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Assessment of Groundwater Quality for Irrigation Purposes using Hydrochemical Diagrams and Chemical Indexes

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Abstract: This work deals with groundwater quality under the effect of aridity. The case study is the region surrounding a sabkha named Sed Masjoun, located in the province of Kalâat des Sraghna, central Morocco. For this purpose, 67 hung-dug and borehole wells were investigated in the dry seasons in summer. Water samples were analyzed for chemical characteristics such as electrical conductivity, sodium absorption ratio, and sodium percentage. The results were also exploited using statistical analyses, hydrochemical diagrams, distribution maps and chemical indexes. The groundwater was severely affected by salinity but minorly by sodicity. The widespread salt was halite. The suitability of water for irrigation was also evaluated through several indexes. It follows that groundwaters are hard in nature, and have high sodium hazard, but no permeability problem was recorded. The concentration of nitrate and chloride were above the acceptable limit for irrigation in most wells, as shown by the dataset and the distribution map. In such a situation, any strategy promoting best management practices of irrigation and soil management, is highly encouraged to ensure sustainable use of these resources in the context of the severe aridity in Sed Masjoun area.

Keywords: Groundwater, Sed Masjoun, Quality, Salinity, Assessment

Morocco is basically an arid and desert country (93% of the global area) (Debbarh and Badraoui 2002) and rainfall is irregular, either in time or space. The average annual rainfall rate over the entire territory is fated to 150 billion m^3 unevenly distributed and is only 15% of the total area acquires nearly 50% of the precipitations. The northern mountainous areas receive more than 1000 mm, while less than 300 mm is shared annually between the basins of Tensift, Souss-Massa, and Moulouya, and the areas of South Atlas and Sahara (Debbarh and Badraoui 2002, Dahan 2012). This condition makes irrigation an instrumental imperative in the agricultural sector. Effectively, since independence, the Moroccan government has adopted an irrigation policy, as one of the hydro-agricultural management strategies. The 45% of agricultural production comes from irrigated area (13% of the total cultivated areas) (Debbarh and Badraoui 2002). However, excessive and uncontrolled irrigation water use inevitably leads to soil degradation, mainly to salinization and sodification risks (Kielen and Tanji 2002). Among the 350000-ha affected by salinity in Morocco), irrigated land occupies about 160000 ha (Badraoui 2006). The Bahira plain, the subject area of this study, represents the third affected area by salinization, with an area of 21000 ha, after Low Moulouya and Haouz basins. Irrigation water with poor quality, especially salt-rich waters, can bind sodium to the soil adsorbent medium, destroying its structure by dispersion of clays, leading to the loss of permeability, which affects plant growth. Moreover, the accumulation of chemical constituents of polluted waters in surface soils constitutes a serious threat to human health by the contaminating food, drinking water, and air. As a consequence of agriculturally degraded lands due to irrigation water in Morocco, the cost corresponds to 940 Million MAD annually (Croitoru and Sarraf 2010). Irrigated agriculture in the world depends mainly on groundwater resources (Foster and Shah 2012), especially in arid regions where surface water resources are restricted. In this regard, assessing and monitoring groundwater resources have become a priority worldwide. Numerous types of research have been performed in many basins around the world (Moujabber et al 2006, Baghvand et al 2010, Gouaidia et al 2013, Gautam et al 2015 and Abu-alnaeem et al 2018). Groundwater resources present an important legacy in Morocco. However, intensive use and strong evaporation in arid and semi-arid regions pose qualitative and quantitative problems, such as the degradation and the scarcity of freshwater resources. The Bahira plain is considered one of the most representative aquifers of this situation in Morocco. The arid climate and the succession of drought years lead consequently to the overuse of groundwater resources by the rural population, agricultural and domestic activities. This work's objective is to evaluate groundwater quality around the sabkha of Sed Masjoun and its suitability for irrigation.

MATERIAL AND METHODS

Study area: This study concerns the area surrounding the Sabkha of Sed Masjoun, (also named Sed El Mejnoun, Sed El Mesjoune, and Sed El Majnoon in previous studies), located in the central Bahira, and corresponded to the lowest altitude (404 m) of the great Bahira. Sed Masjoun is a seasonal lake extending over 32 Km^2 (El Mokhtar et al 2012). The Bahira plain is a vast central Morocco area 35 km north of Marrakech. It occupies a surface of about 5000 Km^2, bounded by the wavy uplands of Rhamna in the north, the mountain series of Jbilet in the south, the alluvial cone of Oued Tassaoute in the east and the Gantour uplands in the west, (Karroum et al 2014) (Fig. 1 , 2).

The water runoff coming from the surrounding elevations, mainly Jbilet (estimated at 33 Mm^3 / year) (Tensift Watershed Agency (ABHT)), is the main component of the natural recharge of the groundwater in the Plain and also the origin of the submersion during the winter of the depressions of Sed El Mesjoune at the central Bahira and Zima at the western Bahira. These two sites are considered evaporative machines during hot seasons, which salinize the water table. Under the plain of Bahira, waters circulate in the recent formations of Plio-Quaternary and Lutetian limestones (unconfined aquifer) and in the Upper Cretaceous (confined aquifer). The climate is arid to semi-arid with Saharan influences, the rainfall is low, irregular, and random, with a marked decline over the years (250 and 200 mm/an in 1995 and 2014, respectively) (Karroum et al 2014). Temperatures are high in winter and low in summer (48 and -3,6° C as maximum and minimum, respectively). The water balance is negative, the destocking of water is -4 Mm^3 due to the weak infiltration, the increase of the agricultural levies, and the evaporation. This last reached 2618,7 mm in 2014 (Karroum et al 2014). Cereals (barley, soft wheat, durum wheat, maize) and fallow land make up more than 90% of the utilized agricultural area. Fruit trees and other crops are exclusively present in the irrigated area.

