



Quality assessment and hydrogeochemical characteristics of groundwater in Kerzaz and Beni Abbes along Saoura valley, southwest of Algeria

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Abstract

The present study focused on the hydrochemistry of groundwater in Kerzaz and Beni Abbes in Saoura oases (southwest of Algeria) to assess the quality of groundwater for determining its suitability for drinking and irrigation purposes. The study area experiences a hyper-arid climate characterized by low rainfall 50–100 mm/year and excessive drought. Groundwater samples were collected from 24 locations to ensure a good spatial distribution to cover all the study areas. Standards laboratory methods were used to determine physicochemical groundwater properties. The result for this study showed that the water was to be found unsuitable for drinking purposes except for few samples in Kerzaz and Beni Abbes. Except for PI values, all other physicochemical parameters (EC, SAR, MAR), and according to the US salinity diagram, groundwater in Kerzaz was to be found satisfactory for irrigation especially if the soil permeability is improved and the leaching is guaranteed by applying extra frequently irrigation. In Beni Abbes, 58.33% of water samples show that water can be used if rapid permeability is guaranteed, which is the case in Beni Abbes soils, and 25% present medium salinity and low to medium alkalinity (C2S1, C2S2, C3S3) and only the natural spring presents a low salinity and low alkalinity C1S1 permitting the use of water for irrigation with most crops on most soil. Piper diagram indicates groundwater in Kerzaz belongs to CaCl type, while in Beni Abbes four types were recognized, NaCl, CaMgHCO₃, CaCl and mixed CaCl type with 16.66%, 8.33%, 41.66% and 33.33%, respectively.

Keywords Kerzaz · Beni Abbes · Groundwater quality · Physicochemical parameters · Piper diagram · Drinking and irrigation suitability · Hydrogeochemistry

Introduction

While groundwater is the largest reserve of liquid freshwater in the world (about 8–11 million km³), few studies have sought to quantify the evolution of this precious underground reservoir and to identify its quality to preserve it (Margat 1990; Remini 2016). Groundwater is the main source of supply for the inhabitants of Saoura oases. Since the early 1970s, Algeria has built on the wadi Guir the large

dam of Djorf Torba with a capacity of 360 million m³ for the irrigation of the plain of Abadla with an area of 5400 ha (Kabour et al. 2016). The construction of large equipment like that on Oued Guir disturbed the ecosystem of the region since it drains more than 80% of the total flow of the wadi Saoura and 20% of the flow comes from the wadi Zouzfana. This new situation has led to an appreciable decrease in shallow flows in Oued Saoura and consequently a reduction of the water table and a deterioration of its quality accelerated by excessive pumping and population growth translated into increased consumption of water. Several studies on water quality have been carried out in the Saoura region before and after the construction of the Djorf Torba dam (Dubief 1955; Merzougui 2011; Rezzoug et al. 2017). A comparison of these studies reveals that groundwater in Saoura oases is facing water quality issues. It is in this context that this study aims to assess the quality of the groundwater both of low and high Saoura oasis, respectively, in Beni Abbes and Kerzaz

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and to explain the phenomena at the origin of the mineralization of these waters. The collected data were compared with Algerian, WHO and FAO standards to determine if this water was suitable for drinking and irrigation purposes.

Study area

The oases of Saoura located in the southwest of Algeria admit $26^{\circ}30'$ north latitude and $1^{\circ}29'$ west longitude, considered as green islands dispersed in a vast ocean of dunes which represent the western part of the Algerian Sahara, spread over about $789,000 \text{ km}^2$. From the region of Ighli in the upstream, an important stream named wadi Saoura is born and which is the result of the confluence (fusion) of two streams: wadi Guir (on the high Moroccan atlas) and wadi Zouzfana (on the mountains of ksours between Figuig and Beni Ounif) (Hadidi et al. 2018). The Oued Saoura continues to flow on the surface over a length of 600 km and at each place where the natural conditions are favorable appear a series of oases which are from north to south: Ighli, Beni Abbes, El Ouata, Kerzaz, Timoudi, Ouled Khoder, Elksabi.

