

## Evaluation of groundwater suitability for irrigation in the coastal aquifer of Mnasra (Gharb, Morocco)

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**Abstract:** The coastal area of the Gharb plain constitutes the only hydric resource for region in terms of domestic consumption and agricultural demand which does not cease to increase. It is a very productive and easily accessible groundwater resource, used extensively for irrigation by own pumping. This study was performed to understand the impact of groundwater quality on the crop yields and its suitability for the irrigation for 63 wells and 7 boreholes. Groundwater quality in Mnasra was studied based on different indices for irrigation. The values of SAR, Na %, MAR, SSP, PI, RSC and TDS show that most of the samples fall under good to suitable category. Piper diagram reveals three facies: sodic, calcic and magnesian chlorinated. The results indicate that the order of cation dominance is Na > Ca > Mg > K, while anion dominance is in the order Cl > HCO<sub>3</sub> > SO<sub>4</sub>. Stuyfzand's classification indicates that most of the waters analyzed are fresh with moderate alkalinity. Richard Plot indicates that groundwater in the study area is within the low salinity to low sodium hazard and medium salinity to low sodium hazard class (C2S1 and C3S1). Wilcox Plot shows groundwater to be within excellent to a good class.

**Keywords:** Irrigation, Groundwater, hydrogeochemical, agriculture, Mnasra, Morocco.

### 1. Introduction

Irrigation has made a substantial contribution to meeting the growing food needs of the population on the one hand, and to promote economic and social development around the irrigated areas, on the other hand, <sup>1-2</sup>. In arid and semi-arid areas, the supply of irrigation water is one of the determining factors for the expansion of agricultural production, both in terms of crop intensification and the extension of irrigated areas <sup>3</sup>. However, these large-scale irrigation practices have changed the functioning of the soil, sometimes leading to a decline in soil fertility, productivity and environmental quality, thus jeopardizing the sustainability of the resource.

The coastal region of Mnasra, the geographical area of our study, is the most agricultural area of the Gharb plain, it is a very productive and easily accessible groundwater resource, is exploited in a fast way for irrigation by single pumping <sup>4</sup>. The number of wells dug in the aquifer, exceeding 20,000, shows its agricultural importance. Freshwater resources in such arid coastal aquifers are vulnerable to degradation due

to: (i) its proximity to seawater, (ii) scarce subsurface recharge and annual precipitation and, (iii) the sensitivity of fresh groundwater floating over deep saline water, due to pumping induces <sup>5</sup>.

Groundwater quality depends on the nature of recharging water, precipitation, subsurface and surface water and hydro-geochemical processes in aquifers <sup>6-7</sup>, land-use/land-cover change <sup>8-13</sup>. Temporal changes in the constitution and origin of the water recharge, and the human factor, frequently cause periodic changes in groundwater quality <sup>14-15</sup>. Groundwater quality degrades in twofold, first, due to geochemical reactions in the aquifers and soils and, second, time when it is supplied through improper canals/drainages for irrigation. Therefore, it is necessary to perform a regular assessment of irrigation and drinking water quality <sup>16-19</sup>. Irrigation demands sufficient water supply of good quality. The index based on composition and concentration of dissolved elements in water can be useful in determining its applicability for agricultural utilization <sup>20-22</sup>. The suitability of groundwater for irrigation depends on the nature of the mineral

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elements in the water and their impacts on both the soil and plants<sup>23-24</sup>. This study seeks to evaluate the quality and suitability of groundwater for irrigation in the region of Mnasra.

## 2. Materials and method

### 2.1. Study site

The Mnasra region is the most agricultural area of the Gharb plain, forming the geographical continuity along the Atlantic Ocean. It covers an area of 488 km<sup>2</sup> between the city of Kenitra in the south, the Oued Sebou extended by the parallel line passing through Sidi Allal Tazi in the east, Merja Zerga near Moulay Bouselham in the north. The study area is an integral part of the Gharb Subsidized Sedimentary Basin. It is located in the contact zone between Morocco's two major structural areas: the primary meseta coastal,

which gradually plunges south to the north, and the Rifain domain, which belongs to the Alpine domain around the Mediterranean. The geological building is formed at the base by a primary basement, composed of schists and quartzites, located at a depth of more than 2500 m in the center of the plain. A powerful marl series of up to 2000 m is deposited on the primary formations. This series of "blue marls" constitutes the impermeable floor of the Gharb aquifer system. From the Pliocene onwards, sedimentation became regressive, consisting of lumachelles, sandstone and conglomerates. On these formations are deposited over a thickness of 200m, Pliocene sediments of marine origin. They are located in the coastal zone and are made up of sands, sandstones and calcareous sandstones, in which thin clayey-silt levels are interspersed. These formations constitute a major aquifer reservoir (Fig. 1).

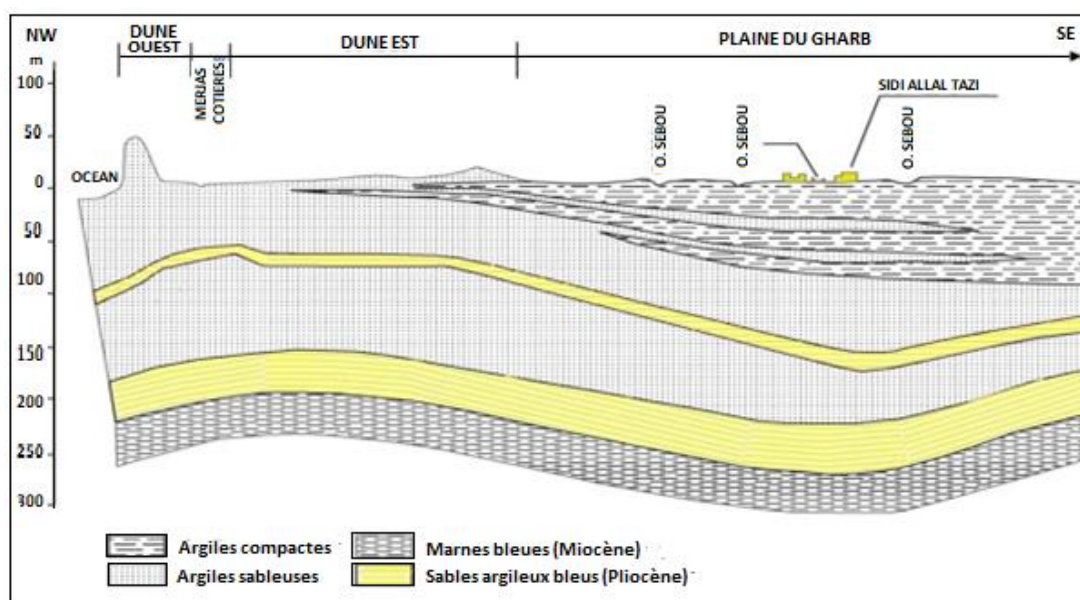


Figure 1. NW-SE geological section of the Gharb coastal zone<sup>25</sup>

The aquifer system of the Gharb coastal zone can be presented by the succession of two different layers: a sandstone surface layer that has a thickness of between 5 and 10 m in the inland dunes, and between 20 and 30 m in the dune belt. Within this layer, we find the groundwater table characterized by a shallow depth at the level of the inland dunes (2 to 10 m), and a somewhat depth in the coastal cordon (10 to 40 m). The second layer containing the deep water table is very thick compared to the first and is mainly made of sandstone. The hydraulic communication between these two levels is carried out through a red clay-sand screen, whose thickness varies from 10 to 20 m<sup>26</sup>. It should also be noted that the soil of the region is occupied by heavy soils (vertisols and fluvisols). The sandy soils of the coastal zone cover about 39,000 ha or 15% of the area of the Gharb plain<sup>27</sup>. The climate is the Mediterranean with oceanic influence. It receives an average annual rainfall of about 551 mm. The rainfall period extends from October to the end of

April, with a maximum for November, December and January. Mean temperatures range from 12°C in winter to 23°C in summer. Potential evaporation exceeds 150 mm during the dry months of June to September and is less than 80 mm during December to February<sup>28</sup>.

