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Mapping groundwater quality Index for irrigation in the Dibdibba aquifer at Karbala - Najaf plateau, central of Iraq

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Abstract

Mapping groundwater quality Index for irrigation is of great importance for agricultural issues. As groundwater is a vital source of water for domestic and agricultural activities in Iraqi Western Desert area, where the study area (Dibdibba aquifer) represents the extreme eastern part of it, evaluation of groundwater quality and its suitability for irrigation is important. This study aims to develop decision support tools for identifying the optimal locations of groundwater regarding its quality to meet the future demands of the study area. Samples were collected during the wet season (April-May 2017)and analyzed for determining the physicochemical properties. The indices used in the quality assessment were the sodium adsorption ratio (SAR), sodium percentage (%Na^+), magnesium hazard (MH), and irrigation water quality index (IWQI), incorporating the spatial variation using the GIS-based multi-criteria system highlighted the spatial variation of groundwater quality for irrigation in the study area. This spatial distribution indicated that groundwater is generally of moderate quality in the Dibdibba aquifer.

Key words: Water quality Index, Irrigation, Dibdibba, GIS, Western Desert

رسم خرائط لمؤشر جودة المياة الجوفية لاغراض الري ضمن خزان الدبدبة الجوفي في هضبة كربلاء – نجف، وسط العراق

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الخلاصة

رسم خرائط مؤشر جودة المياه الجوفية لاغراض الري مهم للغاية بالنسبة للقضايا الزراعية. وبما أن المياه الجوفية هي مصدر حيوي للأنشطة المنزلية والزراعية في منطقة الصحراء الغربية العراقية حيث تمثل منطقة الدراسة (هضبة كربلاء – نجف) اقصى الجزء الشرقي منها، حيث تقييم جودة المياه الجوفية ومدى ملاءمتها للري أمر مهم. تهدف هذه الدراسة إلى تطوير أدوات دعم القرار لتحديد المواقع المثلى للمياه الجوفية فيما يتعلق بجودتها لتلبية المتطلبات المستقبلية لمنطقة الدراسة. تم جمع العينات خلال الفترة الرطبة (أبريل- مايو 2017) وتحليلها لتحديد الخصائص الفيزيائية والكيميائية. وكانت المؤشرات المستخدمة في تقييم الجودة هي نسبة امتصاص الصوديوم ونسبة الصوديوم المئوية ومخاطر المغنيسيوم ومؤشر جودة مياه الري ، تم دمجها

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لبيان الاختلاف المكاني باستخدام نظام المعايير المتعددة المعتمد على نظم المعلومات الجغرافية ، حيث أبرزت الاختلاف المكاني لتوزيع نوعية المياه الجوفية المستخدمة لأغراض الري في منطقة الدراسة. يشير هذا التوزيع المكاني إلى أن المياه الجوفية ذات جودة متوسطة بشكل عام في خزان الدبدبة الجوفي ضمن منطقة الدراسة.

1. Introduction

Groundwater is used for domestic and industrial water supply and irrigation all over the world. Turkey, located at the headwaters of the Tigris and Euphrates, controls water flowing downstream through Iraq and to the Arab Gulf. Turkey began with the implementation of the great Anatolia project GAP. The GAP project has effectively reduced water flows in the Euphrates to 1/3 its original annual average. Karbala city depends mainly on the Euphrates River to secure its water needs for drinking, irrigation, and other purposes. The reducing of the Euphrates flow rate in the future requires researchers to put plans to avert the threat of water scarcity by exploring and classifying other water sources like groundwater as quantity and quality to fulfill water needs of the city for various purposes. The Dibdibba aquifer began to be exploited for agriculture in the mid-1980s. The number wells exploited in the Dibdibba aquifer area more than 3000 wells, but that number start decreases because many investment projects were established in this area at this time, for that reason became the Dammam aquifer is essential in the study area. The water demand in the study area has progressively increased during the last decade. The mismanagement of aquifer may lead to mining of groundwater reserve and deterioration of groundwater quality. Therefore, it is very important to develop groundwater resources to manage this finite resource properly. The primary objective of this study is to study the quality of groundwater and its suitability for irrigation usage to Dibdibba aquifer. The degradation of irrigation water quality is induced by several factors, including the concentration of dissolved salts as expressed by the dry residue or EC, salinity, and relative concentration of sodium [1]. The quality of irrigation water is interpreted by determining the number of parameters such as salinity, adsorption ratio (SAR), percentage (%Na^+) and magnesium hazard (MH). Among all methods available for assessing groundwater water quality, water quality index (WQI) is widely used. WQI is a technique of rating that provides the composite influence of individual groundwater quality parameters on the overall quality of groundwater. It is an essential technique for demarcating groundwater quality and its suitability for drinking purposes [2]. It also serves as a mean of communicating information on the overall quality of water using a single number both spatially and temporally[3].

