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ASSESSMENT OF GROUNDWATER QUALITY FOR IRRIGATION PURPOSE USING IRRIGATION WATER QUALITY INDEX (IWQI)

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Highlights:
- groundwater quality assessment by Irrigation Water Quality Index (IWQI);
- spatial and temporal characterization by geographic information system (GIS);
- most of the individual indicators of irrigation water quality were recorded to suit irrigation purposes;
- most of the samples in the study area by (IWQI) were indicted mostly suitable for irrigation purposes.

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Abstract. Groundwater represents an important natural resource for sustaining life. This study was conducted to evaluate groundwater in the Doukkala region in Morocco, using the Irrigation Water Quality Index (IWQI) and uses Inverse Distance Weighting (IDW) in GIS was to show the spatial distribution of water quality parameters. It collected 97 of samples from groundwater and were estimated the sodium concentration (Na%), and sodium absorption rate (SAR), Also, Residual sodium carbonate (RSC), Kelly index (KI), magnesium content (MR), salinity potential (PS), and permeability index (PI). According to the distribution map of the Irrigation Water Quality Index (IWQI) for the study area, about 22.7% of samples fall into the severe restriction (SR) category, which can be used to irrigate plants with high salinity tolerance, 34.02 of samples fall under the high restriction (HR) category, 23.7% of samples fall into the moderate restrictions (MR) category, 17.52% of samples fall under the low restriction (LR) category, and 2.06% of samples fall under the no restriction (NR) category. The results of (IWQI) indicated that the groundwater quality in the study area is mostly suitable for irrigation purposes.

Keywords: Doukkala region, irrigation factors, GIS, IDW, IWQI.

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1. Introduction

Maintaining water quality has become essential because water is the basis of life. In recent years, there has been a significant decline in the quality of the water (Yu et al., 2020; Belhassan, 2021; Bedoui et al., 2022; Gupta & Gupta, 2021). One of the greatest problems the world is currently dealing with is the water issue. Population growth and the rising demand for water resources for a variety of uses, including agricultural, industrial processes, and tourism, are among the most significant factors contributing to the deterioration of water quality (Yang et al., 2019). Morocco's agriculture sector is essential to the region's ongoing economic and social advancement. Moreover, it contributes about 14% to the GDP and provides about 38% of all employment nationwide, with 74% of that in rural regions (Benabdelkader et al., 2021; Boulakhbar et al., 2020). In the last ten years, agriculture in Maroc has achieved extraordinary economic and commercial success (Bounif et al., 2021; Montanari & Bergh, 2019; Onyiriuba et al., 2020). However, Maroc has a lengthy suffered from a incessant deterioration of resources of natural and biodiversity (Water, Soil, Forests, etc.) due to arbitrary and irrational practices by users in agricultural production methods and investments (El Jazouli et al., 2019). With a total irrigated area of around 100,000 hectares, the Doukkala is among the most important agricultural areas in Morocco (Adell et al., 2021; Sabir et al., 2022). Nonetheless, agricultural sustainability largely depends on keeping the soil and natural water resources. Therefore, it is necessary must keep a close eye on how the utilization of agricultural regions is developing. In order to prevent the degradation of these resources, a system of constant monitoring is needed. During the execution of significant expenditures, the ongoing degradation of these resources may hinder the fulfillment of the anticipated output objectives. Water scarcity, pollution, and declining soil quality are major problems in the region. However, Morocco has long suffered from persistent demarcation, necessitating close monitoring of agricultural land use development. To prevent resource degradation, a system of continuous monitoring is required. Despite significant investments, ongoing resource deterioration may hinder the achievement of expected output targets. Water scarcity, pollution, and deteriorating soil quality are major issues in the region (Boughrous et al., 2007; Perrin et al., 2014; Zouahri et al., 2015; El Khodrani et al., 2016; Mohammed et al., 2018; Darwesh et al., 2019).

In Morocco's Doukkala Coast region, population growth has led to over-exploitation of the aquifer to meet industrial, agricultural and domestic requirements. Some previous studies in coastal areas were highlighted by (Adnani et al., 2020; Jamaa et al., 2020, 2023; Mbaki et al., 2017; Mghaiouini et al., 2023; Ouakkas et al., 2022). Their findings reveal that the intensive extraction of groundwater stems from water requisites. Excessive pumping of groundwater and industrial and agricultural consumption lead to environmental degradation and decline in groundwater levels, subsequently causing both quantitative and qualitative degradation of this vital resource. Therefore, regular monitoring and evaluation of irrigation water quality in the Doukkala region is necessary to understand the potential impacts of rapidly declining water levels, geological composition and human activities on soil quality and crop production. Consequently, this study holds significance in understanding water quality and ensuring its preservation using the Irrigation Water Quality Index (IWQI), which offers a qualitative and quantitative assessment of water quality. The study uses Inverse Distance Weighting (IDW) in GIS was to show he spatial distribution of water quality parameters, and IWQI with the aim of comprehensively assessing of groundwater for agricultural in the Doukkala region, Morocco. The study has two main objectives: firstly, to evaluate groundwater quality for agricultural suitability using irrigation water quality index and GIS techniques. Secondly, to assess various agricultural parameters such as residual sodium carbonate (RSC), magnesium content (MR), Kelly index (KI), salinity potential (PS), and permeability index (PI).