### 2.2. Sampling and analysis

A sampling campaign was carried out at 63 wells and 7 boreholes during June and July 2017. The choice of sampling sites was based primarily on two criteria: the depth of the aquifer and salinity levels of irrigation water.

Water samples were collected into 1-l polyethylene bottles which were pre-cleaned with concentrated hydrochloric acid and distilled water.

To assess the quality of well water and particularly salinity, the following analyses were performed: EC, pH, total dissolved solids, and ionic balance. Measuring the EC of the water was carried out using

the Orion laboratory conductivity meter, model 162. The pH of the water was measured using the Metrohm pH meter, model 691. The total dissolved salts of the water were determined by the gravimetric method, evaporating a certain amount of water at 105°C<sup>29-30</sup>. The dosage of Na<sup>+</sup> and K<sup>+</sup> was carried out by flame photometry. Ca<sup>2+</sup> and Mg<sup>2+</sup> were analyzed by the EDTA titrimetric method<sup>31</sup> Alkalinity as CaCO<sub>3</sub> and

HCO<sub>3</sub><sup>-</sup> were analysed by acid-base titration<sup>31</sup>. Sulfates were measured by nephelometric method<sup>31</sup>. Chloride (Cl<sup>-</sup>) was determined by standard AgNO<sub>3</sub> titration<sup>29</sup>.

The validation of the results of the chemical analyzes was carried out by the verification of their percent charge balance errors (% CBE). The latter was calculated according to the following equation<sup>32-33</sup>:

$$\text{CBE (\%)} = [(\sum \text{ cations} - \sum \text{ anions}) / (\sum \text{ cations} + \sum \text{ anions})] * 100 \quad \text{Eq.1}$$

Generally, the ion-balance error does not exceed ± 6%.

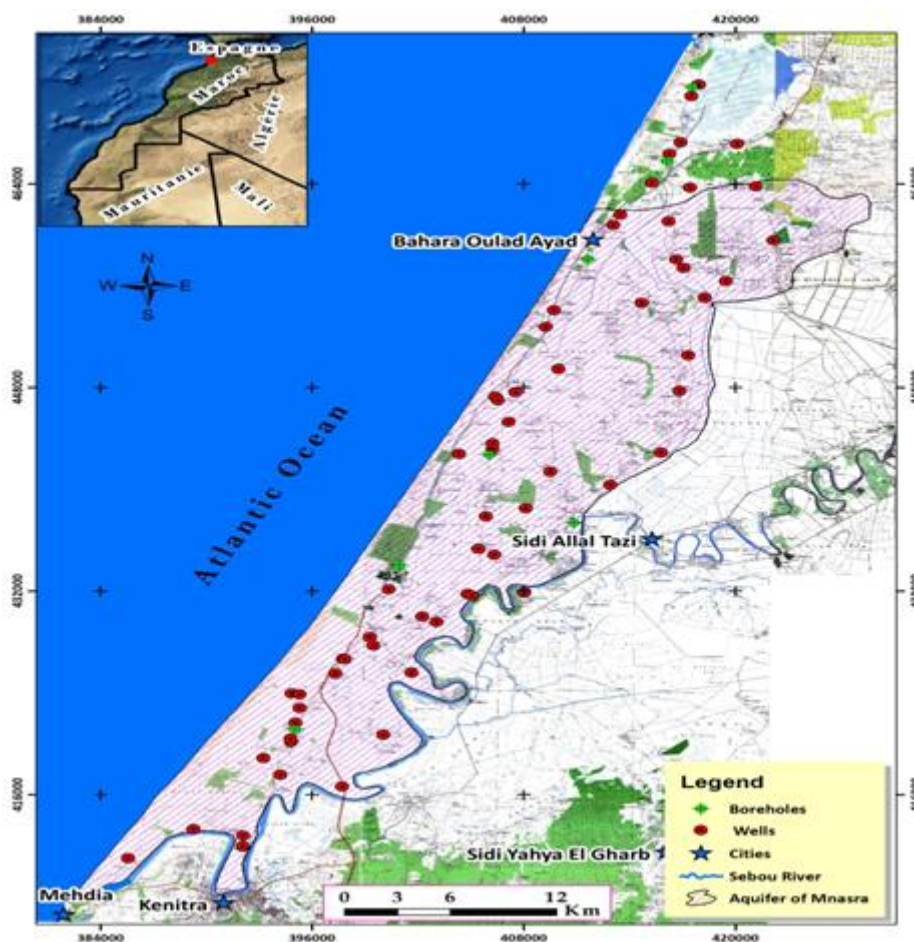


Figure 2. Location of sampling points

### 2.3. Hydrochemical methods

The hydrochemical methods for water characterization and classification adopted in this study are essentially based on the Piper diagram<sup>34</sup> and the Stuyfzand classification<sup>35</sup>. The Piper diagram is used to represent cationic, anionic and global facies. Stuyfzand's classification is used to determine the chemical characteristics, namely the main type, type, subtype and class. The main type and type are determined based on chloride content and alkalinity index. Subtype classification is determined from cations and dominant anions. The class is determined from the sum of Na<sup>+</sup>, K<sup>+</sup> and Mg<sup>2+</sup><sup>36</sup> using Stuyfzand's equation 2, which calculates the Base Exchange Index (BEI):

$$\text{BEI} = \text{Na} + \text{K} - 0.8768 \text{ Cl} \quad \text{Eq.2}$$

### 2.4. Qualitative methods

Groundwater is widely used for irrigation in the Mnasra region. The quality of irrigation water is a reflection of its mineral composition and its effect on plants and soil<sup>37</sup>. The chemical composition of irrigation water directly affects plants and agricultural soils and leads to less productivity<sup>38</sup>.

Therefore, a water quality assessment for irrigation is very important for thriving agricultural production. In this study, irrigation water quality was evaluated by the parameters of the SAR, MAR, SSP % Na, PI, RSC and TDS. These indicators were obtained using the following formulas<sup>39-42</sup>:

- Sodium adsorption ratio

$$(\text{SAR}) = \text{Na}^+ / \sqrt{[\text{Ca}^{2+} + \text{Mg}^{2+}] / 2} \quad \text{Eq.3}$$

- Magnesium adsorption ratio

$$(\text{MAR}) = [\text{Mg}^{2+} / (\text{Mg}^{2+} + \text{Ca}^{2+})] * 100 \quad \text{Eq.4}$$

- Soluble Sodium Percentage

$$(\text{SSP}) = (\text{Na}^+ * 100) / (\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+) \quad \text{Eq.5}$$

- Percentage of sodium

$$(\% \text{Na}) = [(\text{Na}^+ + \text{K}^+) / (\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+)] * 100 \quad \text{Eq.6}$$

- Permeability index

$$(\text{PI}) = (\text{Na} + \sqrt{\text{HCO}_3}) / (\text{Na} + \text{Ca} + \text{Mg}) * 100 \quad \text{Eq.7}$$

- Residual sodium carbonate

$$(\text{RSC}) = (\text{CO}_3^{2-} + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+}) \quad \text{Eq.8}$$

- Total dissolved salts

$$(\text{TDS}) = \text{Sum of cations and anions}$$

Where all ionic concentrations are expressed in meq/L.

