Journal of Ecological Engineering

Journal of Ecological Engineering 2023, 24(2), 50–60
https://doi.org/10.12911/22998993/156691
ISSN 2299–8993, License CC-BY 4.0

Received: 2022.10.27
Accepted: 2022.12.08
Published: 2023.01.01

The Effects of the Quality of Irrigation Water Used on Agricultural Soils in Coastal Chaouia, Morocco

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ABSTRACT

The Coastal Chaouia region is located south of the Casablanca city (Morocco). Since the 1970s, groundwater has been used intensively for irrigation, previously for growing citrus and currently for vegetables and forages. The increase of irrigated soils by pumping has induced environmental problems such as the degradation of groundwater quality and salt water intrusion. For these reasons, this work aimed to study the impact of the irrigation water quality upon the agricultural soils. During the study, 71 samples of well water and soil were taken to represent the whole considered area, which comprised 3 different zones (0–1.8 km, 1.8–4.5 km, and 4.5–11 km from the coast). The analyzed parameters were salinity and pH. The results showed firstly that the soil pH average values decrease for the three zones with 7.73, 7.57, and 7.52, respectively. However, the water pH averages vary from 7.24 to 7.49. For the soil electrical conductivity, it represents a light decrease moving from the nearest zone to the sea to the far one (average of 3.54, 2.66, and 2.33, respectively). A similar result is for observed water electrical conductivity with average of 6.83, 5.30, and 2.06, respectively, for the three zones. The analyses of the soil and water salinity show that both salinities decreased moving from the coast to inland. Richard and Wilcox charts have confirmed the strong mineralization and the poor quality of most of the well water which are close to the sea.

Keywords: Coastal Chaouia, irrigation, well water, soil, salinity.

INTRODUCTION

The major agricultural regions in Morocco are based on the irrigation system, where it is an assurance of income for many farmers, particularly for fruits and vegetables. The salinity problems observed in irrigated agriculture are often associated with the presence of uncontrolled use of groundwater located between 1 and 2 m from the ground surface (Foster et al., 2003). When the groundwater is shallow, the water penetrates into the root zone by capillary action and, if the water is salty, it becomes a permanent source of salts as the water is used by crops or it evaporates to the soil surface. Soil and water salinity constitutes a major problem in many countries (Gouaidia, 2012, Wada et al., 2016, Pandit et al., 2020). Thus, the salts may disrupt the physical plant development (Tanget al., 2015, Yadav et al., 2020). Due to the absorption of water, the effects can be observed on the osmotic process, or chemically by metabolic reactions such as those caused by toxic components. In addition, salts can cause changes in the soil structure, permeability and ventilation (Person, 1978). Suitability of water for irrigation or various uses depends on types and concentrations of dissolved minerals. Groundwater has higher mineral concentrations in comparison with surface water (Mirabbasi et al., 2008). The presence of soluble salts in irrigation water and evaporating power of the air in irrigated areas often lead to soil salinization, especially in arid and semi-arid zones (Najib, 2016), which threatens the sustainability of irrigated systems and profitability of agricultural land (Hafmann et al., 2000).

Water is the key constraint restricting the agricultural productivity in semi-arid locations, such as the coastal Chaouia. Water quantity and quality, on the other hand, have a significant impact on soil structure and quality (Najib et al., 2016). Nowadays, irrigated agriculture is threatened by the risk of salinity that can be assessed by the electrical conductivity (EC) and that of alkalizing soil. The latter is due to ion exchanges and is related especially to sodium, calcium and magnesium, between the water and soil clays. It is evaluated by the sodium absorption ratio (SAR) (Bouksila, 2011). The coastal Chaouia undergoes a pumping groundwater activity that started since 1960 and secures exclusively irrigation of vegetable crops (Moustadraf et al., 2008). The irrigation of these crops by groundwater and the evapotranspiration lead to an accumulation of salts in the soil that increase each year, occasion ally leading to the abandonment of any agricultural activity (Najib et al., 2016). In this region, the intensive agricultural use of the aquifer has led to saline intrusion in the coastal part and lower groundwater levels in the inner part of the aquifer (Berahmani, 2011).This study aimed to evaluate the change in salinity of agricultural soils as well as the water wells used to irrigate these soils, to derive the influence of the quality of the irrigation water on soil salinity levels and investigate the consequences of irrigation on the crops.