2. Materials and research methods

2.1. Region of study

The studied area is the Doukkala region in the north- western part of Morocco, it is located between the governorates of El Jadida and Safi, it is located between latitudes 31°15′ and 33°15′ north and longitudes 7° and 9°15′. It has a total area of 7,700 km^2, of which approximately 150 km are land (Bouasria et al., 2021; Ouakkas et al., 2022). The climate is semi-arid with a minimum temperature of 21 °C in winter and a maximum temperature of 37.3 °C in summer. The average rainfall is 540 mm in 2021. According to climate data, since 2010–2021, the average annual rainfall in Jdeideh station was 370, and the, the average rainfall per month (85.37 mm). The maximum rainfall per month (235 mm) occurred in November 2014 while it was 28 mm in 2021. At the regional level, there is a fluctuation in rainfall in 2021 because it is a year of little rain compared to 2014 (Figure 2). The Doukkala Abda region is situated within the expansive geological unit known as the Moroccan meseta. This geological unit is characterized by the presence of flat layers of secondary and tertiary deposits that overlay primary terrains, which have undergone significant folding due to the Hercynian orogeny.

2.2. Sampling and physicochemical measurement

In the Doukkala region, the 196 samples were taken from the groundwater of 97 wells that were drilled in June during the period of 2018 covering dry periods each sample was triplicate testing (Figure 1). These wells are located in urban and rural areas characterized by activities (agricultural, industrial, etc.), and their depths vary between 20–150 meters. In the field, temperature and pH measurements were taken using a specific type of pH meter (models WTW). The electric conductivity (EC) was promptly measured using a STAR Thermo ORION 3 instrument. The water samples were collected in 500 mL polyethylene bottles (World Health Organization, 2011). The bottles were cleaned thoroughly with distilled water before filling and washed with local sample water three times, and Transport and storage of the samples were carried out at temperatures ranging from 0 °C to 4 °C. The sampling procedures followed the guidelines outlined in the Standard Methods for the Examination of Water and Wastewater (Adams, 2017).

The concentrations of Ca^{2+}, Mg^{2+}, were determined using titration. Na^+ and K^+ cations were estimated using a microprocessor flame photometer. Chloride (Cl^-) and carbonate (CO_3^{2-}), and bicarbonate (HCO_3^-) levels were measured by titration, while nitrate (NO_3^-) and sulfate (SO_4^{2-}) were measured using specific ion electrodes, specifically HANNA 4013, 4012, respectively (World Health Organization, 2011). To estimate the groundwater pollution index and its suitability for irrigation, many irrigation-related factors were calculated. All spatial distribution map for each parameter was produced by Geographical Information System (GIS) (ArcGIS 10.8) using the interpolation backstage (IDW) technique.

2.3. Individual indicators for irrigation water quality

The chemical properties of groundwater affect yield, plant, and soil properties. the degree of irrigation water quality was assessed salinity (*TDS*), percentage of sodium (Na%), Kelly ratio (*KR*), sodium absorption percentage (*SAR*), residual sodium carbonate (*RSC*), magnesium percentage (*MR*), Salinity Potential (*PS*), and permeability index (*PI*), are estimated using Equation (7):

$$\text{Na\%} = \frac{\text{Na}+\text{K}}{\text{Ca}+\text{Mg}+\text{Na}+\text{k}}; \tag{1}$$

$$KR = \frac{\text{Na}}{\text{Ca} + \text{Mg}}; \tag{2}$$

$$PI = \frac{\text{Na} + \sqrt{\text{HCO}_3}}{\sqrt{\text{Ca} + \text{Mg} + \text{Na}}} \times 100; \tag{3}$$

$$RSC = \left(\text{HCO}_3 + \text{CO}_2\right) - \left(\text{Ca}+\text{Mg}\right); \tag{4}$$