Saoura region experiences a hyper-arid climate characterized by low rainfall 50–100 mm of rain per year (Rezzoug et al. 2017) and excessive drought. With a clear sky, almost without clouds, the region of Saoura is above all "the country of the sun" (Fig. 1).

Methodology

A series of two sampling campaigns were carried out during December 2017 and April 2018 in Beni Abbes and Kerzaz to collect 24 samples (21 open wells, 2 boreholes and 1 natural spring) using a 1 L sampler. The sampling sites were carefully selected to ensure a good spatial distribution in the oases. Water samples collected in polyethylene bottles of 1 L capacity are stored in the dark and cool with the aid of a refrigerator. All the physicochemical analyses were performed following standards methods (APHA 1998; Rodier et al. 2009). Temperature T, hydrogen potential pH, electrical conductivity EC and turbidity NTU are the physical parameters measured on-site using a multi-parameter meter (Horiba U10). Calcium Ca, magnesium Mg, potassium K, sodium Na were determined by flame atomic absorption spectrometry. The concentration of chloride and sulfates was determined by the Mohr titration methods and the turbidimetric method, respectively; nitrate (NO_3) was determined by a spectrophotometric technique. Bicarbonate present in the water samples was calculated from the measured total alkalinity values which were determined by neutralization of a certain volume of water by a dilute mineral acid, in the presence of a colored indicator.

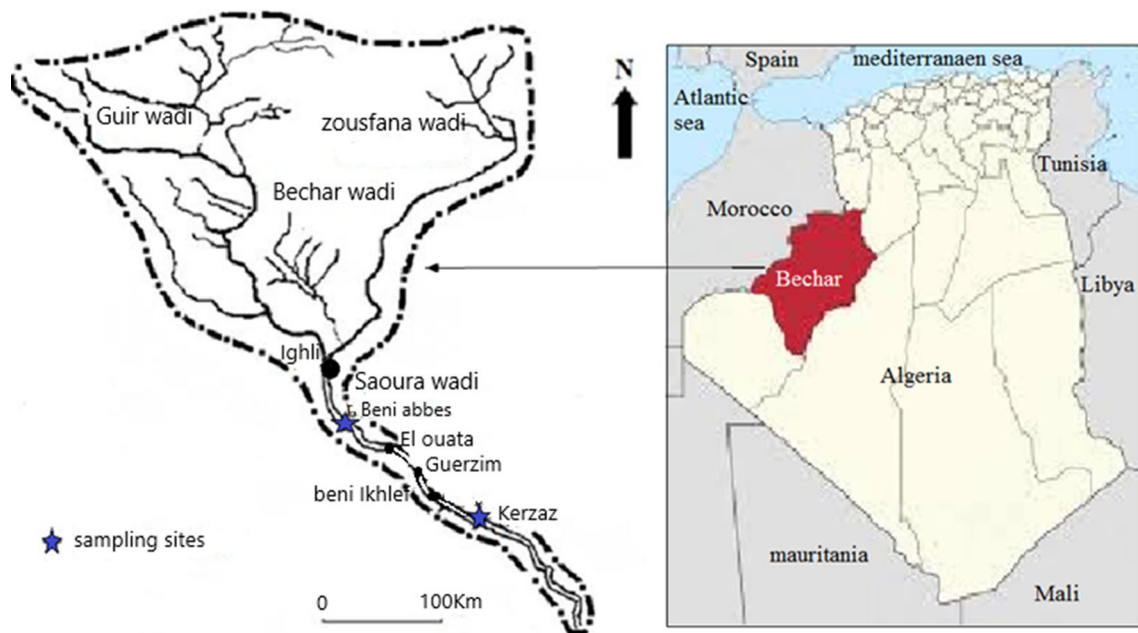


Fig. 1 Geographic locations of the study area

Results and discussion

Physicochemical analysis of water from all studied wells and boreholes in Kerzaz and Beni Abbes is summarized in Tables 1 and 2.

The biological production of water is directly related to its temperature because it affects the physical and chemical properties of it; in particular, its density, its viscosity, the solubility of its gases (oxygen particularly) and the speed of chemical and biochemical reactions (Rice et al. 2017). The results obtained show that the temperature does not vary greatly from one well to another with a maximum of 26.5 °C in the two oases and it was well within the safe limits of drinking water (Algerian standards).