2. The study area

The considered area locates in the central part of Iraq between Karbala and Najaf cities and geographically between (31°55′–32°45′) latitude and (43°30′–44°30′) longitude. It is a cone-shaped plateau encompasses an area about of (2700 km^2), Figure-1. Two scraps bound the plateau; from the northeast by a Tar Al-Sayyed and in the south by Tar Al-Najaf. In the northern part of the plateau, the Razzaza lake location and from the east, the quaternary sediments is found. The surface of the plateau is nearly flat, dissected by some shallow flat-floor valleys, and almost covered by pebbly or gypsiferous pebbly soil or gypcrete. Aeolian sand sheets and shrub dunes are present too [4]. The topography elevation ranges from 13 to 207 m with an average 83m. Generally, elevation decreases from west to east. From the geology point of view, the plateau covers by gypcrete deposits except where the Razzaza Lake, Ta-Alsayed and Tar-Al-Najaf are located [4]. The stratigraphic column consists of the following formations (from older to younger): Dammam, Euphrates, Fatha, Nfayil, Injana, and Dibdibba [4,5], and depending on the wells drilling by the General Commission of Groundwater, Figure-2. Table-1 provides a brief explanation of these formations. Tectonically, the plateau lies in the northwest part of the Euphrates subzone that is the west part of the Mesopotamian zone of the stable shelf [4]. The study area is considered stable, and the sedimentary cover ranges 7 to 8 km overlying basement rocks [6].

