ASSESSMENT OF THE GROUNDWATER SALINITY USED FOR IRRIGATION AND RISKS OF SOIL DEGRADATION: EXAMPLE OF OUED EL MALEH, REGION OF MOHAMMEDIA (MOROCCO)

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Abstract

Morocco has an arid and semiarid climate. Irrigation is imperative for agriculture. Oued El Maleh region is considered as a very important agricultural area, known nationally for its high potential for market gardening. This intensification has been accompanied by an excessive use of agrochemicals, and a poor control of irrigation and drainage. Consequently, salinization phenomena and deterioration of soil structure as well as water quality are about to create an alarming situation. Therefore, the objective of this research work was to assess the quality of irrigation water and the risk of soil degradation. The study site is located in a coastal area and dedicated to intensive land use for growing vegetables in a peri-urban agricultural zone. A field survey was conducted to assess soil and water quality in the region focusing on physicochemical parameters and analyzing their spatial dependency on a regional scale. Monitoring physicochemical parameters of water and soil were carried out in 78 wells and 78 soil sample in order to assess the state of salinity of water and soil in the region. The obtained results from sample wells show relatively higher values of nitrate and electrical conductivity exceeding Moroccan national standards, revealing that the water quality of the Oued El Maleh is deteriorating with an alarming rate. Therefore, this water is considered not suitable for human consumption and can induce a degradation of soil. The results of the studied soil show that pH of these soils is weakly to moderately basic; they are usually non-saline with moderately organic matter content. Moreover, very high concentrations of nutrients (potassium, phosphorus and nitrogen) were recorded, highlighting the mismanagement of fertilization of vegetable crops in the region of Oued El Maleh.

1 Introduction

Around the world, pressure on water resources, particularly on groundwater resources, is on the rise, mainly due to growing demand and degradation of water quality [1]. Groundwater quality depends on many factors, which include geology, source water quality, land use type, etc. [2-7]. In the arid and semi-arid regions of Morocco, groundwater is the main limiting factor for the extension and intensification of agriculture. The development of agriculture in these regions depends on irrigation resources, which then becomes a requirement to produce enough to meet the food needs of an increasingly large population. This agricultural intensification was accompanied by the misuse of agrochemicals and a poor control of irrigation and drainage. The irrigation with water rich in salts can involve retention the sodium on adsorbing components of the soil, leading to a process of salinization with its possible consequences for soil properties, which include the tendency to dispersion of clays, degradation of the structure, loss of permeability, and asphyxiation of the plants. The intensity of the salinization process depends on the characteristics of soil, the quality of water used, and the conditions of their usage, in particular, the efficiency of the system of drainage. However, these practices of irrigation generated the modification of the functioning of the soils and increased the risk of salinization [8]. The Oued El Maleh region of the Mohammedia city, is characterized by intensive farming, and is no exception to the previously stated issue because of the misuse of agrochemicals and the careless pumping of groundwater since the few small rivers (Oued El Maleh, Oued Haçar, and Oued Nfifikh) are impacted by sewage discharges [9, 10]. Indeed, groundwater (Berrechid and coastal Chaouia) are already overexploited and of poor quality [11]. Similar studies have been carried out in other regions of Morocco, namely Skhirat [7], Gharb [12, 13], Tadla [14], etc. In view of this situation, the protection and rational management of existing water resources as well as the search for unconventional water resources have become a strategic necessity for the sustainable development of the region. In this context, a study of the physicochemical quality of irrigation water is highly necessary to assess the degree of degradation of these resources.

Therefore, the objective of this research work was to assess the quality of irrigation water and the risk of soil degradation.

2 Materials and Methods

2.1 Description of the study Oued El Maleh area

The region of Oued El Maleh is located at 65 km south of Rabat and 20 km north of Casablanca. It covers a total area of approximately 310 km^2 and is part of the large Sahel area of Mohammedia - Ben Slimane, which corresponds to a plateau inclined towards the sea crossed by the two long and wide valleys of the Oued El Maleh and Nfifikh (Figure 1). This zone belongs to the western part of the coastal Meseta, characterized by a sub-tabular geological structure with secondary, tertiary and quaternary formations (continental silts) following a pleated primary base. These discordant formations, which constitute a permeable cover, correspond to Quartzitic deposits of the Cambro-Ordovician, pelitico-basaltic Permo-Trias, Cretaceous marl-limestones, and Quaternary limestones [15]. The paleozoic base, impermeable, folded and tectonized, is schistose in nature of the Cambrian age [16]. The climate of the Oued El Maleh region is of the dry sub-humid

Mediterranean type, which typically characterizes the Moroccan Atlantic coastal area [17]. However, the continental phenomenon influences this climate and places it in the semi-arid bioclimatic stage with annual rainfall of up to 400 mm, but which undergoes a spatial disparity with annual and inter-annual variations, while temperatures vary between a minimum of 13 °C and a maximum of 23 °C with an average of 22 °C. Soils in the region consist mainly of Hamri (well-drained clay soil or vertisol), shots (vertisol), Rmel (sandy soil), and dendun (calcimorphous soil) [16].

