sustainability

Article

Assessment of Groundwater Suitability for Agricultural Purposes: A Case Study of South Oued Righ Region, Algeria

Abdelaziz Kadri [1,*], Kais Baouia [1], Samir Kateb [2], Nadhir Al-Ansari [3], Saber Kouadri [1], Hadee Mohammed Najm [4], Nuha S. Mashaan [5], Moutaz Mustafa A. Eldirderi [6] and Khaled Mohamed Khedher [7,8]

1 Laboratory of Water and Environment Engineering in Saharan Environment, University of Ouargla, PB 147 RP, Ouargla 30000, Algeria; kais_baouia@yahoo.fr (K.B.); kouadri.saber@univ-ouargla.dz (S.K.)
2 Research Laboratory in Exploitation and Development of Natural Resources in Arid Zones, University of Kasdi Merbah—Ouargla, PB 147 RP, Ouargla 30000, Algeria; katebsamir30@gmail.com
3 Department of Civil Environmental and Natural Resources Engineering, Lulea University of Technology, 97187 Lulea, Sweden; nadhir.alansari@ltu.se
4 Department of Civil Engineering, Zakir Husain Engineering College, Aligarh Muslim University, Aligarh 202002, India; gk4071@myamu.ac.in
5 Faculty of Science and Engineering, School of Civil and Mechanical Engineering, Curtin University, Bentley, WA 6102, Australia; nuhas.mashaan1@curtin.edu.au
6 Department of Chemical Engineering, College of Engineering, King Khalid University, Abha 61421, Saudi Arabia; maldrdery@kku.edu.sa
7 Department of Civil Engineering, College of Engineering, King Khalid University, Abha 61421, Saudi Arabia; kkhedher@kku.edu.sa
8 Department of Civil Engineering, High Institute of Technological Studies, Mrezgua University Campus, Nabeul 8000, Tunisia
* Correspondence: kadriabdelaziz1440@gmail.com

Citation: Kadri, A.; Baouia, K.; Kateb, S.; Al-Ansari, N.; Kouadri, S.; Najm, H.M.; Mashaan, N.S.; Eldirderi, M.M.A.; Khedher, K.M. Assessment of Groundwater Suitability for Agricultural Purposes: A Case Study of South Oued Righ Region, Algeria. *Sustainability* **2022**, *14*, 8858. https://doi.org/10.3390/su14148858

Academic Editors: Mohamed Ksibi, Fernando António Leal Pacheco, Marianna D. Kharlamova and Mohammed Abdul Rasheed

Received: 21 May 2022
Accepted: 14 July 2022
Published: 20 July 2022

Abstract: Groundwater in the Touggourt region—or as its named, Oued Righ—in southeastern Algeria, is the only source of irrigation. To assess its suitability for agricultural purposes, we collected 72 samples from wells at this region, physical and chemical measurements were carried out for each water sample, and calculations of the sodium adsorption ratio (SAR), permeability index (PI), soluble sodium percent (SSP), residual sodium carbonate (RSC), magnesium hazard ratio (MHR) and Kelley's ratio (KR) were carried out, as these indices are often used to assess the suitability of groundwater for irrigation uses. Based on the irrigation water quality index (IWQI) values, a spatial distribution map for each parameter using the inverse interpolation technique (IDW) was produced by Geographical Information System (GIS). According to the IWQI map, about 35% of the water samples analyzed fall into the Severe Restriction category (SR), making it unsuitable for irrigation under normal circumstance. Again, the remaining 65% of the groundwater has a high restriction (HR) for use. Groundwater in the study area could be used for irrigation in highly permeable soils where salt-tolerant crops are grown. Adequate drainage and continuous monitoring of water quality are recommended.

Keywords: groundwater; Oued Righ region; sodium adsorption ratio; irrigation water quality index (IWQI); GIS

1. Introduction

Water is a very important natural resource that is essential for life on earth. Polluted drinking water is responsible for around 80% of all illnesses worldwide [1]. Pressure on the world's water supply is increasing due to climate change, high population growth rates worldwide, and the spread of some regional wars between countries. The result is an increase in demand and a decline in water quality. These pressures are exacerbated by widespread demand for drinking water, irrigation, urban growth, industrial development, and tourism [2]. During the last two decades, Algeria has experienced a momentous growth in population and economic and social development., thus necessitating the implementation of water treatment projects to make the water drinkable or appropriate for industrial and agricultural purposes. Regardless of the country's efforts in recent years, it will face a 1 billion m^3 shortfall by the Horizon of 2025 [3]. For most of the southern regions, whether urban or industrial, groundwater is the only supply of water. The deterioration of the natural environment, particularly aquifers, has become a worldwide issue, which necessitates reliance on groundwater as the main source of water supply for various uses. Groundwater is straightforward to extract and it represents a unique and essential resource in dry regions [4]. Therefore, groundwater quality monitoring and control are critical for the long-term management of this vulnerable resource [4].

This study was conducted to evaluate the suitability of groundwater in the South Oued Righ region (Touggourt region) for agricultural uses by determining the irrigation water quality index (IWQI) then using the Geographical Information System (GIS) technology to sett up spatial distribution map. This method has been employed successfully and on a broad scale in recent years [5,6]. Through the integration of composite data, it provides a great insight into the state of groundwater. Until recently, researchers used to rely on the irrigation water standards set by the United States Salinity Laboratory (USSL, 1954) and Wilcox (1955) diagrams to assess the water for irrigation purposes. In 2010, Meireles et al. [7] developed an IWQI model to assess water used for irrigation purposes based on Electrical Conductivities (EC), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), chloride Cl^-, and bicarbonate (HCO^{3-}) parameters, which reflect soil salinity, sodicity hazards, and water toxicity to plants [8,9]. Many recent studies have shown the success of this approach and its widespread use in assessing the quality of water for agricultural uses [10–19]. The studies showed that this method is a quick way to get an overview of the groundwater state through the available and specific data of water and to prepare the spatial distribution of the quality as an indicator, allowing the best use of water for irrigation in the future. In a previous study, [20,21] investigated geothermal waters of the continental intercalary aquifer of the Oued Righ region that extend from southern palmeraie El Goug to Chott Merouane; this is based on a hydrogeochemical study that showed that the waters of the Albian aquifer of Oued Righ are undersaturated with respect to carbonate and evaporitic minerals. In effect, a dissolution of these minerals seems to contribute to the acquisition of the mineralization of these underground waters. On the other hand, the sample waters were mediocre to acceptable for irrigation.

While the study of [22] based on the water quality of the terminal complex aquifer for drinking water supply showed that they are not suitable, in reference to the standards of the World Health Organization (WHO) and to the standards Algerian drinking waters, they are highly mineralized and very hard. As for its quality for irrigation, based on Riverside standards, they settle in the class of mediocre waters. Similar to these studies, we divided the IWQI values of water samples in this study area into two cases: severe restriction or high restriction, which affirmed the vulnerability of the groundwater after taking into account the salinization as the main cause of water quality degradation. In general, the mechanisms that are responsible for the salinity of hydrological systems are diverse and complex. Thus, mineralization processes are related to the lithology of the aquifer by evaporites and carbonates. The phenomena of water−rock interaction are at the origin of the spatial variation of the groundwater geochemistry. On the other hand, climatic conditions are responsible for the variations of concentrations by precipitation (dissolution) and the evaporation due because of the high temperatures recorded in this region. The current study aims to assess the quality of groundwater and assess its suitability for irrigation in the South Oued Righ region by integrating GIS with the IWQI approach developed by [7].

2. Materials and Methods

2.1. Study Area Description

2.1.1. Location

The valley of Touggourt or, as its named, Righ valley, is a geographical entity located in south−eastern Algeria. It is located in the Righ Valley area, which is a rectangular lowland approximately 160 km long and 30–40 km wide, straddling the Wilayas, El−Oued, and Ouargla, with the characteristics of a desert. Palm groves cover a large part of its area. It is considered to be one of the largest centers of population in the Righ. It lies between 32°54′ to 34°09′ North latitude and 05°50′, 05°75′ East longitude as shown in Figure 1. It is bounded to the north by the Stil plateau, to the east by the Erg Oriental, to the south by the extension of the Erg Oriental, and to the west by the sandstone plateaus. This region is characterized by a depression elongated from South to North (towards the great chotts), the altitude passes gradually from +100 m at El−Goug in the upstream (the highest coast) to −30 m at Chott Marouane downstream [23].