The world health organization prescribed pH water of 6.5–8.5 for drinking purposes (WHO 2011). The pH value does not show a large variation from one well to another with a minimum of 7.11 at point P9 and a maximum of 8.3 at the natural spring in Beni Abbes oasis which reflects slight alkalinity of the waters due to bicarbonate. All pH values are within the prescribed limit for drinking water. The conductivity electric is the conductance of a water column between two metal electrodes; it allows evaluating the overall mineralization of water (Weast 1968; Rodier et al. 2009). For all the samples of Kerzaz and Beni Abbes, the conductivity is between 192 and 4450 $\mu\text{S cm}^{-1}$. The waters closest to the western erg have lower conductivity values compared to those located near the wadi Saoura. This can be explained by an increase in dry residues due to the drying up of the wadi Saoura after the construction of the Djorf Torba dam in 1969, the uncontrolled evolution of the surface wells abandoned by the farmers and the phenomenon of evaporation led to a deterioration of the water quality reflected by high conductivity electric exceeding the international standard. Almost all samples cross the permissible limit of 600 $\mu\text{S cm}^{-1}$ (WHO 2008) except P4, P5, P7 and the natural spring in Beni Abbes.

The total dissolved solids (TDS) values in Kerzaz and Beni Abbes oases vary from 541 to 845 mg/L and from 286 to 1087 mg/L, respectively. In both oases, TDS increases from the Hamada slope in the east to the wadi Saoura in the west with a high value which exceeds the WHO limits (1000 mg/L) in Beni Abbes with 25% of samples. 75% and 25% of samples were within the acceptable limits set by WHO (WHO 2008) in Kerzaz and Beni Abbes, respectively. This can be explained by the dissolution of the salts contained in the quaternary formation sand, the evaporation in wells of large diameter and the rise of the waters of the infero-flux charged with salts by pumping and diffusion phenomenon.

The total hardness is mainly due to the dissolved salts of calcium and magnesium; their concentration too strong

makes the water very hard. The hardness of natural water depends on the geological structure of the soils crossed; it is considered as an indicator of the level of limestone in the water (Amadou et al. 2014; Rice et al. 2017). Virtually all values of total hardness presented by wells and boreholes are found in the range of (267–661 mg/L) in Kerzaz and (141–936 mg/L) in Beni Abbes. Most of them are within the recommended limit set by WHO with less than 500 mg/L in Kerzaz, in contrast to Beni Abbes samples where almost all values are well above this limit with a maximum of 936 mg/L. This can be explained by the lithological nature of quaternary limestone, and it is proportional to Ca and Mg contents in all wells and boreholes.

Calcium is a major component of water hardness and usually the dominant element of drinking water. Its content varies mainly according to the nature of the lands crossed. Calcium contents range from 267 to 650 mg/L in Kerzaz and from 73 to 667 mg/L in Beni Abbes oases. The WHO sets a maximum value of 50 mg/L as an allowable drinking water limit (WHO 2008). This value is largely exceeded by the waters of the alluvial aquifer. Calcium is due to the dissolution of calcium carbonate in the quaternary limestone in geological formations of the Saoura Valley (Merzougui 2011).

The magnesium ion is a significant element of water hardness; its content depends on the composition of the sedimentary rocks encountered (dolomitic limestone, Jurassic or Middle Triassic dolomites) (Sayad et al. 2017). More than half of the samples have a magnesium concentration higher than the standard recommended by WHO at 75 mg/L (WHO 2008) in both locations of Kerzaz and Beni Abbes. This can be explained by the exchange of ions between the water and the magnesium clay contained in the quaternary sands in the region Saoura Valley.

Sulfates result from runoff or infiltration into gypsum soils. They also result from the activity of certain bacteria (chlorothiobacteria, rhodothiobacteria, etc.). This activity can oxidize toxic hydrogen sulfide (H_2S) to sulfate (Oga et al. 2010). The sulfate contents vary between 84.5 and 2986.5 mg/L in Beni Abbes and 17–403 mg/L in Kerzaz exceeding the standard fixed by WHO (250 mg/L) (WHO 2011). This is due to leaching clays and marl present in the quaternary formation.