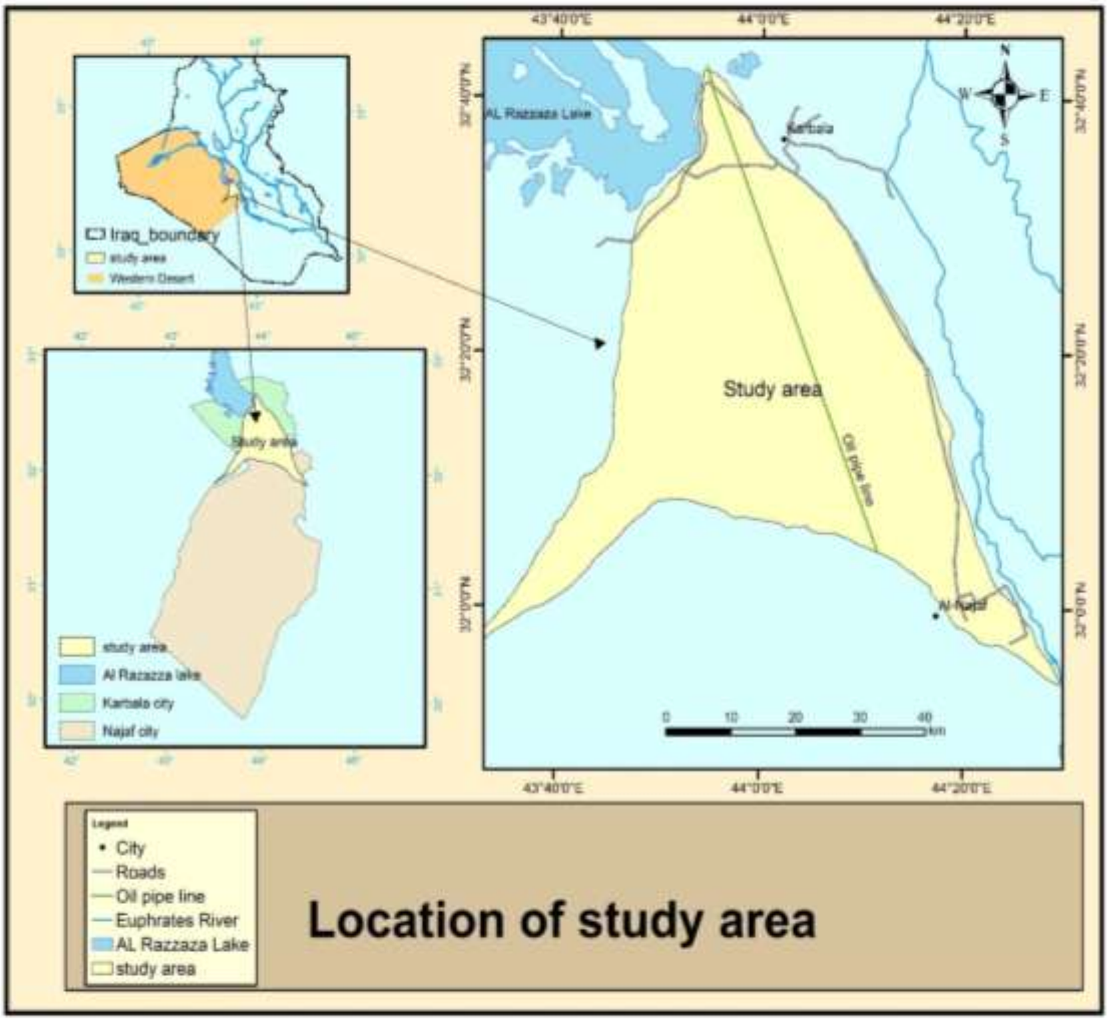

Figure 1-Location of the study area

Table 1- Formation description in the study area according to (Jassim and Goff 2006)

Formation	Age		Environment	Lithology description
Dibdibba	TERTIARY	Upper Miocene Pliocene (AP11)	Freshwater environment (Delta)	Sand, pebbles, claystone, sandstone, and silt
Injana		Upper Miocene (AP11)	Lagoon environment	Sandstone, siltstone, and claystone with thin limestone
Fatha		Middle Miocene (AP11)	deposited in broad basin following a marine transgression	Mudstone, gypsum, and silt, interbedded with limestone and marl.
Euphrates		Late lower Miocene (AP11)	Deposited reef and behind the reef	Basal breccia, limestone, and marl
Dammam		Middle-Late Eocene (AP10)	Deposited on a shallow marine shelf with high energy nummulitic shoals and deposited in a lagoonal environment in a subtropical sea.	Consists mainly of neritic shoal limestones often recrystallized and/or dolomitized, nummulitic

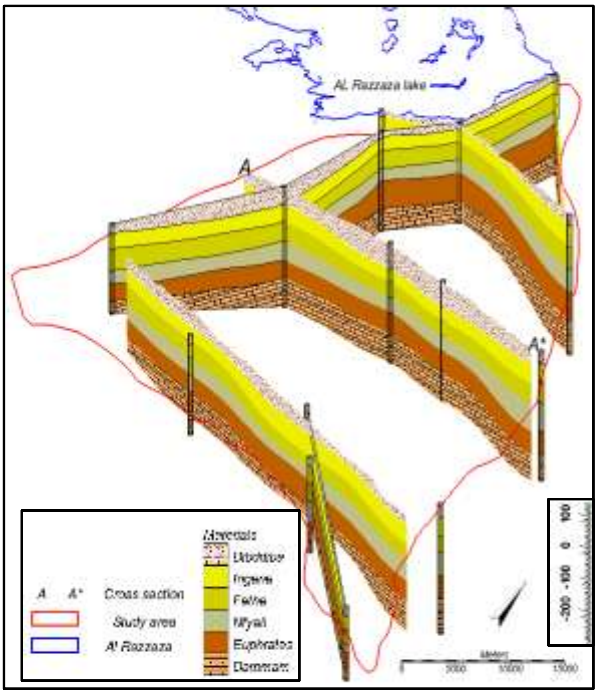

Figure 2-Boreholes and Cross Sections in the study area (Three-dimension view) by GMS software.