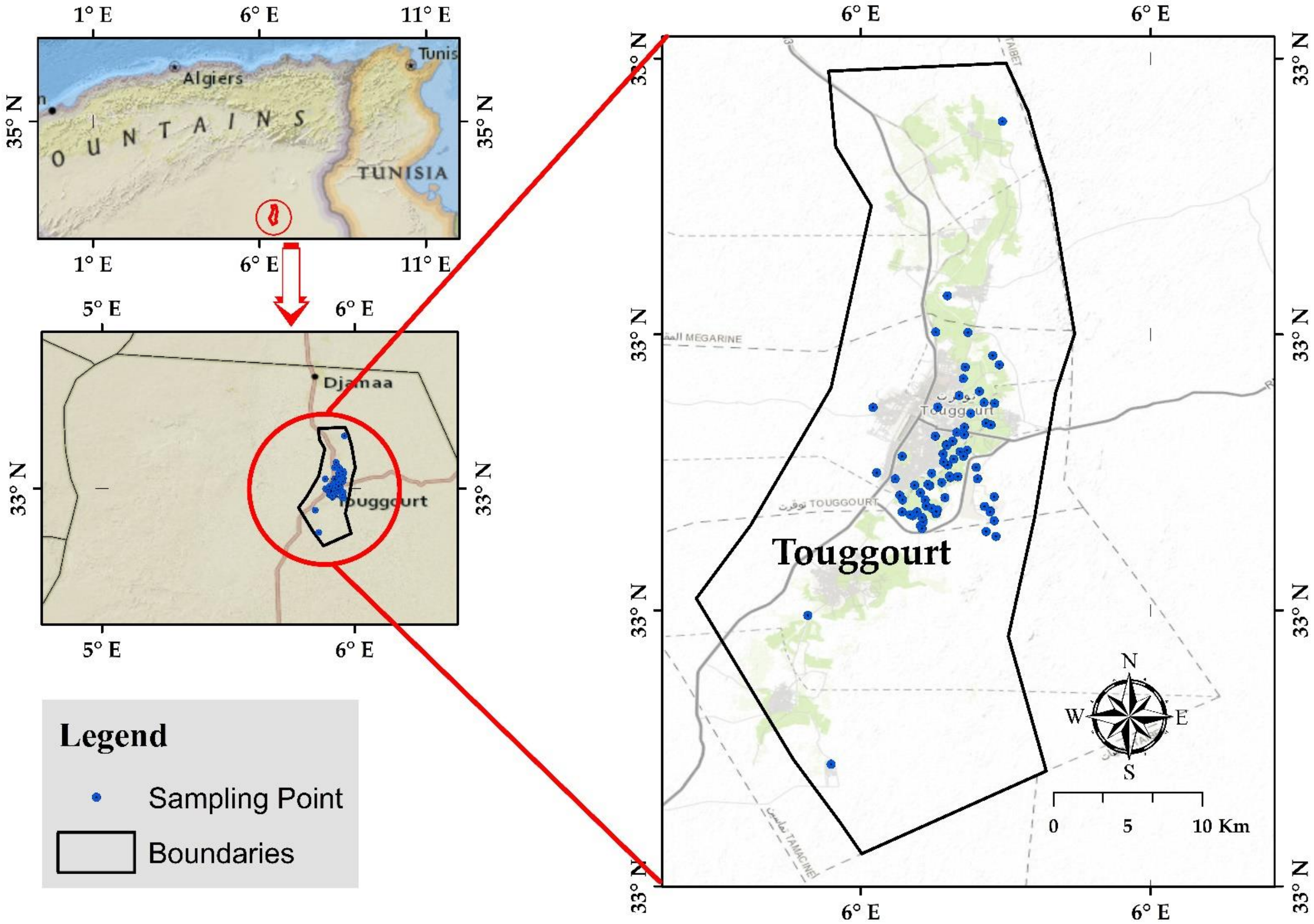


Figure 1. Location map of the sampling points.

2.1.2. Geology and Hydrogeology Aspect

The Wadi Righ region is a synclinal basin of the Lower Sahara (as shown in Figure 2), which is part of a large N−S trough. All the terrains, from Cambrian to Tertiary, are largely concealed beneath the Grand Erg Oriental. The depth of the Precambrian basement is located at a thickness of about 4000 m [24–28]. The lithostratigraphic correlation of 21 deep wells in the Oued Righ region using the Rockworks software allowed [29] to build the 3D geological model. The 3D geological model clearly shows the geometry of the geological units, which are identified and modeled from base to top: (1) Barremian;

(2) Aptian; (3) Albian; (4) Cenomanian; and (5) Turonian; (6) Senoninan; (7) Eocene; and (8) Mio-pliocene [29].

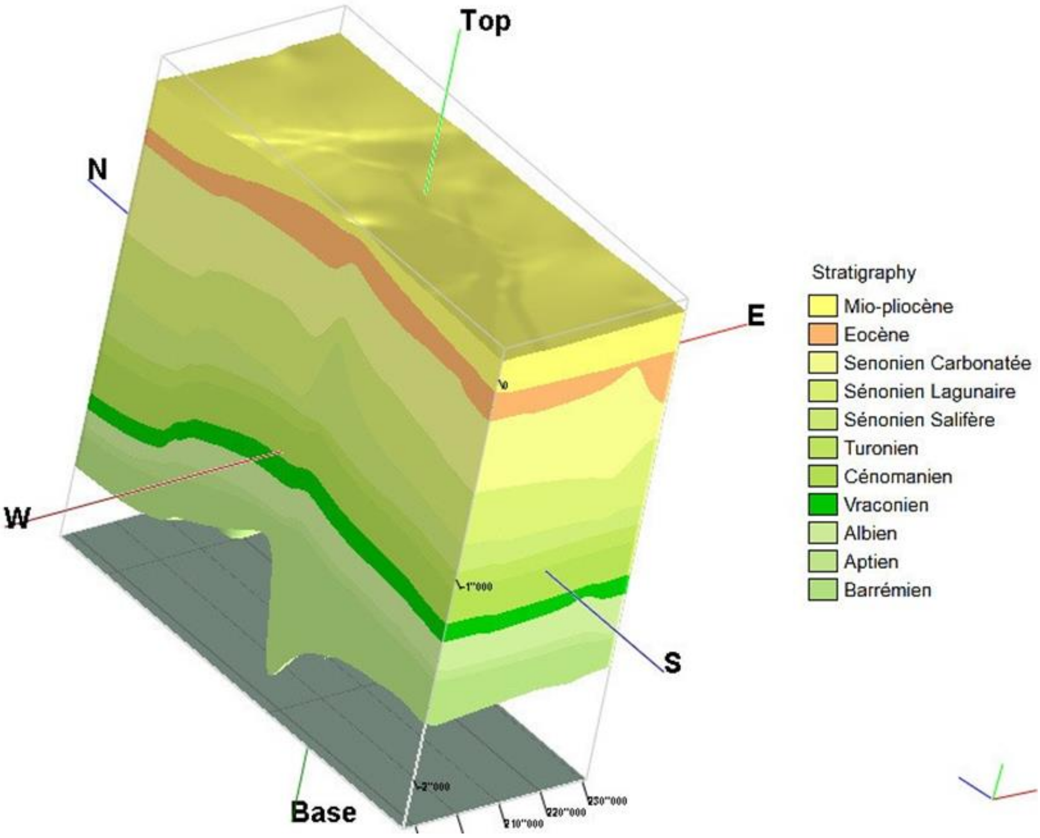


Figure 2. 3D geological model of the Oued Righ region [29].

The geological series allows distinguishing two important post-Paleozoic hydrogeological units [24,25]: the Terminal Complex (TC) and the Intercalary Continental (IC).

In the region of South Wadi Righ (Touggourt), there are three aquifers [24,27,30,31]:

- The first one is the deep and extensive Intercalary Continental: largely made up of sands and sandstones of Albian and Barremian age.
- The second is multilayered, and less extensive than the first called the Terminal Complex, consisting of two different sets (marine comprising limestone of Senonian-Eocene age and continental consisting of sands, gravels, sandstones with intercalation of gypsum and clay; Mio-Pliocene age, it is the first and second layer of TC) [32,33].
- The last one is a free superficial aquifer that overlies these two sets, called phreatic nappe contained in the fine to medium sands of Quaternary age (Figure 3).

In this study, the groundwater samples collected from terminal complex aquifer (TC) were exploited for agriculture usage.

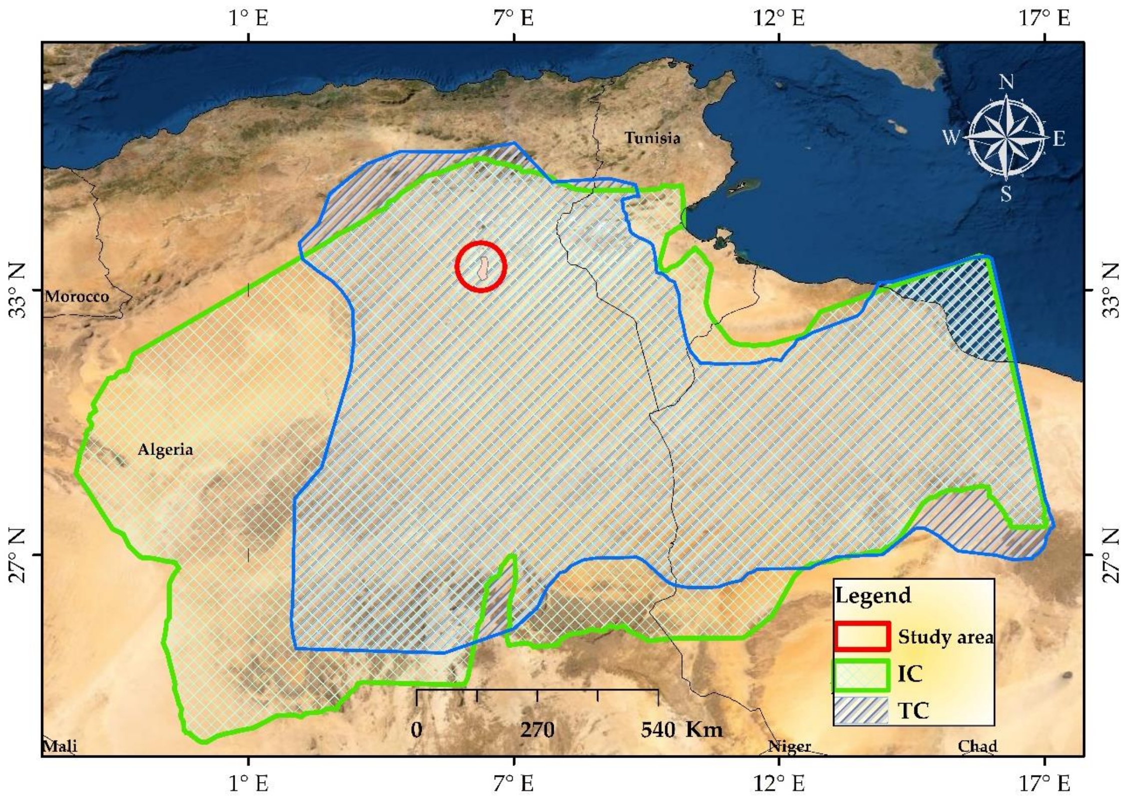


Figure 3. Map of The Northern Sahara Aquifer System [27].