PRESENTATION OF THE STUDY AREA

Geography and climate

The study area belongs to the low Chaouia (coastal Chaouia), which constitutes the most agricultural part in the coastal Chaouia. It is a subatlantic plain that has evolved on the border of the Atlantic Ocean between the cities of Casablanca and Azemmour. This plain is limited on the southwest by the Oum-er-Rbia River, on the northwest by the Atlantic Ocean, on the northeast by the El Hank quartzite, and on the southeast by the Berrechid plain. This area has a small inclination toward the sea. The ocean's edge is marked by old and new dunes (ABHBC, 2012). This region is characterized by semi-arid climate with oceanic influence, low temperatures and abundant rainfall in autumn as well as high temperatures during summer period (DMN, 2015) (Fig. 1).

Geology

Different scientists have studied the geology of the coastal Chaouia (Fig. 2) (Piqué, 1994; Ouadia, 1998; El Attari, 2001; Michard et al, 2010). The stratigraphy includes Paleozoic, Cenomanian, and Plio-Quaternary formations, which are covered by Plio-Quaternary deposits. The Palaeozoic bedrock is made up of an impermeable or semi-permeable layer that correlates to Cambrian and Ordovician sandstones, schists, and quartzite formations. The upper and weathered parts of the schists offer excellent groundwater flow conditions. Permeable calcareous sandstone and dune formations of Pliocene and Quaternary age are

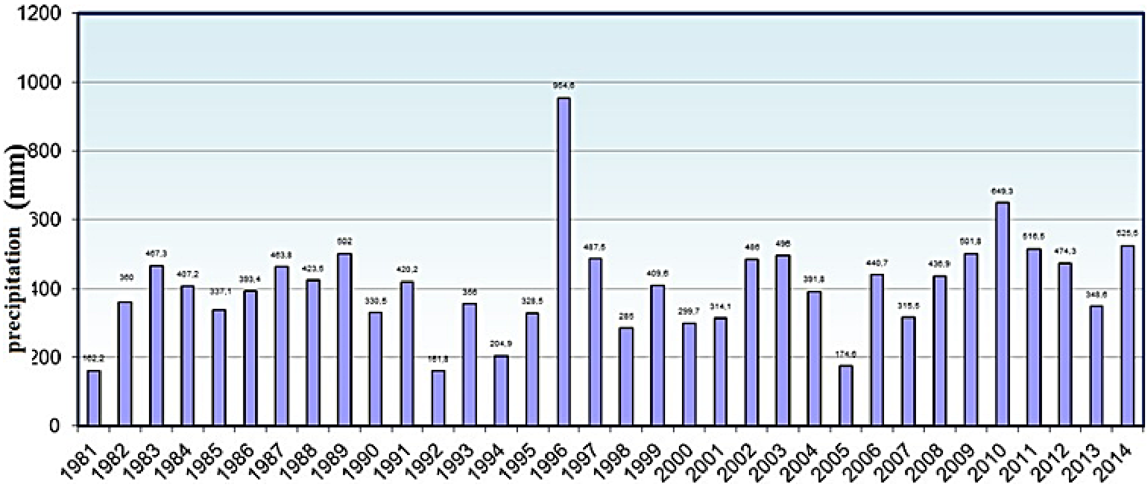

Figure 1. Evolution of the total annual precipitation in the station of El Jadida (1981–2014) (DMN, 2015)

overlain on the Palaeozoic bedrock. Plio-Quaternary deposits overlie a Cenomanian marly-limestone formation in the southwest and perform an important hydrogeological role. The Cenomanian formation, which is formed of marls, might operate as an impenetrable layer depending on the lithological facies. However, where it is made up of limestones, it allows for groundwater circulation. Finally, groundwater in the coastal Chaouia can be found in Palaeozoic schists, the the Cretaceous, or the Plio-Quaternary, depending on location. When weathered, Palaeozoic schists can act as an aquifer. The thick- ness of weathered schist zone varies from a few meters to a maximum of 30 meters. When bro- ken, quartzites can potentially serve as an aquifer. The Cenomanian marly limestones that make up the Cretaceous formation can be found in the southwest under Plio-Quaternary deposits. The saturated thickness of Plio-Quaternary becomes essential in coastal settings, and is generally linked to the structure of the primary pedestal bowl, which has an effective porosity of 0.1 to 7%. (DRPE, 1999). The Plio-Quaternary aquifer is significantly strained by a large number of wells for vegetable irrigation in these microcracked aquifers and porous areas (Najib, 2014).