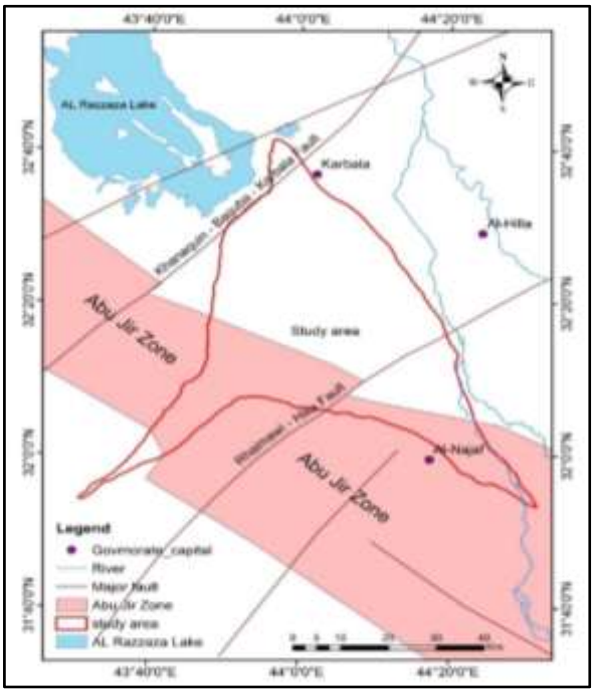

Figure 3-Structural map of the study area {modified from the tectonic map of Iraq (GEOSURV, 1996)}.

The area is influenced by extension deformations and tectonic tension over the Arabian plate of the Permian/Triassic-Lower Cretaceous Periods. The area is characterized by the presence of two groups of faults. The first group is trending NE-SW and includes Rhaimawi – Hilla Fault and Khanaquin - Baquba - Karbala Fault, Figure-3**.** There are also two faults oriented in the same direction but basement only. The second group trends NW-SE similar to Abu Jir fault zone which is represented by Heet-Abu Jir fault in the western part of the study area [7].

From the hydrogeological point of view, The Dibdibba aquifer represents the top main unconfined aquifer in the study area and covers an area of 1100 km^2 from the Karbala-Najaf plateau. The aquifer is fed by seasonal flow stream from direct rainfall within the Plateau [8], Figure-4. The seasonal flow stream-oriented 40°N towards the Mesopotamian Basin. The Dibdibba alluvial fan delta formed in the early Miocene as a result of a drainage system which remains visible upstream on the Western Desert’s carbonate platform [8] .The Dibdibba fan delta appears disconnected today from this drainage system, most likely because of recent tectonic movement along the active Abu Jihr fault. The delta of Dibdibba alluvial fan might have also received water from discharging aquifers in the Ma’ania depression located 100 km from the SW, outside the area [8]. The gravels and sand of the Dibdibba formations date from the end of the Pliocene have been altered by calcite and gypsum [9]. After collecting information from the wells drilled in the study area by the General Commission for Groundwater, Karbala Branch, to build hydrogeological section in the current study for water table in the Dibdibba aquifer Figure-5, The flow direction of groundwater for Dibdibba aquifer in the study area was generally from southwest to northeast (i.e., towards Euphrates River) which it is within the regional groundwater flow direction of Iraq as observed in flow net map (Figure-4). The value of the hydraulic gradient in the study area ranges from (0.0011) to (0.0005),[5].

