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Assessment of Groundwater Quality for Irrigation Purposes in Sidi Slimane, Morocco Using the Irrigation Water Quality Index

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ABSTRACT

Groundwater pollution is a major problem in most countries, including Morocco. This study was aimed at evaluating the suitability of groundwater for irrigation in Sidi Slimane, Morocco, using the irrigation water quality index (IWQI). Water samples were collected from 20 wells in 2018. Electrical conductivity (EC), sodium adsorption rate (SAR), sodium ions (Na^+), chloride ions (Cl^-), and bicarbonate ions (HCO^{3-}) were measured, and the parameter values were used to compute and plot the irrigation water quality index (IWQI). The results showed that the average values for EC and SAR of the groundwater samples were 4915±3772 µS/cm and 11.22 ±5.36, respectively. Water toxicity was calculated in terms of sodium ion concentration (Na^+), yielding a mean value of 32.09±22.03 meq/L. Furthermore, the average chloride and bicarbonate ion concentrations in the study area were 31.31±22.86 meq/L and 7.568±2.599 meq/L, respectively. The IWQI map revealed that more than 65% of the water samples were in the excellent category, which is dominant in the large areas in the west; 35% of the water samples were in the good category in the center of the study area, and 5% of the water samples were in the poor category in the east of the study area. The findings of this study should be taken into account for the management of groundwater for irrigation in the Sidi Slimane region of Morocco.

Keywords: GIS, Individual hazard group, Irrigation water quality index, Water sample.

Introduction

Groundwater quality is an important factor at the present time, as it directly affects the health of humans and other living organisms.[1,2] Understanding the quality of groundwater is as important as understanding its quantity because it is the primary factor determining its suitability for drinking, domestic, agricultural, and industrial purposes. Groundwater quality is affected by a variety of factors, including the degree of weathering of various rocks, the regional climate, and the impact of human pollution sources (urban, agricultural, and industrial activities).[3,4] Water is used for a variety of purposes in our daily lives, the most important of which is irrigation, as the suitability of water for irrigation is determined by the water properties (risks of salinity and alkalinity), the physical and chemical properties of the soil, and the tolerance of saline and alkaline crops.[5] Electrical conductivity and sodium are important factors in determining the suitability of water for irrigation, as the high salinity of irrigation water causes salinization of agricultural soil. As a result of the high salinity in the plant's environment, the plant finds it difficult to absorb water and nutrients from the soil. Due to increased osmotic pressure, it may also transfer water from the plant to the soil.[6] However, the electrical conductivity reflects the number of dissolved salts in groundwater and is always expressed in terms of a standard temperature of 25°C to allow for the comparison of electrical conductivity in different climatic conditions.[7] Meanwhile, the risk of alkalinity is the adsorption of sodium by clay particles, this leads to deterioration of soil structure and thus decreases soil permeability, making it unsuitable for plant growth.[8,9] The salinity problem, on the other hand, can be divided into four categories: salinity risk, infiltration and permeability issues, specific ion toxicity, and miscellaneous issues.[10] This study was conducted to assess groundwater quality for irrigation in Sidi Slimane, Morocco using the irrigation water quality index (IWQI).

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Materials and Methods

Study area

Sidi Slimane is located in Morocco's Rabat-Salé-Kénitra locale, covering an area of 1,492 square kilometers (Figure 1) and is located between the scopes of 34°13′N and 5°42′W. The city is a very important agricultural center in the western plain of Morocco, where it produces and exports all the different grains and vegetables.[11–14] The temperature during 2020 is below an annual average of 26°C in which the highest and the lowest temperatures are 30 and 13°C, respectively and the precipitation is between 1 and 97 mm per year.[15]

Sample collection

In this study, 20 wells of water sources in the province of Sidi Slimane were chosen, and samples were collected in the third month of 2018. The sampling locations for the study are shown in Figure 1. The samples were collected and transported to the laboratory in polythene bottles (1 L), where they were kept at 4°C and analyzed according to the standard methods.[16] In the laboratory, a pH meter (WTW) and a conductometer (Thermo ORION 3 STAR) were used to determine the concentration of hydrogen ions (pH), and chloride and bicarbonate were measured using a titration method.[16] Sodium was measured with photometers and a flame.[17] Finally, ArcGIS 10.3 was used to calculate the numerical spatial distribution of the parameters.