Sampling and analytical methods

The sampling was carried out in June 2014 and 2015, after deciding for the location of points to be taken from a topographical map of the study area. Each point was positioned with a hand GPS (Global Positioning System) instrument. The collection thus applies to three areas: the first area is located along the coastal part (near the sea: 0–1.8

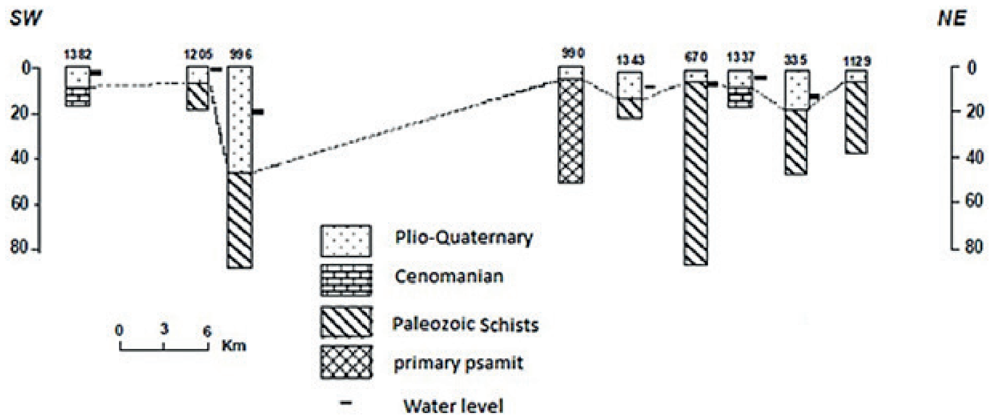

Figure 2. Lithological crosses in the unconfined aquifer of coastal Chaouia (Amraoui, 1999)

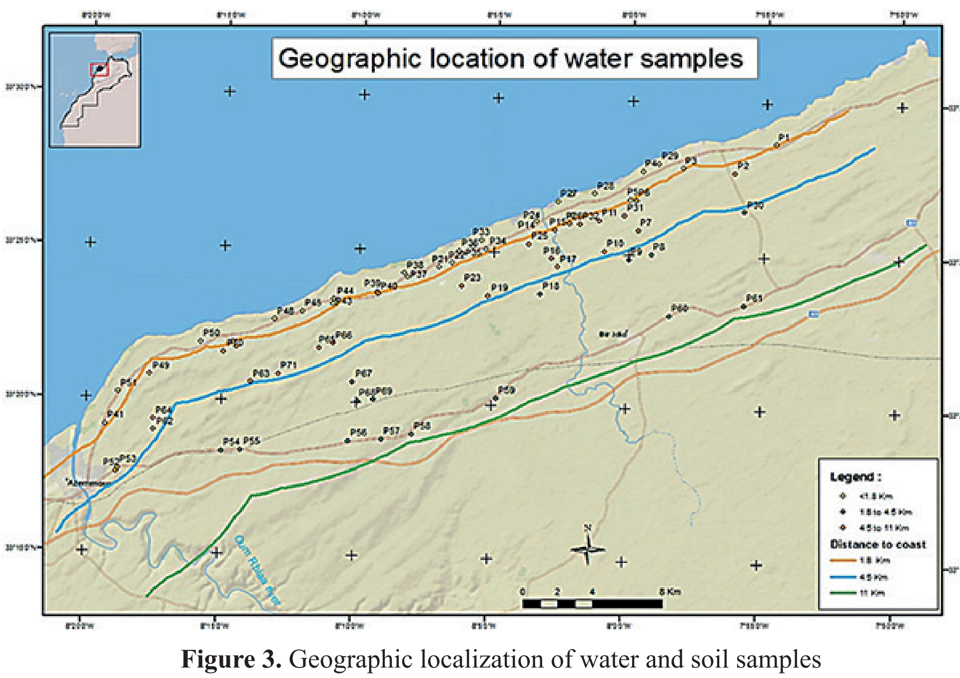

Figure 3. Geographic localization of water and soil samples

km) with 28 samples, the second area is an intermediary zone (far from the sea by 1.8–4.5 km) with 28 samples, and the farthest zone from the sea (far from the sea by 4.5–11 km) with 18 sam ples. This sampling was done for soil and wells used for their irrigation (Fig. 3).