Methodology: To evaluate groundwater quality and its suitability for irrigation in the area surrounding Sed Masjoun dry lake, a field survey was conducted during the dry season in June, July, and August, through the investigation of 67 wells, including boreholes and hand-dug wells, with depths ranging from 25 to 450 m. The levy was performed after the identification of sampling points using of a topographic map and GPS receiver (Fig. 3).

Before taking the samples, the well water pumps were opened sufficiently so that the sample became representative of the concerned well. Groundwater samples were placed into pre-conditioned bottles cleaned previously with nitric acid, washed afterward with distilled water, and rinsed finally by the water sample. In the field, samples were analyzed for some of their physicochemical parameters, such as electrical conductivity (EC), pH, temperature, and piezometric level, using portable conductivity, pH meter, a thermometer, and a level probe, respectively. Samples were kept airtight, over ice in an icebox, and transported to the laboratory for analysis. The physicochemical analyses, including ionic balance, pH and EC, were carried out in the Laboratory of Soil Chemistry at the National Institute of Agricultural Research (INRA) of Rabat (Table 1). The results were expressed in milliequivalent per liter (meq/l) except NO_3^- and NH_4^+ (ppm), pH, and EC (dS/m).

Statistical analysis: Data measured and calculated were submitted to statistical analysis using the SPSS software. Distribution maps were generated using the IDW spatial interpolation using ArcGIS. Water quality diagrams were drawn using Diagrammes - hydrochemistry software, 4.0 version (Simler 2007).

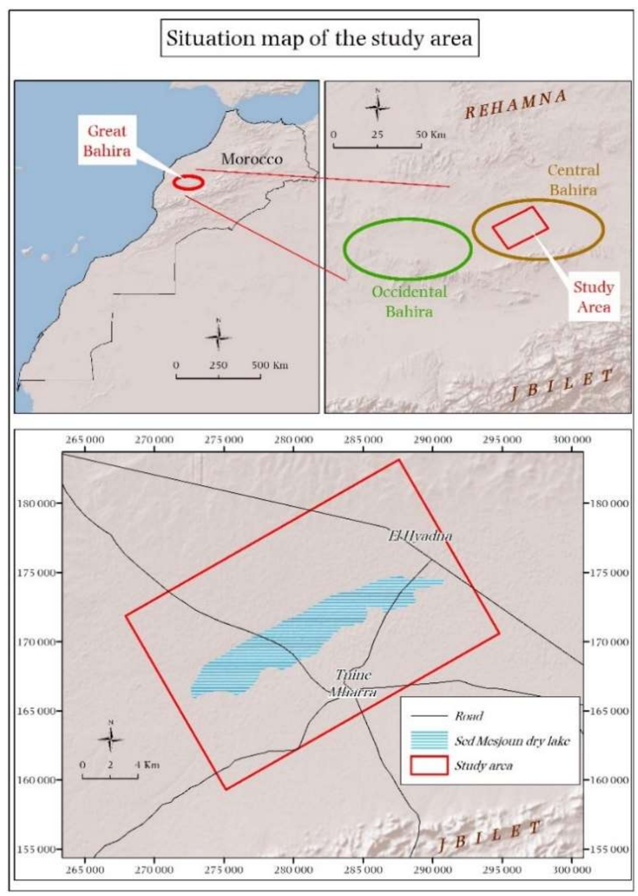

Fig. 1. Site map of the study area

RESULTS AND DISCUSSION

Salinity and chemical composition: Electrical conductivity (EC) is one of the most important criteria to assess irrigation water quality. An excessive amount of salts in irrigated soil adversely affects soil permeability, bulk density, and structural stability (Tejada and Gonzalez 2005), ultimately impacting plant growth. The groundwater in the surrounding area of Sed Masjoun show that EC varies between 1.3 and 77.2 dS/m with an average of 5.7 dS/m. The 61% of the wells violated the permissible limit for irrigation use (Wilcox 1955), with 37 and 24% of the wells doubtful and not suitable for irrigation, respectively. In contrast, only 39% of the wells were classified as permissible. Consequently, none of the samples belonged to the good or the excellent categories. The majority of wells with no suitable water are located on the south side of Sed Masjoun, especially toward the southeast part except wells P67 and P65, which have questionable water quality. This category also includes some wells on the north side (P27) in the sabkha borders and certain wells in the eastern part (P43, P44, P49 and P50). The area with doubtful groundwater to use is extended in the north and the southwest, whereas the water with permissible use occupies some locations in the far north, the north-south, and the southwest areas (Fig. 4).

Pearson correlation (Table 5) was significant between EC and Cl^- (0.83), Na^+ (0.85), SO_4^{2-} (0.76), and Ca^{2+} (0.58), which highlights the responsibility of these three elements for water salinity. Cl^- showed a strong correlation with Na^+ (0.99), presuming the existence of the halite (NaCl) in the water. The correlation between Mg^{2+} and SO_4^{2-} (0.81), indicate existence of specific quantities of magnesium sulfate ($MgSO_4$) precipitant. Considering the anionic and the cationic groups separately, a significant correlation was between Cl^- and SO_4^{2-} (0.74) in part and between Ca^{2+} and Mg^{2+} (0.50) in the other part, indicating the probable common source of every two ions.

