Research Article

Spatial and Temporal Variations of Water Quality of Mateur Aquifer (Northeastern Tunisia): Suitability for Irrigation and Drinking Purposes

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The present study aims to assess the spatial and temporal variations of the hydrochemical characteristics of Mateur aquifer groundwaters, a crucial water resource in the northeast of Tunisia. The aquifer was subject to water quality deterioration due to salinization and nitrate contamination, and a new assessment of water quality was needed. For this purpose, 40 groundwater samples were collected during wet and dry seasons and analyzed for salinity, pH, T, O₂, major cations and anions, and nutrient elements using standard methods and Water Quality Index (WQI). The results showed that most of the groundwater parameters were not within the permissible limits set by the World Health Organization in both seasons. The geochemical data were interpreted using WQI for drinking water. The spatial distribution maps of Water Quality Index showed that the highest quality was found, during both seasons, in the northwest and the southeast part of the aquifer, corresponding to the recharge zone, whereas the poor and very poor water quality was found in the outflow part of the aquifer. According to sodium adsorption ratio (SAR) and Na% values, most of the groundwater samples were not suitable for irrigation purposes and characterizing the eastern part of the aquifer and the outflow part of the aquifer, around the Ichkeul marshes.

1. Introduction

Groundwater is becoming the major source of water supply for domestic, industrial, and agricultural sectors of many countries all over the world. It is estimated that approximately one-third of the world's population uses groundwater for drinking [1]. Several Mediterranean countries are already facing a situation of severe water quality degradation, mainly due to anthropogenic activities (agriculture, industry, urban development, and increasing exploitation of water resources) as a direct impact of climate change. Water quality is rapidly declining worldwide, particularly in developing countries, due to natural and anthropogenic processes [2, 3]. Water pollution affects human health, economic development, and social prosperity [4]. The importance of

water quality in human health has recently attracted a great deal of interest.

An understanding of the spatial variation and processes affecting water quality is essential in sustaining usable water supplies under changing climate and local environmental pressures. Temporal changes of recharged water composition, hydrologic and human factors, may cause periodic changes in groundwater quality [5]. The quality of alluvial groundwater in rural areas is sensitive to contaminants originating from agricultural chemicals, such as, fertilizers, pesticides, and lime [6, 7]. The use of nitrogen fertilizers frequently leads to extremely high nitrate concentrations in groundwaters and may cause serious health problems [8, 9].

In such circumstances, the knowledge of temporal and spatial trends of water quality should help in the decision-making

FIGURE 1: Location, geology [14], and sampling points of the study area.

process, particularly in developing countries, where there are insufficient data [10].

In Tunisia, where the climate is dry over most of its territories, water resources are both scarce and unequally distributed through time and space, with a potential decrease, due to overexploitation, exploitation of nonrenewable deep aquifer, salinization, and pollution [11]. Agriculture uses approximately 80% of all water resources [12]. Mateur alluvial plain is one of the major agricultural regions in Tunisia, and its water resources originate mainly from the alluvial aquifer, which support the local domestic and agricultural water supply with 49% and 51%, respectively [13]. Although Mateur is not a particularly water-stressed region, brine water around Ichkeul marshes and salty soils contribute to water salinization in some shallow wells. Even more, excessive agricultural activities may be the cause of its water contamination with nitrate.

This paper highlights the spatial and temporal variations in groundwater quality in an alluvial agricultural plain in Mateur region and evaluates the suitability of groundwater

FIGURE 2: Ombrothermic diagram.

for irrigation and drinking purposes for sustainable agriculture and basic human needs. For these purposes, we used an integrated Water Quality Index (WQI), the sodium

FIGURE 3: Hydrogeological cross sections: (a) Mateur and (b) Ras el Ain [15].

adsorption ratio (SAR), the sodium percentage (% Na), and the permeability index (PI).

2. Setting and Methods

2.1. Location and Climate. Mateur plain is located in Bizerte region, in the northeast of Tunisia (Figure 1) and has a surface area of 260 km² in the vast Ichkeul catchment (2600 km²). The climate is typically Mediterranean, subhumid with a considerable variation in mean monthly temperatures. The coldest month is January, with a mean temperature of 11°C, and the hottest is August, with a mean temperature of 27°C. The ombrothermic diagram (Figure 2) shows two periods: a wet period which lasts 7 months from November to May and a dry period which lasts 5 months from June to October. The mean annual precipitation (1998–2008) in the area is 518 mm and the mean annual evapotranspiration is 1074 mm.