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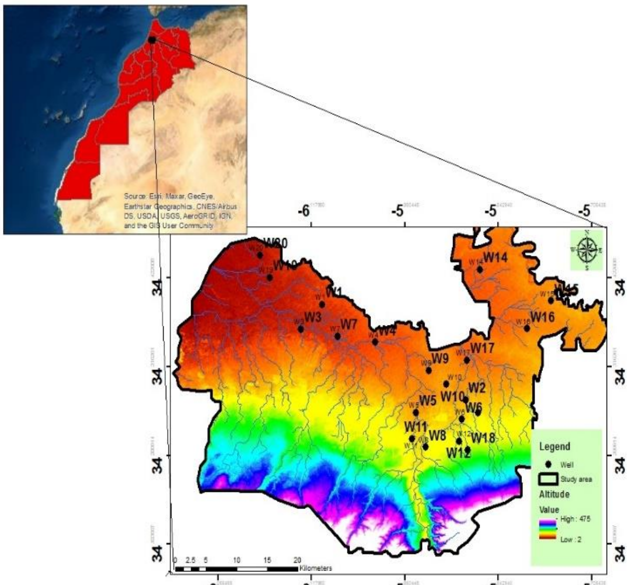

Figure 1: Location of the study area in Sidi Slimane, Morocco.

Irrigation water quality index (IWQI) model

The quality of irrigation water varies from field to field depending on cropping patterns, soil, and climatic conditions.[18–20] In this regard, the calculation of the IWQI is considered a valuable instrument for the spatially distributed valuations of water quality factors by Geographic Information Systems (GIS).[20] As a result, AGIS provides a critical platform for visualizing such maps and making comparative assessments. A critical phase of the quality management procedure is, in addition to individual calculations, collectively evaluating all the parameters mentioned in the previous section. In recent years, the water quality index (WQI) has been widely used to determine the suitability of groundwater for drinking and irrigation.[21]

$$IWQI = \sum W_i Q_i = \sum \left[\left(\frac{w_i}{\sum_{n}^{i=1} w_i} \right) * \left(\mathbf{q_{iamp}} - \left(\frac{(\chi_{ij} - \chi_{inf}) * (\mathbf{q_{iamp}})}{\chi \mathbf{amp}} \right) \right) \right] \ldots\ldots\ldots\ldots 1$$

Where q_{imax} is the maximum value of q_i for the class; χ_{ij} is the observed value for the parameter; χ_{inf} is the corresponding value to the lower limit of the class to which the parameter belongs; q_{iamp} is the class amplitude; χ_{amp} is the class amplitude to which the parameter belongs.

To evaluate χ_{amp}, of the last class of each parameter, the upper limit was considered to be the highest value determined in the physicochemical and chemical analyses of the water samples. Each parameter weight used in the IWQI was obtained according to Meireles *et al*, 2010, as shown in Table 3.[23] The w_i values were normalized such that their sum equated one**.**

Results and Discussion

Sidi Slimane is an agricultural region in Morocco. Most wastewater in the city finds its way directly to the cultural region, due to an insufficient treatment capacity of treatment plants. The contaminants also reach the groundwater aquifers, rendering them unfit for human consumption. As it is shown in Table 4, the results indicated parameters (EC, SAR, Na^+, Cl^-, HCO_3^-, and IWQI) for irrigation.

Assessment of individual hazard groups

Electrical conductivity

Electrical conductivity, which reflects the number of dissolved salts in irrigation water, is a good indicator of the salinity hazards of irrigation water on crops and soil. It is measured in µS/cm or µmhos/cm.[24,25] The electrical conductivity values in samples collected from 20 wells are presented in Table 1. The spatial distribution of EC values in the study area is shown in Figure 2. The EC values ranged from 1540 to 17550 µS/cm, with a mean value of 4915±3772 µS/cm (Table 1) and the value increased to the north, as well as the west-north part of the study area.