2.2 Analytical methods

After delimiting the two study areas on a 1/50,000 scale topographic map and field visit, water sampling points were located (Figure 1). Sampling campaign covered the entire two perimeters. A total of 78 samples were taken from Oued El Maleh for physicochemical analyses during the period from April to October 2014. These samples were collected in hermetically sealed plastic bottles, coded and stored in a cooler until storage in the laboratory. Some parameters were measured in-situ such as pH using a portable pH meter, temperature, electrical conductivity (EC) with a portable conductivity meter, and water levels were measured using a piezometric probe. Finally, the coordinates (X, Y, Z) of each site were recorded using a GPS. The physicochemical analysis (temperature, pH, EC, K^+, Na^+, Ca^{2+}, Mg^{2+}, NH_4^+, NO_3^-, Cl^-, CO_3^{2-}, HCO_3^-, and SO_4^{2-}) were carried out in the laboratories of 'Research Unit on Environment and Conservation of Natural Resources, Regional Center of Rabat, National Institute of Agricultural Research (INRA). A Mettler Toledo Seven Easy-728 Metrohm pH meter, and an ORION type 162 conductivity meter were used. Sodium (Na^+) and potassium (K^+) were determined using a flame photometer model CL 378. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions are complexed with ethylenediamine tetraacetic acid (EDTA 0.02 N) in the presence of colored indicators (black calconanderiochrome T) [18]. Carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-) were determined by acid-base titration with HCl 0.05 N in the presence of the colored indicators phenolphthalein and methyl orange [19]. Ammonium (NH_4^+) and nitrate (NO_3^-) were determined by the conventional distillation "Kjeldahl method" of Büchi unit B-323. This method is based on the recovery of distillate in boric acid solution and titration with hydrochloric acid (HCl 0.02 N) after the addition of 1 to 2 g of calcined MgO for the determination of ammonium, and the addition of 0.5 to 1 g of Devarda alloy for the determination of nitrate [20]. Chloride (Cl^-) was determined by Mohr's method in a neutral medium by a standard solution of silver nitrate (0.02 N) in the presence of potassium chromate (10%). Sulfate (SO_4^{2-}) was measured by the nephelometric method. Its principle consists of precipitating SO_4^{2-} ions in a hydrochloric medium in form of barium sulfate. The precipitate obtained is stabilized with a solution of "TWEEN20"; the homogeneous suspension is measured with a UV-vis spectro-photometer at a wavelength of 650 nm [19].

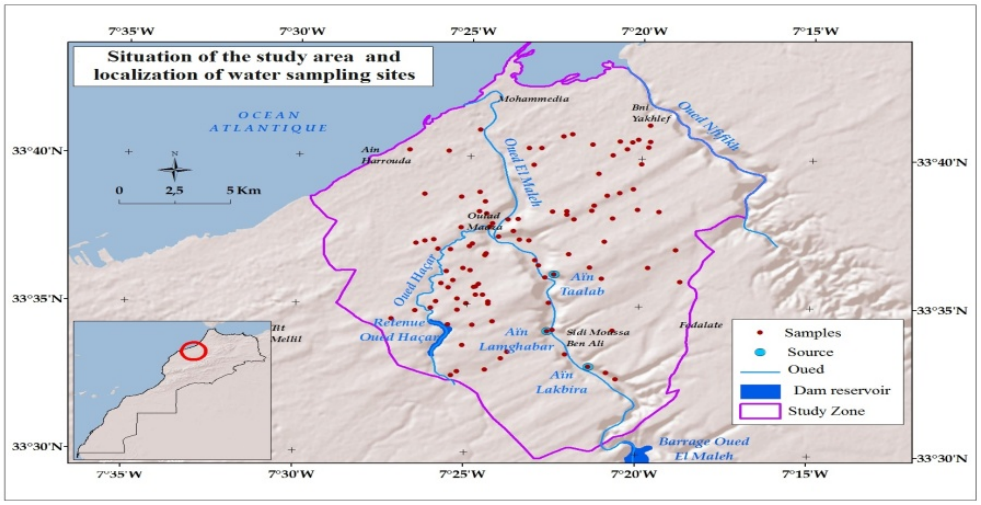

Figure 1: Location of the study sites of Oued El Maleh

3 Results and Discussion

3.1 Evaluation of the water quality

Physicochemical analyses of groundwater in the Oued El Maleh region for the period of observation are presented in Table 1. Parameters used usually for the estimation the quality of irrigation water included salinity, expressed by the electrical conductivity (EC), residual sodium carbonate (RSC), percentage of sodium (%Na), Sodium Absorption Ratio (SAR), and concentration of chloride.

