ORIGINAL ARTICLE

ASSESSMENT OF WATER SUITABILITY FOR IRRIGATION PURPOSES IN QALAAT MGOUNA AREA, MOROCCO

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ABSTRACT

Background: The groundwater suitability for irrigation is an important factor for sustainable development of the Qalaat Mgouna region, situated South of Morocco under Saharan climate conditions. The irrigation practice is locally related to the expansion of agricultural activities of demographically developing population in an environment of limited water resources. **Objectives:** This study is aimed to the assessment of the groundwater quality and its suitability for irrigation purposes as well as the identification of possible water-rock interactions that control the groundwater geochemistry. **Material and Methods:** The groundwater suitability for irrigation in Qalaat Mgouna area was evaluated by processing available data on major ions concentrations, pH and electrical conductivity (EC) besides calculating quality indices including total dissolved solids (TDS), total hardness, sodium percentage, residual sodium carbonate (RSC), sodium adsorption ratio (SAR) and permeability index (PI). Principal component analysis was conducted to assess the relationships between the used variables, while processes controlling the water chemistry were revealed by determining the water facies according to Piper classification and using geochemical diagrams. **Results:** The data processing showed acceptable values for pH (7.31-7.73), Salinity (502.93-1457.42 mg/l) and total hardness (22.82-70.44 °fH). Mixed, Ca-Mg-HCO_3 and SO_4-Cl-Ca-Mg water types were detected reflecting thus possible water-rock interaction. The Wilcox diagram revealed that waters are mainly of good to permissible quality. **Conclusions:** The geochemical study helped to conclude that water quality in Qalaat Mgouna is controlled by water-rock interaction processes and water is suitable for irrigation according to internationally used standards.
Keywords: *Groundwater Quality, Water Chemical Facies, Water-Rock Interaction, Environmental Sustainability, Qalaat Mgouna, Morocco*

1. INTRODUCTION

The advanced regionalization program has proposed a new territorial rearrangement in Morocco as strategic reform targeting the establishment of viable and durably stable regions [1]. The Qalaat Mgouna region is concerned by territorial reorganization to improve the lifestyle of inhabitants and to ensure their integration in the socio-economic development processes. In this part of arid Morocco where agriculture is the main human activity, sustainable development is strongly conditioned by water resources availability and quality.

Agricultural yields depend on irrigation water quality that is influenced by the concentration of dissolved salts [2]. Besides major ions analysis, computation of derived quality indices is gaining eminence as water quality approach. Indeed, the assessment of water quality based on the concentration of dissolved salts and the calculation of quality indices is widely used for different natural waters including groundwater [3,4,5,6,7,8,9,10], surface waters, especially fluvial waters [11] and dam ones [12].

The hydrochemistry-based assessment was thus undertaken to estimate groundwater quality and its suitability for irrigation purposes in Qalaat Mgouna region. The study focused on the groundwater behavior by determining the water facies and the possible processes controlling the water geochemistry.

2. MATERIALS AND METHODS

2.1 Study site

The Qalaat Mgouna area constitutes a Plateau between the High Atlas Mountains to the North and the Anti-Atlas to the South, within latitudes 31°9′ and 31°24′ N and longitudes 5°59′ and 6°13′ W (Moroccan coordinate system). At 1400m as average altitude, annual rainfall ranges from 150 to 200 mm northwest of Dades river but it decreases to 100-150 mm

southeast of the study area [13,14]. Saharan and cold climate conditions are dominant in the region with remarkable evolution to drier conditions [14,15]. Landform is mainly a plain modeled by surface water runoff through Mgoun and Dades rivers and their tributary streams. Indeed, slopes are limited between 0° and 11.25° in the plateau except on the riverbanks and mountain domains where the topography becomes more rugged and the slope-related hazards such as erosion due to the torrential streaming (when slopes >22.5°) and the erosion of cliffs (slopes >45°) are significant [14].