$$SAR = \frac{\text{Na}}{\sqrt{\text{Ca} + \text{Mg}}} \times 100; \tag{5}$$

$$MR = \frac{\text{Mg}}{\text{Ca} + \text{Mg}} \times 100; \tag{6}$$

$$PS = \text{Cl} + \text{SO}_4 / 2\,. \tag{7}$$

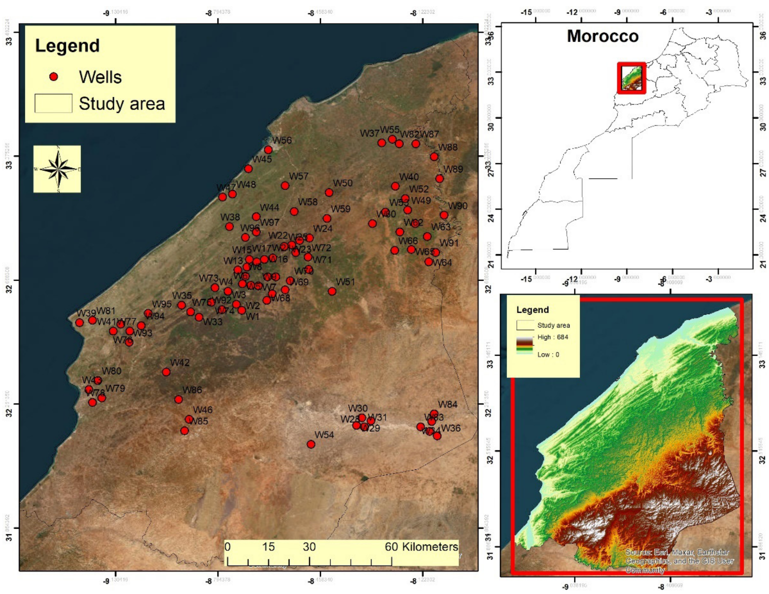

Figure 1. Study area in the Doukkala region of Morocco

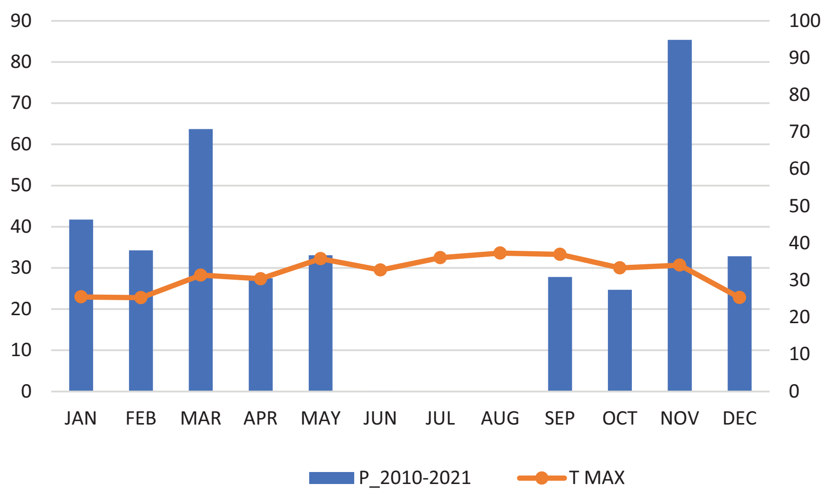

Figure 2. Monthly variation in precipitation (mm) and temperature MAX (T MAX °C) from 2010 to 2021

2.4. Irrigation water quality index (IWQI)

The Irrigation Water Quality Index (IWQI) is used to assess the overall quality of groundwater for irrigation (Adimalla & Qian, 2019; Gibrilla et al., 2011; Khalaf & Hassan, 2013; Varol & Davraz, 2015). The IWQI measurement has been determined by Meireles et al. (2010). The overall quality of groundwater for irrigation in the study area was evaluated using the following Equation (8).

$$IWQI = \sum\left[\left(\frac{w_i}{\sum_{n}^{i=1} w_i}\right)\times\left(q_{iamx}-\left(\frac{\left(\chi_{ij}-\chi_{inf}\right)\times\left(q_{iamp}\right)}{\chi_{amp}}\right)\right)\right], \quad (8)$$

where, q_{iamx} = The maximum value of each class in Table 2; χ_{ij} = It represents the measured value for each parameter; χ_{inf} = It represents the minimum value of the class that follows the parameter; q_{iamp} = It represents ampleness of classes; χ_{amp} = The corresponding value to which the parameter belongs.

The maximum value discovered during the physicochemical investigation of the water samples was taken into consideration for evaluating χ_{amp} of the final class of each parameter. The weighting value was determined by Meireles' model based on the value and effect of each parameter on the quality of irrigation water (Table 1). The calculation of the water quality index is presented in Table 2. There are five different classes of irrigation estimation using the IWQI (Table 3). The parameters were considered more relevant to the irrigation use were considered according to the criteria set by Ayers and Westcot (1999) as shown in Table 2.

Table 1. Physicochemical parameters for determining IWQI: Irrigation water quality index [IWQI] (Meireles et al., 2010)

Parameters	(*Wi*)
EC (µs/cm)	0.211
Na^+ (meq/l)	0.204
HCO_3^- (meq/l)	0.202
Cl^- (meq/l)	0.194
SAR	0.189

Note: IWQI: Irrigation water quality index; CE: Electrical conductivity; Wi: Weight importance; SAR: Sodium absorption rate.

Table 3. Classification of water quality range and types based on IWQI (Meireles et al., 2010)

IWQI	Restrictions for water use
0–40	Severe restriction [SR]
40–55	High restriction [HR]
55–70	Moderate restriction [MR]
70–85	Low restriction [LR]
85–100	No restriction [NR]

Note: IWQI: Irrigation water quality index.

3. Results and discussion

The statistical summaries of the physicochemical properties of the groundwater samples under investigation reveal significant variations across the various parameters listed in Table 4.

Table 4. Statistical summary of Individual indicators for irrigation water quality and Irrigation water quality index (IWQI)

Variable	Unite	Minimum	Maximum	Mean	Std Dev
TDS	mg/l	192.4	2957.5	1344.5	768.3
EC	(µs/cm)	296	4550	2094	1202
Na%	%	18.04	76.45	43.24	13.81
SAR	$(meq/l)^2$	0.37	7.58	2.847	1.786
RSC	No unit	–20.67	1.4	–7.197	6.012
MR	No unit	54.5	87.96	37.56	15.44
PS	No unit	1.25	42.2	15.87	11.17
PI	No unit	33.62	85.66	5.686	1.248
IWQI	No unit	23.3	86.6	54.97	50.98

Note: TDS: Dissolved salt; EC: Electrical conductivity; SAR: Sodium absorption rate; RSC: Residual sodium carbonate; MR: Magnesium ratio; PS: Potential salinity; PI: Permeability index; IWQI: Irrigation water quality index.