Table 1: Descriptive statistics for calculated water quality parameters

	EC	SAR	RSC	Cl	%Na
Unit	dS/m	$meq^{1/2}/L^{1/2}$	meq/L	mg/L	%
Min	0.83	1.1	-51.60	131	12.80
Max	9.74	21.63	1.85	3,301	79.56
Mean	3.88	8.13	-14.76	999	52.22

The maximum values of EC are about 9.74 dS/m, which corresponds to a very strong salinity. The average value of conductivity is about 3.88 dS/m indicating that the groundwater of the zone is of bad quality. Nevertheless, some sampling points are of acceptable to medium quality (EC lower than 0.9 dS/m). The SAR values for groundwater calculated from ion balances varied, ranging from 1.1 to 21.63 $meq^{1/2}/L^{1/2}$, with an average of 8.13 $meq^{1/2}/L^{1/2}$. The wells analyzed were found to be in the excellent category and, therefore, have low alkalizing power. On the basis of RSC values, the irrigation water is of good quality, and does not present any risk of sodicity. For chloride, the very high concentration is clear, since all wells are considerably higher than 70 mg/L; these waters present a significant risk to chloride ions, particularly the sensitive crops. Percentage of Na ranges

from 12.80% to 79.56%, with a mean value of 52.22%, indicating that no well belongs to the excellent class.

3.2 Chemical facies of waters obtained using the Piper diagram

According to the Piper trilinear diagram (Figure 2), five types of groundwater can be distinguished: sodium chloride for most of the wells (90%), sulfate calcium (4%), sulfate sodium (4%), bicarbonate sodium (1%), and bicarbonate magnesium (1%). In the Oued El Maleh region, waters are characterized by a predominance of chloride ions over sulfate and bicarbonate. Sodium is the most dominant cation, followed by calcium, which highlights the salinity of these waters dominated by sodium chloride.

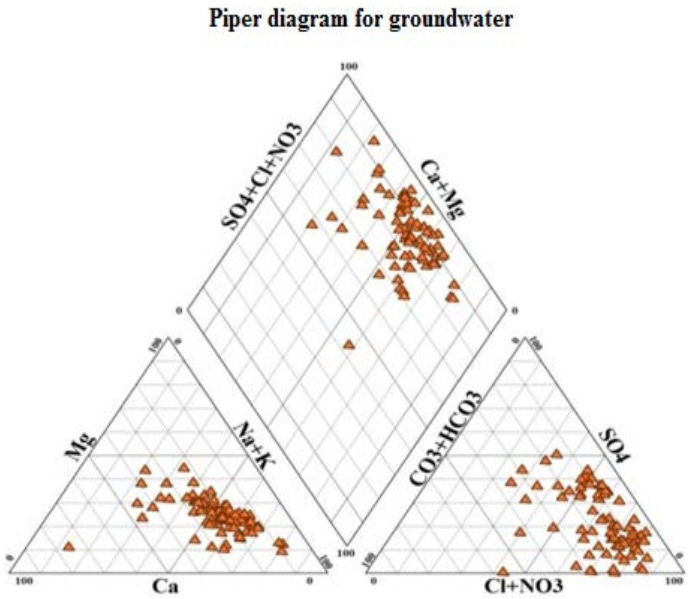

Figure 2: Piper diagram for irrigation water of Oued El Maleh.

3. 3 Status of water quality for agricultural use

To maintain adequate infiltration conditions in irrigated soils, care should be taken to prevent soil exchange complexes from becoming loaded with Na^+. The sodium adsorption coefficient (SAR) with SAR = $Na^+/[(Ca^{2+}+Mg^{2+})/2]^{1/2}$, where Na^+, Ca^{2+} and Mg^{2+} are given in meq/L, is expressed as the danger of sodicity of an irrigation water. The alkalinity of the irrigation water is evaluated using the SAR. The greater the SAR, the more water presents a risk of soil sodicity due to the ion exchange, which will occur at the equilibrium between Na^+ of the soil solution and Ca^{2+}/Mg^{2+} of the absorbent complex [21]. SAR values for groundwater of the Oued EL Maleh, calculated from ion balances, varied, ranging from 1.10 to 16.03, with an average of 7.70 $meq^{1/2}/L^{1/2}$. According to the standards [22], the SAR distribution showed that 78% of groundwater of Oued El Maleh was excellent, because none of the samples exceeded 10 $meq^{1/2}/L^{1/2}$. The remaining 22% of wells have

an SAR between 10 and 20 $meq^{1/2}/L^{1/2}$, and have, therefore, low alkalizing power. Soils irrigated by these waters must be regularly monitored for possible soil alkalinity problems.