2.2. Geological and Hydrogeological Setting. Mateur plain covers different stratigraphic units ranging from Triassic to Quaternary [14]. The stratigraphic sequence primarily consists of carbonate formations, which characterize the Tertiary deposits of Ichkeul Mountains. In the Mateur plain, outcrops prior to Quaternary are found only on the three Campanian hills of Sidi Mbarek, Mateur, and Ras El Ain.

Miocene is mainly developed in the east of Mateur plain and the north of Ichkeul lake, and it is composed of gypsum and marl. The Quaternary and recent alluvium cover the major part of the plain and are composed of silt and detrital formations. The aquifer system is made up of multilayers, which are either saturated or unsaturated [15] (Figure 3). These layers are composed of alluvial, eolian, and minor lacustrine deposits [16]. The main sources of alluvial aquifer recharge are rainfall infiltration and leakage of rivers (Joumine, Tine, Sejnane, Melah, and Rezala). According to piezometric maps (Figure 4), Mateur aquifer groundwater flow is roughly oriented northward in the upstream part of the plain, whereas in the downstream part, it is controlled by the draining action of the Joumine River.

Water loss from the aquifer is through discharge to the lake Ichkeul, evaporation, and pumping for domestic and agricultural purposes. The water table generally lies within 8–10 m of land surface, facilitating additional groundwater loss via evapotranspiration. The alluvial aquifer has transmissivity values ranging from $2 \cdot 10^{-5}$ to $20 \cdot 10^{-2}$ m²/s.

2.3. Soil Type and Agriculture Practices. According to Mori [17], two major soil types are observed in Mateur plain: fluvisol and hydromorphic and holomorphic soils with high salinity.

FIGURE 4: Piezometric maps of Mateur plain: (a) wet season and (b) dry season.

TABLE 1: Details of fertilizer application for different crops in the study area.

Fertilizer type (kg·ha ⁻¹)	Cereals				Fodder		Legumes		Tree crops	
	Nov	Jan	Feb	March	Sept	Jan	Dec	Jan	Oct	Feb
DAP N-P ₂ O ₅	150	—	—	—	—	—	—	200	—	—
Ammonium	—	150	150	150	—	150	—	200	—	150
Super 45 P ₂ O ₅	—	—	—	—	100	—	100	—	150	—

TABLE 2: Statistical summary of hydrochemical parameters of the study area.

Unit		Wet season (May)			Dry season (October)		
		Min	Max	SD*	Min	Max	SD*
Cl ⁻	mg/L	67.45	2406.90	524.66	106.50	4402.00	844.89
SO ₄ ²⁻	mg/L	223.53	2483.48	497.45	221.89	3591.36	583.38
HCO ₃ ⁻	mg/L	54.92	622.40	150.35	86.65	693.19	146.93
Ca ⁺⁺	mg/L	20.00	480.00	82.33	10.00	763.40	135.97
Na ⁺	mg/L	49.00	1728.00	376.45	11.25	170.13	40.30
Mg ⁺⁺	mg/L	12.70	140.00	27.33	39.33	2576.00	491.23
K ⁺	mg/L	0.78	101.60	17.84	0.00	169.00	29.88
T	°C	16.20	26.80	2.16	18.20	26.70	1.98
Conductivity	mS/cm	0.54	8.64	1.94	0.72	14.59	2.98
Salinity	g/L	0.41	6.55	1.47	0.54	11.07	2.26
pH		6.18	8.39	0.39	7.13	9.08	0.33
O ₂	mg/L	1.20	7.60	1.36	0.60	5.20	1.09
NO ₃ ⁻	mg/L	0	273.15	79.76	0.72	278.6	64.99
NH ₄ ⁺	mg/L	0	6.63	1.08	0	0.2	0.03
NO ₂ ⁻	mg/L	0	1.56	0.37	0	0.23	0.06
HPO ₄ ²⁻	μg/L	10	6.37	1.02	20	4.82	0.82

*Standard deviation.