## 2.5. Regionalization of results

The spatial distribution of indicators for assessing the irrigation suitability of Mnasra's groundwater is illustrated by graphical representations in the form of iso-content maps. The mapping of the spatial distribution of these parameters was carried out using an ArcView 3.2 GIS Geographic Information System. The spatial interpolation of these parameters is based on the geostatistical approach using the kriging method, which allows a linear estimation with the minimum variance<sup>43-44</sup>.

## 3. Results and Discussions

### 3.1. Physico-chemical parameters

The main descriptive statistics for groundwater EC, pH, cations and anions are given in Table 1. It is seen from this table that the water constituents are highly variable with respect to cationic and anionic constituents. However, this variability depends on the constituents. The most variable element is K with a coefficient of variation (CV) of 369, 7 %, although it is a minor constituent with a mean value of 8, 12 mg/l and values ranging between 0, 19 and 250, 24 mg/l. This is due to its selective adsorption by clays<sup>45</sup>.

The second most variable constituent is Na with a CV of 188, 1 %; it is the predominant cation with a mean of 108, 43 mg/l and values varied from 16, 31 to 1636, 79 mg/l. The third variable constituent is Cl with a CV of 158, 7 %; it is the predominant anion with a mean of 194, 41 mg/l and values varied from 17, 75 to 2449, 5 mg/l. Generally, Cl<sup>-</sup> comes from weathering of silicate-rich rocks, excess application of fertilizer, seawater intrusion, and animal and human waste contribute Cl<sup>-</sup> to groundwater<sup>46-47</sup>.

Many other constituents have a variability of the same magnitude ranging from 42 to 58 %: CO<sub>3</sub>, Ca, SO<sub>4</sub>, HCO<sub>3</sub> and Mg. To summarize, the importance, in average, of cations is Na > Ca > Mg > K while for anions, it is Cl > HCO<sub>3</sub> > SO<sub>4</sub> > CO<sub>3</sub>. However, this importance may vary from one observation to another depending on the spatial location where the sample was taken, which in turn is the function of climate, parent material, anthropogenic activities, etc.

**Table 1.** Descriptive statistics for measured water quality parameters.

Parameter	Min	Max	Mean	CV
<b>pH</b>	6,91	8,65	7,49	4,40
<b>CE (µS/m)</b>	267	9870	1567	94,80
<b>Na<sup>+</sup> (mg/l)</b>	16,31	1636,79	108,43	188,10
<b>Ca<sup>2+</sup> (mg/l)</b>	8,02	144,36	60,35	42,60
<b>Mg<sup>2+</sup> (mg/l)</b>	2,43	65,61	23,20	58,00
<b>K<sup>+</sup> (mg/l)</b>	0,19	250,24	8,12	369,70
<b>Cl<sup>-</sup> (mg/l)</b>	17,75	2449,5	194,41	158,70
<b>HCO<sub>3</sub><sup>-</sup> (mg/l)</b>	61	610	175,94	56,30
<b>SO<sub>4</sub><sup>2-</sup> (mg/l)</b>	0,48	47,62	25,92	49,70
<b>CO<sub>3</sub><sup>2-</sup> (mg/l)</b>	0	15	0,643	42,50

In comparing our results to some recently published research works, there is a difference in the order of the major cations and anions. For example, from a study based on 300 groundwater samples from India, Chaudhary (2018)<sup>48</sup> found that the most abundant cation was Na followed by Ca whereas in our case, it was the same. In contrast, Srinivasamoorthy et al. (2014)<sup>49</sup> found that, in a study of 87 groundwater samples in India, the most abundant anion was HCO<sub>3</sub>

followed by Cl compared to our study it was the inverse.

### 3.2. Hydrochemical classification

Based on chloride contents, 16 wells have the main fresh-salt type with code "B", 6 wells are brackish type with code "B'" and 45 wells are fresh-salt type with code "F" (Table 2). Based on the average of the chemical elements, the water subtype is characterized

by the dominance of  $\text{Cl}^-$ ,  $\text{Na}^+$ , and  $\text{HCO}_3^-$ . The concentrations of  $\text{HCO}_3^-$  measured vary between 1 and 10 meq/l. As a result, the alkalinity of the water

(types) is moderate to moderately low, it is generated by the dissolution of limestone ( $\text{CaCO}_3$ )<sup>50</sup>.

**Table 2.** Stufzand classification.

Main type	Classification levels	Code	Number of samples
<b>Type</b>	<b><math>\text{Cl}^-</math> (meq/l)</b>		
Very oligohaline	< 0,141	G	-
Oligohaline	0,141 – 0,846	g	1
Fresh	0,846 – 4,231	F	45
Fresh-brackish	4,231 – 8,462	f	16
Brackish	8,462 – 28,206	B	6
Brackish-salt	28,206 – 282,064	b	2
Salt	282,64 – 564,127	S	-
Hyperhaline	> 564,127	H	-
	<b><math>\text{HCO}_3^-</math> (meq/l)</b>		
Very low	< 0,5	*	-
Low	0,5 - 1	0	2
Moderately low	1 - 2	1	24
Moderate	2 - 4	2	35
Moderately high	4 - 8	3	7
High	8 - 16	4	2
Very high	16 - 32	5	-
Extremely high	32 - 64	6	-
Extremely high	> 64	7	-
<b>Classe</b>	<b>(Na + K +Mg) (meq/l)</b>		
Deficit of (Na + K + Mg)	< $-\sqrt{1} / 2 \text{Cl}$	-	-
Equilibrium of (Na + k + Mg)	$\geq -\sqrt{1} / 2\text{Cl}$ et $\leq 1/2\text{Cl}$	0	-
Surplus of (Na + k + Mg)	> $1 / 2\text{Cl}$	+	70

For the water class, Stuyfzand's equation 2 revealed a single code class (+) for all water points. This is due to dissolution processes of carbonate rocks<sup>51</sup>; cationic exchanges involved<sup>50</sup> as well as irrigation water and fertilizer inputs.

### 3.3. Geochemical facies of water

The projection of the water points in the Piper diagram showed that Mnasra's groundwater is different. Three geochemical facies emerged:

- Calcic chlorinated facies: the cationic composition is  $\text{Ca}^{2+} > \text{Na}^+ > \text{Mg}^{2+}$  and  $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+$  (51, 42 % water), the anionic composition is  $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-}$  (100% water);

- Magnesian chlorinated facies : the cationic composition is  $\text{Mg}^{2+} > \text{Ca}^{2+} > \text{Na}^+$  and  $\text{Mg}^{2+} > \text{Na}^+ > \text{Ca}^{2+}$  (10 % water) the anionic composition is  $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-}$  (100% water);

- Sodic chlorinated facies: the cationic composition is  $\text{Na}^+ > \text{Mg}^{2+} > \text{Ca}^{2+}$  and  $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+}$  (38.58 % water), the anionic composition is  $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-}$  (100% water).