2.2. Sampling and Analysis

The samples are taken in polyethylene vials with a capacity of 1000 mL. The bottles are rinsed beforehand with the water to be taken. In the case of an irrigation borehole, the samples were taken directly from the head of the borehole. In the case of a water tower, the samples were taken after the suspension of the bleaching process and emptying of the pipe [34]. In this study, a total of 72 water samples were collected during 2018–2021, which were identified with the number and coordinates of the water point, the date, and the depth and static level of the well. Samples were carried out from boreholes capturing the aquifer of the Terminal Complex, which is considered as a multilayer aquifer that is shallow and less extensive than the Intercalary Continental (IC); it consists of two different sets (marine constituted by limestones of Senonian-Eocene age, and continental constituted by sands, gravels, sandstones with intercalation of gypsum and clay, of Mio-Pliocene age.

These samples were stored according to the methods of [35] and subsequently transported in a cool box at 4 °C. At the ANRH laboratory in Ouargla, measurements and analyses were carried out using standard techniques. For each of the water samples, the parameters like temperature, pH, and electrical conductivity were measured immediately after sampling by tester of Hanna Instruments HI98129 Waterproof. Sulfates calcium, sodium, potassium, and chlorides were measured with the DR2000 spectrophotometer (HACH). The measurements of physicochemical parameters are performed by using Waterproof Handheld Eutech Instruments type (CYBER SCAN SERIES 600).

2.3. Irrigational Suitability Indices

The suitability of water quality for agricultural purposes is often evaluated based on some classifications of groundwater indices such as total dissolved solids (TDS), sodium absorption ratio (SAR), soluble sodium percentage (SSP), permeability index (PI), residual sodium bicarbonate (RSC), Magnesium absorption (MAR), and Kelly's ratio (KR).

The (SAR), (SSP), (RSC), (PI), (KR), and (MHR) were calculated using the standard formulas mentioned as follows:

$$\mathrm{SAR} = \mathrm{Na}^{+} / \sqrt{\left(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}\right)/2} \quad (1)$$

$$\%\mathrm{Na} = (\mathrm{Na}^{+} + \mathrm{K}^{+})/(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{Na}^{+}) \quad (2)$$

$$\mathrm{RSC} = (\mathrm{HCO}^{3-} + \mathrm{CO_3}^{2-}) - (\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}) \quad (3)$$

$$\mathrm{PI} = \left(\mathrm{Na}^{+} + \sqrt{\mathrm{HCO}_3^{-}}\right) \times 100/\left(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{Na}^{+}\right) \quad (4)$$

$$\mathrm{KR} = \mathrm{Na}^{+}/\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} \quad (5)$$

$$\mathrm{MHR} = (\mathrm{Mg}^{2+}/\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}) \times 100 \quad (6)$$

where all ions are expressed in meq/L.

2.4. Irrigation Water Quality Index (IWQI)

The IWQI was established by [7] to assess the water suitability for agricultural purposes. It is a simple method used for the analysis of general quality using a group of parameters [6] with reducing large amounts of data to a single number, usually dimensionless, thus defining the IWQI by a single number [8]. The following equation (Equation (7)) is used to calculate the irrigation water quality parameter (qi) in this model, according to the tolerance limits of the parameters as shown in Table 1.

$$\mathrm{qi} = \mathrm{qimax} - [(\mathrm{xij}-\mathrm{xinf}) \times \mathrm{qiamp}]/\mathrm{qamp} \quad (7)$$

where qi is the quality of the ith parameter, qimax denotes the maximum value of qi for each class; xij denotes the observed value of each parameter; xinf denotes the value corresponding to the lower limit class of the parameter; qiamp is the class amplitude of the parameter; and xampp is the last value of the parameter expressed in the upper limit of the identified chemical parameter.

Table 1. Parameter-limiting values for quality measurements (qi) [7].

q_i	EC (μS cm^{-1})	SAR (mmol L^{-1})$^{1/2}$	Na$^+$ (meq L^{-1})	Cl$^-$ (meq L^{-1})	HCO$_3{}^-$ (meq L^{-1})
85–100	$200 \leq EC < 750$	$2 \leq SAR < 3$	$2 \leq Na < 3$	$1 \leq Cl < 4$	$1 \leq HCO_3 < 1.5$
60–85	$750 \leq EC < 1500$	$3 \leq SAR < 6$	$3 \leq Na < 6$	$4 \leq Cl < 7$	$1.5 \leq HCO_3 < 4.5$
35–60	$1500 \leq EC < 3000$	$6 \leq SAR < 12$	$6 \leq Na < 9$	$7 \leq Cl < 10$	$4.5 \leq HCO_3 < 8.5$
0–35	$EC < 200$ or $EC \geq 3000$	$SAR < 2$ or $SAR \geq 12$	$Na < 2$ or $Na \geq 9$	$Cl < 1$ or $Cl \geq 10$	$HCO_3 < 1$ or $HCO_3 \geq 8.5$

After we standardize the wi values, their sum is equal to 1 according to Equation (8) [10].

$$\mathrm{wi} = \Sigma^{k}{}_{j=1} F_j\, A_{ij} / \Sigma^{k}{}_{j=1} \Sigma\, n_{j=1} F_j \quad (8)$$

where wi signifies the weight parameter for the WQI; F implies the component 1 auto value; Aij is the ability of the parameters i by factor j; i is the number of chemical parameters designated by the model (1 to n); and j is the number of factors selected in the model (1 to k) [10]. Table 2 present the relative weight of every parameter. The following equation is used to calculate the IWQI values.

$$\mathrm{IWQI} = \boldsymbol{\Sigma}^{k}{}_{j=1}\, q_j \cdot \mathrm{wi} \quad (9)$$

Table 2. Relative weight wi of each parameter in IWQI [7].

Parameters	Wi
EC	0.211
Na	0.204
HCO_3	0.202
Cl	0.194
SAR	0.189
Total	1

The IWQI ranges between 0 and 100, which functions according to its concentration or measurement; wi is the normalized weight of the ith parameter, which varies from one parameter to another according to its weight and relative importance to the quality of groundwater.

The IWQI proposed is divided into classes based on the existing water quality indices; these categories have been developed based on the risks posed by salinity, water infiltration reduction into the soil, and plant toxicity [36].

The concentration ions of Ca++, Mg++, Na^+, Cl^-, and HCO_3^- in meq L^{-1} were determined using laboratory experiments. Table 3 shows the physical and chemical parameters.

Table 3. Hydrochemical properties of groundwater samples in study area.

Sample Number	Parameters									
	pH	EC	TDS	TH	Ca	Mg	Na	Cl	SO_4	HCO_3
W1	7.06	3.84	1920	1020	10.02	10.53	15.22	19.78	10.75	2.33
W2	7.15	4.27	2135	1230	10.62	11.54	19.57	20.65	18.75	2.25
W3	7.16	3.05	1525	840	8.42	8.51	13.61	18.81	7.96	2.11
W4	7.25	2.83	1415	900	10.02	8.1	10	16.26	10	2.25
W5	7.08	6.26	3130	1420	12.63	16	29.57	37.54	23.96	2.69
W6	6.67	4.73	2365	1520	13	17.62	19.57	26.44	16.67	2.47
W7	6.96	7.19	3595	2010	20.84	19.64	26.09	37.79	32.21	2.69
W8	7.74	4.53	2265	1300	13.83	12.36	14.78	25.93	19.4	2.25
W9	6.8	6.33	3165	1650	26.05	7.17	26.09	30.17	21.38	1.6
W10	7.13	12.48	6240	3300	31.26	35.24	39.13	78.55	60	2
W11	6.94	6.5	3250	1800	16.83	17.42	26.52	30.51	29.17	2.39
W12	6.93	5.89	2945	2080	21.44	20.45	17.91	23.26	30.1	2.11
W13	7.2	7.1	3550	1973	7.23	32.23	13.85	24.41	27.08	1.95
W14	7.2	6.7	3350	1930	7.24	31.36	36.06	51.07	21.04	2.2
W15	7.24	6.9	3450	1813	6.57	29.68	19.66	25.72	28.13	2.06
W16	7.3	6.6	3300	1822	7.32	29.12	26,39	32.42	27.65	2.73
W17	7.28	7.9	3950	2285	7.97	37.74	18.66	35.03	27.21	2.24
W18	7	7.3	3650	1888	6.83	30.94	16.03	30.27	21.67	1.95
W19	7.6	7.1	3550	1729	5.58	29	12.79	22.75	22.5	2.24
W20	7.2	7.4	3700	1722	6.95	27.5	38.78	42.4	27.29	2.04
W21	7.3	5.8	2900	1741	8.96	25.87	43.32	50.04	25.25	2.28
W22	7.2	6.1	3050	1835	6.43	30.28	14.25	22.4	26.5	2.17
W23	7.3	6	3000	1600	6.76	25.25	20.13	24.88	25.63	1.98
W24	7.4	5.9	2950	1686	6.53	27.19	32.17	41.46	22.71	2.08
W25	7.4	5.6	2800	1797	4.05	31.88	22.61	29.66	27.19	1.95
W26	7.2	5.5	2750	1488	4.1	25.66	38.99	40.61	26.46	2.03
W27	7.4	6.2	3100	1415	4	24.31	41.65	43.17	25.21	1.94
W28	7.1	5.4	2700	1642	5.66	27.19	34.69	41.18	24.79	2.2
W29	7.2	4.9	2450	1502	5.62	24.42	37	43.86	21.71	2.36
W30	7.35	5.2	2600	1390	4.41	23.38	30.51	30.31	25.63	2.21
W31	7	6.4	3200	1848	7.62	29.33	45.97	52.04	28.54	1.81
W32	7.1	6.5	3250	1372	5.6	21.83	41.65	43.15	25.21	1.93