The skewness coefficients (Table 3) show that all parameters were positively skewed (especially Na^+ (7,2) and Cl^- (6,9)), except for pH (0,0) and HCO_3^{2-} (0,5), where the data was pretty symmetrical. The kurtosis values were high for the majority of parameters, which means the profusion of outliers, this was more pronounced for Na^+ (55.1) and Cl^- (52.2) where the presence of some abnormally high (circles) or some extreme (stars) values (Fig. 5).

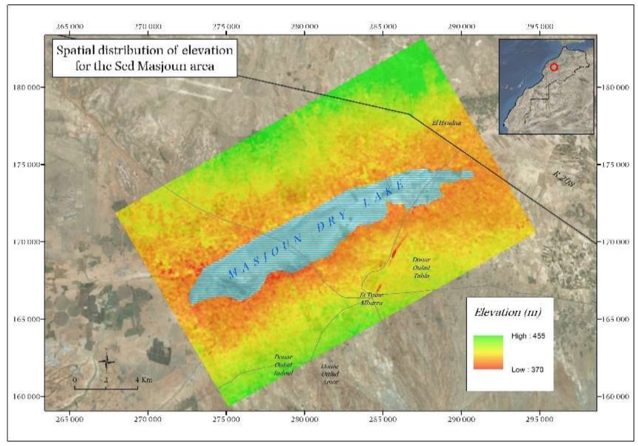

Fig. 2. Spatial distribution of elevation for the studied area

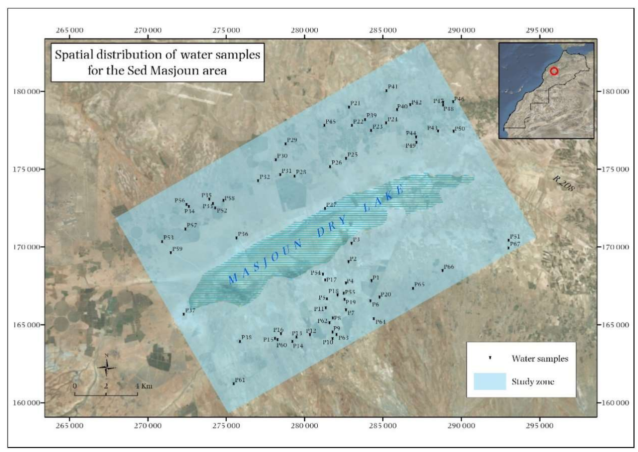

Fig. 3. Spatial distribution of water samples for the Sed Masjoun area

Table 1. Measured physicochemical parameters and the corresponding methodology

Parameters	Method
Electrical conductivity (EC)	Orion laboratory conductivity meter, model 162
pH	Metrohm pH meter, model 691
Sodium and potassium (Na^+ and K^+)	Flame photometry (Jackson 1967), photometer Jenway, PFP7 model
Calcium and magnesium (Ca^{2+} and Mg^{2+})	Complexometric titration with EDTA (Page 1982)
Carbonate and bicarbonate (CO_3^{2-} and HCO_3^-)	Acid–base titration (Rodier 1984).
Sulfate (SO_4^{2-})	Nephelometric method of precipitating sulfates as barium sulfate in HCl medium (Rodier 1984)
Chlorides (Cl^-)	Mohr's method (Rodier 1984)
Nitrates and amonium (NO_3^- and NH_4^+)	Steam distillation (Büchi unit B-323 model)

The abundance, in average, was in the order $Na^+ > Mg^{2+} > Ca^{2+} > NH^{4+} > K^+$ for the cations and $NO_3^- > Cl^- > SO_4^{2-} > HCO_3^- > CO_3^-$ for the anions. The anion classification showed no difference compared with some studies in countries with the same or similar climatic conditions. However, cation abundance was slightly dissimilar. In fact, by studying 60 samples of groundwater taken from the Hail region in Saudi Arabia, Abdel-Satar et al (2017) found that Ca^{2+}, followed by Na^+, constitute the predominant cations, while Ebrahimi et al (2016) pointed out the prevalence of Na^+ followed by Ca^{2+}, after analyzing 15 samples of groundwater collected from the Damghan basin in Iran. Considering variability, Cl^- is the most variable concerning anions (CV = 255%), with values ranging from 6.8 to 880 meq/l with a mean of 43.2. Na^+ shows the highest variability among cations, with values ranging from 4.3 to 1036, and a mean value of 43.4 meq/l. High variability was also for K^+ (CV=260%) with values ranging between 0.0084 and 16.4 meq/l and a mean of 0.93. However, it constitutes the minor element that did not play any role in groundwater hydrochemistry and didn't show any correlation with the other elements.