The natural origin of chloride in water is weathering of rock salts and atmospheric deposition of oceanic aerosols, while the anthropogenic sources include industrial or domestic sewage effluents and runoff from agricultural fields through fertilizers (Chattopadhyay et al. 2005). In general, chlorides present in drinking water do not have toxic consequences for humans even at high concentrations (1000 mg/L) but can be harmful to the taste of water by giving it a salty taste and an effective laxative, besides they promote the process of corrosion. More than half of

Table 1 Results of physicochemical and major ions in Kerzaz

Location N°	Kerzaz											
	T (°C)	pH	EC (µs cm ⁻¹)	TDS (mg/L)	TH (mg/L)	Ca ²⁺ (mg/L)	Mg ²⁺ (mg/L)	SO ₄ ²⁻ (mg/L)	Cl ⁻ (mg/L)	HCO ₃ ⁻ (mg/L)	Na+ (mg/L)	NO ₃ ⁻ (mg/L)
F1	24	7.27	822	541	300	297	72.91	17	106.5	41	607	19.49
P1	25	7.53	3130	695	311	320	196.87	403.25	754.5	89	180	16.26
F2	24.9	7.66	1090	556	267	270	31.59	85.3	177.5	39	20	22.52
P2	25	7.28	3180	702	288	295	48.61	191.5	781	40.5	200	34.86
P3	25	7.25	1450	405	301	314	36.45	54	355	87	60	69.99
P4	25	7.4	1770	425	487	497	87.49	110	390.5	125	80	57.59
P5	25	7.15	2850	715	468	480	138.53	110.65	852	110	190	98.78
P6	25	7.86	2790	650	661	650	111.8	66.6	710	255	140	40
P7	24.5	7.59	4450	845	263	267	245.48	106.5	1562	37	230	18.3
P8	25	7.52	862	570	286	294	26.73	109.3	142	40	8	31.76
P9	25	7.53	1160	578	302	304	36.45	8.65	248.5	54	20	42.52
P10	25	7.66	1400	550	540	545	63.19	172	213	165	70	26.69
Min	24	7.15	822	405	263	267	26.73	8.65	106.5	37	8	16.26
Max	25	7.86	4450	845	661	650	245.48	403.25	1562	255	230	98.78
Mean	24.81	7.48	2159	605.86	385.57	389.29	97.74	131.9	568.64	98.18	106.86	42.41

Table 2 Results of physicochemical and major ions in Beni Abbes

Location N°		Beni Abbes												
	T (°C)	pH	EC (µs cm ⁻¹)	TDS (mg/L)	TH (mg/L)	Ca ²⁺ (mg/L)	Mg ²⁺ (mg/L)	SO ₄ ²⁻ (mg/L)	Cl ⁻ (mg/L)	HCO ₃ ⁻ (mg/L)	Na+ (mg/L)	NO ₃ ⁻ (mg/L)		
P1	25.5	7.13	1205	4074	141	91	348.87	500	2187	293	523	33.73		
P2	25	7.52	1312	2025	123	85	378.12	250	950	284	432	34		
P3	24	7.31	1500	2016	647	412	505.10	2986.5	705	471	621	31.15		
P4	24	7.30	500	10.870	756	565	630.24	96	696	312	2300	42.56		
P5	25.5	7.39	556	1417	810	601	510.00	150	584	354	1410	154		
P6	25.5	7.22	765	1544	936	667	485.15	250	701	376	450	163		
P7	25	7.34	300	1546	845	610	365.00	211	503	265	783	36.07		
P8	24	7.52	910	980	645	410	38.36	170	649	219	865	35.60		
P9	25	7.11	1210	1193	580	352	195.01	100	815	458	345	36		
P10	24	7.42	1100	2046	786	580	74.24	124	445	346	250	42.13		
P11	25	7.31	1475	1000	611	396	65.10	117	511	281	189	29.11		
N spring	26.5	8.3	192	286	115	73	58.98	84.5	140	271	8	24		
Mfin	24	7.11	192	286	115	73	38.36	84.5	140	219	8	24		
Max	26.5	8.3	1500	10,870	936	667	630.24	2986.5	287	471	2300	163		
Mean	24.96	7.45	908.36	2868.07	574.71	398.71	308.77	579.29	800.93	330	748.86	60.6		

the samples have a chloride concentration higher than the standard recommended by WHO at 250 mg/L (WHO 2011); all values range from 106.5 to 1562 mg/L and from 140 to 2187 mg/L in Kerzaz and Beni Abbes, respectively. This can be explained by the fact that the chlorides have a geological origin linked to the leaching of the quaternary, clay and marly alluvial formations.

