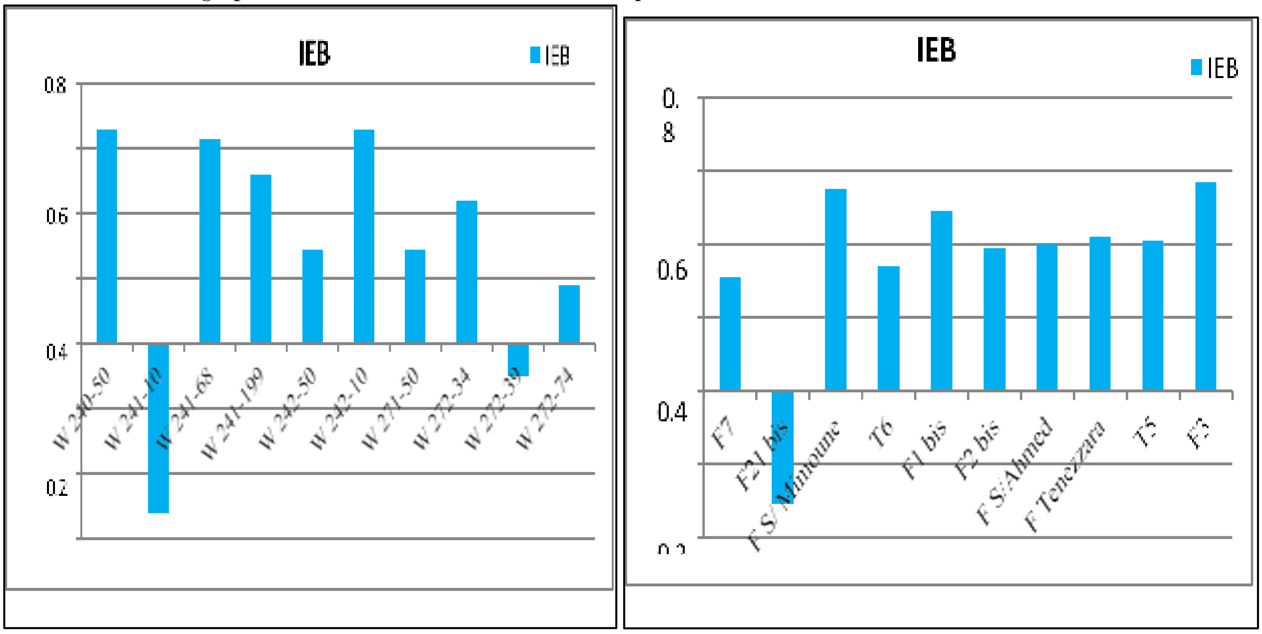

Figure 11: Variation of the EBI of the groundwater of the plains of Sidi-Bel-Abbès and Tenira.

In both plains, the Ion Exchange Balance (IEB) indicates that groundwater generally exchanges Na^{+} and K^{+} from water for Ca^{2+} and $Mg^{2+}$from the soil (IEB > 0), (Figure11) with few exceptions at specific points (W241-10 and W272-39 in Sidi Bel Abbès; F21 bis in Tenira) where the reverse occurs. This suggests that the aquifers release more calcium than alkalis, and that the waters are enriched in chloride faster than in sodium and potassium, reflecting active ion exchange processes between water and the aquifer matrix. Major anions the hydrochemical differences observed between the Sidi Bel Abbès and Tenira plains reflect contrasting geological settings and levels of anthropogenic influence. The predominance of a sodium–chloride facies and high mineralization in Sidi Bel Abbès indicate strong interactions with evaporitic formations and possible contamination from urban and agricultural activities. In contrast, the calcium–chloride facies in Tenira suggest a system mainly controlled by the dissolution of carbonate and gypsum-bearing rocks, resulting in comparatively better groundwater quality. The distributions of bicarbonate, chloride, and sulfate (Figure12) further highlight these contrasts(Table 8), with exceedances of drinking water standards concentrated in Sidi Bel Abbès and only occasionally in Tenira. Although SAR values remained low in both plains, indicating limited sodium hazards, the high salinity hazard, particularly in Sidi Bel Abbès, poses risks to long-term irrigation and soil health. The absence of significant bacteriological contamination confirms that both aquifers remain suitable for drinking purposes, although minor traces in Sidi Bel Abbès reveal greater vulnerability to surface water inputs. Overall, the results underline the need for targeted groundwater management, with priority attention to Sidi Bel Abbès where chemical degradation and human pressures are more pronounced.