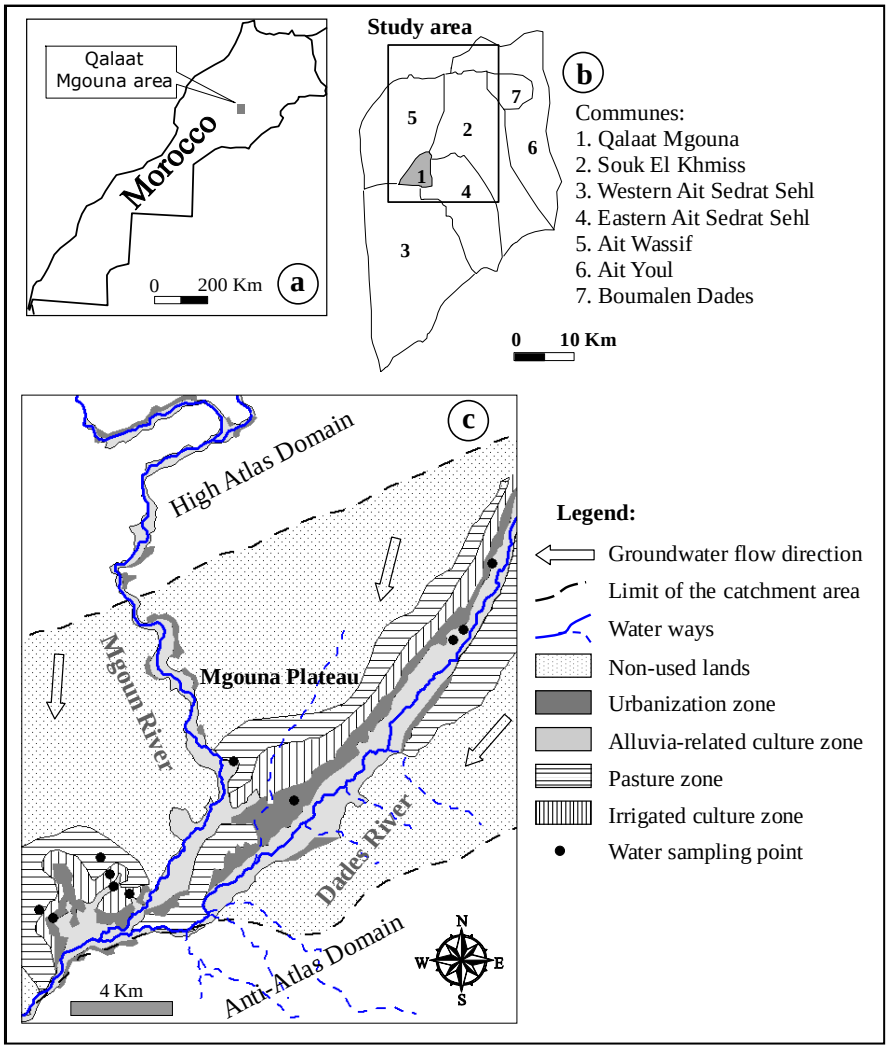

Figure 1: The figure presents the location (a), neighboring communes (b) and land use (c) maps of Qalaat Mgouna area.

2.2 Demography, poverty and land use

The territorial rearrangement of 1997 put Qalaat Mgouna and neighboring communes in the Souss-Massa-Draa region. But according to the last rearrangement of 2015, the area is in the newly created province of Tinghir and belonging to the eighth Moroccan region called Draa-Tafilalte.

The population of Mgouna region is continuously growing, with relatively elevated growth rates for Qalaat Mgouna (3.5) and western Ait Sedrat Sehl (2.2) communes. The lowest rate was recorded for Souk El Khmiss center (0.4). The communes with more poverty are Ait Youl, western Ait Sedrat Sehl and Ait Wassif; these localities remain the most vulnerable to poverty and reveal high rates of relative poverty severity (Table 1) [16]. Low risk of poverty is observed in centers with relatively active economy (e.g., Qalaat Mgouna, Souk El Khmiss and Boumalen Dades) that record significant human development rates, although social development rates are not higher.

Human activities in the region of Mgouna are mainly related to the availability of water resources [17,18]. Besides pasture zone that occupies 13.51% of the study surface of 392.5 sq. km and corresponding to the area of the aquifer extension, agriculture is mainly practiced on the alluvial plains representing 15.29% of the area and it is related to Mgoun and Dades rivers (Fig. 1). Irrigated lands constitute only 5.79% but are continually growing. The remaining area represents 60.37% of the study area and remains non-exploited.