The use of the American classification chart, proposed by [24] makes it possible to assign to each water a quality grade in terms of the risk of salinization and alkalinization, in case it is used for irrigation.

Plotting all water points on the diagram (Figure 3, Table 2) according to the electrical conductivities and the SAR values shows the distribution of classes of salinity and alkalinity of water. It is noted that most of water samples fall in the category of C4–S3, C4–S2, and C5–S3, indicating that the irrigation water of Oued El Maleh presents a high danger of salinization and a low to medium risk of alkalinization.

Table 2**:** Repartition of classes of salinity and alkalinity of irrigation water

Class of salinity (C) and alkalinity (S)	Percents of wells
C3-S1	10
C3-S2	5
C4-S2	26
C5-S2	3
C4-S3	27
C5-S3	13
C3-S4	1
C4-S4	10
C5-S4	5

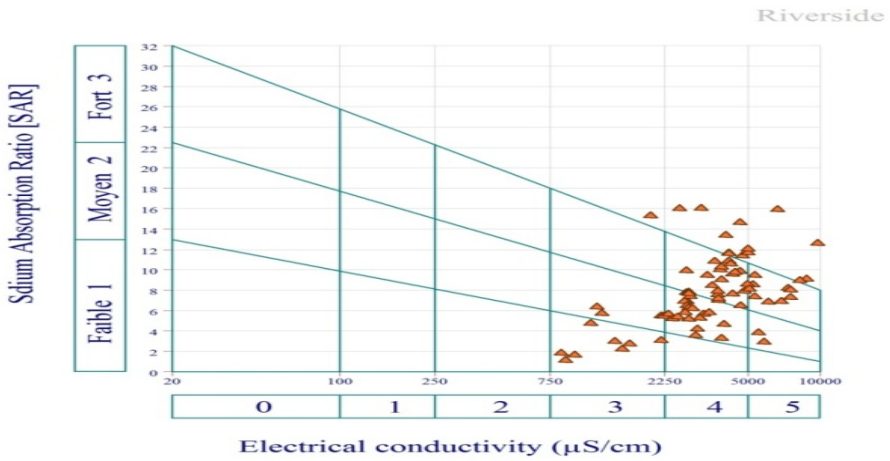

Figure 3: Diagram for determination of the quality of irrigation water

3.4 Residual Sodium Carbonate (RSC)

RSC values were calculated to determine the hazardous effect of carbonate (CO_3^{2-}) and bicarbonate (HCO^-_3) on the water quality for agricultural purpose [23; 24]. The RSC varied, in the range from -51.60 to 1.85 with an average value of about (-14.76) (Table 1).The classification of irrigation water according to the RSC values indicates that, 99 % of wells have good water whereas only 1% of the wells have doubtful water and no well has unsuitable water(Table 4). Thus, the irrigation water does not present any risk of sodicity.

Table 4: Groundwater quality based on RSC [24]

RSC	Water class	Percent of wells
< 1.25	Good	99
1.25–2.50	Doubtful	1
> 2.50	Unsuitable	0

3.5 Risk related to chloride

Chloride is a common ion in irrigation waters. Although chloride is essential to plants in very low amounts, it can cause negative impacts to sensitive crops at high concentrations. According to [25], a problem can occur when the concentration of chloride ions in irrigation water exceeds 70 mg/L, especially for sensitive crops. The results obtained showed that 100% of wells exceeded 70 mg/L, of which 86% exceeds 350 mg/L. Only 3% of the wells have a concentration between 70 and 140 mg/L (Figure 4). The chloride concentration in well waters varies widely, ranging from 131 to 3,301 mg/L, with an average of 999 mg/L (Table 1). These waters present a significant concentration of chloride ions, which can affect sensitive crops.