3.1. Individual indicators for irrigation water quality

The descriptive statistics of parameters such as TDS, EC, Na%, SAR, RSC, MR, KR, PS, and PI were calculated to determine the suitability of the study area's groundwater quality for irrigation. Table 4 provides information for

Table 2. Valuable of rated water quality (*qi*), according to different parameter values (Ayers & Westcot, 1999)

qi	EC (µs/cm)	Na^+ (meq/l)	HCO_3^- (meq/l)	Cl^- (meq/l)	SAR (meq/l)
From 85 to 100	From 200 to 750	From 2 to 3	From 1 to 1.5	< From 4	< From 3
From 60 to 85	From 750 to 1500	From 3 to 6	From 1.5 to 4.5	From 4 to 7	From 3 to 6
From 35 to 60	From1500 to 3000	From 6 to 9	From 4.5 to 8.5	From 7 to 10	From 6 to 12
From 0 to 35 From 0 to 35	From 200< > From 3000	From 2< > From 9	From 1< > From 8.5	> From 10	> From 12

Note: EC: Electrical conductivity; SAR: Sodium absorption rate.

each of the groundwater hadrochemical parameters of the wells, Table 5 shows the classifications of irrigation water in the past and an assessment of its quality parameters.

Table 5. Classification and evaluation of irrigation water quality parameters

Irrigation Water Quality	Grade	Scale of category	No of sample	% of sample
TDS	Fresh	<1000	36	37
	Brackish	1000–10,000	61	63
	Saline	10,000–100,000		
	Brine	>100,000		
EC	Excellent	<250		
	Good	250–750	10	11
	Doubtful	750–2500	60	61
	Unsuitable	>2500	27	28
NA%	Good	20–40	41	42
	Permissible	40–60	41	42
	Doubtful	60–80	15	16
KR	Suitable	<1	71	73
	Unsuitable	>1	26	27
RSC	Excellent	<0	4	5
	Suitable	0–2.5	93	95
	Unsuitable	>2.5		
PS	Safe	<3	7	8
	Unsafe	>3	90	92
MR	Suitable	<50	79	81
	Unsuitable	>50	18	19
PI	Good	>75	5	5
	Fair	25–75	92	95
SAR	Excellent	<10	97	100
	Good	{10–18}		
	Doubtful	{18–26}		
	Unsuitable	>26		

3.1.1. Dissolved salts and electrical conductivity of water samples

The studied samples' TDS levels ranged between 192 and 2957.5 mg/l, with an average of 1344.5 (Table 5 and Figure 3). Approximately 37% of the samples from the study region were fresh and 63% were brackish for irrigation. For irrigation purposes with respect to electrical conductivity, water quality can alternatively be categorized as Excellent with EC (250 µs/cm), Good (250–750 s/cm), Permissible (750–2500 µs/cm), and Unsuitable (>2500 µs/cm). The electrical conductivity ranged between 296 and 4550 µs/cm, with an average of 2094 (Table 5 and Figure 4). About 11% of the wells are "good" 61% are "doubtful", and 28% are "unsuitable" for irrigation activities. It can a higher of EC and TDS values in most wells were caused by geological origin. Increased EC values may be caused by ion exchange and evaporation, and increasing salinity in most groundwater samples lowers crop yields and plant characteristics (Satish Kumar et al., 2016; Tóth, 1999).