The Piper trilinear diagram (Piper 1944) was used to bring out the chemical relationships among water samples, and

Table 2. Calculated indices and their corresponding equations

Indice	Equation
Sodium percentage (Na %)	$Na\% = 100 * \frac{Na}{Ca + Mg + Na + K}$
Sodium adsorption ratio (SAR)	$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$
Residual sodium carbonate (RSC)	RSC= CO3+ HCO3 - (Ca+ Mg)
Permeability index(PI)	$PI = 100 * \frac{Na + \sqrt{HCO3}}{Ca + Mg + Na}$
Kelly's ratio (KR)	$KR = \frac{Na}{Ca + Mg}$
Total hardness (TH)	TH = 50 * (Ca+ Mg)
Magnesium hazard(MR)	$MR = 100 * \frac{Mg}{Ca + Mg}$

Table 4. Descriptive statistics of the calculated indices

Index	Maximum	Minimum	Mean	SD	CV%
% Na	96,1	24,7	51,5	17,4	33,9
PI	95,4	25,4	52,1	17,0	32,7
RSC	0 ,0	-123,8	-15,4	23,1	-150,2
KR	24,7	0,3	2,1	3,7	177,2
TH	6316,0	270,0	1121,2	1192,0	106,3
MR	90,3	16,9	54,8	17,5	31,9
SAR	142,3	1,4	11,6	22,8	196,3

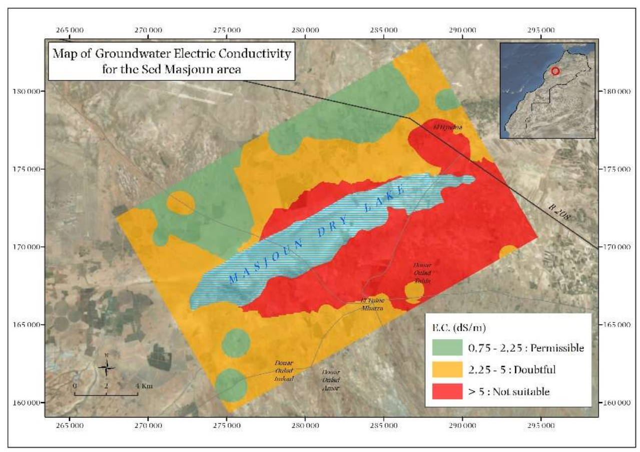

Fig. 4. Distribution map of groundwater electrical conductivity for the Sed Masjoun area

Table 3. Descriptive statistics of water level and major ion chemistry in the study area

Parameter	Mean	Median	SD	CV (%)	Min	Max	Skewness	Kurtosis
Well depth (m)	112,1	104,0	79,4	7,6	25	450	1,9	5,7
pH	7,7	7,8	0,4	4,7	7,0	8,5	0,0	-0,9
EC (dS/m)	5,7	2,7	10,9	193,5	1,3	77,2	5,2	30,0
NH^{4+} (ppm)	6,1	3,6	5,7	93,4	0,0	18,0	1,0	-0,2
NO_3^- (ppm)	49,1	49,6	34,1	69,5	3,9	161,2	1,1	1,9
Cl^- (meq/l)	43,2	20,4	110,2	254,8	6,8	880,0	6,9	52,2
CO_3^{2-} (meq/l)	0,5	0,0	0,7	156,8	0,0	2,5	1,5	1,4
HCO_3^- (meq/l)	6,6	5,5	3,9	59,6	1,0	15,0	0,5	-1,1
SO_4^{2-} (meq/l)	16,9	3,3	40,9	242,8	0,1	268,9	4,5	23,2
Ca^{2+} (meq/l)	8,1	5,6	6,9	84,9	2,6	43,4	2,9	11,1
Mg^{2+} (meq/l)	14,3	6,4	19,7	137,1	1,4	111,3	3,1	10,8
Na^+ (meq/l)	43,4	15,6	129,0	297,4	4,3	1036,3	7,2	55,1
K^+ (meq/l)	0,9	0,1	2,4	260,4	0,01	16,4	4,9	27,2

define hydrochemical facies. Most facies are sodium chloride, calcium chloride and magnesium (Fig. 6). This finding corroborates those reported by El Mokhtar et al (2012). El Mokhtar et al (2012) explained the magnesian component by a cation exchange between groundwater and the clay complex, rich in Mg, well-developed in plioquaternary deposits when flow gradients are low.

To sum up, groundwater in the basin surrounding the sabkha of Sed Masjoun generally has high saline charge; many wells are brackish to saline. The analyzes were carried out by El Mokhtar et al (2012) using stable isotopes of Oxygen 18 (^{18}O) and Deuterium (^{2}H) after sampling at different depths and salinity levels. The results showed the effect of evaporation on the salinization process, whether in the surface or deep water. This phenomenon occurs habitually by water from rain and runoff that undergo evaporation before and during infiltration.

Sodicity: The sodicity measures the quantity of sodium in water. Sodium hazard can be quantified by sodium abundance with regard to either Ca^{2+} and Mg^{2+} contents using SAR or to the number of total cations existing in water using Na%. These two indices are both connected with EC by two diagrams.

Sodium percent: The percentage of sodium (Na%) with respect to the other cations expressed by Na% is defined by equation 1 (Table 2). An excessive amount of sodium in irrigation water may affect soil permeability and cause osmotic effects leading to a restriction in agricultural yields (Raju 2007). This parameter ranged between 25 and 96% in the study area, with an average of 51%. However, none of the samples belongs to the excellent category (Table 6).

The combined consideration of Na% and EC by Wilcox diagram (Fig. 7) showed that 27 wells out of the 67 (40.3%) fell in the range of the excellent category, 25.4,26.9 and 7.4 % in the good, the permissible limit and the doubtful categories, respectively.