Table 3. *Cont.*

Sample Number	Parameters									
	pH	EC	TDS	TH	Ca	Mg	Na	Cl	SO_4	HCO_3
W33	7	6.9	3450	2044	9.88	31	17.87	26.31	27.33	2.2
W34	7.1	6.9	3450	1849	6.77	30.2	19.28	32	22.08	2.17
W35	7.15	6.8	3400	1728	9.97	24.59	20.22	31.35	21.46	2.3
W36	7.2	4.9	2450	1631	5.71	26.92	61.28	70.31	20.17	2.48
W37	7.2	5.8	2900	1702	5.45	28.59	13.94	20.9	25.1	2.36
W38	7.2	9.6	4800	2491	7.55	42.26	24.77	44.8	27.5	2.26
W39	7.3	10	5000	2020	6.68	33.72	42.04	52.14	27.81	1.95
W40	7.25	10.2	5100	2055	7.37	33.74	61.32	70.04	28.54	2.73
W41	7.3	7.7	3850	2229	8.56	36.02	20.17	34.32	27.69	1.93
W42	7.1	7.9	3950	2258	8.14	37.02	14.03	33.24	24.08	2.11
W43	7.15	7.8	3900	2137	6.71	36.02	30.82	43.12	28.33	1.98
W44	7.2	7	3500	2075	7.8	33.7	23.3	40.99	21.67	2.09
W45	6.9	6.4	3200	2537	8.31	42.43	34.32	55.23	25.1	3.9
W46	7.3	5.8	2900	2373	10.05	37.42	29.74	44.51	30.83	2.66
W47	7.3	6	2280	2446	9.7	39.23	20.57	37.32	28.56	2.15
W48	7.2	6.3	1405	2693	9.2	44.65	15.17	36.48	28.65	2.99
W49	7	7.5	2380	2310	10.6	35.61	23.3	39.52	25.67	2.5
W50	7.25	8.4	2740	2311	7.4	38.82	22.48	37.75	28.13	1.86
W51	7.4	9.2	2295	2605	8.35	43.75	20.78	36	30.94	3.87
W52	7.1	5.9	2750	1893	6.04	31.83	26.54	35.23	27.73	2.27
W53	7.78	5.78	2890	2249	19.15	25.82	19.57	14.73	48.75	2.23
W54	7.1	5.95	2975	2115	18.2	24.1	16.96	23.1	31.58	1.36
W55	7.36	6.12	3060	2741	20.6	34.21	16.87	30.65	42.38	1.56
W56	7.14	6.63	3315	2414	14.65	33.63	17.15	28.65	37.08	1.59
W57	7.22	6.46	3230	2602	18.9	33.14	17.04	24.03	40.81	2.08
W58	7.12	6.29	3145	2933	20.75	37.91	29.26	34.34	54.96	1.9
W59	7.91	6.29	3145	2806	23.15	32.98	19.7	27.41	45.06	2.03
W60	7.4	6.46	3230	3191	23.85	39.97	18.3	27.55	54.96	1.95
W61	7.28	6.63	3315	2421	19.3	29.11	18.48	17.1	45.75	1.85
W62	7.16	6.8	3400	2688	19.8	33.96	22.43	27.18	50.38	1.79
W63	7.2	6.97	3485	3021	23.65	36.76	24.26	28.73	57.21	1.98
W64	7.21	5.95	2975	3264	22.6	42.68	26.57	38.31	45.15	1.87
W65	7.07	7.82	3910	2584	15.75	35.94	25.61	25.92	44.38	1.72
W66	7.7	7.99	3995	2165	17.8	25.49	21.43	22.87	41.31	1.61
W67	7.9	8.33	4165	2831	19.45	37.17	23.39	34.11	39.52	2.16
W68	7.52	8.5	4250	3001	20.3	39.72	27.13	37.44	44.56	2.02
W69	7.64	7.31	3655	2952	19.9	39.14	28.61	37.41	44.5	1.36
W70	7.41	8.5	4250	3185	19.45	44.24	25.74	41.86	49.71	1.57
W71	7.18	9.18	4590	2971	16.25	43.17	31.13	35.13	52.65	2.05
W72	7.26	7.48	3740	3246	17.8	47.12	28.35	37.8	53.98	1.82

All parameters except pH are defined in meq L^{-1}; TDS: total dissolved solids; TH: total hardness.

2.5. Geospatial Analysis

GIS could be a powerful tool for water supply management, zone mapping, determining water availability, risk assessment of environmental problems, producing solutions, and making quick policy decisions [37,38]. In this paper, we used Microsoft Excel 2019 software for the calculation of parameters and preparation of the data in ArcGIS 10.3 to prepare the spatial distribution maps of quality groundwater parameters such as electrical conductivity (EC), total dissolved solids (TDS), water quality indices (Table 4) (SAR, PI, SSP, RSC, MHR, KR), anions, cations, and irrigation water quality index (IWQI).

Table 4. Water Quality Index Characteristics [7].

IWQI	Water Use Restrictions	Recommendation	
		Soil	Plant
85–100	No restriction (NR)	«May be used for the majority of soils with low probability of causing salinity and sodicity problems, with it being recommended for leaching within irrigation practices, except for in soils with extremely low permeability.»	«No toxicity risk for most plants»
70–85	Low restriction (LR)	«Recommended for use in irrigated soils with light texture or moderate permeability, being recommended for salt leaching. Soil sodicity in heavy-texture soils may occur, with it being recommended to avoid its use in soils with high clay.»	«No toxicity risk for most Plants.»
55–70	Moderate restriction (MR)	«May be used in soils with moderate to high permeability values, with it being suggested for moderate leaching of salts.»	"«Plants with moderate tolerance to salts may be grown.»
40–55	High restriction (HR)	«May be used in soils with high permeability without compact layers. High frequency irrigation schedule should be adopted for water with EC above 2000 µS cm^{-1} and SAR above 7.0.»	"«Should be used for irrigation of plants with moderate to high tolerance to salts with special salinity control practices, except water with low Na, Cl, and HCO_3 values.»
0–40	Severe restriction (SR)	«Should avoid its use for irrigation under normal conditions. In special cases, may be used occasionally. Water with low salt levels and high SAR require gypsum application. In high saline content, water soils must have high permeability, and excess water should be applied to avoid salt accumulation.»	«Only plants with high salt tolerance, except for waters with extremely low values of Na, Cl, and HCO_3.»

3. Results and Discussion

3.1. Hydrochemical Properties of Groundwater Quality

The findings of the chemical analysis of the groundwater in the study area show a wide variation in the different individual parameters (Table 3). The pH values of the groundwater samples range from 6.67 to 7.91 with an average value of 7.24. In general, the normal pH range for irrigation water is about 6.5–8.4 [39], indicating that the groundwater in this study area is acceptable. An abnormal value is a warning that the water requires further evaluation. Irrigation water with a pH outside the normal range may cause a nutritional imbalance or may contain a toxic ion [39].

3.1.1. Salinity Hazard

The electrical conductivity levels reflected by salinity damage are highly important considerations in evaluating the suitability of water used for irrigation because of its effect on the osmotic pressure of the soil solution and the ability of plants to absorb water via its roots [35]. Table 3 indicated a high electrical conductivity value that ranged between 4.9 and10.2 dS cm^{-1} in the TC aquifer. According to some previous study [11], it can be concluded that the salinity and water mineralization is caused by geological origin. This is explained by the lithological composition of the layers that contain evaporated salts, gypsum, and dolomite, causing the water quality to deteriorate.

3.1.2. Sodicity Hazard

The graphical representation in Figure 4 shows a strong correlation between Na^+ and Cl^-, which is explained by the mechanism of salinity acquisition in natural waters due to the dissolution of halite contained in evaporites. This increase is due to the phenomenon of base exchange, as water interacts with clay minerals that fix a calcium ion after the release of two sodium ions [21,22].

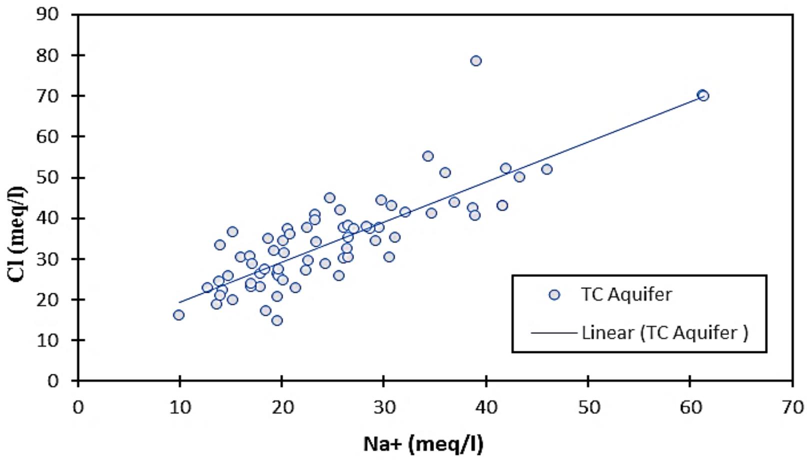


Figure 4. Na vs. Cl in TC Oued Righ region aquifer.

High concentrations of sodium are undesirable in water because sodium adsorbs on to the soil cation exchange sites, causing soil aggregates to break down (deflocculation), sealing the pores of the soil, and making it impermeable to water flow [40].