Seventy-one soil samples were collected from the top horizon (AP 0–20 cm). The samples have a weight of about 1.5 kg. They were first air dried over one week then they were crushed in porcelain mortar and sieved at 2 mm. Soil salinity was characterized by determining the electric conductivity. The extraction was based on the saturated paste according to Richards (1954). The pH ½ was evaluated by the method of Mc. Lead (1982). Regarding water, 71 points were taken at the existing wells near the soil samples. The water samples were collected into polyethylene bottles. Subsequently, bottles were completely filled with water and kept in a cooler(2–4 °C) at most 72 hours and then brought tothe laboratory for analysis of ionic balance (Na^+, Ca^{2+} and Mg^{2+}). The pH and electrical conductivity (EC) were measured on the spot by using portable pH meter and conductivity meter, respectively.

The study of salinity is essentially based on a combination of factors: The electrical conductivity, the pH and the sodium adsorption ratio (SAR) calculated from the cations (Na^+, Ca^{2+}, Mg^{2+}). From the measured parameters (in meq/l), many others were calculated per the following formulas:

- Sodium adsorption ratio (Agrinter, 2004):

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

- Sodium percentage (Todd and Mays, 2005):

$$(\%Na) = 100 * Na/\,(Ca + Mg + Na + K) \quad (2)$$

Statistical analyses

For both observed and calculated water and soil quality indicators, statistical parameters (min imum, maximum, mean, and coefficient of variation) were determined. The Pearson correlation coefficients were calculated for the soil and the water quality parameters. These correlation coefficients were statistically tested for their significance. Moreover, analysis of variance (ANOVA) was carried out to assess the significance of the effect of distance to sea on all variables. When ANOVA led to significant results, Duncan test was used to identify homogeneous groups of distances to sea. The ANOVA and Duncan tests were based on original data (pHw and pHs), square root (SAR), or logarithmic (ECw and ECs) transformation in order to normalize the distributions and/or to stabilize the variances. SAS software was used to do the statistical calculations (SAS, 2000). The specific hydrogeological program "diagrammes" was used to create certain graphical representations.

RESULTS AND DISCUSSION

Soil analyses

pH

Soil pH for the areas adjacent to the sea (from 0 to 1.8 km) has an average of 7.73±0.38 with a minimum of 6.78 and a maximum of 8.39 (slightly basic). These results are somewhat similar to soil pH in the 2 other areas (intermediate and far from the sea): they vary from 6.66 to 8.14 and from 7.06 to 8.26 with average values of 7.57 ± 0.35 and 7.52 ± 0.35, respectively (Table 1). This shows that the entire soil pH is optimal for production of most plant species (Nisbet and Vernaux, 1970). Worldwide, most coastal soils are slightly alkaline to alkaline, with pH of 7.5–8.5 in China (Wang et al., 1993). Balkhair (2015) evalu ated the quality of western region of Saudi Arabia soil and found that most of the soils have an approximate pH value of 7.9.

Electrical conductivity

The electrical conductivity (EC) of the saturated soil-paste is generally higher in the vicinity of the sea in 2 zones (near and intermediate). It varies from 0.30 to 10 and from 0.8 to 12.26 dS/m with an average of 3.54 ± 2.55 and 2.66 ± 2.30 dS/m. However, the soils far from the sea have the electrical conductivity values ranging from 0.70 to 5.36 dS/m with and an average of 2.33 ± 1.35 dS/m (Table 1). The median value for the soil EC is the highest near the sea, whereas it is the lowest in the intermediate zone. Moreover, there are two outliers at the soil samples 20 and 24 (10dS/m) near the sea, while there is an extremely high value (12.26 dS/m) for the soil sample 46 (zone 2). These results are likely related to the proximity of the sea, the nature of the irrigation water, and the sandy texture of the soil (Rafik et al., 2015) which promotes the leaching of salts. Chen et al. (2010) showed that the average of the soil electrical conductivity varied between 1.7 and 14.7 dS/m according to the levels of water salinity in arid region of northwest China.