Sodium adsorption ratio (SAR)

Sodium adsorption ratio (SAR) is an irrigation water quality parameter used in sodium-affected soil management.[26] It is a water indicator that is suitable for use in agricultural irrigation. The sodium adsorption ratio is a measure of the amount of sodium ions (Na^+) in the water extract from saturated soil relative to calcium ions (Ca^{2+}) and magnesium ions (Mg^{2+}). It is also a standard diagnostic parameter for the sodality hazard of soil, as determined by analysis of pore water extracted from the soil. According to Richards (1954), groundwater is classified into four categories based on SAR, with values below 10 being excellent, 10 to 18 being good, 18 to 26 being also suitable, and values above 26 being unsuitable for irrigation.[27] SAR values for groundwater samples in the study area ranged from 3.73 to 21.82, with an average of 11.22±5.36 (Figure 3). Most of the samples were less than 10 and were deemed excellent for irrigation.

Ion toxicity

The sodium concentration is important for irrigation because it reduces soil permeability by partially filling the void space.[7] The concentration of Na^+ ranged from 8.08 to 85.19 meq/L, with an average of 32.09±22.03 meq/L (Figure 4). The other parameter that defines the specific ion toxicity is chloride concentration. The results (Figure 5) of the chemical analysis of water samples indicate that chloride concentrations in the study area ranged between 7.46 and 82.5 meq/L, with an average of 31.31±22.86 meq/l. Due to geological influences in the study area, the majority of the samples contained high concentrations of sodium and chloride. The concentration of bicarbonate ions is the most important contributor to groundwater alkalinity. The levels of bicarbonate ions (HCO^{3-}) in water samples ranged from 2.38 to 13.10 meq/L, with a mean value of 7.568±2.599 meq/L (Table 1). Bicarbonate concentrations of less than 90 mg/L (1.5 meq/L) are generally regarded as ideal for irrigation.[28] Figure 6 depicts the spatial distributions of bicarbonate concentrations. In general, bicarbonate concentrations of less than (1.5 meq/l) are thought to be ideal for irrigation.

Table 1: Calculation of water sample quality index.[22]

qi	EC (µs/cm)	SAR (meq/L)m	Na(meq/L)	Cl (meq/L)	HCO_3 (meq/L)
85-100	200-750	<3	2-3	<4	1-1.5
60-85	750 -1500	3 - 6	3 - 6	4 - 7	1.5 – 4.5
35 - 60	1500 - 3000	6 - 12	6 - 9	7 - 10	4.5 – 8.5
0 -35	200<	>12	2<	>10	1<
0 -35	>3000		>9		3>8.5

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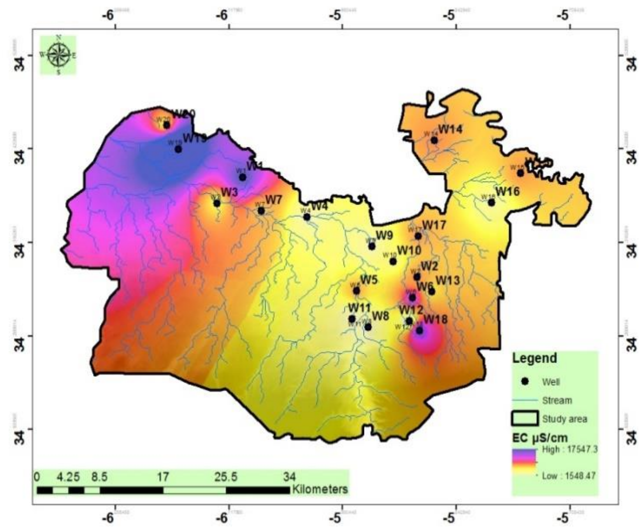

Figure 2: Spatial distribution of electrical conductivity of water samples from the study areas in Sidi Slimane, Morocco.