Mateur region land is mainly used for growing cereals and fodders. A large amount of synthetic fertilizers (DAP, ammonium, and super 45) are applied during the farming season (winter through spring) [18]. Fertilizer quantities

(kg/ha) and application time are given in Table 1. Almost all farmers apply more than the recommended dose. Besides, over the last few decades, fertilizer management has been dramatically modified, and for economic considerations,

FIGURE 5: Spatial distribution maps of salinity: (a) wet season and (b) dry season.

crop rotations are rarely applied and cereals are the predominant land use for many successful agricultural years. With regard to livestock, cattle livestock is the main practice in the irrigated areas of Mateur. Animal resources are estimated for the year 2012 of around 45,627 head of sheep and 7,789 head of cattle [19]. NO_3 fluxes from farm discharges are estimated to be about 120 kg/ha/year [20].

2.4. Sampling and Analytical Methods. Groundwater samples were obtained from monitoring wells in the alluvial aquifers. A total of 70 samples were collected in wet and dry seasons in order to capture seasonal variability in water quality.

The piezometric level, pH, electrical conductivity (EC), dissolved oxygen, and temperature were measured in situ. Samples were kept at 4°C for their subsequent chemical analyses. Afterwards, the samples were filtered through a 0.45 μm Millipore filter. Chloride was determined by standard AgNO_3 [21]. Sulfate (SO_4^{2-}) content was measured by the gravimetric method using BaCl_2 . Sodium (Na^+) and potassium (K^+) were measured by flame photometry, and calcium (Ca^{2+}) and magnesium (Mg^{2+}) were measured with atomic absorption. Alkalinity was determined by titration with HCl.

The quality of chemical analysis was checked by making an ionic mass balance, accepting an error rate lower than 5%. Nitrate, nitrite, ammonium, and ortho-P were analyzed by colorimetric methods described by Rodier [21], using sodium salicylate, diazotization, blue of indophenol, and phosphomolybdate methods, respectively. The obtained

results were applied to statistical study using Andad software [22]. Statistical summaries of the parameters analyzed for this study are presented in Table 2. Data were made available in a format that is accessible via GIS. Surfer 8 was used to generate different spatial distribution maps of various chemical constituents in the study area. Water Quality Index (WQI), sodium adsorption ratio (SAR), sodium percentage (% Na), and permeability index (PI) were used to evaluate the suitability of groundwater for irrigation and drinking purposes.

3. Results and Discussion

3.1. Mateur Groundwater Geochemistry

3.1.1. pH and $T^\circ\text{C}$. The pH values of Mateur alluvial aquifer water range from 7.18 to 8.39 during the wet season and between 7.02 and 8.11 throughout the dry season.

The spatial and temporal variations of pH are controlled by the quality and the infiltration rate of recharge water, the replenishing water rate and water-rock interaction in the aquifer. These pH values are all in the desirable limits set by the World Health Organization (WHO) [23].

The temperature values of groundwater varied from 18.9°C to 25.6°C during the wet season and from 18.2°C to 26.7°C during the dry season. The highest temperature values, for the same well or borehole, are recorded during dry season. The spatial variation of temperature is a function of the recharged water and of the infiltration transfer time, which in turn both depend on porosity, lithology, and

FIGURE 6: Bivariate plot of (a) Na^+ versus Cl^- and (b) salinity versus Cl^- .

FIGURE 7: Spatial distribution maps of calcium (Ca^{++}): (a) wet season and (b) dry season.

thickness of the unsaturated zone. For the same sampling period, the spatial variation is marked by a decrease as the depth increases.

3.1.2. Salinity, Sodium, and Chloride. Water salinity of the Mateur aquifer varied from 0.1 to 4.5 g/L during the wet season and from 0.1 to 8.4 g/L throughout the dry season. The highest values were recorded during the dry season

(October), whereas the lowest values were recorded during the wet season (April). The spatial distribution maps of salinity (Figures 5(a) and 5(b)) show that the lowest values are recorded both during the wet and the dry season in the northwest and southwest parts of the aquifer. These parts correspond to the natural recharge area (dilution effect) with an increasing trend of salinity values in the water flow direction. The high salinity levels are related to the infiltration of salty water from Ichkeul marshes and of salty soil leachate

FIGURE 8: Spatial distribution maps of sulfate (SO_4^{2-}): (a) wet season and (b) dry season.

FIGURE 9: Geochemical relationship of $(2\text{HCO}_3 + \text{SO}_4)$ versus 2Ca .