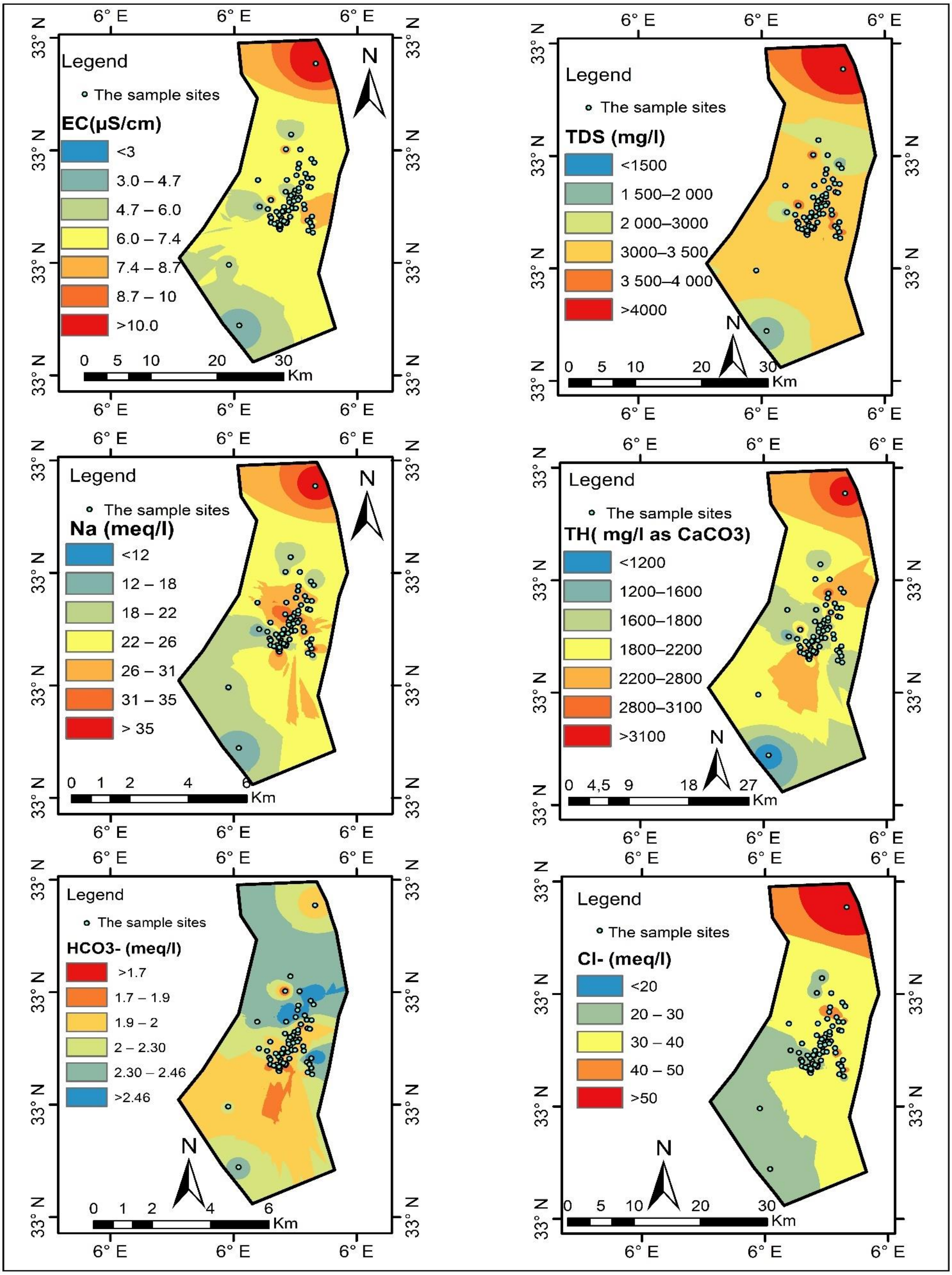
The sodium ion (Na^+) concentration of the water samples ranged between 230 and 1410 mg L^{-1} with a mean of 588.07 mg L^{-1}. Figure 5 shows the spatial distributions of the sodium ion (Na^+) concentrations in the study area. The present results show a slight variation in the sodium distribution patterns.

3.1.3. Alkalinity Hazard

The Sodium Adsorption Ratio (SAR), the most common water quality characteristic that determines the normal rate of water infiltration, is used to indicate alkaline danger. SAR is calculated by using equation (01) [39]. The SAR values in the water samples studied ranged from 2.92 to 15.17 meq/L; these values were input into a GIS system to construct a spatial distribution map of SAR as shown in Figure 5. According to SAR categories, the groundwater is unsuitable for irrigation if the value is greater than 18 [41]. According to the Richards classification [42] based on SAR values as shown in Table 5, all of the samples were found to be suitable for irrigation purposes in the investigated groundwater.

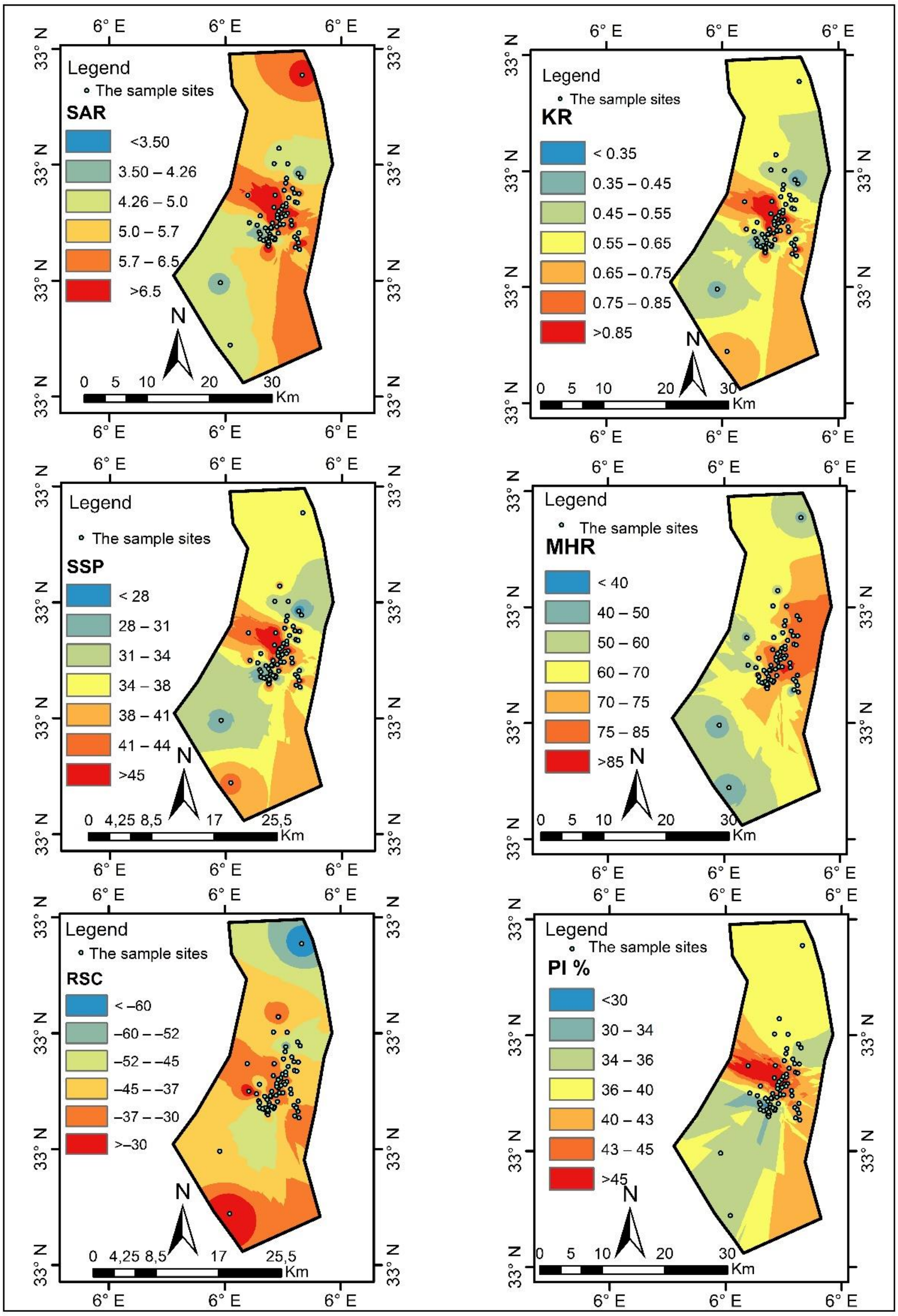
Table 5. Water classification based on SAR values [43].

Sodium Adsorption Ratio (SAR)	Status
Below 10	Excellent
10–18	Good
18–26	Doubtful
Above 26	Unsuitable



(**a**)

Figure 5. *Cont.*



(**b**)

Figure 5. (**a**) Geospatial distribution of EC, TDS, Na, TH, HCO_3, and Cl. (**b**). Geospatial distribution of SAR, KR, SSP, MHR, RSC, and PI%.

3.1.4. Toxicity and Miscellaneous Effects

Chloride concentrations is the other parameter introduced as an index, which defines the specific toxicity of ions. In the study area, the chemical analysis of water samples showed that the average of chloride ion concentrations is 1234.23 mg L^{-1}, whereas the maximum and minimum values are 2749.38 mg L^{-1}, and 523 mg L^{-1}, respectively (as shown in Table 3). The spatial distributions of chloride ion concentrations are shown in Figure 4. This variation in chloride may be due to the geological composition of the study area or agricultural drainage, which is discharged into the Oued Righ stream. Plants are affected by chloride concentration for two reasons; firstly, chlorine is a mineral nutrient and its deficiency causes metabolic problems that interfere with growth; secondly, excess chloride results in severe physiological dysfunctions impairing both quality and yield formation [44]. Compared to the criteria mentioned in Table 5, the chloride ion concentrations in all water samples were very high. Thus, in terms of chloride ions, the water may not be suitable for irrigating sensitive crops (Table 6).

Table 6. Chloride classification of irrigation water [43].