Table 1: The table shows the demography, poverty and development indices for Qalaat Mgouna and neighbouring communes. Governmental data, Haut-Commissariat au Plan (2007) [16]

Centre	Population 1994	Population 2004	Rate of demographic increase	Poverty rate 2004	Vulnerability to poverty 2004	Poverty rate 2007	Severity of relative poverty index	Human development index	Social development index
Qalaat Mgouna	10524	14190	3.5	14.1	15.4	10-15	2.1	0.63	--
Souk El Khmiss	15719	16387	0.4	17.6	20.7	10-15	2.1	0.59	0.74
Western Ait Sedrat Sehl	12211	14864	2.2	23.6	24.6	15-30	3.0	0.53	0.75
Eastern Ait Sedrat Sehl	11650	13082	1.2	24.8	24.5	15-30	3.2	0.54	0.56
Ait Ouassif	6717	7591	1.3	24.7	25.9	30-52	3.1	0.49	0.50
Ait Youl	3972	4466	1.2	29	24.4	15-30	3.9	0.58	0.83
Boumalen Dades	9908	11179	1.3	15	16.5	10-15	2.2	0.63	--

Table 2: The table presents the hydrochemical data and calculated indices used for the characterization of studied waters.

Sample	Ca (meq/l)	Mg (meq/l)	Na (meq/l)	K (meq/l)	HCO3 (meq/l)	Cl meq/l)	SO4 (meq/l)	NO3 (meq/l)	pH	CE (mS/cm)	Calculated indices						
											TDS (mg/l)	TH (°fH)	Na %	RSC	SAR	PI	Water facies
1	3.08	1.51	6.25	0.09	6.62	3.10	3.02	0.39	7.46	0.76	567.12	22.82	57.22	2.03	4.13	81.42	Mixed
2	3.50	1.31	6.25	0.10	5.82	3.15	3.97	0.25	7.48	0.81	591.17	23.94	56.02	1.01	4.03	78.33	Mixed
3	8.16	6.03	11.93	0.09	6.94	13.46	9.35	0.78	7.46	1.79	1298.02	70.44	45.52	-7.24	4.48	55.77	SO_4-Cl-Ca-Mg
4	9.13	4.26	16.67	0.09	10.14	10.20	10.96	0.45	7.49	1.90	1457.42	66.62	55.29	-3.25	6.44	66.04	SO_4-Cl-Ca-Mg
5	3.57	1.97	2.83	0.07	7.42	3.10	1.52	0.63	7.58	0.68	502.93	27.51	33.59	1.89	1.70	66.43	HCO_3-Ca-Mg
6	5.28	3.33	6.22	0.16	6.06	5.80	6.28	0.09	7.53	1.10	812.10	42.80	41.51	-2.55	3.00	58.54	SO_4-Cl-Ca-Mg
7	5.49	3.38	6.04	0.12	6.54	5.86	5.91	0.12	7.56	1.11	812.97	44.06	40.17	-2.33	2.87	57.66	Mixed
8	4.48	2.87	5.27	0.09	5.34	4.90	5.74	0.21	7.73	0.95	718.15	36.49	41.47	-2.00	2.75	60.10	SO_4-Cl-Ca-Mg
9	5.16	3.15	4.47	0.10	10.54	4.17	2.83	0.11	7.57	0.97	729.19	41.30	34.72	2.23	2.20	60.39	HCO_3-Ca-Mg
10	5.07	3.16	4.48	0.10	9.90	4.11	2.69	0.10	7.58	0.98	699.83	40.89	34.96	1.67	2.21	60.00	HCO_3-Ca-Mg
11	6.21	3.46	5.18	0.20	11.50	5.13	2.92	0.71	7.31	1.13	833.04	48.05	34.43	1.84	2.36	57.75	SO_4-Cl-Ca-Mg

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2.3 Geological and hydro-geological frameworks

The Mgouna Plateau Unit corresponds to non-deformed deposits of Miocene to Quaternary ages overlapped by older and deformed rocks of the High Atlas [14]. The Eocene is represented by fluvial sandstones and silts as well as gypsious silts and clays of alluvial plain, while the Quaternary corresponds to the filling of a subsident basin (conglomerates, sandstones and lenticular lacustrine limestone) [14-19]. The unit is unconformable on Precambrian bedrock to the South. The recent deposits are alluvia resulting from the erosion of the High Atlas and Anti-Atlas reliefs drained by Dades and Mgoun rivers and their affluents [20].