FIGURE 10: Bivariate plot of Ca^{2+} versus Mg^{2+} .

located south of Ichkeul. The main factors contributing to the groundwater salinity are dilution or evaporation, the thickness and the nature of sediments in the vadose zone, and the salty water intrusion around Ichkeul lake [11].

The concentration of chloride varied from 67 to 2406 mg/L during the wet season and from 49 to 4402 mg/L throughout the dry season. Sodium contents ranged between 49 and 1728 mg/L during wet season and between 39 and 2576 mg/L during dry season. Concentrations of chlorides and sodium show little seasonal variation. A slight decrease, more

important in the most mineralized waters, can be explained by the dilution caused by rainwater infiltration during the wet season (April), whereas evaporation contributes to ion concentration increase throughout the dry season.

Cl shows a strong positive correlation with Na (Figure 6(a)) and with salinity (Figure 6(b)), indicating that these ions seem to be dominant in the groundwater mineralization process and have the same origin: the dissolution of halite occurring in saline surface deposits and marshes around the Ichkeul lake and around salty soils.

FIGURE 11: Piper diagram.

3.1.3. Ca^{2+} , Mg^{2+} , HCO_3^- , and SO_4^{2-} . The spatial distribution maps of Ca^{2+} levels show that the highest values characterize the northeastern and the outflow parts of the aquifer (Figures 7(a) and 7(b)). An increasing trend with the flow direction is registered, especially during the wet season. The spatial distribution maps of sulfate contents (Figures 8(a) and 8(b)) show that higher sulfate values characterize the northeastern and the outflow parts of the aquifer.

A good positive correlation of Ca^{2+} versus HCO_3^- and SO_4^{2-} (Figure 9) shows that the calcium originates, in addition to the dissolution of the calcite, from the dissolution of gypsum (R1 and R2), where the dissolution of one mole of calcite and one mole of gypsum was put into solution of two moles of Ca^{++} , one mole of SO_4^{2-} , and two moles of HCO_3^- :

Magnesium contents in Mateur aquifer ranged from 10 to 290 mg/L during the wet season and from 11 to 170 mg/L during the dry season. The lowest values are recorded throughout the wet season, while the highest values are recorded throughout the dry season.

A relationship of Ca versus Mg shows a positive correlation ($R^2 = 0.59$) (Figure 10), indicating the common origin and the similar geochemical behavior of these ions, which could be derived from the dissolution of magnesium calcite $\text{Ca}_{1-x}\text{Mg}_x\text{CO}_3$.

3.1.4. *Chemical Water Types*. The Piper diagram (Figure 11) shows that groundwaters of the studied area are classified into two predominant facies:

- (i) Mixed facies: $\text{Ca-Na-SO}_4\text{-Cl}$ and $\text{Ca-Na-HCO}_3\text{-Cl}$

(a)

(b)

FIGURE 12: Spatial distribution maps of nitrate (NO_3^-): (a) wet season and (b) dry season.

- (ii) Na-Cl facies: they characterize discharge zone and are well influenced by the leaching of salty deposits.

3.1.5. NO_3^- , NO_2^- , NH_4^+ , and O_2 . To assess the possible anthropogenic effects on groundwater quality, water samples were classified into three groups based on the NO_3^- concentration during the study period as (a) below 50 mg/L, (b) 50–150 mg/L, and (c) above 150 mg/L. Figures 12(a) and 12(b) illustrate a complex spatial pattern of nitrate within the aquifer. Nitrate has a WHO (World Health organization) guideline value of 50 mg/L and exceeded this

FIGURE 13: Bivariate plot of NO_2^- versus NH_4^+ (a) and NO_3^- (b).