Sodium absorption ratio: The Sodium Absorption Ratio (SAR) is an important index to evaluate the suitability of water for irrigation purposes. This parameter is defined by equation 2 (Table 2). A high concentration of Na^{+} in the soil-soluble state may replace most frequently Ca^{2+} and Mg^{2+} exchangeable cations in the absorbing complex. This displacement leads to the dispersion of sodium- saturated soil particles and then the destruction of soil structure. The average SAR of groundwater of the study area was 11. 6 ($meq^{1/2}. l^{-1/2}$), varying between 1.4 to 142.4 (Table 4) Majority (81%) of wells present low SAR values, while 9, 4, and 6% show medium, high and very high rates, respectively. High SAR values are concentrated in the easternmost and the south sides, distributed gradually toward the dry lake (Fig. 8).

The evaluation of EC and SAR together by plotting the obtained results graphically on the diagram proposed by Richards (1954) (Figure 9) reveals that the majority of samples fall in C3S1, C2S1, and C3S2 classes, meaning their good to moderate quality for irrigation use.

Residual sodium carbonate: Residual sodium carbonate *(*RSC), calculated by equation 3 (Table 2), is another index to evaluate sodium hazard. This is supported by the fact that sodium amount in water with a high level of bicarbonates

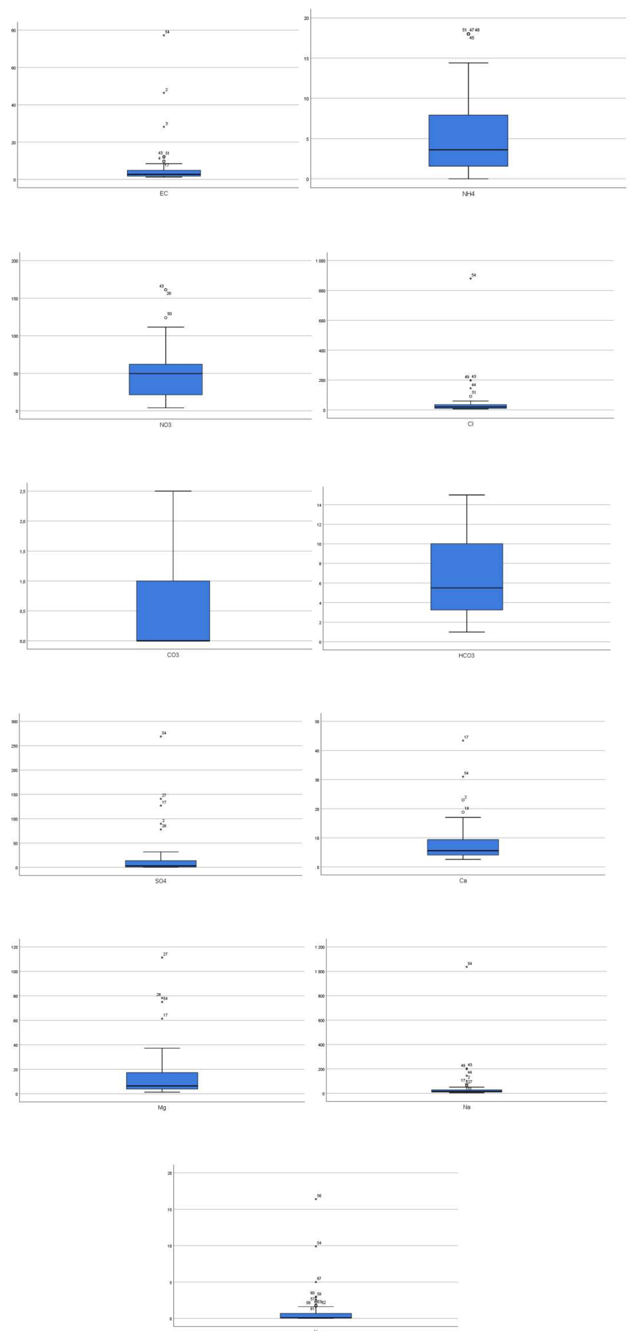

Fig. 5. Boxplots of the groundwater measured parameters

increases in the $NaHCO_3$ state, leading, as a consequence, to the precipitation of the divalent cations of Ca^{2+} and Mg^{2+} (Reddy 2013). The presence of carbonate and bicarbonate in groundwater is mainly owed to the dissolution of carbonate weathering and carbonic acid in the aquifers (Kumar et al 2009). All water samples had negative RSC values except one with a null value, which is the maximum value, while -15.39 and -123.82 are the mean and the minimum values, respectively. The negative values reveal that the level of carbonate and bicarbonate in water were lower than calcium and magnesium levels, which implies the nonexistence of a residual amount of carbonate to react with sodium and then intensify the alkali hazard in the soil.

pH and piezometric level: The pH had the lowest variation (CV of 4.7%), with values ranging from 7.0 to 8.5 and an average value of 7.8. The distribution map of pH (Fig. 10) indicates that most wells in the area around Sed Masjoun had alkaline pH, except for some sporadic spots, where the pH is slightly alkaline. This finding is also asserted by the Spearman correlation, where a strong correlation was found between pH and CO_3^{2-} (0.72), rather than NH_4^+ (0.54).

The piezometric level in the study area ranged between 268 and 408 m, with 360 m as the mean value. The distribution map of the piezometric level (Fig. 11) showed relatively lower values in the northeast side of Sed Masjoun, especially in the easternmost part. In contrast the high values were recorded on the south side, more strongly toward the middle part.