The sandy limestones, conglomerates with calcareous matrix and silty clayey rocks hold groundwater in the Mgouna Plateau. Piezometric map reveals groundwater flow from Northeast to Southwest with non-variable gradient (Fig. 1), whereas depth to water varies mainly from few meters up to 40m [14]. A previous study carried out by Agoussine et al. (2004) revealed that groundwater was of good to average quality within the township [21]. Under these conditions water-rock interaction may cause transformations in water facies and quality as shown in arid regions of Morocco [3-22].

2.4 Data processing

The used data was provided by the "Office Régional de Mise en Valeur Agricole de Ouarzazate" ORMVAO for 11 selected groundwater samples from Qalaat Mgouna. The observation points, although few in number, represent the waters upstream and downstream of the aquifer as well as the waters at different depths. The samples are taken from the northeast to the southwest parallel to the flow path of the aquifer and from zones showing different levels of aquifer vulnerability as described by Ettazarini (2011) [14]. In addition, the sampling zone covers the area of irrigation practice. Physical - chemical information concerned conductivity CE and pH as well as major ions (Ca, Mg, Na, K, HCO_3, Cl, SO_4 and NO_3). The database helped to estimate groundwater quality by computing the irrigation indices commonly used as follows:

1. Salinity in terms of total dissolved solids (TDS), calculated from conductivity as shown by equation 1:

$$\mathrm{TDS}\ (mg/l) = \mathrm{CE}\ (\mu S/cm)/0.64 \qquad \text{(Eq. 1)}$$

2. Total hardness TH, expressed in French degree and defined as Eq. 2:

$$\mathrm{TH}\ (°\mathrm{fH}) = 2.5[\mathrm{Ca}] + 4.1[\mathrm{Mg}] \qquad \text{(Eq. 2)}$$

When concentrations are expressed in mg/l

3. Sodium percentage Na%, calculated as follows in Eq. 3:

$$Na\ \% = \frac{(Na+k)/(Ca+Mg+Na+K)}{100} \qquad \text{(Eq. 3)}$$

4. Residual sodium carbonate RSC defined in equation 4 as:

$$\mathrm{RSC} = \mathrm{HCO_3} - [\mathrm{Ca} + \mathrm{Mg}] \qquad \text{(Eq. 4)}$$

5. Sodium adsorption ratio SAR that gives information on the level to which water undergoes cation exchange reaction in soil. It is calculated shown in equation 5:

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{\frac{\mathrm{Ca+Mg}}{2}}} \qquad \text{(Eq. 5)}$$

6. Permeability index PI is also used and computed as follows (Eq. 6):

$$\mathrm{PI} = 100 * \left[\mathrm{Na} + \sqrt{\mathrm{HCO_3}}\right]/[\mathrm{Na} + \mathrm{Ca} + \mathrm{Mg}] \qquad \text{(Eq. 6)}$$

For Na%, SAR, RSC and PI indices calculation, concentrations are expressed in meq/l.

Water hydrochemical facies was checked to determine the groundwater regime in Qalaat Mgouna according to Piper (1944) classification [23]. Besides descriptive statistics, principal component analysis and relevant diagrams according to Richards (1954) and Wilcox (1955) were used to illustrate water quality and suitability for irrigation [24,25].

3. RESULTS

Socio-economic data show that agriculture is the main human activity offering opportunities for development and poverty severity attenuation in Qalaat Mgouna region. Due to the importance of the irrigation water quality and its impact on crop yields, hydrochemical data and calculated quality indices are presented (Table 2).

3.1 Statistical analysis

Statistical description is given in table 3, showing the minimum, maximum, mean and standard deviation for all used variables and revealing acceptable values. The principal component analysis approach was also used to emphasize the relationships between variables (Fig. 2). The two first factors account for 74.64% of the explained inertia. The TDS, CE, Cl, Ca, Mg, TH, SO_4 and Na variables are strongly correlated with the first factor F1 that explains 55.45% of total variability, while RSC is negatively correlated. Following the second factor F2, significant correlation was shown with PI, Na% and SAR, whereas K and HCO_3 are negatively correlated. Weak correlations with the first two factors are observed for pH and NO_3 variables. These relationships revealed between the studied variables are common to subsurface waters [3].