concentration in 48% and 32% of samples in wet and dry seasons, respectively. The highest values were 485 mg/L and 336 mg/L during wet and dry seasons, respectively. High concentrations of nitrate are recovered in the northwestern and central part of the aquifer. Areas where nitrate concentrations are lower than 50 mg/L are located in the western part of the aquifer, which corresponds to the natural recharge zone. Considering the temporal pattern, a similar distribution pattern was observed in the dry and the wet seasons, but the magnitude of concentration was higher during the wet season. Elevated nitrate concentration was noted during the wet season due to the combination of high nitrogen fertilizer applications from January to May and the subsequent irrigation. Throughout the dry season, elevated nitrate concentration can be explained by irrigation with NO_3^- -rich water. Indeed, fertilizer management adopted by farmers is most probably partially responsible for the observed pollution of the groundwater. This spatial distribution is also controlled by the physical, environmental, and chemical properties of the soil [24] and the particle size, lithology, and the thickness of the unsaturated zone [25]. Indeed, in spite of the position of the wells 2, 14, 26, 22, and 25 in the irrigated perimeter, they have lower nitrate concentration. This is explained by a clay unsaturated zone with a low permeability ranging between 86 and 433 mm/day. High permeabilities (4335 mm/day) with the correspondingly silty sand and silty unsaturated zone are also consistent with the higher groundwater nitrate concentrations in the wells 10, 15, 17, 19, and 28. Point nitrate groundwater pollution does not seem to be important in the studied area. Indeed, industrial and urban wastewater discharge into the Joumine River, which plays a groundwater drainage role to

the Ichkeul Lake, cause, locally, eutrophication in its southern part.

Groundwater samples in the studied area are fairly oxygenated, so NO_2^- and NH_4^+ concentrations were almost absent, except few wells which have dramatically higher values. Nitrite contamination is indicative of local and recently generated contamination [26, 27], whereas the presence of ammonium ions in groundwater is generally an indicator of groundwater pollution [28]. High nitrite values are related to wastewater leaching. The ammoniacal nitrogen may originate from the degradation of dissolved organic matter or from the infiltration of leachate water of fertilized soils.

The absence of correlation between the different inorganic nitrogen compounds (NO_3^- , NO_2^- , and NH_4^+) and O_2 (Figures 13(a) and 13(b)) and (Figures 14(a)–(c)) shows that nitrates within the Mateur aquifer waters are mainly derived from the infiltration of leaching water from cultivated land in addition to a small proportion related to nitrification.

3.1.6. Ortho-P. The solubility of inorganic forms of phosphorus, mainly represented by orthophosphates, is pH dependent. The equilibrium reactions between orthophosphates are the following [29]:

FIGURE 14: Bivariate plot of O_2 versus NO_3^- (a) NH_4^+ (b) and NO_2^- (c).

TABLE 3: Weight and relative weight of chemical parameters used for WQI computation.

	S_i	w_i	W_i
Salinity	1500	5	0.152
Bicarbonates		1	0.030
Chlorides	400	5	0.152
Sulfates	400	5	0.152
Nitrates	50	5	0.152
Calcium	300	3	0.091
Magnesium	150	3	0.091
Sodium	200	4	0.121
Potassium		2	0.061
		Total $w_i = 33$	Total $W_i = 1$

These reactions indicate that HPO_4^{2-} is the dominant form within a pH range of 7.2 and 12.5. According to the pH values of groundwater in the study area, the dominant form of orthophosphates is HPO_4^{2-} with contents between 10 and $482 \mu\text{g/L}$ during the wet season and between 20 and $637 \mu\text{g/L}$ during the dry season. The highest orthophosphate contents are recorded in the outflow parts of the aquifer and might be connected to the fertilization of agricultural land by phosphorus fertilizers (diammonium phosphate and super 45). Indeed, the repeated phosphorus fertilization increases the transfer of phosphorus to the aquifer [30, 31]. High orthophosphate levels would be related also to the discharge of urban wastewater in Joumine River.

3.2. Groundwater Suitability

3.2.1. Suitability for Drinking Purposes Using Water Quality Index (WQI). Water Quality Index is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policymakers. It is an important parameter for the assessment and management of groundwater. WQI is defined as a rating reflecting the composite influence of different water quality parameters [32]. By mapping the index, the areas of high and low water

TABLE 4: Water Quality Index (WQI) ranges and percentage of samples during wet and dry seasons.

WQI range	Water quality	Wet season	Dry season
<50	Excellent	12.50	10
50–100	Good	40	45
100–200	Poor	35.50	35
200–300	Very poor	5	2.50
>300	Unsuitable for domestic purposes	7.50	7.50

quality can easily be distinguished by scientists as well as by policymakers or the general public, for treatment before various uses [33].