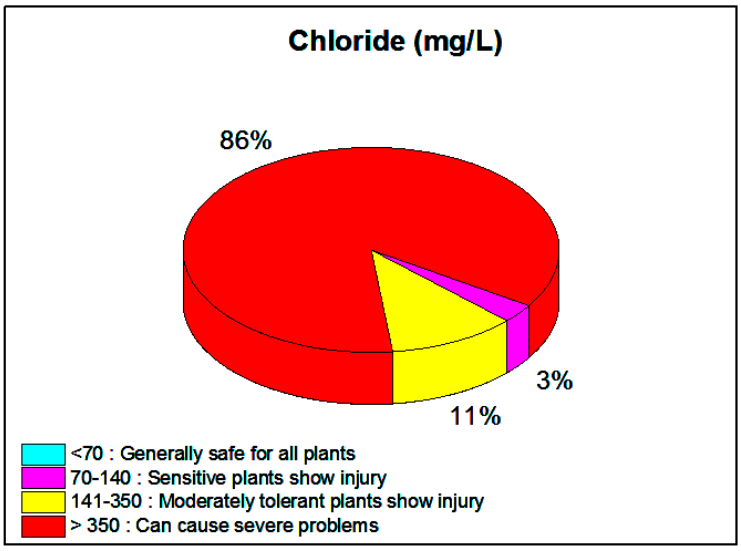

Figure 4: Chloride ion content in irrigation water of Oued El Maleh

3.6 Percentage of sodium (%Na)

At higher concentration of sodium in irrigation water, its ion form (Na^+) tends to be absorbed by clay particles and replaces Ca^{2+} and Mg^{2+} ions that are released into water. This ion exchange reduces the soil permeability and eventually results in poorly drained soil.

On the basis of Wilcox classification of groundwater for irrigation purposes by correlating percent sodium and electrical conductivity, variation of EC versus %N shows that 6 of 78 samples (7.69%) belong to good to permissible, 3 samples (3.85%) to permissible doubtful, 20 samples (25.64%) to doubtful unsuitable, and 49 samples (62.82%) to unsuitable category of water (Figure 5) [26, 27].

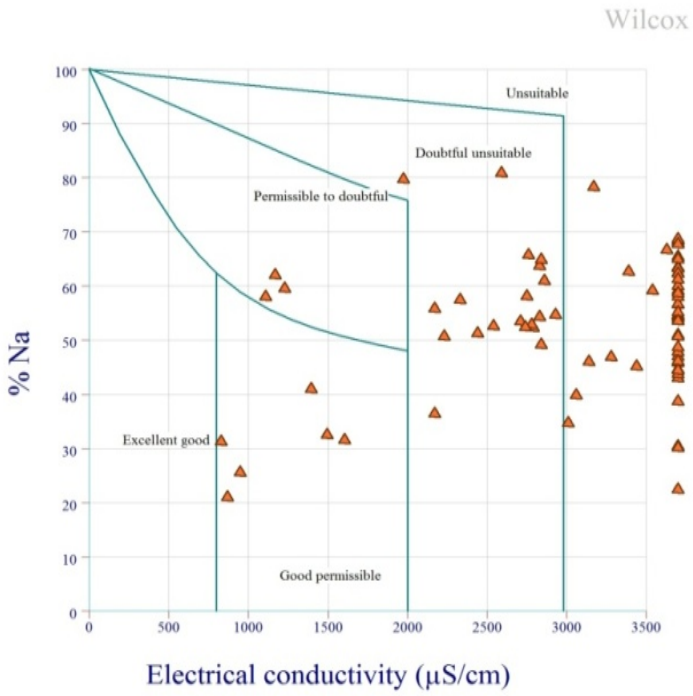

Figure 5: Percent sodium vs EC plot [27]

4 Conclusions

In this work, it was tried to estimate the quality of groundwater used in irrigation in the region of Oued El Maleh during the period 2014-2015. The evaluation of the quality of these waters through determination of various physicochemical parameters revealed that these waters are of a very high and non-suitable salinity for irrigation. Nevertheless, these waters are used in irrigation without any measures of mitigation to avoid problems of soil degradation. According to SAR, which remains in average lower than 10 meq/L, these resources present a low danger of alkalinization. The classification of the results of the chemical analysis obtained from the triangular diagram to load allows identifying five groups for underground waters of Oued El Maleh, the sodic chlorinated

facies of which stays the most dominant (90%). The US Salinity Laboratory (USSL) diagram reveals that the dominating water quality classes are C4-S3, C4-S2, and C5-S3. It follows that irrigation water of Oued El Maleh has a high to very high risk of salinization and a medium to high risk of alkalinization. From this classification, it is clear that the groundwater is unfit for irrigation. From Wilcox plot, it is observed that most of the samples from the study area fall in the permissible to doubtful classes for irrigation purposes. The determination of the residual alkalinity showed that there is no impact in terms of sodicity for waters analyzed on grounds.

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