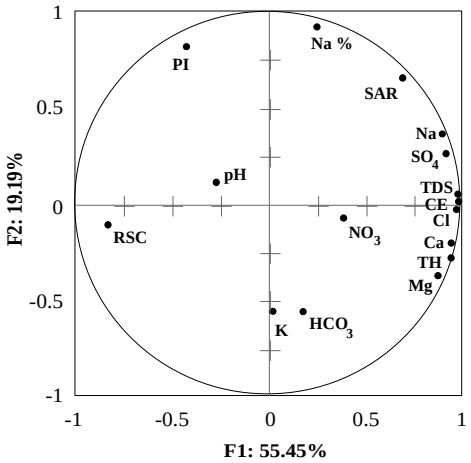

Figure 2: The figure illustrates the principal component analysis results for Qalaat Mgouna groundwater.

3.2 General parameters

Considering observed pH values from 7.31 to 7.73, all the samples fall in the interval 6.5-8.4 of pH values, acceptable for water irrigation (Tables 2 and 3). Waters are under neutral conditions and are favorable for nutrient availability and mobility [26]. Electrical conductivity CE varies from 0.68 to 1.9 mS/cm for the studied samples, while water conductivity values up to 12 mS/cm are tolerable for irrigation purposes. The total dissolved solids (TDS) vary from 502.93 to 1457.42 mg/l meaning acceptable values (TDS<7680 mg/l) according to the Moroccan standards for irrigation water.

3.3 Hydrochemical facies

Information obtained from water samples analysis helped to determine the hydro-geochemical regime of Qalaat Mgouna aquifer. Indeed, table 2 shows that three water facies are identified for the studied samples according to Piper (1944) classification [23]. The mixed water facies is observed southwest of the study area. The SO_4-Cl-Ca-Mg facies is the most represented in all parts of the region. While the HCO_3-Ca-Mg facies is met northeast and at the center of the study region. These water types indicate that water chemistry is influenced by the aquifer lithology dominated by limestone and silty clayey rocks including evaporitic minerals.

Table 3: The table shows the statistical data description.

Variable	Min.	Max.	Mean	Standard deviation
Ca	3.08	9.13	5.38	1.89
Mg	1.31	6.03	3.13	1.31
Na	2.83	16.67	6.87	3.96
K	0.07	0.20	0.11	0.04
HCO_3	5.34	11.50	7.89	2.19
Cl	3.10	13.46	5.73	3.26
SO_4	1.52	10.96	5.02	2.98
NO_3	0.09	0.78	0.35	0.26
pH	7.31	7.73	7.52	0.11

CE	0.68	1.90	1.11	0.39
TDS	502.93	1457.42	820.18	297.49
TH	22.82	70.44	42.27	15.47
Na (%)	33.59	57.22	43.17	9.15
RSC	-7.24	2.23	-0.61	3.08
SAR	1.70	6.44	3.29	1.37
PI	55.77	81.42	63.86	8.60

CE: Electrical conductivity; **TDS**: total dissolved solids; **TDS**: Total Dissolved Solids; **RSC**: Residual sodium Carbonate; **SAR**: Sodium Adsorption Ratio; **PI**: permeability index.

3.4 Processes controlling the water chemistry

Geographically high total dissolved solids (TDS) values are observed southwest of the study area. But the evolution of global salinity is not conforming to the groundwater circulation direction indicating the occurrence of variable water-rock interaction processes governing the water quality. Indeed, the Gibbs (1970) diagrams comparing TDS to cations and anions amounts are useful to check water-rock interaction possibility [22-27,28]. Figure 3 suggests that water-rock interaction and evaporation can be the two main processes guiding groundwater quality in Qalaat Mgouna.