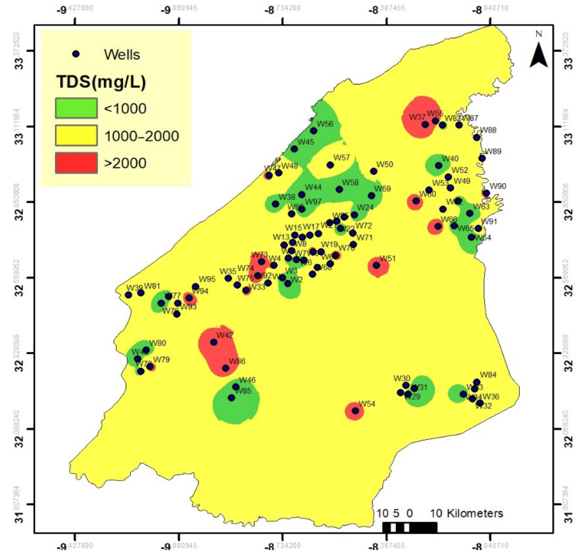

Figure 3. Spatial distribution in dissolved salt of groundwater samples

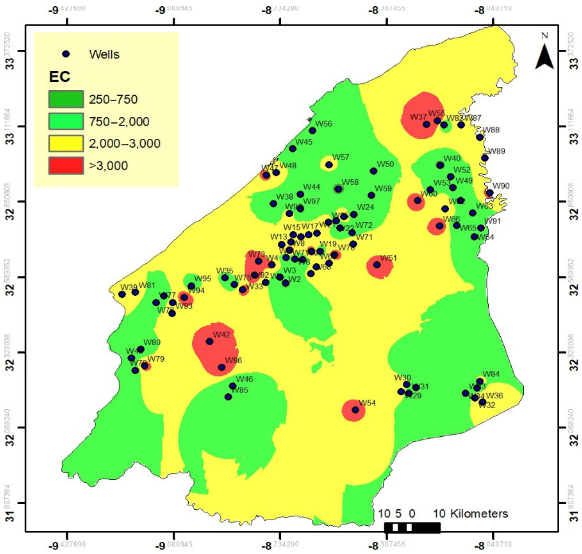

Figure 4. Spatial distribution of EC for groundwater samples

3.1.2. Sodium concentration in water samples

The quality of irrigation water can be assessed by the percentage of sodium (Na%), which can be calculated using the concentration of four dissolved cations in milliequivalents per liter (sodium, potassium, magnesium and calcium) (Doneen, 1962). The average percentage of sodium (Na%) was 43 and ranges from 18 to 76 with a mean of 43.24 (Table 3). According to the Wilcox diagram of the sodium percentage (Na%) (Wilcox, 1955) of the samples studied were as follows: approximately 41% were tolerable, 41% were in the good categories, and 15% were doubtful for irrigation (Table 5 and Figure 5). A Wilcox diagram is a chart that ranks water samples in terms of suitability for irrigation. Based on the classification of Wilcox diagram approximately, 23% of the samples were unsuitable, 29% were doubtful to unsuitable, 8% were permissible, 20% were good, and 17% were excellent for watering (Figure 6).

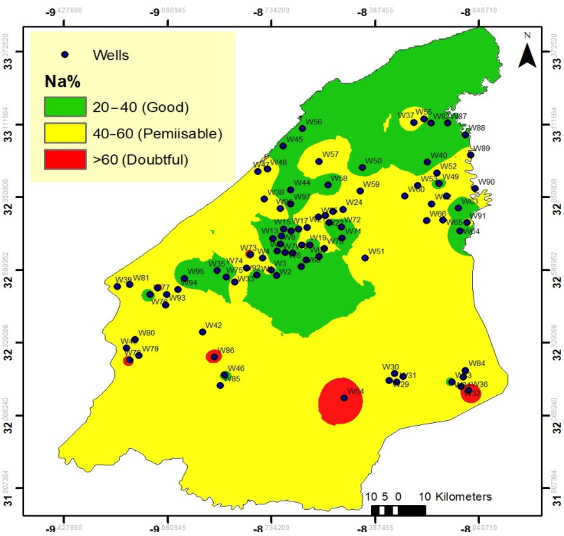

Figure 5. Spatial distribution of Na% for groundwater samples

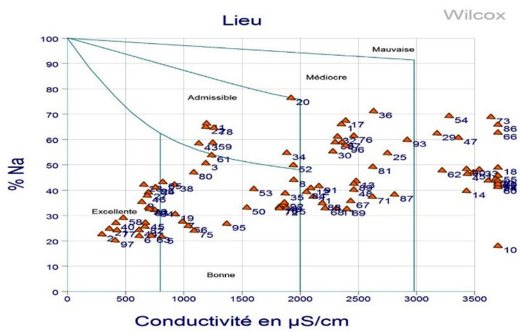

Figure 6. Wilcox distribution for groundwater samples

3.1.3. Sodium adsorption ratio of water samples

High sodium concentration increases soil alkalinity, deteriorates soil structure and texture, and affects vegetative growth (Lanza et al., 2019; Tijani, 1994; Todd & Mays, 2004). According of Richards (1954), divided the SAR for groundwater into this categories: "excellen" SAR is <from10), "good" is from10 to18), "doubtful" is from18 to 26, and "unsuitable" is > from26) (Richards, 1954). The values of SAR for all samples varied from 0.336 to 7.56 with an average of 2.78 (Table 4). It was observed that all studied well samples had excellent irrigation quality (Table 5 and Figure 7).

3.1.4. Residual sodium carbonate of water samples

The RSC values according to Richards are in three categories: "excellent" are < from 0, acceptable are from 0 to 2.5, and unsuitable for irrigation are > from 2.5 (Richards, 1954), as existing in Table 5. The RSC values of samples varied from –20.66 to 1.4, with an average of –7.2. About 95% of the samples are excellent and 5% are acceptable (Tables 4 and 5; Figure 8). Almost all samples fall within the permissible limit for irrigation. This is due to the alkaline earth exceeding the concentration of carbonates in groundwater. Also, a large number of carbonates and bicarbonates can lead to high sedimentation in the alkaline earth and poor soil structure in addition to the possibility of activating sodium present in the soil (Janardhana Raju et al., 2011; Rawat et al., 2018).