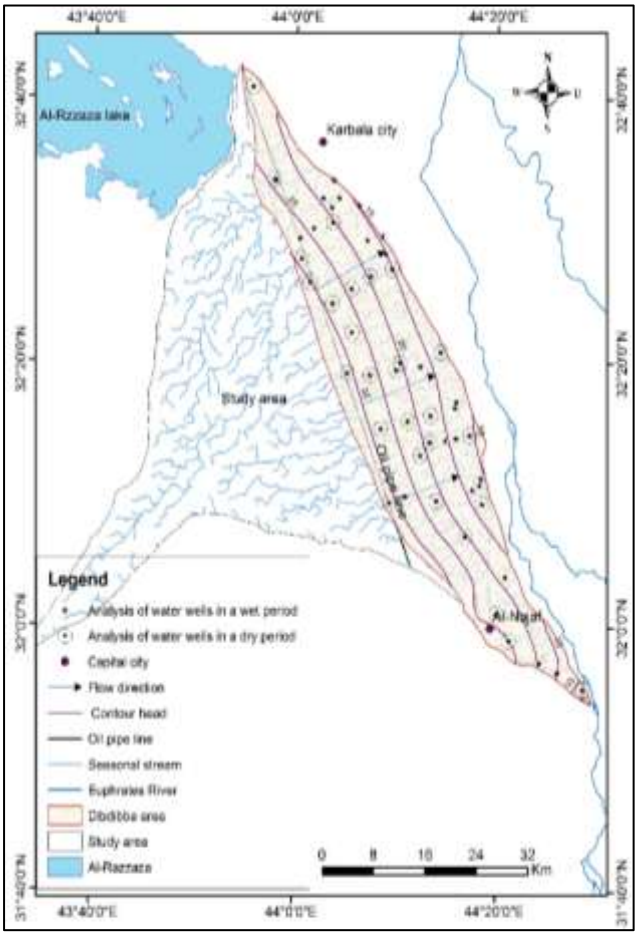

Figure 4-The flow net, seasonal flow stream and selected wells for chemical analyses of the Dibdibba aquifer in the study area.

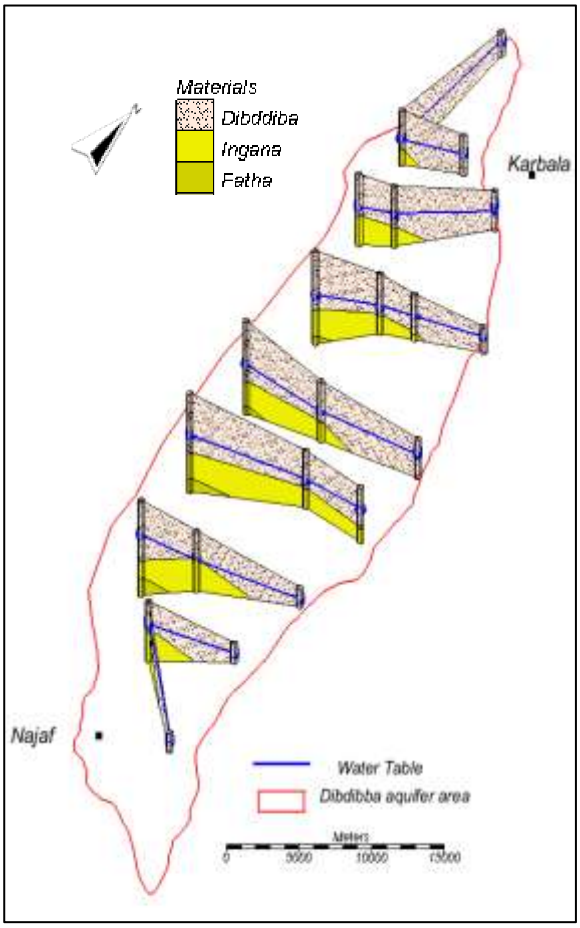

Figure 5-Three-dimension view to Hydrogeological section show water table in Dibdibba aquifer in the study area.