Chloride (mg/L)	Effect on Crops
Below 70	Generally safe for all plants
70–140	Sensitive plants show injury
141–350	Moderately tolerant plants show injury
Above 350	Can cause severe problems

The bicarbonates ion HCO_3^- values of water samples ranged between 83 and 238 mg L^{-1} with a mean of 131,11 mg L^{-1} (Table 3). The bicarbonate concentrations of less than 90 mg L^{-1} (1.5 meq/L) are generally regarded as optimum for irrigation [39]. Figure 5 shows the spatial distributions map of bicarbonate ion concentrations in the study area. The bicarbonate ion concentration is low in comparison to the chloride and sulfate ion concentrations, which range from 382 to 2880 mg L^{-1} with averages of 1493.17 mg L^{-1} (Table 3 and Figure 5). The presence of bicarbonates in water is due to the action of carbon dioxide in water on carbonate rocks such as limestone and dolomite, bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) produce an alkaline environment. In combination with calcium and magnesium, they cause carbonate hardness [45]. The samples waters are very hard and show excessive mineralizations, expressed by electrical conductivities, with it going up to 8000 μS·cm^{-1} in the most exceptional cases (detailed results are presented in Appendix A Table A1); the obtained results show a spatial evolution of the salinity in the direction North to South. The salinity is locally strong in the central part of Oued Righ valley.

The high salinity in the study area, combined with high bicarbonate concentrations, suggests a possible hydraulic relationship with relatively unmineralized surface (pluvial) water [16,46]. The predominant trend of cations in the Terminal Complex Aquifer (TC) is $Na+ > Ca++ > Mg++$; while the sodium is the dominant cation in the Terminal Complex Aquifer. The major anions abundance in the terminal complex aquifer was in the following order: $SO_4^{2-} > Cl^- > HCO_3^-$. The terminal complex aquifer is rich with a high concentration of sulphate ions, which is the dominant anion.

The Table 7 shows the IWQI values. The geospatial distribution maps of all the characteristics listed above were created using the inverse interpolation technique (IDW) to produce a database of groundwater quality for irrigation water in the study area (Figure 5). As a result, these maps might be used to assess the groundwater quality and determine the best locations for new wells with the fewest dangerous pollutants.

Table 7. IWQI classes and values of groundwater samples.

Sample Number	IWQI Values	IWQI Class	Sample Number	IWQI Values	IWQI Class
W1	46.39	HR	W37	45.7	HR
W2	45.3	HR	W38	39.66	SR
W3	53.96	HR	W39	31.05	SR
W4	54.9	MR	W40	19.17	SR
W5	35.07	SR	W41	43.21	HR
W6	44.36	HR	W42	46.99	HR

Table 7. *Cont.*

Sample Number	IWQI Values	IWQI Class	Sample Number	IWQI Values	IWQI Class
W7	40.36	HR	W43	35.41	SR
W8	45.9	HR	W44	42.03	HR
W9	38.89	SR	W45	30.68	SR
W10	28.41	SR	W46	35.39	SR
W11	37.05	SR	W47	43.5	HR
W12	45.29	HR	W48	45.69	HR
W13	45.58	HR	W49	41.1	HR
W14	33.73	SR	W50	42.22	HR
W15	44.11	HR	W51	38.08	SR
W16	36.2	SR	W52	37.35	SR
W17	42.69	HR	W53	45.58	HR
W18	44.47	HR	W54	49.4	HR
W19	48.24	HR	W55	46.04	HR
W20	33.67	SR	W56	45.71	HR
W21	32.54	SR	W57	45.26	HR
W22	45.77	HR	W58	42.62	HR
W23	44.69	HR	W59	44.71	HR
W24	35.91	SR	W60	45.11	HR
W25	44.17	HR	W61	45.92	HR
W26	34.69	SR	W62	44.38	HR
W27	33.57	SR	W63	43.49	HR
W28	35.42	SR	W64	43.14	HR
W29	34.51	SR	W65	43.39	HR
W30	37.11	SR	W66	44.44	HR
W31	32.56	SR	W67	41.94	HR
W32	33.35	SR	W68	41.19	HR
W33	44.22	HR	W69	45.36	HR
W34	43.42	HR	W70	42.06	HR
W35	43.02	HR	W71	40.16	HR
W36	22.28	SR	W72	42.04	HR

3.2. Irrigation Water Quality Index

The use of GIS clearly showed the variance in the IWQI index map, as shown in Figure 6, where the IWQI decreased from south to north because of the electrical conductivity, whereas SAR, sodium ion, and chloride ion increased in this direction, as shown in Figure 5a,b, respectively.

According to the IWQI map of the study area, the appropriateness of groundwater for irrigation is categorized into two water usage limitations. We found that 65% of groundwater has high use restrictions, indicating that it can cause serious damage to the soil, resulting in damage and hurt to plants. In this case, a modest salt filtration process is required to prevent plant damage. The remaining 35% of samples were classified as severe restriction (SR), meaning that they should be avoided and not used for irrigation in normal conditions. However, this water can be used according to the suggestion in

Table 4 if the permeability of soil is high; particularly when an excess of irrigation water is applied, which avoids the accumulation of salts. Fortunately, the study area is located in the north great Algeria's Sahara, which has extremely high soil permeability (sand), but excessive leaching of the salt from the crop root zone will further pollute the ground water. Therefore, the best that can be recommended is to provide adequate supplies for drainage with planting salt-tolerant crops (see Table 4).

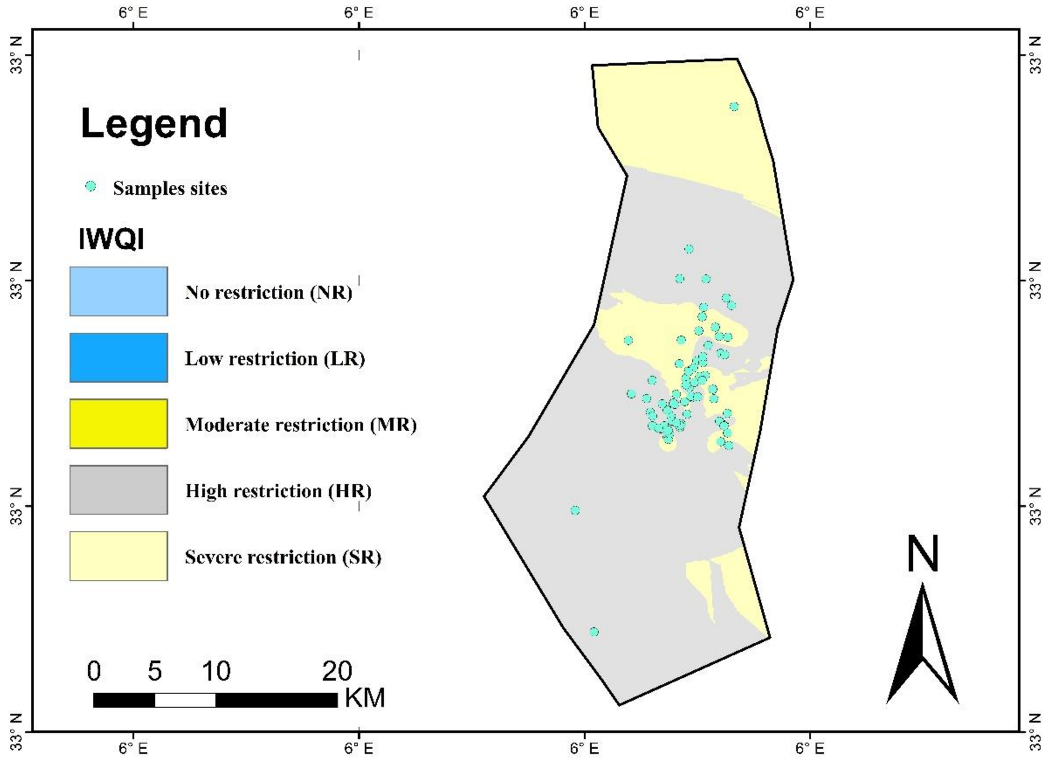


Figure 6. Irrigation water quality index map (IWQI).

4. Conclusions

Based on the findings of this study, we found that 35% and 65% of the groundwater in the study area are categorized as "severe restriction" and "high restriction", respectively. The groundwater could be used for irrigation in only soils with high permeability, where salt-tolerant crops are grown. In such a situation, provision should be made for adequate drainage to avoid further salt contamination of the groundwater.

The GIS and Irrigation Water Quality Index (IWQI) methods are widely used because they are valuable and effective tools for summarizing and reporting monitoring data to decision makers in order to understand groundwater quality status and to have the potential for improved use in the future to develop a strategy to deal with similar problems in other places, especially for the sustainable management of groundwater resources in the study area.