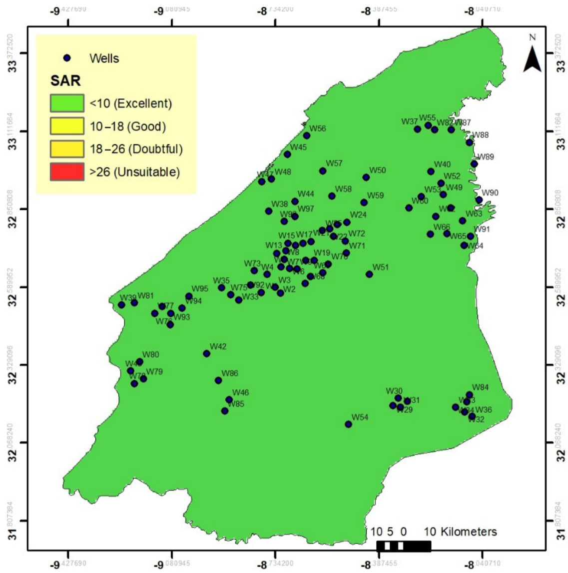

Figure 7. Spatial distribution of SAR for groundwater samples

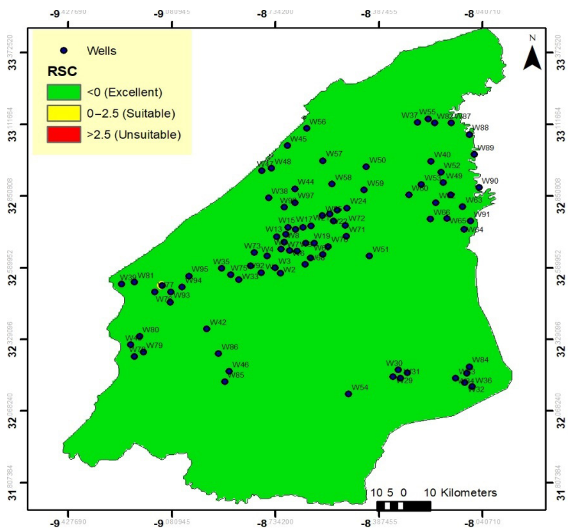

Figure 8. Spatial distribution of RSC for groundwater samples

3.1.5. Kelly's ratio (KR)

According to the Kelly classification, groundwater have two category: <1 suitable for irrigation and >1 not suit-

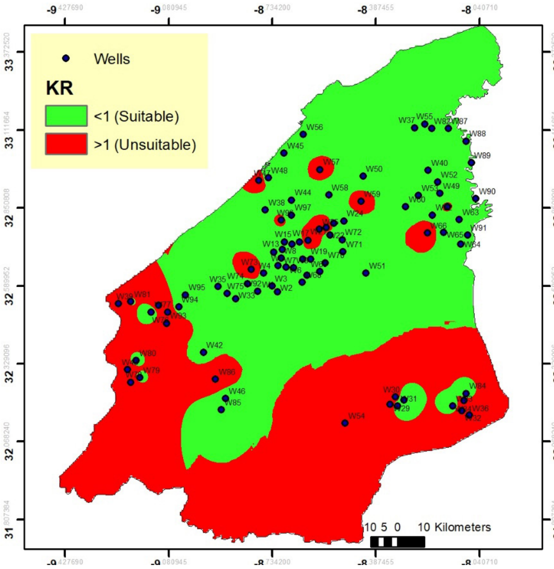

Figure 9. Spatial distribution of Kelly's ratio (KR) for groundwater samples

able for irrigation due to high sodium levels, as shown in Table 5 (Kelley, 1957). In this study, the KR values of samples ranged between 0.18 and 3.2 with a mean of 10.9. Approximately 73% of the samples were suitable and 27% of the samples were not suitable for irrigation (Tables 4 and 5; Figure 9).

3.1.6. Magnesium ratio (MR)

According to Baliwal the classification of the magnesium ratio for groundwater have two categories: >50 unsuitable and <50 suitable for watering (Table 5). The value of the magnesium ratio (MR) in the study area ranged from 45.5 to 87.96 with an average of 37.6. About 81% of the samples were suitable for irrigation, and 19% were unsuitable for irrigation (Tables 4 and 5; Figure 10). Calcium and magnesium

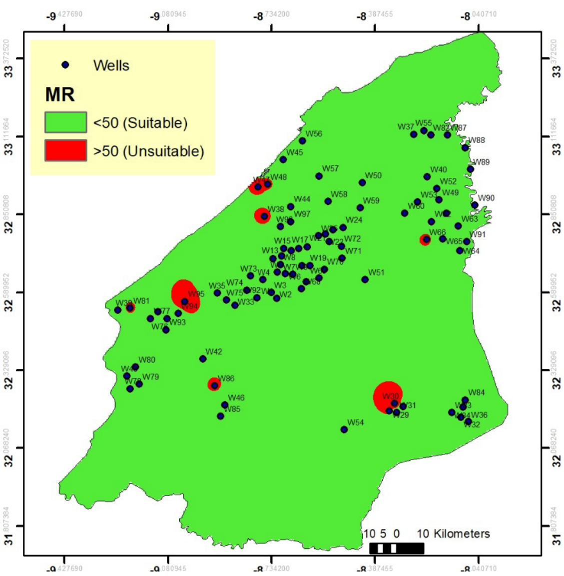

Figure 10. Spatial distribution of the magnesium ration (MR) for groundwater samples

play a vital role in improving the deteriorated structure of the plant and its basic functions. However, irrigation with groundwater affects the MR level, which in turn affects soil alkalinity and agricultural yield (Gautam et al., 2015).

3.1.7. Potential salinity (PS)

According to Rawat et al. (2018), salinity potential (PS) was classified into two categories for irrigation: safe is < from 3 and unsafe is > from 3, as presented in Table 5. The value of potential salinity for all samples in the study area ranged between 1.24 and 42.20, with an average value of 11.17. More than 92% of the studied samples were unsafe for irrigation due to the dominance of chloride concentrations. This could be attributed to the nature of the land, which was derived from the type of halite (Table 5 and Figure 11). Salts also play an important role in soil fertility, as salts with low solubility in most groundwater increase the amount of salt on agricultural lands and are therefore unsafe (Hwang et al., 2017).