The calcic and magnesian chlorinated are due to the presence of dunes. The sodic chlorinated facies could come from the marine intrusion and the infiltration of saltwater from the Sebou wadi and the surface water bodies on its banks (dayas and merjas) which are also brackish and that they can constitute a source of contamination of the waters of the Mnasra aquifer.

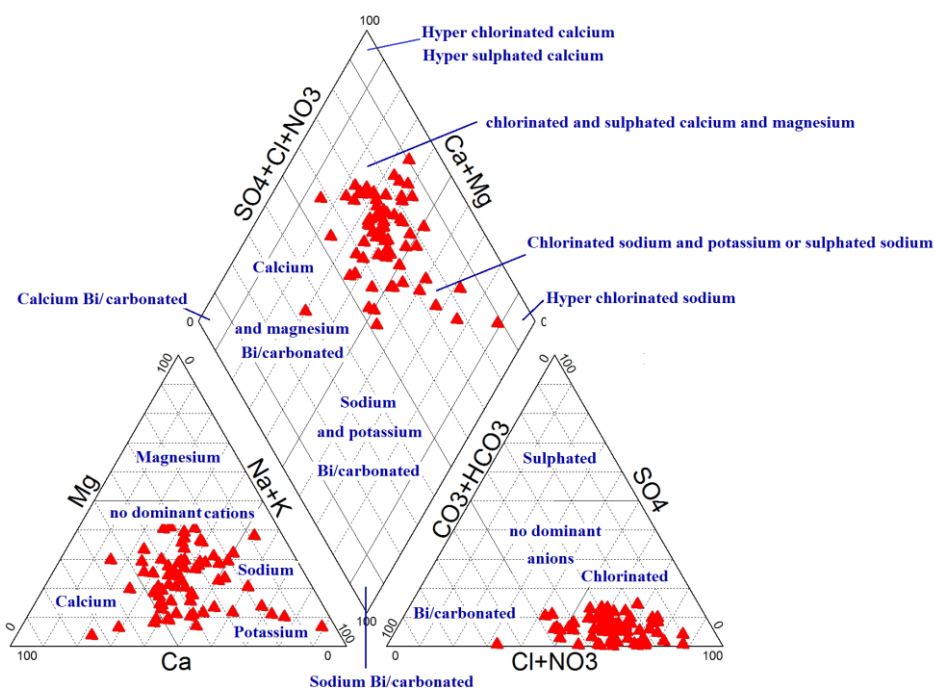


Figure 3. Piper diagram for irrigation water of Mnasra

### 3.4. Spatial distribution of major elements

Figures 4a, 4b, 4c, 4d, and 4e show that the elements  $\text{Na}^+$ ,  $\text{Cl}^-$ ,  $\text{Ca}^{2+}$  and  $\text{HCO}_3^-$  have relatively the same spatial distribution. The highest concentrations of these elements are observed in the south downstream of the Sebou River and in the northeast of the plain where salinity exceeds 6 g/l to reach even 8 g/l. For these points, the groundwater level is close to the ground, which means that the groundwater is more exposed to evaporation and possible contamination by infiltration of irrigation water, which is a major source of salts. Salinization of water can also be attributed to marl, the return of irrigation water to the water resource and upwelling of saltwater trapped in sedimentary series in well catchment areas <sup>52</sup>.

The spatial variation of 4c calcium showed that the maximum concentrations are in the order of 144.36 mg/l and also observed downstream of the Sebou River and north of the plain. This variation takes into account that this  $\text{Ca}^{2+}$  ion is involved in several geochemical processes such as carbonate precipitation and/or basic exchange processes. The high concentrations of  $\text{Mg}^{2+}$  are located in the points

near the dunes and downstream of the Sebou River, this is explained by the phenomenon of de-lomitization which would be caused by the irreversible dissolution of sulphates accompanied by the dissolution of dolomite and the precipitation of calcite <sup>53-54</sup>. As for the sulphate content, the examination of the spatial distribution map (Figure 4f) revealed low concentrations, while bicarbonate concentrations showed maximum concentrations of around 610 mg/l observed downstream of the Sebou wadi and northeast of the plain, due to the precipitation of carbonate formations. The high presence of chlorides and sodium in the groundwater of Mnasra can be the result of the combination of several important factors namely: the infiltration of saltwater from the Sebou River, the return of irrigation water to the water resource, direct marine intrusion is unlikely because the level of the water table remains above sea level. The discharge of domestic wastewater into poorly waterproofed septic tanks also contributes to the contamination of the lowest areas where the groundwater level is close to the ground.