3. Materials and methods

3.1 Sampling and analyses

To obtain representative data of the spatial and temporal variability of groundwater quality of the Dibdibba aquifer area, 52 groundwater samples in the wet period (April-May) have been collected from boreholes and analyzed for physiochemical parameters using standard methods, Figure-4. Samples of groundwater were collected on one-liter capacity pre-cleaned polyethylene bottles. Before collecting the samples, the bottles were thoroughly washed with dilute HNO_3 acid and then distilled water before taking samples. To avoid any possible contamination in bottle, each bottle was rinsed several times by the groundwater sample itself after 15 minutes of the pump running. Groundwater samples were labeled and were kept in a field refrigerator for two days and then transferred to the chemical laboratory of General Commission of Groundwater for chemical analysis. Temperature, electrical conductivity (EC), total dissolved solids (TDS), DO and pH values were measured in the field using a portable conductivity and pH meter HACH model session 156, are used for this purpose. In general, WQI computation involves four step: parameter selection, development of sub-indices, and assignment of weights and aggregation of sub-indices to produce an overall index [10] .The use of conventional approaches (e.g., geophysical, geostatistical, numerical modeling, etc.) for groundwater assessment is often limited by the lack of adequate data [11] .Getting sufficient data to implement such techniques is often expensive, time-consuming, uneconomical and sometimes unsuccessful [12]. With the advent of Remote Sensing (RS) and Geographic Information System (GIS), efficient and powerful techniques for groundwater resources have evolved. These methods are very useful for rapid groundwater studies of the large and inaccessible area. In particular, GIS permits storing and efficient processing of data derived and collected from various sources, maps, satellite imagery, and land surveys [13]. Also, GIS provides a mechanism for integrated different spatial data layers to produce new maps based on criteria determined already by the user.

3.2 Irrigation water quality index

The irrigation water quality index (IWQI) developed in two stages by Meireles [14] was applied in this study. The IWQI is a dimensionless parameter ranging between 0 and 100. The following equation gives it,

$$IWQI = \sum_{i=1}^{n} qi * wi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where *qi* is the parameter quality, and *wi* is the standardized weight assigned to each parameter. In the first stage, parameters that contribute to the variability of irrigation were identified by using the principal component analysis (PCA) and factor analysis (AF). In the second stage, the IWQI was defined, and *qi* and *wi* values were estimated for each parameter used in the index calculation according to irrigation water criteria provided by the University of California Committee of Consultants (UCCC) and the criteria established by [15] (Table-2)

Table 2-Limit values of quality parameters (UCCC, 1999).

	qi	EC (μ/cm)	SAR (meq/l)$^{1/2}$	Na^+	Cl^-	HCO_3^-
				Meq/1		
High	85-100	200≤ EC<750	SAR<3	2≤ Na<3	Cl<4	1≤ HCO_3<1.5
Medium	60-85	750≤ EC<1500	3≤ SAR<6	3≤ Na<6	4≤ C1<7	1.5≤ HCO_3<4.5
Low	35-60	1500≤ EC<3000	6≤ SAR<12	6≤ Na<9	7≤ C1<10	4.5≤ HCO_3<8.5
Very low	0-35	EC<200 or EC≥3000	SAR≥12	Na<2 or Na≥ 9	Cl≥10	HCO_3<1 or HCO_3≥8.5

The following formula gives the quality parameter *qi*:

$$qi = q_{imax} - \left[\left(x_{ij} - x_{inf}\right) \times q_{iamp}\right]/q_{amp} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where q_{imax} is the maximum value of *qi* for the parameter class, x_{ij} is the observed value for the parameter, x_{inf} is the corresponding value of the lower limit of the class to which the parameter belongs, q_{iamp} is the class amplitude, and q_{amp} is class amplitude to which the parameter belongs. The parameter weight (w_i) used in the IWQI was obtained by the (PCA / FA), by the sum of all factors multiplied by the explainable of each parameter. Then *wi* values (Table-3) were normalized such that their sum equals one, according to the following equation (Meireles et al. 2010):

$$w_i = \sum_{j=1}^{k} F_j\, A_{ij} / \sum_{j=1}^{k} \sum_{i=1}^{n} F_j\, A_{ij} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where w_i is the parameter weight, *F* is the component 1 auto value, A_{ij} is the explainability of parameter *i* by factor *j*, *i* is the number of physical-chemical and chemical parameters selected by the model, and *j* is the number of factors selected in the model.

Table 3-Weights of the IWQI Parameters.