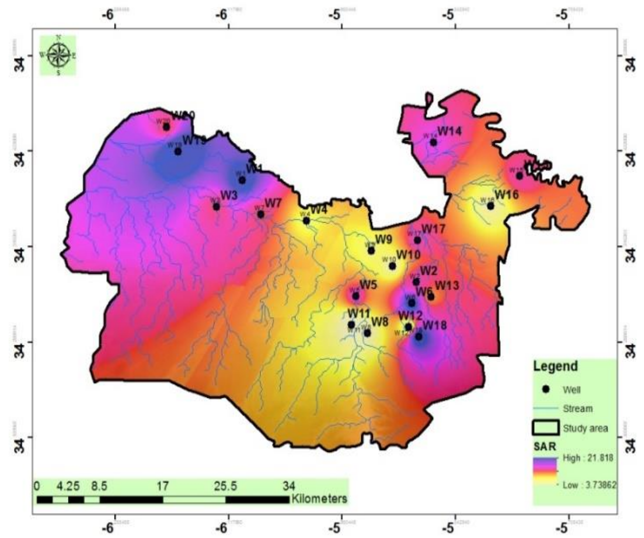

Figure 3: Spatial distribution of sodium adsorption ratio (SAR) of water samples from the study areas in Sidi Slimane, Morocco.

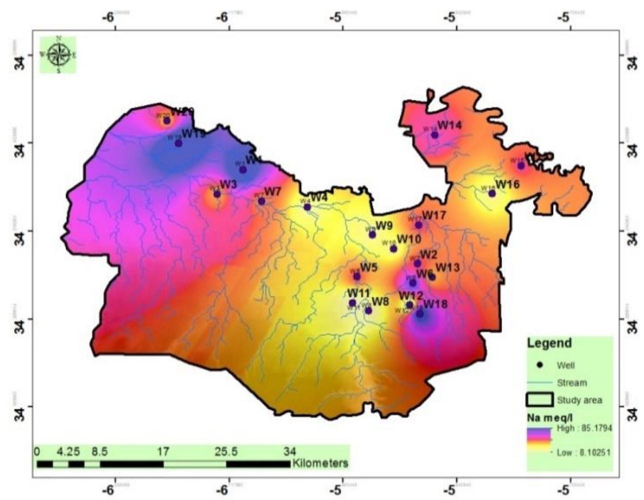

Figure 4: Spatial disbisution of sodium ions (Na^+) of water samples from the study areas in Sidi Slimane, Morocco.

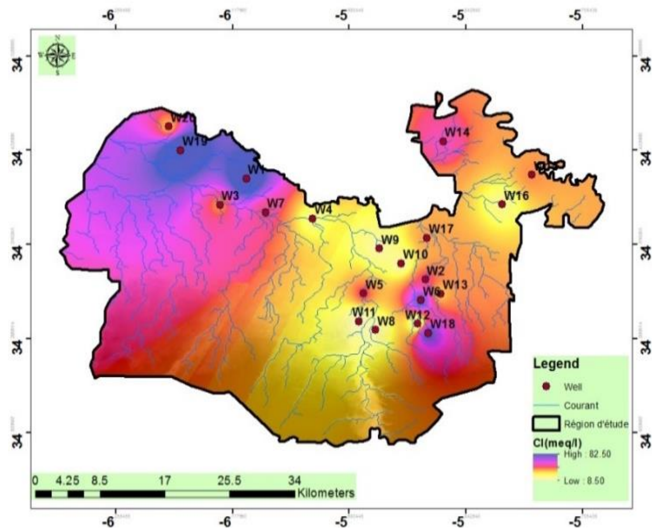

Figure 5: Spatial distribution of chloride ions (Cl^-) of water samples from the study areas in Sidi Slimane, Morocco.