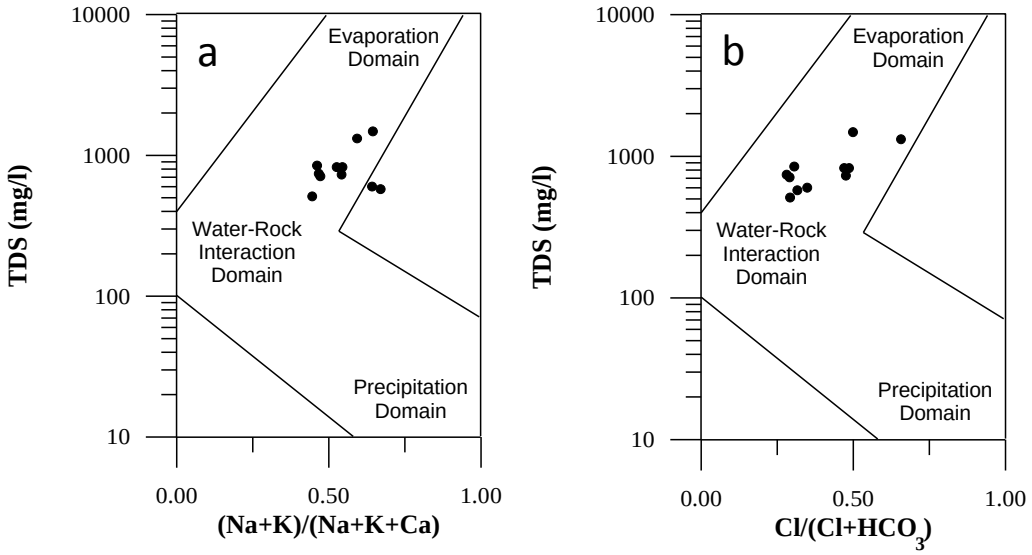

Figure 3: The figure shows the groundwater of Qalaat Mgouna plotted in the Gibbs diagrams. **a**: cations and **b**: anions.

Ion exchange process corresponds to the Ca and Mg capture by Na-rich clays leading to an excess of SO_4+HCO_3 over Ca+Mg, while ion reverse exchange signifies liberation of Ca and Mg in water and values of Ca+Mg/SO_4+HCO_3 can increase up to 1.2 [29,30]. These possible processes were verified by plotting the samples in the Ca+Mg vs. SO_4+HCO_3 diagram (Fig. 4a). All the samples show excess of SO_4+HCO_3 over Ca+Mg in water indicating dominant ion exchange process over the reverse ion exchange one. The HCO_3 vs. Ca+Mg diagram (Fig. 4b) is also employed to reveal waters undergoing direct ion exchange and indirect ion exchange processes [31]. Six samples falling under the line d: 1/1 and showing Ca+Mg>HCO_3 are influenced by direct ion exchange reaction, while the five remaining samples plot above the equilibrium line (Ca+Mg<HCO_3) and indicate possible indirect ion exchange for waters of mixed facies and others of SO_4-Cl-Ca-Mg facies. To predict the behavior of water following HCO_3, Ca and Mg ions, the residual sodium carbonate RSC was calculated (Tables 2 and3). The values ranging from -7.24 to 2.23 indicate that the excess of HCO_3 over Ca and Mg is limited (HCO_3 – Ca – Mg < 1.25 meq/l). Thus the tendency for calcium and magnesium to precipitate resulting in an increase of relative sodium is not favorable.

Considering the existence of evaporitic silts and limestones constituting the host environment of the Qalaat Mgouna aquifer, the dissolution of gypsum and anhydrite was checked by representing the samples in the SO_4 vs. Ca diagram (Fig. 4c). The majority of water samples, of mixed and SO_4-Cl-Ca-Mg facies, plots along the line d: 1/1 indicating significant contribution of anhydrite and gypsum to the water hydrochemistry. In contrast, waters of HCO_3-Ca-Mg type should be controlled by other processes.

The Na vs. Cl diagram is helpful to verify the impact of the halite dissolution on the water hydrochemistry (Fig. 4d). The samples falling close to the line d: 1/1 suggest that halite is the mainly possible source of dissolved sodium and chloride ions, while the remaining samples probably have other source of sodium and chloride.

4. DISCUSSION

Suitability of Qalaat Mgouna groundwater for irrigation is discussed on the basis of the results relating to total hardness, sodium percent, salinity hazard and permeability index, besides the comparison of water characteristics with the mostly used classifications.

Hardness has no known adverse effects but it can have a role in health disease [32]. The total hardness determined for the studied samples varies from 22.82 to 70.44 °fH (Tables 2 and 3). TH values under 75 indicate soft class according to Sawyer and McCartey (1967) classification [33].