Author Contributions: Conceptualization, N.A.-A., A.K., K.B., S.K. (Samir Kateb), S.K. (Saber Kouadri), H.M.N., N.S.M., M.M.A.E. and K.M.K.; methodology, N.A.-A., A.K., K.B., S.K. (Samir Kateb), S.K. (Saber Kouadri), H.M.N., N.S.M., M.M.A.E. and K.M.K.; software, N.A.-A., A.K., K.B., S.K. (Samir Kateb), S.K. (Saber Kouadri), H.M.N., N.S.M., M.M.A.E. and K.M.K.; validation, N.A.-A., A.K., K.B., S.K. (Samir Kateb), S.K. (Saber Kouadri), H.M.N., N.S.M., M.M.A.E. and K.M.K.; formal analysis, N.A.-A., A.K., K.B., S.K. (Samir Kateb), S.K. (Saber Kouadri), H.M.N., N.S.M., M.M.A.E. and K.M.K.; investigation, N.A.-A., A.K., K.B., S.K. (Samir Kateb), S.K. (Saber Kouadri), H.M.N., N.S.M., M.M.A.E. and K.M.K.; resources, N.A.-A., A.K., K.B., S.K. (Samir Kateb), S.K. (Saber Kouadri), H.M.N., N.S.M., M.M.A.E. and K.M.K.; data curation, N.A.-A., A.K., K.B., S.K. (Samir Kateb), S.K. (Saber Kouadri), H.M.N., N.S.M., M.M.A.E. and K.M.K.; writing—original draft preparation, A.K., K.B., S.K. (Samir Kateb), S.K. (Saber Kouadri), H.M.N., N.S.M., M.M.A.E. and K.M.K.; writing—review and editing, N.A.-A.,

A.K., K.B., S.K. (Samir Kateb), S.K. (Saber Kouadri), H.M.N., N.S.M., M.M.A.E. and K.M.K.; visualization, N.A.-A., A.K., K.B., S.K. (Samir Kateb), S.K. (Saber Kouadri), H.M.N., N.S.M., M.M.A.E. and K.M.K.; supervision, N.A.-A., A.K., K.B., S.K. (Samir Kateb), S.K. (Saber Kouadri), H.M.N., N.S.M., M.M.A.E. and K.M.K.; project administration, N.A.-A., M.M.A.E. and K.M.K.; funding acquisition, N.A.-A., M.M.A.E. and K.M.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Department of Civil Environmental and Natural Resources Engineering, Lulea University of Technology, Lulea, Sweden. Also, this research work was supported by the Deanship of Scientific Research at King Khalid University under Grant number RGP. 2/246/43.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data used to support the findings of this study are included within the article.

Acknowledgments: The Authors extend their thanks to the Department of Civil Environmental and Natural Resources Engineering, Lulea University of Technology, Lulea, Sweden for funding this research work. Also, the Authors extend their thanks to the Deanship of Scientific Research at King Khalid University for funding this work through the small research groups under grant number RGP. 2/246/43. Also, we would like to thank the staff of ANRH Regional Directorate of Touggourt who assisted us in providing the data used in this study.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Irrigation water quality parameters of groundwater quality.

Sample Number	EC	SAR	KR	Na%	PI	RSC	MH	Sample Number	EC	SAR	KR	Na %	PI	RSC	MH
W1	3.84	4.75	0.74	42.54	46.81	−18.22	51.24	W37	5.8	3.38	0.41	29.054	32.26	−31.68	83.99
W2	4.27	5.88	0.88	46.89	50.48	−19.91	52.08	W38	9.6	4.96	0.5	33.213	35.23	−47.55	84.84
W3	3.05	4.68	0.8	44.57	49.33	−14.81	50.27	W39	10	9.35	1.04	50.995	52.69	−38.45	83.47
W4	2.83	3.32	0.55	35.56	40.9	−15.87	44.7	W40	10.2	13.53	1.49	59.865	61.48	−38.38	82.07
W5	6.26	7.82	1.03	50.81	53.63	−25.93	55.89	W41	7.7	4.27	0.45	31.151	33.3	−42.65	80.8
W6	4.73	5.00	0.64	38.99	42.12	−28.14	57.54	W42	7.9	2.95	0.31	23.703	26.16	−43.05	81.98
W7	7.19	5.80	0.64	39.19	41.65	−37.79	48.52	W43	7.8	6.67	0.72	41.903	43.82	−40.75	84.3
W8	4.53	4.09	0.56	36.09	39.75	−23.93	47.19	W44	7	5.12	0.56	35.957	38.19	−39.41	81.2
W9	6.33	6.40	0.79	43.98	46.12	−31.62	21.59	W45	6.4	6.81	0.68	40.348	42.67	−46.84	83.62
W10	12.48	6.79	0.59	37.04	38.38	−64.51	52.99	W46	5.8	6.10	0.63	38.518	40.63	−44.81	78.83
W11	6.5	6.41	0.77	43.64	46.19	−31.86	50.85	W47	6	4.16	0.42	29.597	31.71	−46.78	80.18
W12	5.89	3.91	0.43	29.95	32.38	−39.79	48.82	W48	6.3	2.92	0.28	21.979	24.48	−50.86	82.92
W13	7.1	3.12	0.35	25.98	28.6	−37.51	81.68	W49	7.5	4.85	0.5	33.52	35.8	−43.71	77.06
W14	6.7	8.21	0.93	48.30	50.29	−36.4	81.24	W50	8.4	4.68	0.49	32.722	34.71	−44.36	83.99
W15	6.9	4.62	0.54	35.16	37.73	−34.19	81.88	W51	9.2	4.07	0.4	28.513	31.21	−48.23	83.97
W16	6.6	6.18	0.72	42.00	44.63	−33.71	79.91	W52	5.9	6.10	0.7	41.205	43.54	−35.6	84.05
W17	7.9	3.90	0.41	28.99	31.31	−43.47	82.56	W53	5.78	4.13	0.44	30.322	32.64	−42.74	57.42
W18	7.3	3.69	0.42	29.80	32.39	−35.82	81.92	W54	5.95	3.69	0.4	28.62	30.59	−40.94	56.97
W19	7.1	3.08	0.37	27	30.16	−32.34	83.86	W55	6.12	3.22	0.31	23.535	25.28	−53.25	62.42
W20	7.4	9.34	1.13	52.96	54.91	−32.41	79.83	W56	6.63	3.49	0.36	26.211	28.14	−46.69	69.66
W21	5.8	10.38	1.24	55.43	57.36	−32.55	74.28	W57	6.46	3.34	0.33	24.667	26.75	−49.96	63.68
W22	6.1	3.33	0.39	27.96	30.85	−34.54	82.48	W58	6.29	5.40	0.5	33.28	34.85	−56.76	64.63
W23	6	5.03	0.63	38.61	41.31	−30.03	78.88	W59	6.29	3.72	0.35	25.979	27.86	−54.1	58.76
W24	5.9	7.84	0.95	48.82	51.01	−31.64	80.63	W60	6.46	3.24	0.29	22.284	23.98	−61.87	62.63
W25	5.6	5.33	0.63	38.62	41.01	−33.98	88.73	W61	6.63	3.76	0.38	27.627	29.66	−46.56	60.13
W26	5.5	10.11	1.31	56.71	58.79	−27.73	86.22	W62	6.8	4.33	0.42	29.44	31.2	−51.97	63.17
W27	6.2	11.07	1.47	59.53	61.52	−26.37	85.87	W63	6.97	4.41	0.4	28.652	30.31	−58.43	60.85
W28	5.4	8.56	1.06	51.36	53.56	−30.65	82.77	W64	5.95	4.65	0.41	28.928	30.42	−63.41	65.38
W29	4.9	9.55	1.23	55.19	57.48	−27.68	81.29	W65	7.82	5.04	0.5	33.131	34.83	−49.97	69.53
W30	5.2	8.19	1.1	52.33	54.88	−25.58	84.13	W66	7.99	4.61	0.5	33.112	35.07	−41.68	58.88
W31	6.4	10.70	1.24	55.44	57.06	−35.14	79.38	W67	8.33	4.40	0.41	29.234	31.07	−54.46	65.65
W32	6.5	11.25	1.52	60.29	62.3	−25.5	79.58	W68	8.5	4.95	0.45	31.13	32.76	−58	66.18
W33	6.9	3.95	0.44	30.42	32.94	−38.68	75.83	W69	7.31	5.27	0.48	32.641	33.97	−57.68	66.29
W34	6.9	4.48	0.52	34.28	36.89	−34.8	81.69	W70	8.5	4.56	0.4	28.782	30.18	−62.12	69.46
W35	6.8	4.86	0.59	36.91	39.68	−32.26	71.15	W71	9.18	5.71	0.52	34.379	35.96	−57.37	72.65
W36	4.9	15.17	1.88	65.25	66.93	−30.15	82.5	W72	7.48	4.98	0.44	30.396	31.84	−63.1	72.58

SAR and KR are unitless; Na%. PI and MH are percentages (%); RSC is meq L^{-1}; EC is defined in dS cm^{-1}.