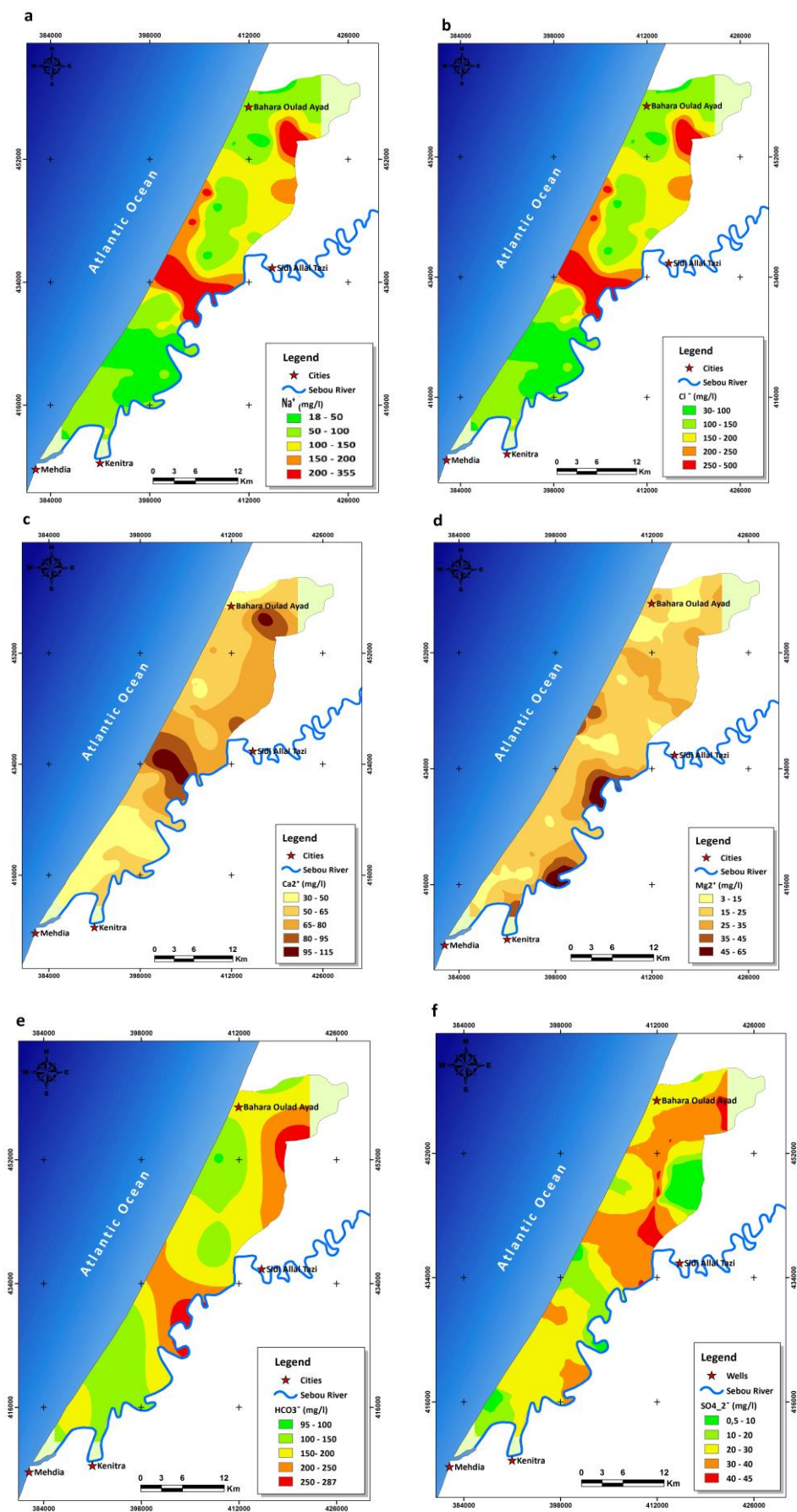


Figure 4. Spatial distribution of groundwater chemical elements of Mnarsa

### 3.5. Groundwater suitability for irrigation

Mnasra's groundwater are reported in [Table 3](#).

The indices for assessing the irrigation suitability of

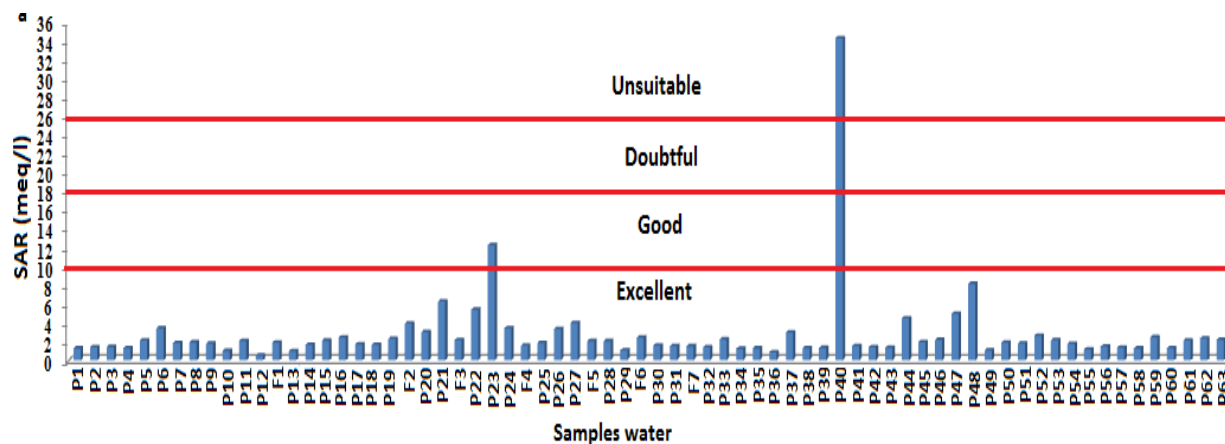
**Table 3.** Statistical results of SAR, %Na, MAR, SSP, TDS, PI and RSC of the waters studied.

Parameters	Max	Min	Average	Standard deviation	Standards	Water class
SAR (meq/l)	34,31	0,50	2,75	4,21	< 10	Excellent
					10-18	Good
					18-26	Doubtful
					>26	Unsuitable
Na (%)	89,24	15,20	41,12	12,55	< 20	Excellent
					20-40	Good
					40-60	Permissible
					60-80	Doubtful
					>80	Unsuitable
MAR (%)	81,81	4,76	38,48	15,28	<50	Suitable
					>50	Unsuitable
SSP (%)	89,22	15,07	40,24	12,60	<50	Suitable
					>50	Unsuitable
TDS (mg/l)	4923	345	710,54	638,94	<500	Desirable
					500-1000	Permissible
					<3000	Useful
					>3000	Unsuitable
PI (%)	93 ,02	43,36	61,69	11,08	> 75	excellent
					25-75	Good
					< 25	Unsuitable
RSC (meq/l)	0,60	-5,80	-2,01	1,44	<1,25	Good
					1,25-2,5	Doubtful
					>2,5	Unsuitable

The results showed that these waters are of good quality for agricultural purposes based on the quantitative parameters listed (SAR, MAR, SSP, PI, TDS and RSC) in [Figure 5](#).

Regarding the risk related to sodium, the SARs of 69 wells are less than 10, thus presenting minimal risk of

sodium accumulation. However, only one well with a SAR more significant than 26, which corresponds to high alkalization risks <sup>55-56</sup>. High sodium levels in irrigation water can saturate the cation exchange complex, and destroy soil structure due to clay dispersion ([Figure 5](#)).



**Figure 5.** Comparison of sodium adsorption ratio Mnasra in aquifer groundwater with WHO standards



The high SAR values were noted at points near Oued Sebou. Based on the overall salinity and SAR, the Richards diagram (Figure 6) was able to identify the presence of the following classes:

- Class C2S1 characterizes water that is good for irrigation and can be used without particular control for the irrigation of moderately salt-tolerant plants. It is found upstream of the slick near the inland dunes. This class appeared with only a small percentage not exceeding (18,57%);
- Classes C3S1, C3S2 refer to water that is acceptable for irrigation of salt-tolerant crops on well-drained or

permeable soils where salinity must be controlled. Class C3S1 characterizes the wells located in the North and Centre of the region with a percentage of 71, 42%;

- Classes C4S2, C4S3 indicate poor water with high mineral content, which may be suitable for irrigation of certain salt-tolerant species and on well-drained and leached soils. They are found in groundwater recharge areas and areas at potential risk of saline level intrusion with a percentage of 7, 15%;
- Class C5S4: water not recommended for irrigation 2, 86%.

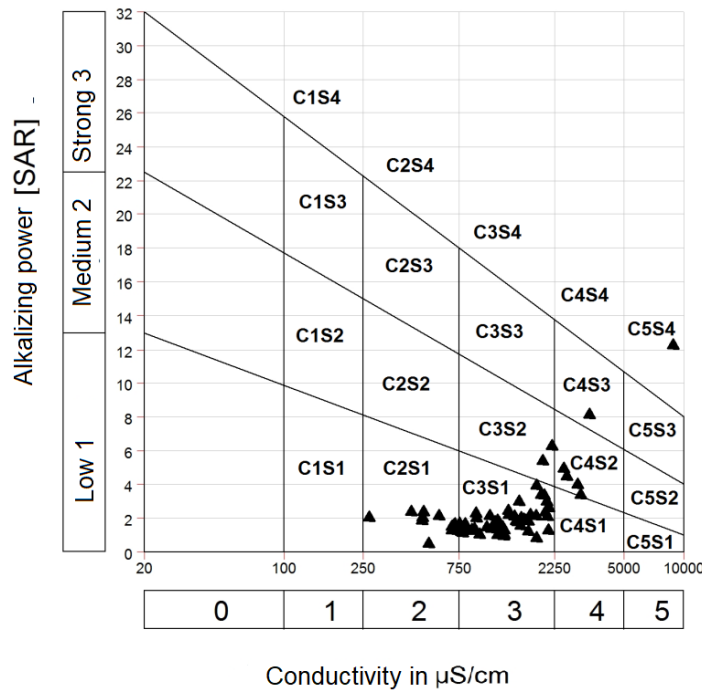


Figure 6. Riverside diagram of groundwater in the Mnasra aquifer

The MAR results showed that 54 wells have concentrations below 50 and can, therefore, be used for irrigation (Figure 7). Nevertheless, 16 wells are

unsuitable for irrigation due to high magnesium contents and are likely to lead to soil salinization and reduced fertility, thus reducing crop yields.