Indices of Water Suitability for Irrigation

Permeability index: Permeability problems are ascribed to the joint effect of irrigation water prolongedly remaining, and the content of sodium, calcium, magnesium, and bicarbonate in soil). The permeability index (PI) is calculated using equation 4 (Table 2). This parameter varied in our case between 25.4 and 95.4%, with 52% as a mean value. According to Doneen (1966), 10% of wells were considered excellent for irrigation (PI>75%), and 90% were good (25<PI<75); however, none of the samples belonged to the not favorable category (PI<25).

Magnesium ratio: Excessive amounts of magnesium in irrigation water can deteriorate soil quality, leading to reduced crop yields. The magnesium hazard is evaluated using the magnesium ratio (MR), calculated according to

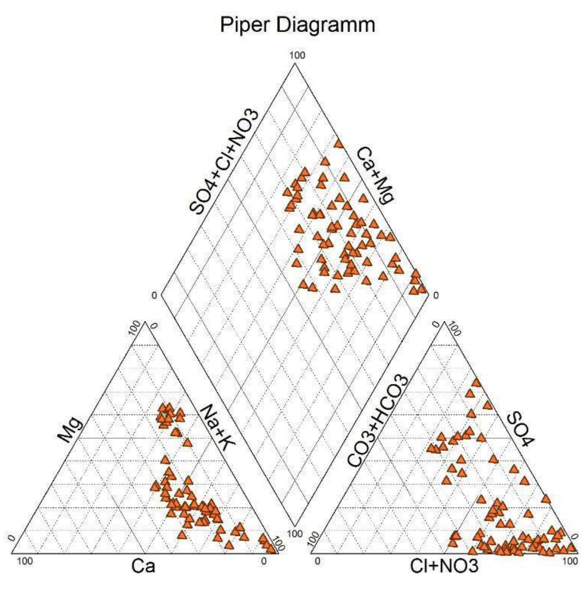

Fig. 6. Groundwater samples plotted in the Piper-Trilinear diagram

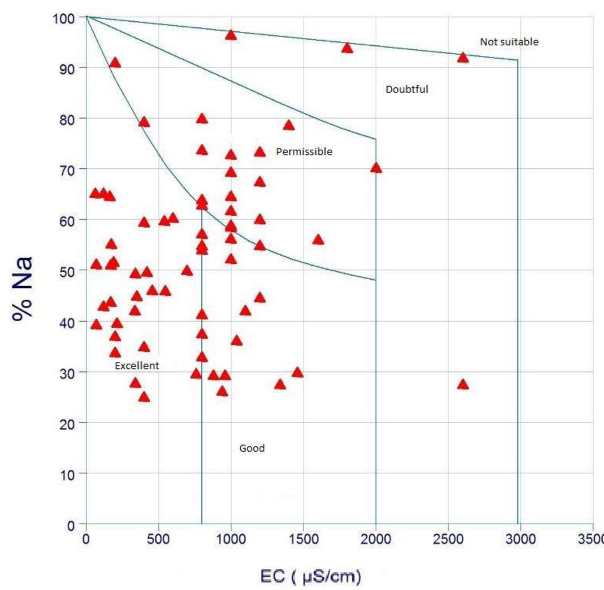

Fig. 7. Suitability of groundwaters for irrigation based on Wilcox diagram

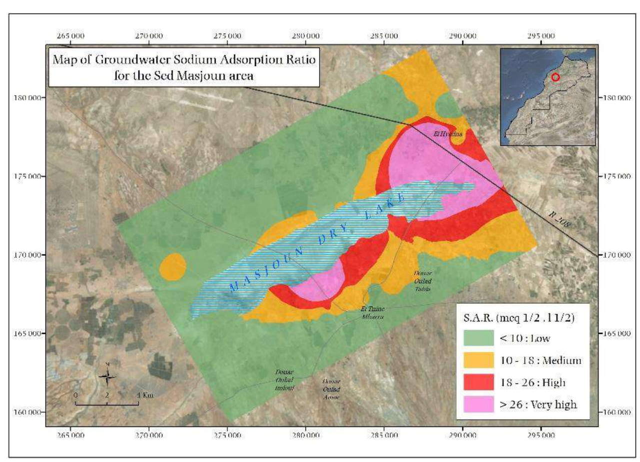

Fig. 8. Distribution map of SAR of groundwater in the study area

equation 7 (Table 2). In the study area, MR varied from 17 to 90%, with a CV of 32% and a mean value of 55%. According to Raghuanth (1987), 43% of wells were classified, in the suitable category (MR<50%), while 57% were not suitable for irrigation (MR>50%).

Total hardness: Total hardness (TH), defined by the equation 6 (Table 2), is an index to evaluate the abundance of the divalent cations of Ca^{2+} and Mg^{2+} in water. TH varied widely (CV=106%) with values ranging from 270 to 6316 mg/l and an average value of 1121. Since all samples exceeded 180, groundwater of the studied area is considered very hard in nature, according to Durfor and Becker (1964), owing to the excessive presence of Ca^{2+}, Mg^{2+}, and HCO_3^- ions.