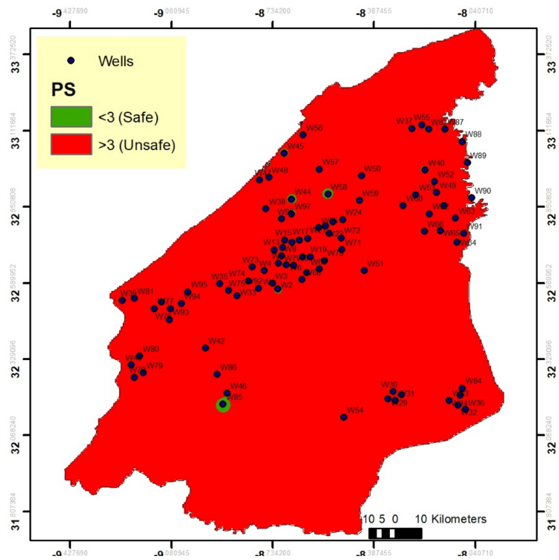

Figure 11. Spatial distribution of potential salinity (PS) for groundwater samples

3.1.8. Permeability index (PI)

The classification of groundwater permeability index (PI) for irrigation, according to Donen's there are three categories: values of PI > 75 (75–25), and (<25) were good, fair, and poor respectively (Doneen, 1962; Selvam et al., 2013). The values of the permeability index (PI) of the studied samples in the study area ranged between 25.82 and 88.88 with an average value of 56.86 (Table 4). According to Donen's classification, about 95% of the samples are in the "fair" category, and 5% of the samples are good. Most samples are suitable for irrigation (Table 5 and Figure 12).

3.2. Irrigation water quality index (IWQI)

The value of the irrigation water quality index ranges between 24.95 and 69.75, with an average value of 51.31.

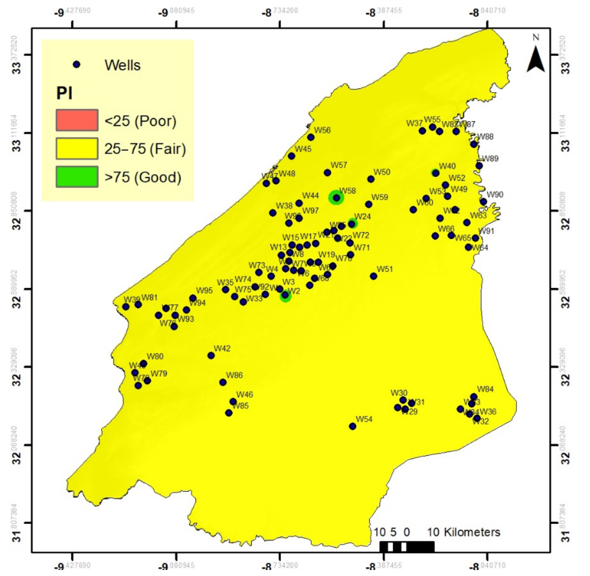

Figure 12. Spatial distribution of the permeability index (PI) for groundwater samples

About, 22.7% of the samples are considered to have severe irrigation (SR) restrictions for the use of irrigation, in which groundwater may only be used to irrigate plants with high salt tolerance, 34.02% of the samples fell under the category of high restrictions showing (HR), that it can seriously harm the soil, harming and killing plants in the process. To avoid causing plant harm in this situation, it is necessary to carry out salt leaching, 23.7% from of samples are considered to have moderate restrictions (MR), it is recommended for mild salt leaching and may be utilized in soils with moderate to high permeability ratings, 17.52% of samples fell under the category of low restrictions (LR), it is advised to utilize irrigated soils with a light texture or moderate permeability. Heavy-texture soils may become sodic, so it is advised against using them in soils with a lot of clay, and 2.06% from area of the study area fell under the category no restriction (NR), may be used to most soils (Tables 4, 6, and 7; Figure 13).

The results indicate that the low IWQI values in some wells may be attributed to the high levels of EC, Na, SAR

Table 6. Groundwater classification based on IWQI

Stat.	IWQI	Restrictions	Stat.	IWQI	Restrictions	Stat.	IWQI	Restrictions
W1	43.28	(HR)	W34	48.02	(HR)	W67	50.08	(HR)
W2	83.16	(LR)	W35	54.34	(HR)	W68	49.81	(HR)
W3	72.27	(LR)	W36	38.85	(SR)	W69	50.30	(HR)
W4	34.84	(SR)	W37	33.09	(SR)	W70	34.28	(SR)
W5	63.06	(MR)	W38	81.69	(LR)	W71	46.34	(HR)
W6	67.59	(MR)	W39	44.39	(HR)	W72	55.61	(MR)
W7	66.28	(MR)	W40	52.87	(HR)	W73	28.63	(SR)
W8	53.70	(HR)	W41	61.76	(MR)	W74	32.87	(SR)
W9	65.15	(MR)	W42	32.97	(SR)	W75	79.11	(LR)
W10	54.19	(HR)	W43	61.70	(MR)	W76	43.75	(HR)
W11	51.43	(HR)	W44	66.68	(MR)	W77	77.36	(LR)
W12	49.63	(HR)	W45	82.40	(LR)	W78	59.69	(MR)
W13	46.93	(HR)	W46	79.92	(LR)	W79	38.71	(SR)
W14	37.35	(SR)	W47	36.13	(SR)	W80	77.25	(LR)
W15	55.09	(MR)	W48	48.84	(HR)	W81	42.47	(HR)
W16	58.00	(MR)	W49	51.50	(HR)	W82	69.16	(MR)
W17	44.05	(HR)	W50	58.19	(MR)	W83	85.86	(NR)
W18	30.39	(SR)	W51	33.90	(SR)	W84	55.75	(MR)
W19	81.99	(LR)	W52	48.58	(HR)	W85	86.62	(NR)
W20	44.01	(HR)	W53	55.75	(MR)	W86	23.31	(SR)
W21	62.30	(MR)	W54	33.11	(SR)	W87	45.94	(HR)
W22	62.17	(MR)	W55	29.80	(SR)	W88	53.83	(HR)
W23	34.54	(HR)	W56	82.39	(LR)	W89	49.33	(HR)
W24	82.62	(LR)	W57	44.35	(HR)	W90	37.93	(SR)
W25	40.85	(HR)	W58	68.29	(MR)	W91	53.76	(HR)
W26	59.08	(MR)	W59	61.14	(MR)	W92	55.78	(MR)
W27	79.39	(LR)	W60	33.57	(SR)	W93	40.02	(HR)
W28	76.85	(LR)	W61	59.74	(MR)	W94	32.28	(SR)
W29	35.28	(SR)	W62	41.17	(HR)	W95	72.44	(LR)
W30	47.97	(HR)	W63	63.99	(HR)	W96	45.18	(HR)
W31	49.69	(HR)	W64	79.97	(LR)	W97	75.79	(LR)
W32	43.23	(HR)	W65	73.22	(LR)			
W33	32.92	(SR)	W66	28.76	SR)			