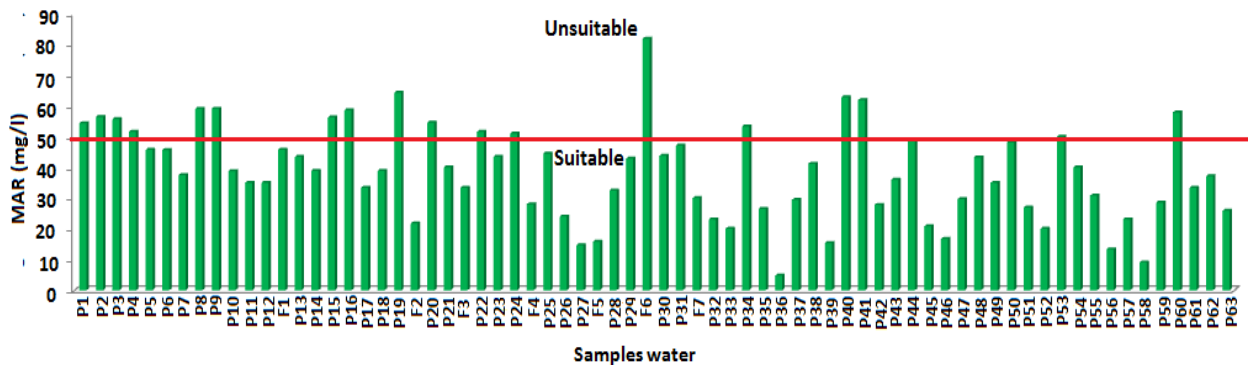


Figure 7. Comparison of magnesium adsorption ratio Mnasra in aquifer groundwater with WHO standards

The SSP values obtained showed that 58 wells are favourable to irrigation, and 12 wells have concentrations higher than 50 and therefore unusable for irrigation purposes (Figure 8).

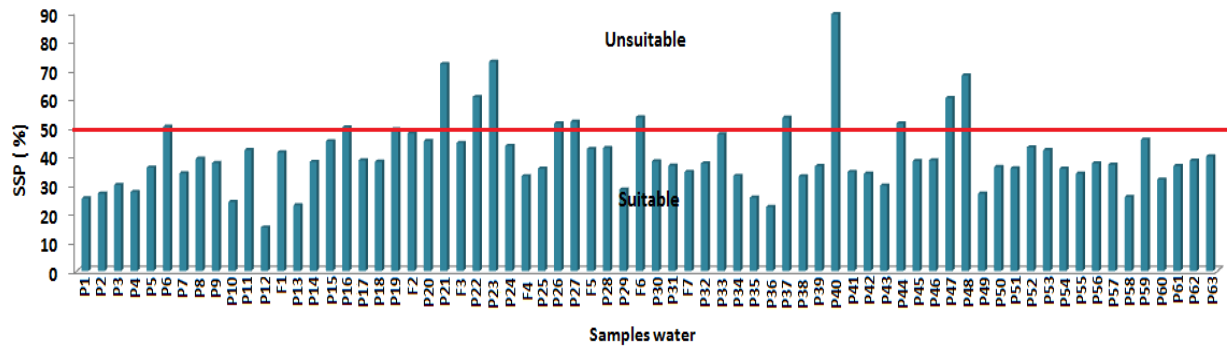


Figure 8. Comparison of soluble sodium percentage in Mnsara aquifer groundwater with WHO standards

The calculation of TDS values indicates that all samples are fresh (61 wells) and slightly saline (2 wells) (Figure 9). For all water samples analysed.

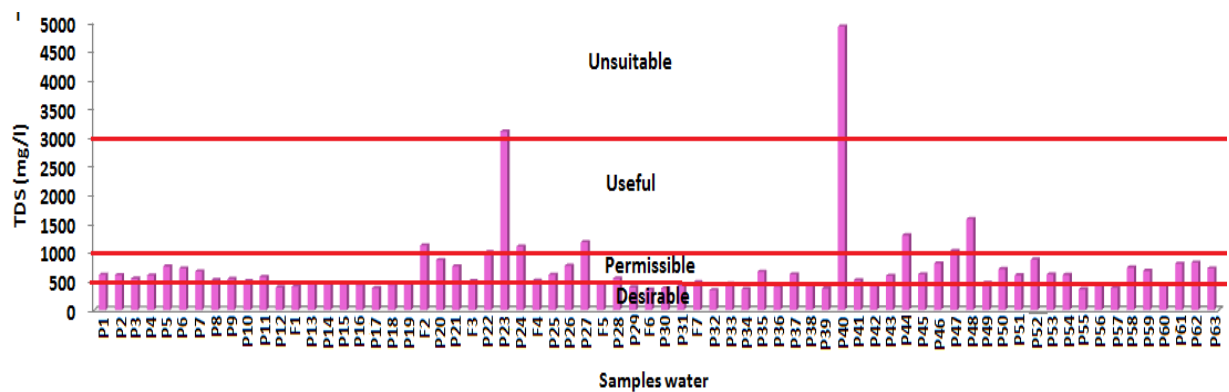


Figure 9. Comparison of total dissolved salts in Mnsara aquifer groundwater with WHO standards

The RSC values are low, not exceeding 1, 25 meq/l, carbonates and bicarbonates (Figure 10), which then eliminates the harmful effects of

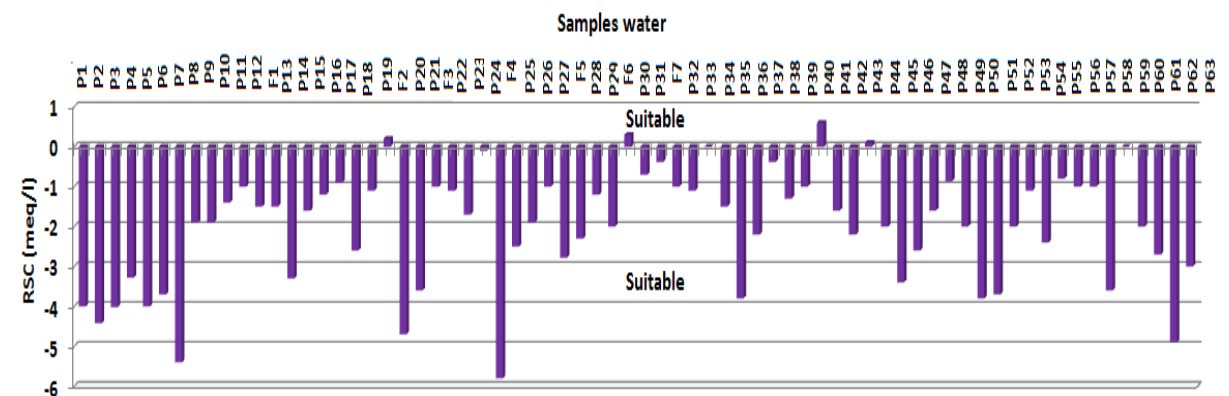


Figure 10. Comparison of residual sodium carbonate in Mnsara aquifer groundwater with WHO standards

The PI values obtained highlighted two classes of category 1 and 2. They vary between 25 and 75%, which makes their use in irrigation acceptable (Figure 11).