In natural waters, the alkalinity results most generally from the presence of hydrogen carbonates, carbonates and hydroxides. The bicarbonates come mainly from the dissolution of free CO₂ in relatively high pH solutions. The bicarbonate content varies between 70 and 250 mg/L in Kerzaz and from 281 to 471 mg/L in Beni Abbes, so the results do not exceed the WHO standards of 500 mg/L (Lachache et al 2018).

The origin of sodium in water is not only the leaching of geological formations containing sodium chloride but also the decomposition of mineral salts such as sodium and aluminum silicates, marine fallout, saltwater in the aquifers and many industrial uses (Rodier et al. 2009). In Kerzaz region, the sodium contents vary between 8 and 230 mg/L; all the water points analyzed have a concentration lower than the value set by the WHO at 200 mg/L (WHO 2011) except for the wells P7; However, in Beni Abbes, the sodium contents vary largely from 8 to 2300 mg/L exceeding the WHO standards in overall samples which can be explained by the leaching of clay formations of quaternary age by water and the rise of saline waters of the infero-flux caused by the overexploitation of the wells in this area by motor pumps.

Nitrates are naturally present in groundwater at low concentrations; however, significant levels in the water are an index of pollution of agricultural origin (fertilizer), urban or industrial; they can come from water by decomposition of organic matter

or by leaching of soils crossed by water (Krishna Kumar et al. 2009). All the samples analyzed were within the acceptable limit of 50 mg/L set by WHO (WHO 2011) except for the wells P3, P4 and P5 in Kerzaz with a maximum of 98.78 mg/L; P5 and P6 within Beni Abbes with a maximum of 60.6 mg/L.

Water quality for irrigation purposes

Water quality plays a major role in determining the quantity and quality of the crop, especially with the deterioration of water quality in recent years due to intensive exploitation. To assess the aptitude of groundwater quality in Kerzaz and Beni Abbes for irrigation purposes, a major parameter was determined such as pH, TDS, EC, SAR MAR and PI and summarized in Table 3. All the equations used to calculate the major element for assessing groundwater quality for irrigation in Kerzaz and Beni Abbes are summarized below (Eqs. 1–4).

$$\text{SAR} = \text{Na}^+ / \sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}} \quad (1)$$

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

$$\text{MAR} = 100 \times \left(\frac{\text{Mg}^{2+}}{\text{Mg}^{2+} + \text{Ca}^{2+}} \right) \quad (3)$$

$$\text{PI} = \left(\frac{\text{Na}^+ + \sqrt{\text{HCO}_3^-}}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^{2+}} \right) \times 100. \quad (4)$$

Table 3 Water quality parameters for irrigation purposes

Parameter	Range	Class	Kerzaz		Beni Abbes	
			No. of samples	% of samples	No. of samples	% of samples
pH	6.5–8.5	Good	<i>n</i> = 12	100	<i>n</i> = 12	100
EC (μs cm ⁻¹)	< 250	Excellent	<i>n</i> = 0	0	<i>n</i> = 1	8.33
	250–750	Good	<i>n</i> = 0	0	<i>n</i> = 3	25
	750–2250	Doubtful	<i>n</i> = 7	58.33	<i>n</i> = 8	66.66
	> 2250	Unsuitable	<i>n</i> = 5	41.66	<i>n</i> = 0	0
SAR	< 10	Excellent	<i>n</i> = 12	100	<i>n</i> = 9	75
	10–18	Good	<i>n</i> = 0	0	<i>n</i> = 3	25
	18–26	Doubtful	<i>n</i> = 0	0	<i>n</i> = 0	0
	> 26	Unsuitable	<i>n</i> = 0	0	<i>n</i> = 0	0
PI	Class I (> 75%)	Excellent	<i>n</i> = 0	0	<i>n</i> = 0	0
	Class II (25–75%)	Good	<i>n</i> = 2	16.66	<i>n</i> = 11	91.66
	Class III (< 25%)	Unsuitable	<i>n</i> = 10	83.33	<i>n</i> = 1	8.33
MAR	Class I (< 50%)	Suitable	<i>n</i> = 10	83.33	<i>n</i> = 5	41.66
	Class II (> 50%)	Unsuitable	<i>n</i> = 2	16.66	<i>n</i> = 7	58.33