References

1. World Health Organization (WHO). *WHO Country Cooperation Strategy 2008–2013: Bangladesh*; WHO Country Office for Bangladesh: Dhaka, Bangladesh, 2007.
2. Nouayti, N.; Khattach, D.; Hilali, M. Evaluation de la qualité physico-chimique des eaux souterraines des nappes du Jurassique du haut bassin de Ziz (Haut Atlas central, Maroc) Assessment of physico-chemical quality of groundwater of the Jurassic aquifers in high basin of Ziz (Central High Atlas, Morocco). *J. Mater. Environ. Sci.* **2015**, *6*, 1068–1081.
3. El-MBellaredj, A.; Hamidi, M. The hydrochemical characterization of the underground waters of the plain of Sidi Bel Abbès (northwestern Algeria). *Alger. J. Environ. Sci. Technol.* **2018**, *4*, 671–682.
4. Abdelbaki, C.; Hacène, F.B. Etude du phénomène de dégradation des eaux souterraines du groupement urbain de Tlemcen. *J. Renew. Energ.* **2007**, *10*, 257–263.
5. Madhav, S.; Ahamad, A.; Kumar, A.; Kushawaha, J.; Singh, P.; Mishra, P.K. Geochemical assessment of groundwater quality for its suitability for drinking and irrigation purpose in rural areas of Sant Ravidas Nagar (Bhadohi), Uttar Pradesh. *Geol. Ecol. Landsc.* **2018**, *2*, 127–136. [CrossRef]
6. Saber, K. Hydro-Chemical Study with Geospatial Analysis of Groundwater Quality Illizi Region, South-East of Algeria. *Publ. Iran. J. Chem. Chem. Eng.* **2021**, *40*, 1315–1329. [CrossRef]
7. Meireles, A.C.M.; De Andrade, E.M.; Chaves, L.C.G.; Frischkorn, H.; Crisostomo, L.A. A new proposal of the classification of irrigation water. *Rev. Cienc. A Gronomica* **2010**, *41*, 349–357. [CrossRef]
8. Stoner, J.D. *Water-Quality Indices for Specific Water Uses*; Department of the Interior, Geological Survey: Arlington, VA, USA, 1978. [CrossRef]
9. Ghazaryan, K.; Chen, Y. Hydrochemical assessment of surface water for irrigation purposes and its influence on soil salinity in Tikanlik oasis, China. *Environ. Earth Sci.* **2016**, *75*, 383. [CrossRef]
10. Aravinthasamy, P.; Karunanidhi, D.; Rao, N.S.; Subramani, T.; Srinivasamoorthy, K. Irrigation risk assessment of groundwater in a non-perennial river basin of South India: Implication from irrigation water quality index (IWQI) and geographical information system (GIS) approaches. *Arab. J. Geosci.* **2020**, *13*, 1125. [CrossRef]
11. Gharbi, A.; Ibn Ali, Z.; Zairi, M. Groundwater suitability for drinking and agriculture purposes using irrigation water quality index and multivariate analysis: Case of Sidi Bouzid aquifer, central Tunisia. *Environ. Earth Sci.* **2019**, *78*, 692. [CrossRef]
12. Al-Hadithi, M.; Hasan, K.; Algburi, A.; Al-Paruany, K. Groundwater Quality Assessment Using Irrigation Water Quality Index and GIS in Baghdad, Iraq. *Jordan J. Earth Environ. Sci.* **2019**, *10*, 15–20.
13. Karakuş, C.B.; Yıldız, S. Evaluation for Irrigation Water Purposes of Groundwater Quality in the Vicinity of Sivas City Centre (Turkey) by Using Gis and an Irrigation Water Quality Index. *Irrig. Drain.* **2019**, *69*, 121–137. [CrossRef]
14. Khanoranga; Khalid, S. An assessment of groundwater quality for irrigation and drinking purposes around brick kilns in three districts of Balochistan province, Pakistan, through water quality index and multivariate statistical approaches. *J. Geochem. Explor.* **2018**, *197*, 14–26. [CrossRef]
15. Omran, I.; Marwa, F. Evaluation of Drainage Water Quality for Irrigation by Integration between Irrigation Water Quality Index and GIS. *Int. J. Tech. Res. Appl.* **2015**, *3*, 24–32.
16. Rasul, M.K.; Waqed, H.H. Evaluation of irrigation water quality index (IWQI) for al-dammam confined aquifer in the west and southwest of karbala city, Iraq. *Int. J. Civ. Eng.* **2015**, *2*, 21–34.
17. AL-Musawi, W.H. *Assessment of Groundwater Quality in UMM ER Radhuma Aquifer (Iraqi Western Desert) by Integration between Irrigation Water Quality Index and GIS*; Report Submitted by Civil Engineering; University of Karbala: Karbala, Iraq, 2014.
18. Rokbani, M.K.; Gueddari, N.; Bouhlila, R. Use of Geographical Information System and Water Quality Index to Assess Groundwater Quality in El Khairat Deep Aquifer (Enfidha, Tunisian Sahel). *Iran. J. Energy Environ.* **2011**, *2*, 133–144.
19. Jerome, C.; Pius, A. Evaluation of water quality index and its impact on the quality of life in an industrial area in Bangalore, South India. *Am. J. Sci. Ind. Res.* **2010**, *1*, 595–603. [CrossRef]
20. Nasereddine, C. Caractérisation hydrochimique et aptitude à l'irrigation des eaux du (CI) dans la région de Touggourt -Ouargla-Oued Righ au sud algérien. In Proceedings of the 1st National Seminar on Geosciences and Environment SGSE'19, Tamanrasset, Algérie, 23–24 October 2019.
21. Chaib, W.; Bouchahm, N.; Harrat, N.; Zahi, F.; Bougherira, N.; Djabri, L. Caracterisation Hydrogeochimique des Eaux Geothermales de la nappe du Continental Intercalaire de la region de l'Oued Righ. *J. Algérien Régions Arid.* **2013**, *2013*, 55–64.
22. Bouselsal, B.; Belksier, M.S. Qualité des eaux de l'aquifère de complexe terminal de Sahara Septentrional: Cas de la région de Taibet (SE Algérie). *Int. J. Environ. Water* **2018**, *7*, 53–61.
23. Dubost, D. Aridité, agriculture et développement: Le cas des oasis algériennes. *Sécheresse* **1992**, *3*, 85–96.
24. Busson, G. *Le Mésozoïque saharien, tômes 1 et 2*; Centre National de Recherche Scientifique: Paris, France, 1970.
25. Fabre, J. *Introduction à la Géologie du Sahara d'Algérie et des Régions Voisines*; SNED: Alger, Algeria, 1976; p. 421.
26. UNESCO. *Study of the Water Resources of the Northern Sahara. (7 vols. and Annexes)*; UNESCO: Paris, France, 1972.
27. SSO (Sahara and Sahel Observatory). *Northern Sahara Aquifer System: Joint Management of a Transboundary Basin*; Synthesis Report; SSO: Tunis, Tunisia, 2003. Available online: http://www.oss-online.org/fr/a-propos-oss (accessed on 20 May 2022).
28. Belksier, M.S. Hydrogeological Characteristics of the Surface Water Table in the Oued Righ Region and Assessment of the Impact of Pollution and Salinity on the Quality of Its Waters. Ph.D. Thesis, Badji Mokhtar-Annaba-University, Algeria, 2017; pp. 76–77.

29. Bouterid, C. Apports des Données Lithostratigraphiques à la Modélisation Géologique 3D dans la ville d'Oued Righ. Master's Thesis, Université L'arbi Ben Mhidi-Oum El Bouaghi, Oum El Bouaghi, Algeria, 2021; pp. 53–56.
30. Busson, G. *Principes, Méthodes et Résultats d'une étude Stratigraphique du Mésozoïque Saharien*; Muséum National d'Histoire Naturelle: Paris, France, 1971; p. 464.
31. Cornet, A. Introduction à l'hydrogéologie Saharienne. *Rev. Géographie Phys. Géol. Dyn.* **1964**, *61*, 5–72.
32. Guendouz, A.; Moulla, A.S.; Edmunds, W.M.; Zouari, K.; Shand, P.; Mamou, A. Hydrogeochemical and isotopic evolution of water in the Complexe Terminal aquifer in the Algerian Sahara. *Appl. Hydrogeol.* **2003**, *11*, 483–495. [CrossRef]
33. Castany, G. Bassin sédimentaire du Sahara septentrional (Algérie-Tunisie). Aquifère du Continental Intercalaire et du Complexe terminal. *Bull. BRGM 2* **1982**, *III*, 127–147.
34. Bouchahm, N. Etude de la Répartition Spatiale des Teneurs en Fluorures des eaux du Sahara Septentrional. Ph.D. Thesis, Thèse de Magistère en Hydraulique, Université de Biskra, Biskra, Algeria, 1999.
35. Rodier, J.; Legube, B.; Merlet, N. L'Analyse de l'eau 9e édition, Entièrement Mise À Jour Dunod Paris. 2009. Available online: https://ulysse.univlorraine.fr/discovery/fulldisplay?docid=alma991006015119705596&context=L&vid=33UDL_INST:UDL&lang=fr&adaptor=Local%20Search%20Engine (accessed on 20 May 2022).
36. Holanda, J.S.; Amorim, J.A. *Management and Control Salinity and Irrigated Agriculture Water*; Congresso Brasileiro de Engenharia Setting: Campina Grande, Brazil, 1997; pp. 137–169.
37. Azlaoui, M.; Zeddouri, A.; Haied, N.; Nezli, I.E.; Foufou, A. Assessment and Mapping of Groundwater Quality for Irrigation and Drinking in a Semi-Arid Area in Algeria. *J. Ecol. Eng.* **2021**, *22*, 19–32. [CrossRef]
38. Singh, P.; Thakur, J.K.; Singh, U.C. Morphometric analysis of Morar River Basin, Madhya Pradesh, India, using remote sensing and GIS techniques. *Environ. Earth Sci.* **2013**, *68*, 1967–1977. [CrossRef]
39. Ayers, R.S.; Westcot, D.W. *Water Quality for Agriculture*; Food and Agriculture Organization of the United Nations: Rome, Italy, 1985. Available online: https://www.fao.org/3/t0234e/T0234E06.htm#ch5.2 (accessed on 20 May 2022).
40. Wetzel, R.G. *Limnology*, 2nd ed.; Saunders College Publishing: Philadelphia, PA, USA, 1983; Volume XI, p. 767.
41. Varol, S.; Davraz, A. Evaluation of the groundwater quality with WQI (Water Quality Index) and multivariate anal410 ysis: A case study of the Tefenni plain (Burdur/Turkey). *Environ. Earth Sci.* **2015**, *73*, 1725–1744. [CrossRef]
42. Richards, L.A. *Diagnosis and Improvement of Saline Alkali Soils: Agriculture, Vole 160. Handbook 60*; US Department of Agriculture: Washington, DC, USA, 1954.
43. Bauder, T.A.; Waskom, R.M.; Sutherland, P.L.; Davis, J.G. *Irrigation Water Quality Criteria—0.506*; Colorado State University: Fort Collins, CO, USA, 2003.
44. Geilfus, C.-M. Review on the significance of chlorine for crop yield and quality. *Plant Sci.* **2018**, *270*, 114–122. [CrossRef]
45. Gouaidia, L.; Laouar, M.S.; Défaflia, N.; Zenati, N. Origine de la Mineralisation des Eaux Souterraines d'un aquifere dans une zone semi—aride, cas de la nappe de la MERDJA, NORD—EST ALGERIEN. *Int. J. Environ. Water* **2017**, *6*, 104–114.
46. Jassim, S.Z.; Goff, J.C. *Geology of Iraq*; Dolin Prague and Moravian Museum: Brno, Czech Republic, 2006; p. 341.