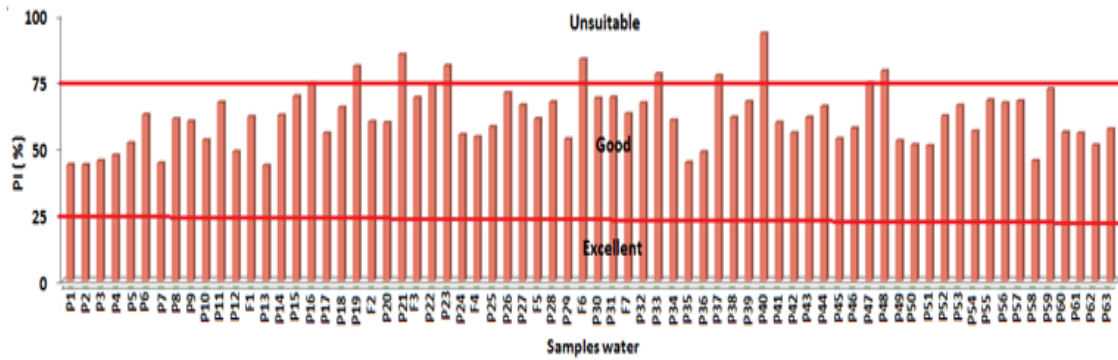


Figure 11. Comparison of permeability index in Mnasra aquifer groundwater with WHO standards

The presence of salts in groundwater directly affects plant growth, soil structure, permeability and aeration<sup>58</sup>. The results of % Na show excellent quality

at a single well, 40 water points have good quality, 20 wells represent acceptable quality, and only 9 wells report poor quality (Figure 12).

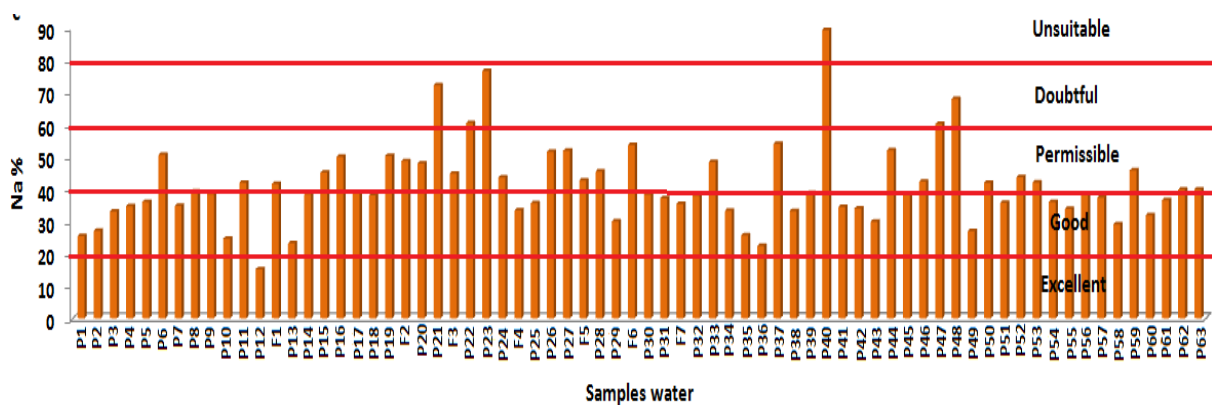


Figure 12. Comparison of percentage of sodium in Mnasra aquifer groundwater with WHO standards

Based on the overall salinity and % Na, the Wilcox diagram showed that 22,86% of groundwater samples are of excellent quality for irrigation; 52,86% of cases

of good quality; 5,71% of cases are within the acceptable level; 12,86% of water points indicate poor quality and 5,7 1% of samples with poor quality.

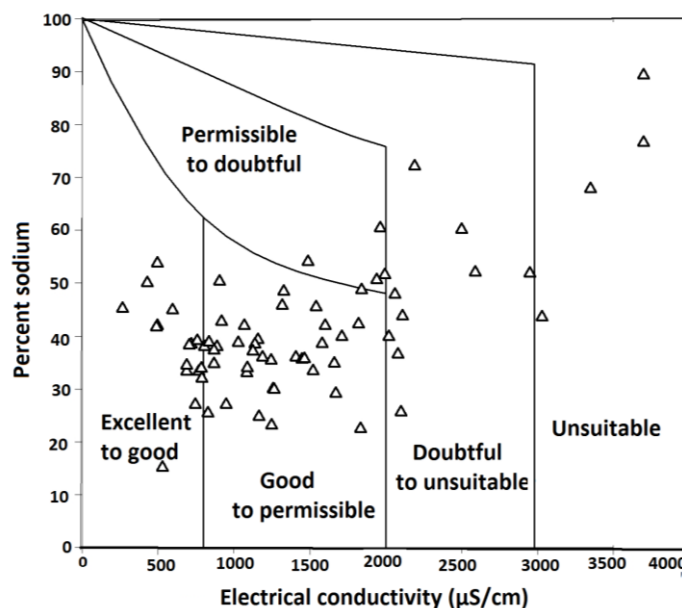
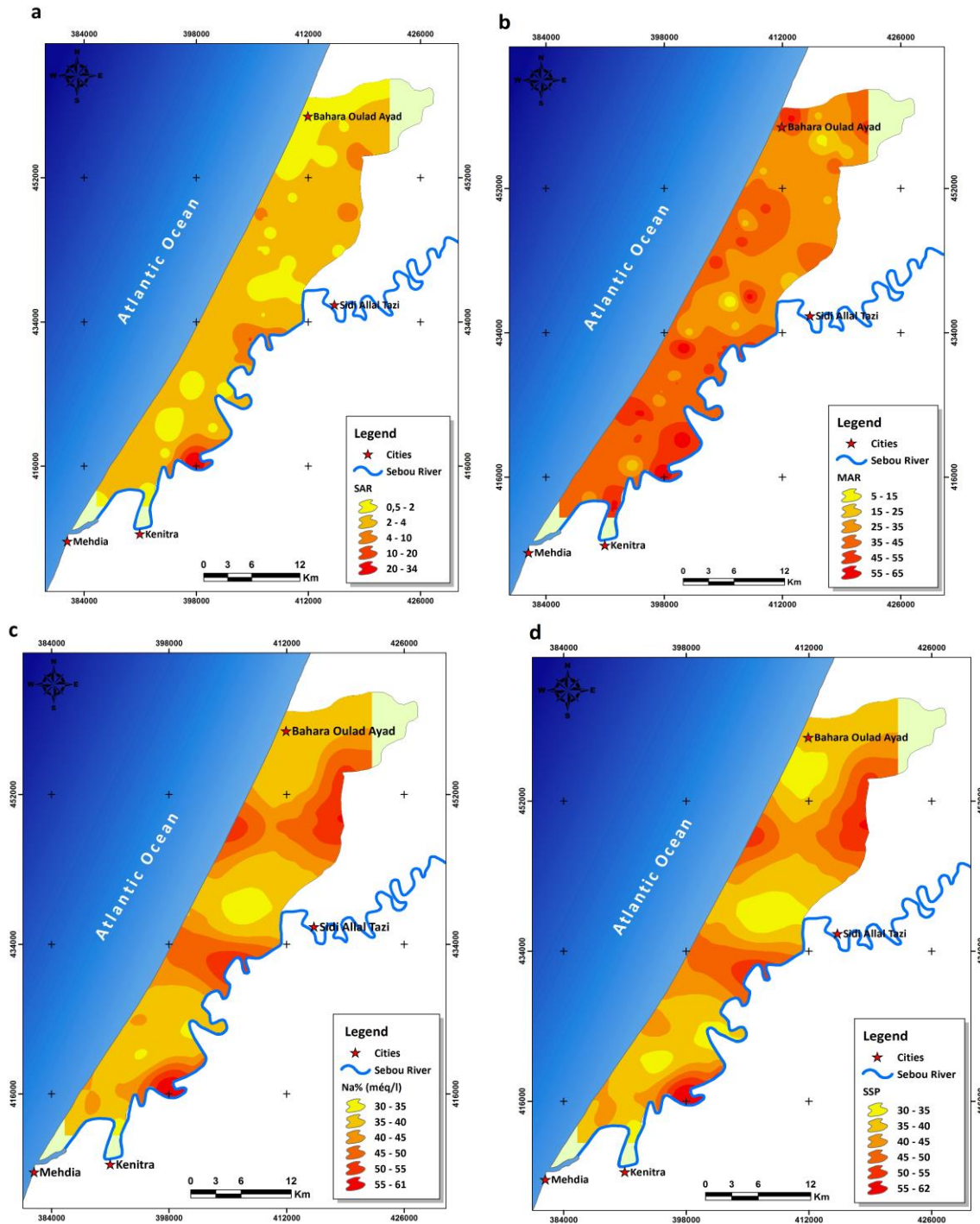