All samples present an acceptable pH range (7.15–7.86) and (7.11–8.3) in Kerzaz and Beni Abbas, respectively, which were within the FAO standards (6.5–8.4) (Bashir et al. 2013; Ayers and Westcot 1985). 58.33% of wells in Kerzaz present an electrical conductivity (EC) which is considered doubtful for irrigation; the rest were unsuitable. While in Beni Abbas 66.66% were doubtful, 25% were good and 8.33% were excellent (the natural spring).

The sodium adsorption ratio (SAR) is a measure of the amount of sodium (Na) relative to calcium (Ca) and magnesium (Mg) in the water extract from saturated soil paste. The SAR values of all samples in the study area of Kerzaz were less than $10 \mu\text{s cm}^{-1}$ which is considered as excellent for irrigation, while in Beni Abbas only 8.33% of samples were excellent and the remaining samples are considered doubtful to good for irrigation with 66.66% and 25%, respectively.

The suitability of water for irrigation use can be determined by using the US salinity diagram (Richards 1954; USSL 1954; Al-Ahmadi 2013; Shahin Hossin et al. 2016; Bahir et al. 2019). The estimated values of EC and SAR in the groundwater samples of Kerzaz oasis fall into the field of C4S1 and C3S2 indicating very high salinity and low alkalinity which cannot be used under ordinary conditions; drainage must be applied adequately and the soil must have rapid permeability. However, 58.33% of water samples collected from Beni Abbas oasis fall into the C3S1 category indicating high salinity and low alkalinity, water can be used with rapid permeability which is the case in Beni Abbas (Hoffman et al. 1990). 25% fall into a class which is considered medium salinity and low to medium alkalinity (C2S1, C2S2, C3S3), and only the natural spring presents a low salinity and low alkalinity C1S1 permitting the use of water for irrigation with most crops on most soil (Fig. 2).

The permeability index is an important parameter for assessing the water quality for irrigation purposes. Following PI, water can be classified as class I (>75%), class II (25–75%) and class III (<25%). Class I and II water are categorized as excellent and good for irrigation, respectively. Class III water is unsuitable with 25% of maximum permeability (Kumar Nag and Shreya 2014). In Kerzaz region, only 16.66% of samples were good for irrigation with PI (25–75%) and the rest (83.33%) were unsuitable. On the contrary, in Beni Abbas region, 91.66% of samples were good and just 8.33% of them were unsuitable for irrigation.

In groundwater, a state of equilibrium is maintained between Mg and Ca. During equilibrium, more Mg^{2+} in groundwater adversely affects the soil quality rendering it alkaline which results in a decrease in crop yield (Kumar et al. 2007; Bashir et al. 2013; Hem 1985). According to the magnesium adsorption ratio value, water can be categorized into two classes (class I $\text{MAR} < 50$) and class II ($\text{MAR} > 50$). Class I water is considered suitable for irrigation, whereas water in class II is considered unsuitable.