The sodium percentage is an important factor controlling water quality. The use of water with high sodium percentage in irrigation leads to sodium-soil reaction and causes damage to the soil structure by reducing its permeability [11-34]. The Na% of Qalaat Mgouna waters ranged from 33.59% to 57.22% (Tables 2 and 3). Based on Na% and following, the Eaton (1950) classification, the samples fall into the safe class [35]. By plotting the samples studied into the Wilcox's diagram (Fig. 5), it is shown that waters are falling in the good to permissible class. The sample recording the highest electrical conductivity belongs to the permissible to doubtful category. While the sample with minimal conductivity value is in excellent to good class [25].

The sodium adsorption ratio SAR is a significant parameter for the determination of water suitability for irrigation. The SAR calculation revealed values between 1.7 and 6.44 (Tables 2 and 3). According to Richards (1954) and Todd (1980) classifications based on SAR [24-36], the values indicate excellent class (S1) for studied waters. Thus, the excess of sodium over calcium and magnesium is not significant [37].

Detailed analysis of water suitability for irrigation is possible by comparing SAR values, representing sodium hazard, with salinity hazard expressed in terms of conductivity. Indeed, the US salinity hazard diagram was helpful for this task (Fig. 6) and it revealed low sodium alkali hazard and medium to high salinity hazard (C2S1 and C3S1) for studied waters. Two samples are falling in the C3S2 class indicating medium sodium hazard and high salinity hazard. The use of waters with medium salinity C2 is possible for soils with an acceptable amount of leaching, while waters of high salinity C3 are not suitable if soil drainage is restricted.

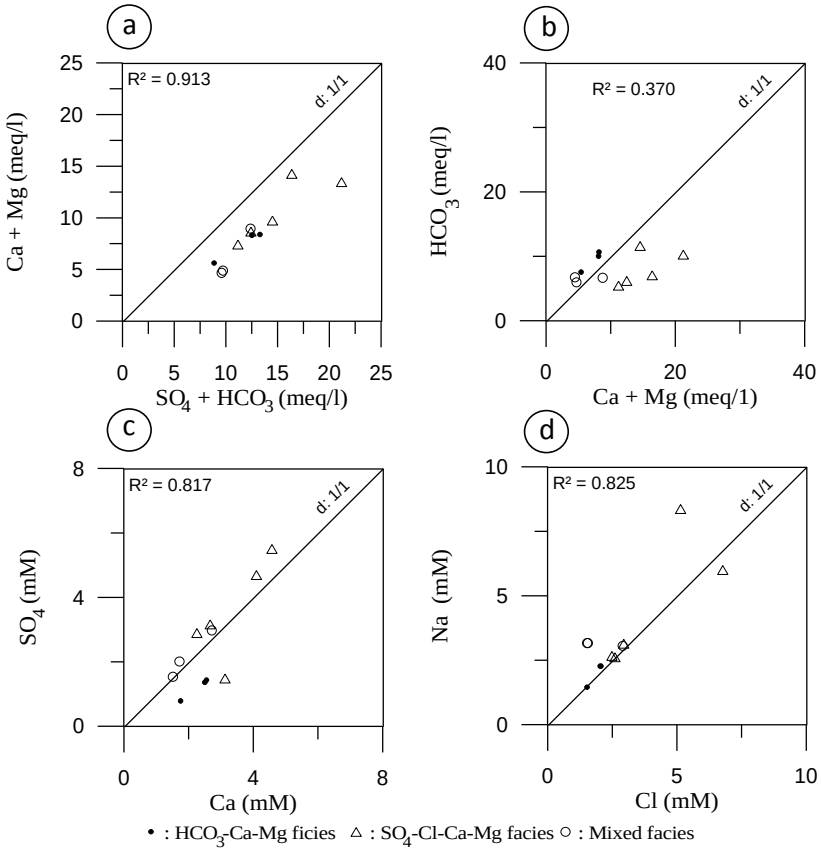

Figure 4: The figure points up the chemical characterization diagrams showing principal processes controlling the water features in Qalaat Mgouna.