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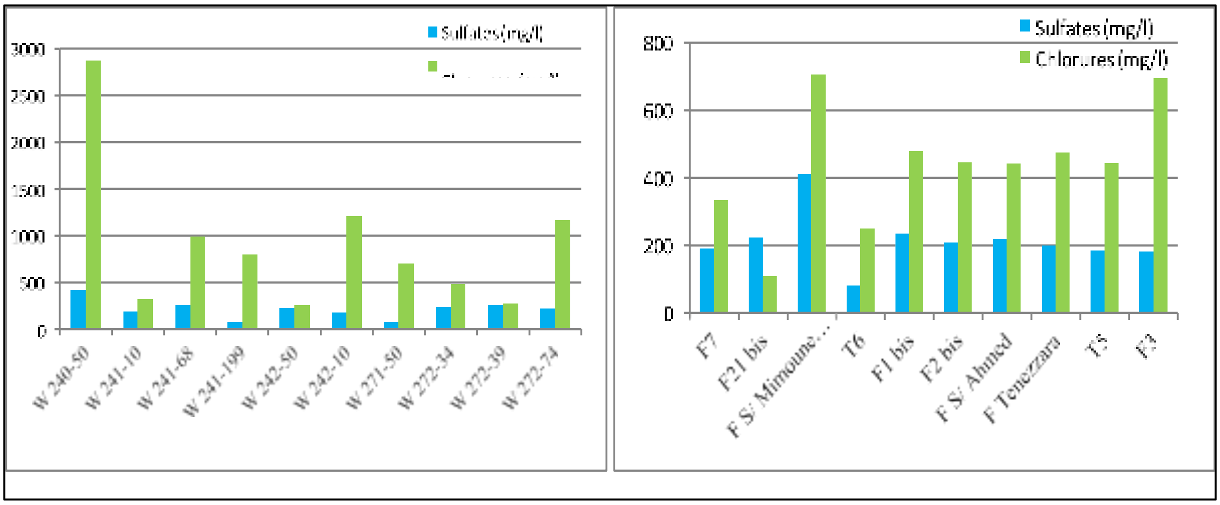

Figure 12: Chloride and sulfate contents of water samples from the plains of Sidi-Bel-Abbès and Tenira.

3- Nitrates and Nitrites For the two plains

The nitrate concentrations were all lower than the standard (50 mg/l) (Table 9). The highest concentrations were observed, at water point W240-50 due to fertilizers used in agriculture [9], at water point W241-199 due to wastewater discharges from the Tissaf Wadi. The infiltration and percolation of which are facilitated by the shallow depth of this water point, which increases its vulnerability to contamination, and at water points F ,Sidi Mimoune bis and F Tenezzar due to the nitrogen products used in agriculture. Nitrites are considered intermediate ions between nitrates and ammonia nitrogen. The nitrite content in all the studied water points of the two plains was less than 0.1 mg/l, which complies with the regulations of the JORA (Table 8).

Table 8: Concentrations (mg/l) major anions of the aquifers of the plains of Sidi-Bel-Abbès.

Water point	HCO_3^- mg/l	Cl^- mg/l	SO_4^{2-} mg/l	NO_3^- mg/l	NO_2^- mg/l	Water point	HCO_3^- mg/l	Cl^- mg/l	SO_4^{2-} mg/l	NO_3^- mg/l	NO_2^- mg/l
W240-50	120	2 873	418	40	0.04	F7	409	335	192	38	0.02
W241-10	518	320	185	15	0.01	F21 bis	355	110	225	24.8	0.01
W241-68	305	994	262	20	0.01	F Sidi Mimoune bis	320	705	410	46.2	0.04
W241-199	180	798	78	45	0.04	T6	363	250	82	27	0.01
W242-50	333	260	226	25	0.01	F1 bis	318	480	235	36.2	0.02
W242-10	350	1 212	180	30	0.01	F2 bis	380	446	210	35,5	0.02
W271-50	320	705	80	35	0.02	F Sidi Ahmed	392	442	220	26	0.01
W272-34	340	486	238	22	0.01	F Tenezzara	370	475	200	40	0.03
W272-39	335	276	260	24	0.01	T5	400	445	185	23.8	0.01
W272-74	338	1 168	218	35	0.02	F3	370	695	182	27	0.01

Bacteriological Parameters to meet national and international standards, the complete absence of pathogenic bacteria is desirable for water of good bacteriological quality. On the other hand, water of poor bacteriological quality is based on the enumeration of pathogenic germs, such as total coliforms, fecal, and sulfito reducing clostridia.

Table 9 reports the concentrations of microbial germs during April 2024.Tenira Points

Water point	CF (CF/100	CF (CF/100	ASR (ASR/20	Water point	CF (CF/100	CF (CF/100	ASR (ASR/20

	ml)	ml)	ml)		ml)	ml)	ml)
W240-50	1	0	0	F7	0	0	0
W241-10	0	0	0	F21 bis	0	0	0
W241-68	0	0	0	F Sidi Mimoune bis	0	0	0
W241-199	3	0	0	T6	0	0	0
W242-50	0	0	0	F1 bis	0	0	0
W242-10	0	0	0	F2 bis	0	0	0
W271-50	2	0	0	F Sidi Ahmed	0	0	0
W272-34	0	0	0	F Tenezzara	0	0	0
W272-39	0	0	0	T5	0	0	0
W272-74	0	0	0	F3	0	0	0

Most groundwater samples from both plains (Table 9) showed no bacterial contamination, fully complying with the JORA and WHO [11] standards. Minor total coliform traces detected at a few Sidi Bel Abbès sites remained below the permissible limits and were likely linked to shallow groundwater or nearby domestic discharges. Overall, the bacteriological quality of groundwater in both plains was good

4. CONCLUSION

Groundwater in the Sidi Bel Abbès and Tenira plains exhibited distinct hydrochemical characteristics, with generally poor quality in the former and better quality in the latter. Despite the limited risk to soil structure, salinity remains a concern for irrigation. Sustainable management, including the regulation of abstraction, protection of recharge zones, and diversification of water resources, is essential for preserving these aquifers

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