To compute the WQI, three steps are followed [34]. In the first step, each of the 9 parameters is assigned a weight (W_i) according to its relative importance in the overall quality of water for drinking purposes (Table 3). In the second step, the relative weight (W_i) is computed from the following equation (6):

$$W_i = \frac{w_i}{\sum_{i=1}^n w_i}, \quad (6)$$

where w_i is the weight of each parameter and n is the number of parameters.

To compute the WQI (9), the SI is first determined for each chemical parameter, which is then used to determine the WQI as in the following equation (7):

$$SI_i = W_i * q_i, \quad (7)$$

$$q_i = \left(\frac{C_i}{S_i} \right) * 100, \quad (8)$$

where C_i is the concentration of each chemical parameter in each water sample in mg/L.

S_i is a World Health Organization's standard for each of the major parameters in drinking water [23].

FIGURE 15: Spatial distribution maps of WQI.

$$WQI = \sum SI_i, \quad (9)$$

where SI_i is the subindex of i th parameter, q_i is the rating based on the concentration of i th parameter, and n is the number of parameters.

The computed WQI values are classified into five types, from “excellent water” to “water, unsuitable for drinking” (Table 4) [32]. In the current study, a total of nine chemical parameters (salinity, Na^+ , Cl^- , Ca^{2+} , Mg^{2+} , SO_4^{2-} , K^+ , HCO_3^- , and NO_3^-) of 40 water samples were used to calculate WQI, in order to assess the suitability of the Mateur aquifer groundwater for domestic (drinking) use. The weights assigned to the parameters ranged between 1 and 5 (Table 3) and were based on the health effects of these parameters. The highest weight (5) was assigned to salinity and nitrate due to their major importance in water quality assessment and the health implications of the high concentration of these chemical parameters in water [35, 36].

The spatial distribution of Water Quality Index (Figure 15) shows the highest quality (12.5% and 40% of groundwater samples fell into excellent to good, resp., during both seasons). These two categories characterize the northwest and the southeast part of the aquifer, corresponding to the recharge zone. The water samples within poor quality, very poor quality, and unsuitable for drinking purposes contributed 35.5%, 5%, and 7.5% of groundwater samples, respectively in the wet season with no remarkable difference in the dry season. Poor and very poor water qualities were

found in the center and east part of the aquifer and cannot be used for drinking without any treatment and conventional disinfection, whereas water “unsuitable for drinking purposes” could only be used for aquaculture, irrigation, and industrial purposes and characterizes the outflow part of the aquifer [37].

3.2.2. Suitability for Irrigation. The long-term effect of irrigation water on physical and chemical properties of soil and crop productivity depends on the conductivity and sodium contents, dissolved inorganic carbon and alkaline earth elements (Ca and Mg) of irrigation water, and initial physical properties of soil [36].

In order to assess the irrigation suitability of Mateur aquifer groundwaters, the following parameters were used: sodium percentage (% Na), sodium adsorption ratio (SAR), and permeability index (PI).

(1) Sodium Adsorption Ratio (SAR). The sodicity hazard of water is generally described by the sodium adsorption ratio. Indeed, there is a significant relationship between SAR values of irrigation water and the extent to which sodium is adsorbed by the soil [24]. If water used for irrigation is high in sodium and low in calcium, the cation exchange complex may become saturated with sodium, which can destroy the soil structure due to the dispersion of clay particles [38]. SAR is computed from the following equation (10), where the concentrations are reported in meq/L.

FIGURE 16: USSR diagram for the study area.

TABLE 5: Irrigation quality of groundwater based on sodium percentage.

	C2S1 (%)	C3S1 (%)	C4aS2 (%)	C4bS2 (%)	C4aS1 (%)	C4bS4 (%)	C4bS3 (%)	C3S4 (%)
Wet season	5	42	21	2	—	3	—	—
Dry season	3	36	18	3	12	—	—	3

$$SAR = \frac{Na}{\sqrt{(Ca + Mg/2)}} \quad (10)$$

The SAR values in the study area range between 4.08 and 13.9. All the sampling points on the US salinity diagram are shown in Figure 16 and summarized in Table 5. Figure 16 illustrates that the majority of water samples fall into C3S1 and C4aS2 fields during both seasons. 42% and 36% of groundwater samples fall into C3S1 during wet and dry seasons, respectively, indicating water of medium-to-high salinity and low SAR category, without risk of soil destabilization. This water falls into admissible class (C3S1) characterizing groundwater samples located in the natural recharge zone of the aquifer and can be used for irrigation of plants having a good salt tolerance, on well-drained soils or good permeability, with salinity control [39]. 23% and 21% of groundwater samples fall into C4S2 field poor class (C4S1-C4S2) in wet and dry seasons, respectively, indicating very high salinity and medium alkalinity hazards. This class is characterized by strongly mineralized water presenting

important risk of soil salinization, but with medium risk of alkalization. It is found in the center and the east part of the aquifer (Figure 17). Very high salinity waters are unsuitable for irrigation with a suitable drainage. An adequate drainage with low salinity waters and plants having good salt tolerance should be selected.