Kelley's ratio: Kelley's ratio (KR) is a parameter suggested by Kelley et al (1940) to report the ratio of sodium to the sum

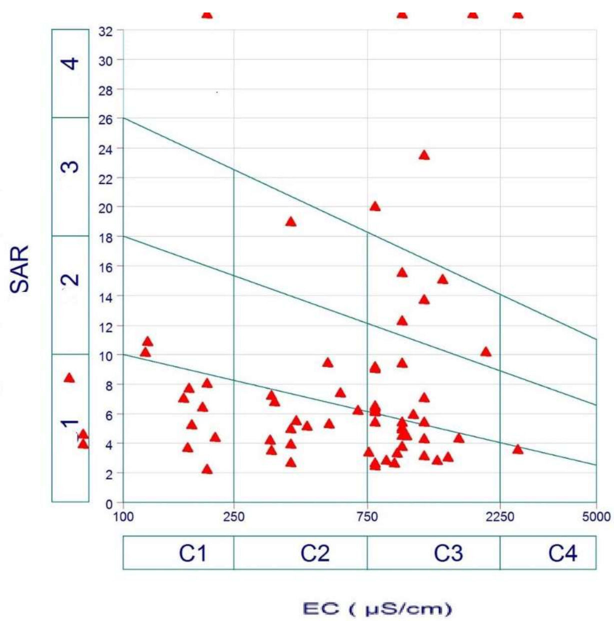

Fig. 9. USSL classification of groundwater in the study area

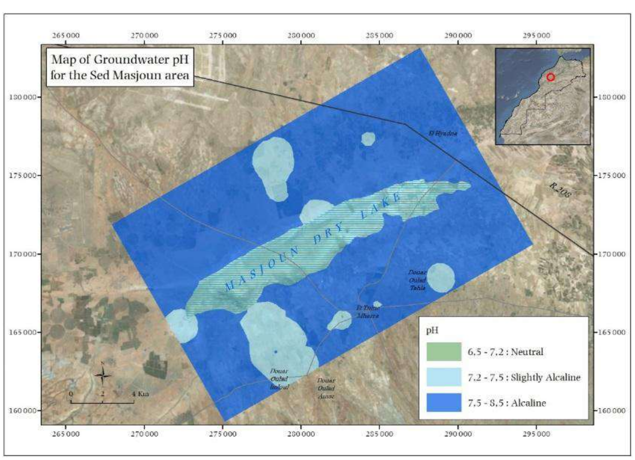

Fig. 10. Distribution map of pH in the study area

of calcium and magnesium, according to equation 5 (Table 2). This index should not exceed one. If so, water becomes not suitable for irrigation owing to the excessive amount of sodium. KR had a wide range between 0.3 and 24.5 with a mean value of 2.1, and 58% of wells were unsuitable for irrigation purposes.