Table 1. The results of the analysis of the salinity of water and soil from coastal Chaouia

Distance from the sea 00_1.8Km						
Parameters	Variable	Mean	Median	Minimum	Maximum	Coef of Variation (%)
Water	EC (dS/m)	6.83	7.56	1.34	9.76	33.58
	pH	7.24	7.23	6.30	8.51	6.97
	SAR	10.34	8.63	1.18	20.59	56.45
Soil	pH	7.73	7.65	6.78	8.39	4.93
	EC (dS/m)	3.54	2.83	0.30	10.00	72.19
Distance from the sea 1.8_4.5Km						
Parameters	Variable	Mean	Median	Minimum	Maximum	Coef of Variation (%)
Water	EC (dS/m)	4.82	4.79	1.13	7.63	42.72
	pH	7.36	7.30	6.89	7.89	3.65
	SAR	10.16	8.75	3.05	26.98	53.10
Soil	pH	7.57	7.52	6.66	8.14	4.74
	EC (dS/m)	2.66	1.75	0.80	12.26	86.71
Distance from the sea 4.5_11Km						
Parameters	Variable	Mean	Median	Minimum	Maximum	Coef of Variation (%)
Water	EC (dS/m)	2.31	1.60	1.00	5.00	59.76
	pH	7.42	7.44	7.12	7.87	3.37
	SAR	9.46	7.90	2.22	20.52	51.85
Soil	pH	7.52	7.36	7.05	8.26	4.65
	EC (dS/m)	2.33	2.00	0.70	5.36	58.25

Irrigation water analyses

pH

The pH is an important indication of water quality, since it provides important information on geochemical balance and it is used to calculate the solubility of micronutrients (Hem, 1985). It depends on the origin of water, the geological nature of substrate and the crossed watershed (Dussart, 1966; Bermond et al., 1973).In the presented case, the pH in the proximate portion of the sea ranged from 6.3 (neutral) to 8.51 (slightly basic) with an average 7.24 ± 0.5 (weakly basic), while the pH of the intermediate and the farthest parts, oscillates values between 6.89 and 7.83 (neutral) and between 7.12 and 7.87 (slightly basic) with average of 7.34 ± 0.25 and 7.42 ± 0.25 (weakly basic), respectively (Table 1). When Wang (2013) evaluated the quality of 60 groundwater samples used for irrigation in China, he discovered an alkaline pH of 8.2 (with values ranging from 7.5 to 8.8).

These results are slightly similar to the soil pH. According to Peterson (1999), the pH of the water used for crop irrigation should be between 6 and 7, because at these values the solubility of most micronutrients is optimal. Thus, the majority of analyzed wells are valid for irrigation (pH side only), while other wells require a pH correction. The high pH values found are probably due to high concentrations of Na^+ and Cl^-.

Electrical conductivity

If the EC is higher than 3 dS/m, crop yield suffers greatly, whereas EC less than 0.25 dS/m is ideal. (Westcott and Ayers, 1984). Coastal Chaouia waters showed significant variations in mineralization (Rafik et al., 2016). The electrical conductivity is very high in the vicinity of the sea in the first two zones and the oscillates were between 1.34 and 9.76 dS/m and between 1.13 and 7.63 dS/m with average values of 6.83 ± 2.29 and 4.82 ± 2.06 dS/m, respectively. EC decreased notably in the region far from the sea with a maximum of 5 dS/m, a minimum of 1 dS/m, and an average of 2.31 ± 1.38 dS/m (Table 1). This high concentration of EC in the water is may be due to the appeal of salt water intrusion due to the proliferation of pumping and the decrease of supplied water (Zerouali et al., 2001; Najib et al., 2016).

The median water EC is decreasing when we move from the coast to the inland. In addition, there are four extremely low values near to the sea at the wells 43 and 51 (1.34 and 1.60 dS/m). In contrast, for the farthest zone from the sea, there are two extremely high values for the wells

9 and 30 (4.23 and 4.83 dS/m, respectively). When comparing the presented case study to the 50 groundwater samples from Jordan, Al-Tabbal and Al-Zboon (2012) discovered a less variable EC (values ranging from 0.5 to 7.1 dS/m) and a less salty groundwater (average EC value of 0.96 dS/m).