Note: IWQI: Irrigation water quality index; SR: Severe restriction; HR: High restriction; MR: Moderate restriction; LR: Low restriction.

Table 7. Types of groundwater based on IWQI in the study area

IWQI	Restrictions for water use	Number of samples	Percentage %
0–40	SR	22	22.7
40–55	HR	33	34.02
55–70	MR	23	23.7
70–85	LR	17	17.52
85–100	NR	2	2.06

Note: IWQI: Irrigation water quality index; SR: Severe restriction; HR: High restriction; MR: Moderate restriction; LR: Low restriction; NR: No restriction.

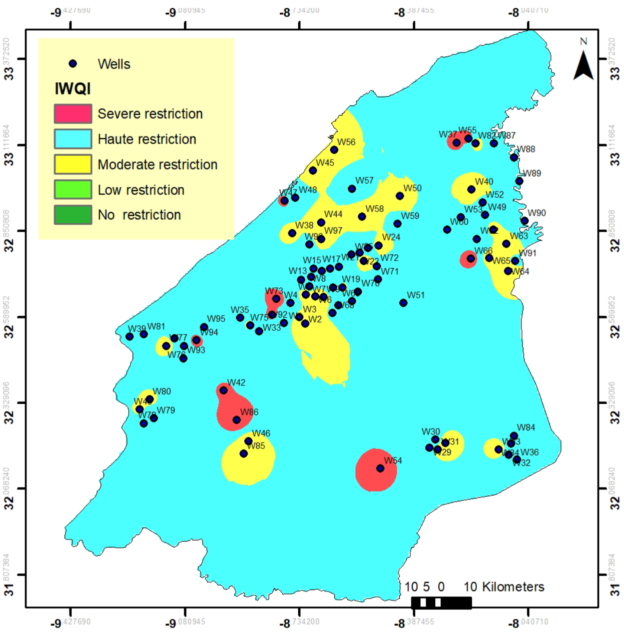

Figure 13. Spatial distribution of irrigation water quality index (IWQI) for groundwater samples

and Cl possibly caused by sewage flows and excessive use of fertilizers in agricultural lands. Moreover, the results obtained from this evaluation were compared with the results of a previous study conducted by researchers who evaluated the water quality in the same study area, Manasra and Sidi Slimane. The researchers used GIS and analyzed the physical and chemical indicators based on Moroccan standards. The results of the latest study concluded that almost all samples showed water pollution due to urban and agricultural activities (Mbaki et al., 2017; Adnani et al., 2020; Jamaa et al., 2020, 2023; Aziane et al., 2020; Bedoui et al., 2022; Ouakkas et al., 2022; Mghaiouini et al., 2023).

4. Conclusions

In this research, the Irrigation Water Quality Index (IWQI) was used to assess the quality of groundwater for irrigation purposes. Geographic Information System (GIS) was used for spatial and temporal characterization of the studied samples. The results of the IWQI irrigation water quality index evaluation showed the following distribution of water quality classes: About, 22.7% of the samples fell into the severe restriction category, which is only suitable for plants with high salinity tolerance. In addition, 34.02% fell into the high restriction category, 23.7% into the moderate restriction category, 17.52% into the low restriction category, and 2.06% into the no restriction category, it is indicated that the groundwater quality in the study area is mostly suitable for irrigation purposes. Also, the Individual indicators for irrigation water quality values of the investigated wells (TDS, Na%, EC, RSC, SAR, KR, MH, PS, and PI) showed that most of them are excellent to good for irrigation. The study suggests a comprehensive strategy for sustainable water management in the Doukkala region, involving water quality monitoring, public awareness campaigns, cultivation of salinity-resistant crops, and pollution prevention regulations.

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Author contributions

Conceptualization, H. S. A.-A., and F. A.; methodology, H. S. A.-A. software, E. A. and F. A.; validation, A.-B. A.-O. and N. A. Y. A.; formal analysis, A.-J. M. A.-A. and O. M. investigation, F. A.; resources, F. A.; data curation, H. S. A.-A. and O. M.; writing–original draft preparation, A. R. A.-A.; writing–review and editing, H. S. A.-A., and A.-B. A.-O. visualization, H. S. A.-A. All authors have read and agreed to the published version of the manuscript.

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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