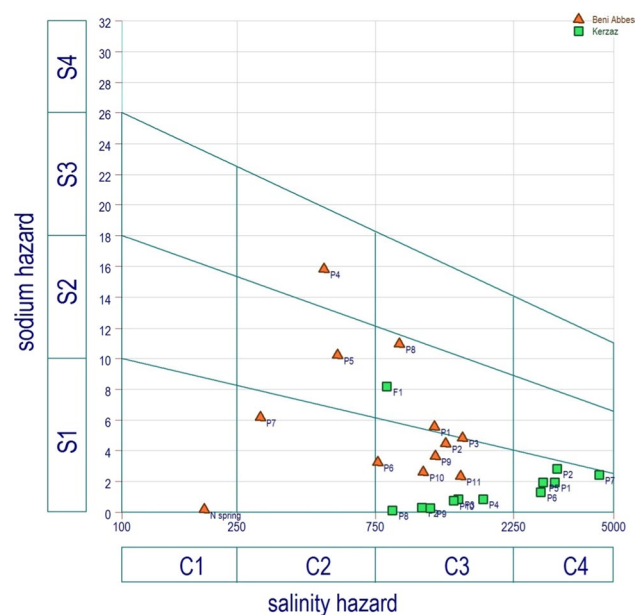


Fig. 2 Salinity versus alkalinity hazard in the US salinity diagram of groundwater samples (Kerzaz and Beni Abbas)

The MAR values of almost all samples in Kerzaz area (83.33%) were less than 50 which is considered as suitable for irrigation; two wells (P18, P12) were unsuitable with MAR value of 60.51%, 50.63%, respectively. In Beni Abbas, 41.66% of samples were suitable for irrigation and 58.33% were unsuitable (Table 4).

Hydrogeochemical facies

During their journey, the chemical composition of groundwater evolves through the crossing of different geological faults according to several modifying phenomena (Mansour 1993); according to its chemical composition, we can classify them in families using the logarithmic diagram of Piper which is composed of two triangles representing the distribution of the anions and that of the cations, respectively, and a rhombus representing a synthetic distribution of major ions. This diagram reveals similarities and differences among water samples because those with similar qualities will tend to plot together as groups (Todd 1980; Makoba and Muzuka 2019).

The representation of chemical results of waters taken from the oasis of Kerzaz and Beni Abbas on Piper diagram (Figs. 3, 4) shows that all the water samples of Kerzaz (100%) belong to one type of CaCl, while in Beni Abbas four types were recognized, NaCl, CaMgHCO_3 , CaCl and mixed CaCl with 16.66%, 8.33%, 41.66% and 33.33%, respectively.

Table 4 Sodium adsorption ratio (SAR), electrical conductivity (EC), alkalinity and salinity hazard class

	Kerzaz			Beni Abbes			
	EC ($\mu\text{s cm}^{-1}$)	SAR	Alkalinity and salinity hazard class	EC ($\mu\text{s cm}^{-1}$)	SAR	Alkalinity and salinity hazard class	
F1	822	8.16	C3S2	P1	1205	5.55	C3S1
P1	3130	1.94	C4S1	P2	1312	4.44	C3S1
F2	1090	0.31	C3S1	P3	1500	4.82	C3S1
P2	3180	2.84	C4S1	P4	500	15.74	C2S3
P3	1450	0.85	C3S1	P5	556	10.18	C2S2
P4	1770	0.87	C4S1	P6	765	3.22	C3S1
P5	2850	1.96	C4S1	P7	300	6.17	C2S1
P6	2790	1.33	C4S1	P8	910	10.93	C3S2
P7	4450	2.43	C4S1	P9	1210	3.65	C3S1
P8	862	0.12	C3S1	P10	1100	2.59	C3S1
P9	1160	0.29	C3S1	P11	1475	2.31	C3S1
P10	1400	0.75	C3S1	Spring	192	0.17	C1S1