Abnormally high levels of electrical conductivity are located particularly west to Bir Jdid. They would be related to the shallow depth of the water (Bentayeb, 1972) which promotes high evaporation and thus the salt concentration, in addition to the recycling of water by irrigation which is increasing it more and more. Aquifers salinization in coastal fringe was mainly due to cation exchange because of seawater intrusion, which remains limited to the coastal area at 2 km from the ocean (Najib et al., 2016).

Sodium adsorption ratio

The sodium adsorption ratio is used to determine the alkalinity of irrigation water (SAR). Because of the exchange that will take place in the equilibrium between Na+ from the soil solution and Ca2+/Mg2+ from the absorbent complex, there is a larger risk of water sodicity if SAR is high. Water with a higher salt level has lower permeability, which means less water is accessible to the plant. Sodium replacing adsorbed calcium and magnesium is dangerous, because it damages the soil structure, making the soil compact and impenetrable (Arveti et al. 2011). The SAR values calculated from the ionic balance are variable. In the zone which is near the sea, the SAR ranged between 1.18 and 20.59% with an average of 10.34 ± 5.83 and a coefficient of variation of 56.44%. In the intermediary zone, it ranged between 1.19 and 26.98 with an average of 10.16 ± 5.39 and a coefficient of variation of 53.30%. Finally, in the zone far from the sea (a distance between 4.5 and 11 km) the SAR ranged between 2.22 and 20.52 with an average of 9.48 ± 4.34 and a coefficient of variation of 51.85% (Table 1).

Richards diagram

When the Na^{+} ions are very abundant in the waters, they can replace the Ca^{2+} ions in the absorbing complex (base of exchange). The combination of electrical conductivity and SAR (Sodium Absorption Ratio) allows discerning this risk: the risk is greater when electrical conductivity and SAR are high.

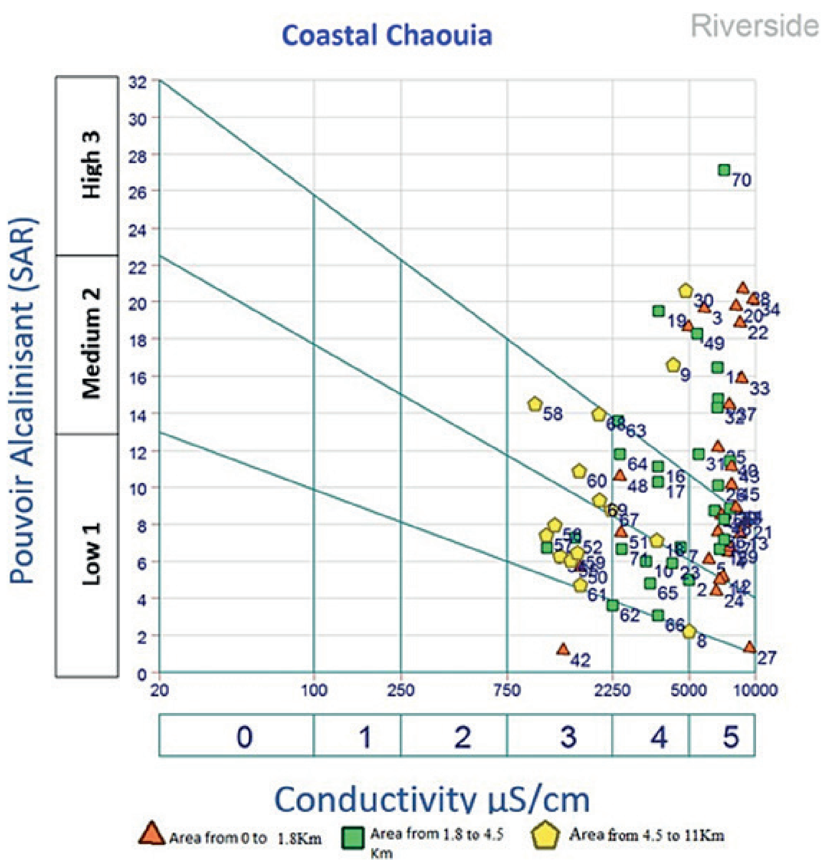

Figure 4. Richards diagram for classification of groundwater quality in the study area

The electrical conductivity and the SAR results of the 71 samples have been plotted in the US salinity diagram (Richards, 1954). Different water samples are given in Figure 4:

- Near the sea and in the intermediate zone: the majority of wells fall in the C5-S3 class. This class, according to Richards (1954), indicates that the water is poor in terms of quality with very strongly mineralized sodium. Water is generally unsuitable for irrigation, unless salinity is low or medium or by adding soluble Ca^{2+} to make it usable. The well 42 is the only exception and belongs to the C3-S1 class, indicating the poor water used only for salt toler ant plants on well-drained and good permeable soil with a salinity that must be controlled.
- Far from the sea: most of the wells belong to the C3-S2 group, indicating that the waters are moderately sodic, presenting a danger of significant alkalizing in fine-textured soils and high exchange capacity, especially in low leaching conditions unless the soil contains gypsum. This water is used in coarse textured soils or very permeable organic soils. The presence of some wells that belong to the C3- S3 class, indicating very strongly sodic waters, was also noted.

Wilcox diagram

The quality of well water was also assessed using the Wilcox diagram, which involves the electrical conductivity and the sodium percentages (Fig. 5):

- the majority of the wells for the two zones (near and intermediate) (46/56=82.14%) belong to the unsuitable class except the wells 42, 48, and 51 which fall in the good to permissible class and the doubtful to unsuitable class, respectively. From Richard salinity diagram, it is observed that the best waters are those which are sufficiently low mineral. The waters of poor quality are characterized by high mineralization, with significant risk of salinization.
- For the zone 3, well waters belong to four different classes:
  - 9/15 = 60% of the wells belong to the good to permissible class.
  - 1/15 = 6.7% of the wells belong to the permissible to doubtful class.
  - 1/15 = 6.7% of the wells belong to the doubtful to unsuitable class.
  - 4/15 = 26.6% of the wells belong to the unsuitable class.

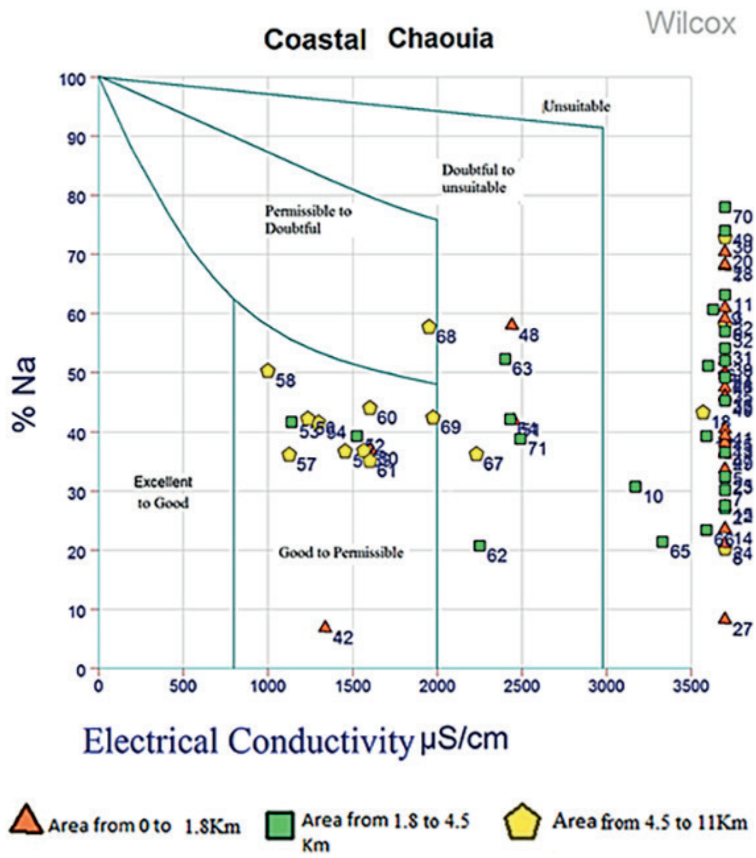

Figure 5. Wilcox diagram for well waters analyses

In addition, based on the percentages of wells for the three zones, it is clear that the importance of good quality water wells increases with moving from the coast to farther from the sea.

Correlation analysis

The correlation coefficient is a commonly used measure to establish the relationship between two variables. A strong correlation between two variables is represented by a high correlation coefficient (near +1 or –1) and a value around zero indicates no relationship between the variables (Jayaprakash et al., 2008). The correlation matrix of water and soil quality (Table 2) shows that near the sea, the highest and only significant coefficient is found between water EC and pH (-0.41). For the intermediate zone, again there are two significant correlation coefficients which are between water pH and SAR (-0.50), and EC and pH (-0.49). Finally, for the farthest zone from the sea, there is only one significant correlation coefficient, the one between SAR and soil pH (0.52).