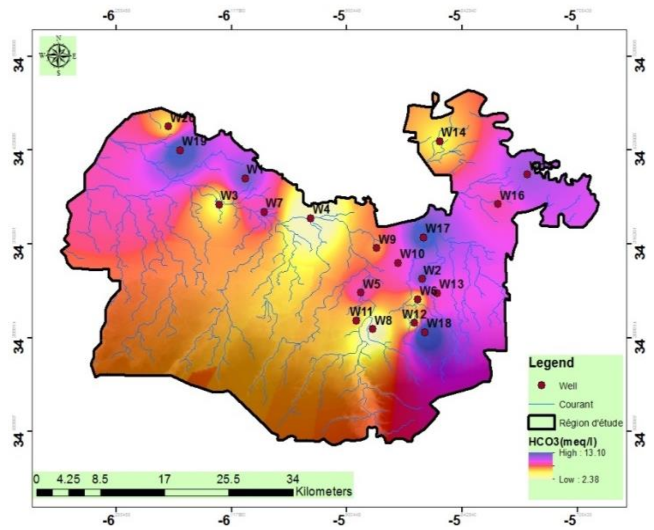

Figure 6: Spatial distribution of bicarbonate ions (HCO_3^-) of water samples from the study areas in Sidi Slimane, Morocco.

The high salinity in the study area, combined with high bicarbonate concentrations, suggests a possible hydraulic connection with relatively mineralized surface (pluvial) water.[10]

Irrigation water quality index (IWQI) analysis

EC, SAR, Na^+, Cl^-, and HCO^{3-} can be used to calculate and plot the irrigation water quality index (IWQI) on a geographical map.[23] The spatial integration for groundwater quality mapping was carried out using the ArcGIS Spatial Analyst extension according to Equation 1.[28] The IWQI is an indicator of the spatial distribution of water quality because it is a general suitability map for providing irrigation water quality in the aquifer. Furthermore, the decision-maker can easily assess the quality of groundwater for irrigation and determine the best locations for drilling wells to extract irrigation water. Figure 7 depicts the spatial distribution of IWQI in the study area, with 65% of the samples classified as excellent water, 30% of the samples classified as good water, and 5% of the samples classified as poor water (Table 1). Furthermore, it was discovered that it ranged from severe restriction (SR) to moderate restriction (MR), according to Meireles and coworkers' classifications and characteristics of general IWQI.[23] Severely restricted water quality could be found in a large area in the west and center of the study area.

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Table 2: Classification of water quality based on the irrigation water quality index (IQWI).[22]

Range	Type of groundwater
<50	Excellent water
50-99.99	Good water
100-199.99	Poor water
200-299.99	Very poor water
>300	Unsuitable for drinking/Irrigation purpose

Table 3: Weights of the IWQI parameters.[23]

Parameter	Weight (W_i)
EC	0.211
SAR	0.189
Na^+	0.204
Cl^-	0.194
HCO_3^-	0.202

IWQI: Irrigation water quality index

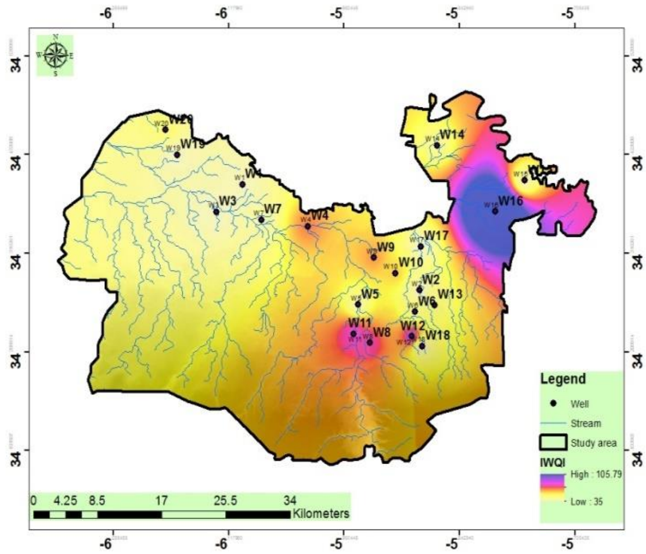

Figure 7: Distribution of irrigation water quality index (IWQI) of water samples from the study areas in Sidi Slimane, Morocco.