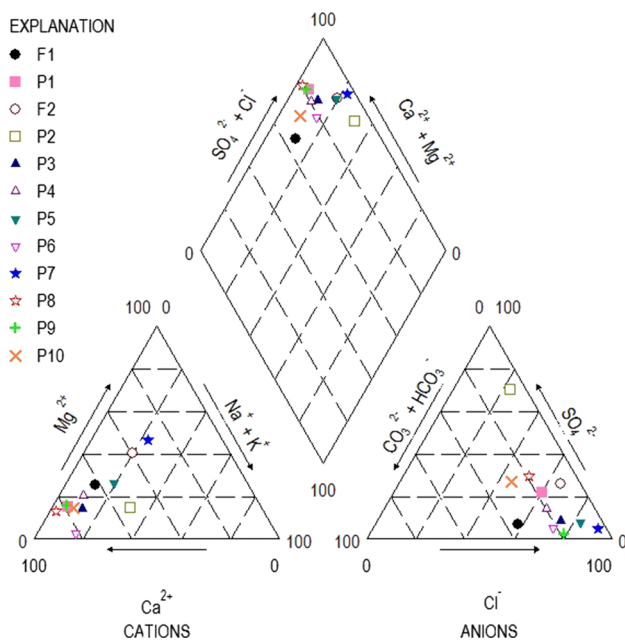


Fig. 3 Piper diagram for water samples of Kerzaz groundwater

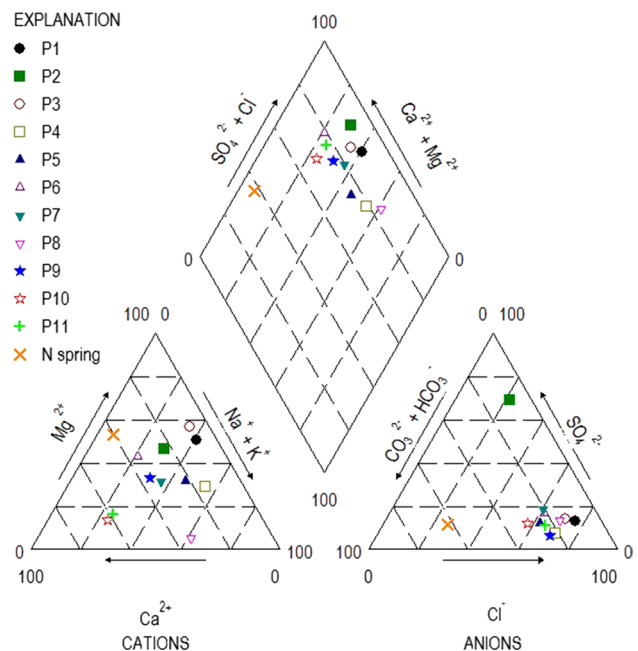


Fig. 4 Piper diagram for water samples of Beni Abbes groundwater

Conclusion

The groundwater quality in Kerzaz and Beni Abbes, southwest of Algeria has been assessed for its drinking and irrigational suitability purposes. The physicochemical analyses show that Cl^- , Ca^{2+} are the dominant ions in Kerzaz and Cl^- in Beni Abbes. This predominance is mainly due to the leaching of Mio-Pliocene limestone and the presence of gypsum lenses and clays on the one hand and chemical processes resulting from evaporation on the other hand.

The groundwater in Kerzaz and Beni Abbes belongs to chlorinated and sulfated calcium and magnesium type. The pH values of both water samples are neutral and within the acceptable limits of drinking purposes. Most of the water samples were found to be moderate in Kerzaz and hard to very hard in Beni Abbes with more than 936 mg/L which is due to the lithology characteristics of the aquifer. In both oases, Only water samples closest to the western erg have lower conductivity and total dissolved solids values ($< 100 \text{ mg/L}$), and the rest (25%) were to be found largely exceeded the WHO standards; this can be explained by the

dissolution of salts contained in the quaternary formation sand, the evaporation in wells of large diameter and the rise of the groundwater table charged with salts by pumping and diffusion phenomenon. The high level of nitrates in some wells is mainly derived from various agricultural and anthropogenic activities. Only a few samples closest to the western erg in Kerzaz and Beni Abbes are within the acceptable limits for drinking purposes; the rest were to be found unsuitable.

According to pH, EC, SAR, PI and MAR, the groundwater samples in Kerzaz is suitable for irrigation, especially if rapid permeability is guaranteed which is the case in Kerzaz soils, while in Beni Abbes more than half of the sampling points indicating that water quality are medium, the rest is good to excellent for irrigation purposes particularly if plants with good salt tolerance are selected.

Establishing monitoring of the quantity and quality of groundwater in the oases, the pretreatment process on sewage before adjoining Saoura wadi and construction of an underground dam perpendicular to the direction of groundwater flow is the main measurement to preserve oases and their fragile ecosystem.

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Compliance with ethical standards

Conflict of interest All the authors of this article state that there is no conflict of interest.

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