Analysis of variance (ANOVA) and multiple comparisons of means

The results of the ANOVA (Table 3) showed the existence of significant differences between the three zones regarding pH with value p = 0.0117. No significant differences were found for the remaining parameters.

Since the ANOVA result showed significant differences between the three zones for pH water, the Duncan pot hoc test was used to identify homogeneous zones (Table 4). For this parameter it was noted that in the three zones (the nearest, intermediate and the farthest zones) there is no significant difference between themes.

Table 2. Pearson correlation coefficients for the three zones

The distance (sea = 0.0–1.8 km)					
Variable	EC_w	pH_w	SAR_w	pH_s	EC_s
EC_w	1.00				
pH_w	-0.41	1.00			
SAR_w	0.17	-0.03	1.00		
pH_s	0.17	0.24	-0.16	1.00	
EC_s	-0.10	0.10	-0.21	-0.10	1.00
The distance (sea = 1.8–4.5 km)					
	EC_w	pH_w	SAR_w	pH_s	EC_s
EC_w	1.00				
pH_w	-0.49	1.00			
SAR_w	0.33	-0.50	1.00		
pH_s	0.36	0.08	-0.08	1.00	
EC_s	0.09	-0.04	-0.05	0.02	1.00
The distance (sea = 4.5–11 km)					
	EC_w	pH_w	SAR_w	pH_s	EC_s
EC_w	1.00				
pH_w	-0.27	1.00			
SAR_w	0.27	0.34	1.00		
pH_s	0.44	0.15	0.52	1.00	
EC_s	0.05	-0.21	-0.06	-0.07	1.00

Table 3. Results comparing the mean values for the three zones using ANOVA

Dependent variable	Sum of squares	Mean squares	F value	Signification Pr>F
EC_w	106.7	53.35	1.62	0.2062
pH_w	0.55	0.27	4.75	0.0117*
SAR	1076.1	583.0	0.29	0.7497
pH_s	0.007	0.003	0.12	0.8915
EC_s	208.0	104.0	0.64	0.5287

Note: * Significant difference between the three zones at the level of 0.05.

Table 4. Duncan's multiple range test for pH_w

Parameter	Mean	Distance from the sea
pH_w	a 7.24	00_1.8 km
	a 7.36	1.8_4.5 km
	a 7.42	4.5_11 km

CONCLUSIONS

The Coastal Chaouia region is an area where agriculture is considered as the main activity of the population. Certainly, the development of this activity is limited by the arid climate, the proximity to the sea and the acceleration of salt water intrusion, the degradation of the quality of irrigation water and the deterioration of agricultural soils. The considered area of Chaouia is an example a region suffering from these phenomena. The components of this climate are on the one hand the factors limiting crop development in the absence of proper irrigation and other parts promote the accumulation of salts in the soil. In the considered study area, the existence of the damage possible caused by water irrigation quality was proven. The electrical conductivity of irrigation water varies with the distance to the sea. This explains the strong mineralization of soil and water that are near the sea due to salt water intrusion and marine spray which exceed the limit at 1.8 km. Low values of soil EC are probably due to the sandy soil texture which promotes the leaching phenomenon of salts.

According to Richards diagram class irrigation water which used index of the SAR and of the electrical conductivity, the water was placed in the C5-S3, C3-S2, and C3-S3 classes. The waters close to the sea are highly sodic, of poor quality and highly mineralized. They are generally not suitable for irrigation, unless salinity is low or medium or the addition of soluble Ca^{2+} can make them usable.

The quality of well water was also assessed using the Wilcox diagram, which involves the electrical conductivity and the percentage of Na^{+}, indicating that the majority of waters near the sea are of poor quality. This result confirms that of Richards diagram.

This study allowed appreciating the effect of mineralization of irrigation water on soil in the coastal Chaouia. The main origins which could be the cause of this water mineralization are: the infiltration of irrigation water loaded with salts and fertilizers in irrigated areas of coastal Chaouia, the marine influence along the coastal part (salt wedge, aerosols and sea spray), and the geological nature of the aquifer rocks through which these waters come to the surface.

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