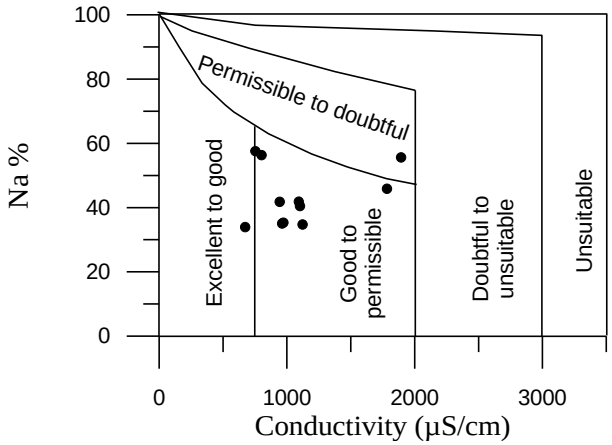

Figure 5: The figure presents the Qalaat Mgouna waters plotted in the Na% vs. conductivity diagram [25].

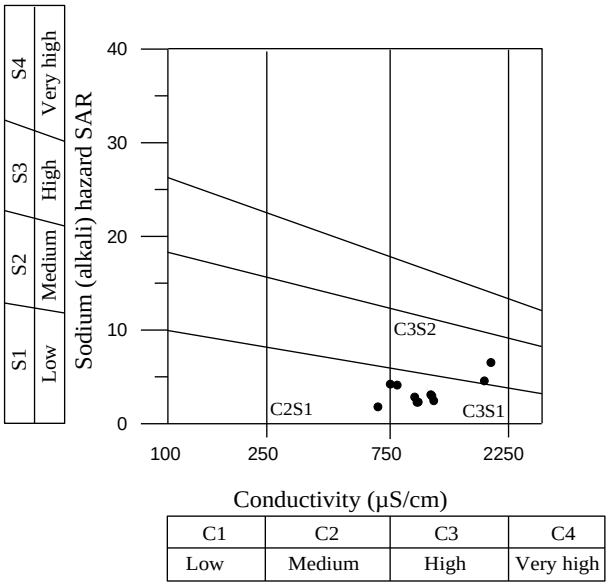

Figure 6: The figure shows the studied waters from Qalaat Mgouna plotted in the US salinity hazard diagram [24].

Another possibility to assess the suitability of water for irrigation is the calculation of the permeability index PI [38,39]. It predicts the impact of long-term use of irrigation water on soil. The permeability index for Qalaat Mgouna waters ranged from 55.77% to 81.42% (Tables 2 and 3). Two samples showing PI values over 75% are ranged in the excellent class (Class I), while the remaining samples for which 25% <PI < 75% are in the permissible class (Class II). The category of unsuitable class characterized by PI< 25% (Class III) was not observed among the studied samples.

5. CONCLUSION

Qalaat Mgouna commune belongs to a newly created province with poor and vulnerable to poverty neighboring communes. In this region, irrigated culture as growing human activity outside of alluvial zone constitutes a real opportunity for sustainable development. Thus, the groundwater resource quality was evaluated for its suitability for irrigation purpose. The investigation also provided important information indispensable for understanding groundwater regime as well as processes controlling the water chemistry.

Geochemical data and diagrams revealed that water chemistry is controlled by the aquifer lithology through variable water-rock interaction processes including ion exchange besides dissolution of limestone, anhydrite, gypsum and halite. This explains the mixed. SO_4-Cl-Ca-Mg and HCO_3-Ca-Mg water facies detected and conditioned by the variability of aquifer media in the Mgouna Plateau.

Statistical description and principal component analysis approach showed that relationships between variables used for the studied area are identical to arid regions where aquifers media are dominated by limestone intercalated with clayey and evaporitic levels.

Calculated indices commonly used for water quality assessment were helpful to compare the Qalaat Mgouna waters to internationally acceptable standards. Indeed, waters are soft based on total hardness. Wilcox classification ranged the quality of studied waters between excellent to good and good to permissible classes, while one sample was specified as of permissible to doubtful quality. In addition, the Richards classification illustrated that waters from Qalaat Mgouna were grouped within C2S1, C3S1 and C3S2 classes indicating low to medium sodium hazard and medium to high salinity. Waters of medium salinity can be used if a moderate amount of leaching occurs but those of high salinity cannot be used for feebly drained soils. Under these conditions, the cultivation of crops tolerant to salinity is suitable. The impact of long-term use of irrigation water on soils is not significant based on permeability index. But by considering the Mgouna region demographic growth and the climate evolution to drier situation, periodic geochemical survey is indispensible to provide important information on water quality evolution reflecting anthropogenic and/or climate change impacts.

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