(2) *Percentage of Sodium (% Na)*. Wilcox [40] used % Na and specific conductance in evaluating the suitability of groundwater for irrigation. % Na is calculated using the following relation (11):

$$\%Na = \left(\frac{Na}{Na + Ca + Mg + K} \right) * 100, \quad (11)$$

where all the ionic concentrations are expressed in meq/L.

All groundwater samples on the Wilcox diagram are shown in Figure 18 and summarized in Table 6. Groundwater samples in the study area fall into five categories: (i) good to excellent categories, which represent 47% to 8% of

FIGURE 17: Spatial distribution maps of the irrigation suitability classes of the study area.

FIGURE 18: Wilcox diagram for the study area.

the groundwater samples during the wet season and 30% to 3% of the groundwater samples during the dry season, respectively; (ii) permissible categories, which are moderately mineralized and represent 2% of groundwater samples during the wet season and 9% throughout the dry season;

TABLE 6: Salinity and alkalinity hazards of irrigation water in US salinity diagram.

	Excellent (%)	Good (%)	Permissible (%)	Doubtful (%)	Unsuitable (%)
Wet season	8	47	2	26	10
Dry season	3	30	9	21	18

and (iii) from poor to very poor quality water, which are the most mineralized, with the highest percentage of sodium. These waters represent 26% to 10% of all water during the wet season and 21% to 18% during the dry season and are located mainly in the eastern part of the web and in the discharge area, in the marshes of Ichkeul.

It is noteworthy that when the sodium content is high in irrigation water, this element tends to replace the Ca and Mg ions in the interlayer space of soil clays, reducing its permeability, and thus, causing poor internal drainage [36, 41].

(3) *Permeability Index*. The permeability index is an important factor, which influences the quality of irrigation water in relation to the soil for development in agriculture [42].

The permeability index (PI) of a water sample is computed from the following equation (12), where concentrations are in meq/L.

$$PI = \left(\frac{Na + \sqrt{HCO_3}}{(Na + Ca + Mg)} \right) * 100. \quad (12)$$

FIGURE 19: A Doneen's chart for the study area.

Permeability indices were plotted with the total ionic content of the groundwater samples on a Doneen's chart [42], which represent three different classes: CI with the best water type for irrigation, CII water generally acceptable, and CIII waters unacceptable [44].

In the study area, the PI ranged from 52.44 to 64.09 with an average of 56.13, Figure 19 shows that all the samples fall within the CI best water type for irrigation purposes.

4. Conclusions

The objective of this study is to assess the seasonal variation in the physicochemical characteristics of water supply wells in the Mateur plain, Northern Tunisia. The WQI was applied to investigate the seasonal changes and the factors influencing groundwater hydrochemistry and hence its suitability for irrigation and domestic purposes. The investigation results suggest the following: (i) The highest quality was found, during both the wet and dry season, in the northwest and southeast part of the aquifer, corresponding to the recharge zone where 12.5% and 40% of groundwater samples fell into excellent to good categories, respectively. Toward the flow direction, groundwaters become poor to very poor and need treatment before consumption. (ii) Most of the groundwater samples fell in doubtful to unsuitable categories, characterizing the eastern part of the aquifer and the outflow part, around the Ichkeul marshes. These waters with high to very high salinity are unsuitable for irrigation purposes in ordinary conditions, an adequate drainage with low salinity waters and plants having good salt tolerance should be selected. (iii) The little seasonal change of groundwaters' quality of Mateur aquifer is mainly related to

dilution in the wet season, evaporation throughout the dry season, and agricultural activities.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Supplementary Materials

A table showing the subindex of i th parameter (SI_i) values during wet and dry seasons was added as supplementary material. (*Supplementary Materials*)

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