Figure 13. Wilcox diagram of groundwater in the Mnasra aquifer

The spatial distribution maps of the SAR, MAR, % Na, SSP, RSC and TDS of the study area, presented in Figures 8a, 8b, 8c, 8d, 8e and 8f, revealed that it is the water points located in the south-east of the plain and near Oued Sebou that have significantly exceeded the allowable limits. This is because these waters are included in areas of vulnerability, such as saline bevel intrusion zones and groundwater recharge zones. As a result, the use of these water points for agricultural purposes may weaken the physical

properties of the soil, particularly the structure. Moreover, the Mnasra region is characterized by the dominance of the sandy-clay and silty-clay texture. This type of texture favours the adsorption of Na on the clay-humic complex.

This raises problems of degradation of the physical and chemical properties of soils, therefore, the decrease in fertility which leads to a reduction in crop yields and sometimes even the disappearance of the plant cover.



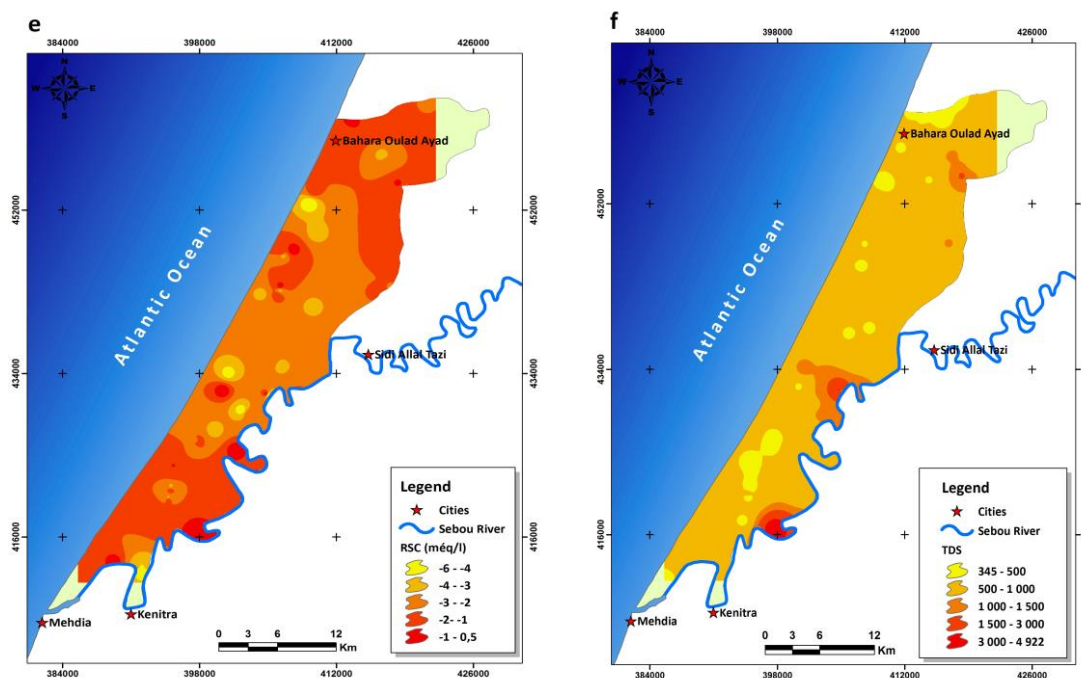


Figure 14. Spatial distribution of qualitative elements of irrigation

#### 4. Conclusion

Physico-chemical parameters and hydrochemical methods were used to characterize the quality of Mnasra groundwater used in irrigation. The study was based on 70 well water samples. The results revealed relatively variable physicochemical characteristics. The Piper diagram identified two facies: calcic and magnesian chlorinated (85, 70%), and a chlorinated sodium facies (14, 30%). Stuyfzand's classification showed that the waters are fresh to fresh-brackish, of moderate alkalinity. These classes reflect the basic exchanges between waters and clay minerals. The spatial distribution of chemical parameters revealed that high concentrations of Cl, Na, HCO<sub>3</sub> and Ca are recorded downstream of the Sebou River and in the northeast of the region; this is due to the calcareous nature of the aquifer. The analysis of water quality indicators for irrigation use has shown, overall, good quality for agricultural purposes. However, in the semi-arid context and particularly in the soil conditions of the study area, this water could be used for irrigation under conditions of proper management and cultural practices, including the adoption of salt-tolerant crops, the practice of leaching. In addition, it should be noted that the water from the wells located around the Sebou River and in the north-east zone of the plain has areas of vulnerability due to the existence of a saline bevel and a groundwater recharge zone par excellence.

#### 5. Recommendations

- Development of irrigation methods, and management and planning of estimated plan irrigation according to climate demand, water quality, soil types, crops and stages of development. Taking into

account the water potential and the valuation of the cubic meter of water;

- Development of drainage techniques, leaching fractions and techniques aimed at combating salinity (improvements) by promoting hydro-agricultural development and monitoring of evaluation: The drainage of irrigated land is very important to control and reduce the salinization of the soil, the drainage water must be drained safely so that it can be recycled by installing treatment plants. Admittedly, the costs of installing drainage are enormous, but natural or artificial drainage is compulsory and must regularly provide doses of leaching to keep the saline composition of the soil solution close to that of the irrigation water;

- Use of mathematical simulation models for efficient management of water irrigation, with control of soil salinity and crop yields;

- The recent pedological study of all the soils in the region appears to be essential and more than necessary makes it possible to identify a certain number of specific characteristics linked to cultivation. The aim is to map soils in order to classify soils favorable to development;

- To better enhance our research work, and as long as the Mnasra region is a pioneer region with an agricultural vocation, the multiplication of the number of weather stations appears more than necessary in order to mastery and control the water balance (ETP, and rain/irrigation).

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