Risk related to chloride: Chloride is a common element in

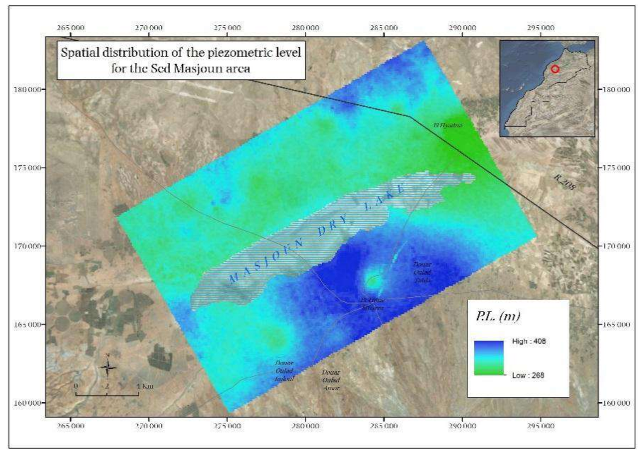

Fig. 11. Distribution map of piezometric level of the study area

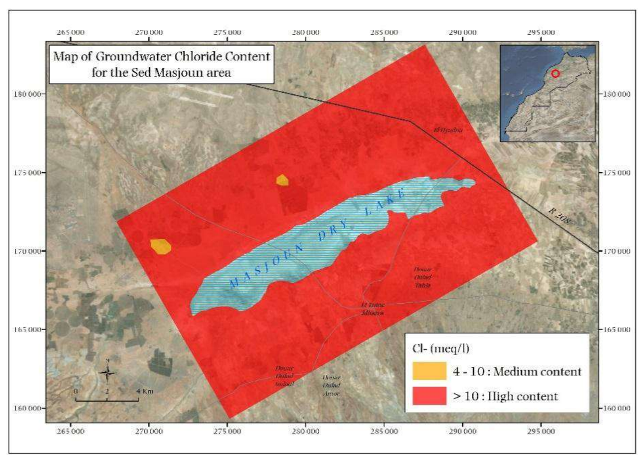

Fig. 12. Distribution map of chloride in the study area

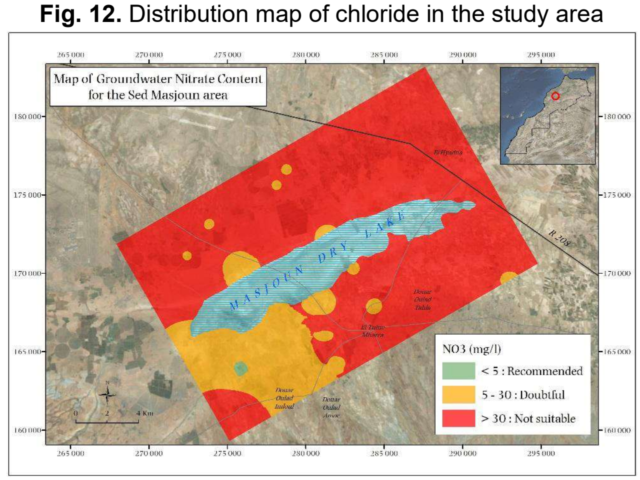

Fig. 13. Distribution map of nitrates in the study area

Table 5. Pearson correlation coefficients for groundwater parameters

Parameter	pH	CE	NH^{4+}	NO_3^-	Cl^-	CO_3^{2-}	HCO_3^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+
pH	1											
CE	0,01	1										
NH_4^+	0,54**	0,01	1									
NO_3^-	0,43**	-0,05	0,49**	1								
Cl^-	-0,02	0,83**	0,11	-0,02	1							
CO_3^{2-}	0,69**	0,01	0,58**	0,34**	-0,04	1						
HCO_3^-	-0,62**	-0,16	-0,28*	-0,19	-0,14	-0,42**	1					
SO_4^{2-}	-0,18	0,76**	-0,05	-0,13	0,74**	-0,18	0,03	1				
Ca^{2+}	-0,42**	0,58**	-0,30*	-0,30*	0,45**	-0,26*	0,18	0,66**	1			
Mg^{2+}	-0,36**	0,35**	-0,08	-0,11	0,38**	-0,26*	0,31*	0,81**	0,50**	1		
Na^+	-0,02	0,85**	0,10	-0,03	0,99**	-0,04	-0,13	0,78**	0,47**	0,41**	1	
K^+	0,08	0,32**	-0,10	-0,03	0,40**	-0,12	-0,32**	0,36**	0,09	0,09	0,41**	1

**. * Correlation is significant at the 0.01 0.05 level (bilateral)

Table 6. Groundwater classification based on percent Na in the study area according to Wilcox (1955)

Percent Na	Classification	Percentage of wells
<20	Excellent	0
20-40	Good	27
40-60	Permissible	46
60-80	Doubtful	21
>80	Unsuitable	6

all-natural water, generally in low concentrations (<10 meq/l). However, when the level increases, Cl^- may intoxicate plants by moving with soil water to accumulate in leaves since it is not absorbed by the soil (Hussain et al 2010). Data from the present study indicate the risk of chloride in the study area. All samples exceeded 4 meq/l, which means, according to Bigak and Nielsen (1972), a tendency to Cl^- toxicity, particularly for sensitive crops, while 85% of wells exceeded the high limit (10 meq/l) enormously. The range was between 6.8 and 880 meq/l, with mean 43.2 meq/l and CV of 255%. The risk related to chloride was also reported by Zouahri et al (2015), where 68% of wells in the Skhirat region (northwest) had Cl^- >10meq/l, while only 3% had Cl^- between 2 and 4. Based on the distribution map (Figure 12). There were only two small localities with $4<Cl^-<10$ meq/l situated in the north area of Sed Masjoun. Chlorides could come mainly from the percolation of irrigation return water through salty soils.

Risk related to nitrate: At varying levels, the nitrogen compounds NO_3^- and NH_4^+ were present in the groundwater samples. For NO_3^- the mean was 49.1, ranging from 3.9 to 161.2, while for NH_4^+ the mean was 6.1 mg/l with a range of 0 - 18 mg/l. However, the highly soluble form is the nitrate that constitutes an index of pollution when present at a high level (Prasad and Ramesh 1997). According to irrigation water quality guidelines (Ayers 1994), high nitrate concentration in water can affect sensitive crops, while the accepted level should not exceed 5 mg/l. When the concentration is between 5 and 30 mg/l, water should be used with specific caution. Regarding the present dataset, only 3 wells out of 67 (45%) respected the recommended level of use, while 43 wells (42,2%) violated the permissible limit by exceeding 30 mg/l. The rest of the samples should be used with moderate to slight restriction. This last category was concentrated essentially in the southwest part of Sed Masjoun (Figure 13). An excessive amount of NO_3^- in water can be ascribed mainly to the overuse of manure, nitrates fertilizers in agriculture, and the domestic wastes likely to convert into nitrates in soil (Kumar et al 2009).

CONCLUSIONS

Due to the arid climatic conditions of the Bahira region, the quality of available water resources is an additional problem to water scarcity. The quality of groundwater around Sed Masjoun, constituting the deepest point of the Bahira basin, depends on the basin geochemistry, evaporation and the mode of exploitation. The primary threat affecting a large amount of these waters is the salinity; that is, only 39% of samples were permissible for irrigation purposes. The salinity problem is mainly due to evaporation, accentuated especially in the southern area of Sed Masjoun, where the piezometric level is higher. The mean ions responsible for the salinity were the chlorides foremost, followed by sodium and calcium, while the most widespread salt was halite. According to Piper trilinear diagram, the dominant facies were sodium chloride, and calcium chloride and magnesium. Since the sodium presence is secondary, the sodicity problem was found to be minor. Regarding % Na, SAR, and RSC values, the majority of wells were grouped within the permissible and good categories to be used in irrigation. The suitability of groundwater for irrigation was equally assessed by using the permeability index, the magnesium ratio, the total hardness, and Kelly's index. It follows that no permeability problem was present; however, the hardness and the magnesium hazards struck a considerable quantity of water. High quantities of chlorides and nitrates severely affected groundwater in the Sed Masjoun area. Shallow water wells are considered the most easily attenable and contaminated. Therefore, many of them are definitively abandoned. In front of this situation, starting from the fact that groundwater resources constitute the major water provider in this area, and also considering the probable direct risk on human health, since the majority of this water is used equally for drinking and domestics purposes, continuous monitoring should be achieved regularly for sustainable development in this area.

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