Table 4: Statistics of physicochemical characteristics and hydro-geochemistry of water quality and irrigation water quality index (IWQI).

N	EC	SAR	Na^+	Cl^-	HCO_3^-	IWQI
W1	9890	18.96	71.59	74.82	9.70	35.00
W2	4910	12.18	33.49	33.70	9.70	35.00
W3	3720	11.33	27.71	29.72	5.68	35.00
W4	2050	7.68	13.86	16.56	2.38	47.56
W5	4750	12.55	33.49	34.10	7.98	37.16
W6	7130	18.95	55.43	58.88	5.84	38.94
W7	4520	10.99	30.02	32.38	7.94	37.19
W8	1590	5.23	9.24	10.10	3.42	51.15
W9	1880	7.16	12.70	10.48	6.86	46.51
W10	2900	5.19	13.86	10.04	8.00	44.14
W11	1700	3.73	8.08	7.46	6.56	52.84
W12	1540	4.90	9.24	8.50	5.10	53.02
W13	3850	9.87	25.40	23.78	8.20	39.56
W14	5110	13.18	36.95	37.12	6.04	38.77
W15	4900	11.96	33.49	28.98	9.12	36.44
W16	2410	5.72	15.01	14.64	7.84	105.79
W17	4900	12.15	33.49	27.80	10.72	35.00
W18	9020	19.99	66.97	58.44	13.10	35.00
W19	17550	21.82	85.19	82.50	11.10	35.00
W20	3980	10.89	26.56	26.12	6.08	40.77
Min	1540	3.73	8.08	7.46	2.38	35
Max	17550	21.82	85.19	82.5	13.1	105.79
Mean	4915	11.22	32.09	31.31	7.568	43.99

N: Number of Well; EC: Electrical conductivity; SAR: Sodium adsorption rate; Na^+: Sodium ions; Cl^-: Chloride ions; HCO^{3-}: Bicarbonate ions

It covers approximately 65% of the study samples, 30% of the study samples were high restriction (HR), and the remaining study samples had water classified as MR quality levels (Table 5). In addition, the IWQI decreased from west to east due to increased electrical conductivity, SAR, sodium ion, and chloride ion in this direction, as shown in Figures 2-5. According to Table 5, this type of water should only be used with soil that has a high permeability.

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Table 5: Spatial distribution of IWQI in the study area

IWQI	Restriction exploitation	Recommendation Soil	Plant
85-100	No restriction (NR)	This type of water can be used for almost all types of soil.	No toxicity risk for most plants
70-85	Low restriction (LR)	Irrigated soils with slight texture or moderate permeability can be adapted to this range. To avoid soil sodality in heavy textured, soil leaching is recommended.	Elevated risks for salt sensitive plants
50-70	Moderate restriction (MR)	This range can be better used for soils with moderate to high permeability values. Moderate leaching of salts is highly recommended to avoid soil degradation.	Plants with moderate tolerance to salts may be grow
40-50	High restriction (HR)	This range of water can be used in soils with high permeability without compact layers. High frequency irrigation schedule	Suitable for irrigation of plants with moderate to high tolerance to salt with special salinity control practices, except water with low Na,Cl and HCO3 values
0-40	Severe restriction (SR)	Using this range of water for irrigation under normal conditions should be avoided.	Only plants with salt tolerance, except for water with extremely low values of Na,Cl And HCO

IWQI: Irrigation water quality index

Conclusion

The findings of this study reveal that the IWQI values of the study locations showed that 65% of the water samples fell into the excellent category, which is prevalent in large areas of the West. In the center of the study area, 30% of the water samples were in good category, and in the east of the study area, 5% of the water samples were in the poor category. Therefore, this study should be taken into consideration when managing groundwater for irrigation purposes in the Sidi Slimane region of Morocco.

Conflict of Interest

The authors declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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