Parameter	EC	Na	HCO_3	Cl	SAR	Total
Weight (wi)	0.211	0.204	0.202	0.194	0.189	1

The subdivisions in classes of irrigation water quality were established on the basis of the IWQI (Table-4). The classes have been defined taking into account the risk of salinity problems, soil permeability reduction, and toxicity to plants as indicated in the classifications established by [16-17], and [14]. The spatial analysis of the ratio (MH) and parameters used for IWQI (Na^+, Cl^-, HCO_3^-, EC, and SAR) calculation was done by making contours using the inversed distance weighting (IDW) interpolation method.

Table 4-Water Quality Index Characteristics (Meireles et al., 2010).

IWQI	Water Use Restrictions	Recommendation	
		Soil	Plant
85-100	No restriction (NR)	May be used for the majority of soils with a low probability of causing salinity and sodicity problems, 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 textured soils may occur, is recommended to avoid its use in soils with high clay	Avoid salt sensitive plants
55-70	Moderate restriction (MR)	May be used in soils with moderate to high permeability values, being suggested 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 pS 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 HCO3 values
0-40	Severe restriction (SR)	Should be avoided its use for irrigation under normal conditions. In special cases, may occasionally be used. 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 HC0$_3$.

4. Generating of thematic layers for IWQI parameters (Dibdibba aquifer)

Results of chemical analyses and calculated water quality parameters are given in **Tables 5 and 6**.

Table 5- Chemical analyses of water wells in a wet period to the Dibdibba aquifer in the study area

ID well	Easting	Northing	pH	EC µs/cm	TDS ppm	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}
No.4	402706.7	3603436	7.18	5125	3280	15.02	11.52	20.1	2.61
No.5	406690.9	3595240	7.3	4484	2870	9.482	6.254	23.92	1.79
No.6	408814.8	3596591	7.35	6719	4300	16.42	13	24.92	2.48
No.7	411622.3	3599483	7.13	6234	3990	17.47	14.07	25.62	2.56
No.8	412750.1	3600760	7.3	6641	4250	16.32	12.84	24.88	2.46
No.9	417122.6	3594847	7.2	5141	3290	15.07	11.6	20.23	2.66
No.10	415892.4	3599720	7.17	6516	4170	17.12	13.91	25.1	2.43
No.11	419489.1	3595394	7.14	5281	3380	13.97	11.11	22.84	2.25
No.12	420925.2	3590838	7.25	5500	3520	15.47	11.93	24.79	2.81
No.13	417634	3589740	7.19	5297	3390	14.22	11.19	22.92	2.28
No.14	414663.7	3588068	7.2	4031	1980	6.737	7.653	5.916	0.38
No.15	411673.6	3586055	7.18	3844	2060	7.136	7.982	6.394	0.49
No.16	413962.1	3576270	7.19	3972	2042	7.086	7.982	6.351	0.46
No.17	417487.5	3576000	7.11	3953	2030	6.986	7.982	6.307	0.43

No.18	421535.8	3576716	7.12	4781	3060	14.97	9.052	16.53	0.82
No.19	422192	3577715	7.1	3844	2160	7.386	8.229	6.612	0.51
No.20	411942.2	3603222	7.11	4563	2920	14.47	8.393	16.31	0.77
No.21	410279.9	3600779	7.12	4344	2780	13.47	7.324	15.66	0.72
No.22	419980.5	3592865	7.13	4219	2700	13.17	6.83	15.49	0.69
No.24	425314.8	3577174	7.12	4000	2560	7.984	9.463	7.395	0.64
No.25	399429.1	3616420	7.1	10625	6800	24.7	17.44	37.45	1.56
No. 26	402943.2	3603238	7.1	4391	2810	11.58	9.052	20.23	0.59
No.27	430925.6	3572192	7.13	4031	2380	11.48	9.545	15.66	0.18
No.28	430716.1	3571383	7.16	3750	2400	11.83	9.875	16.09	0.23
No.29	426909.7	3570311	7.61	4531	2900	12.18	9.957	20.53	0.67
No.30	423350.7	3569521	7.11	3813	2340	10.58	9.052	14.88	0.13
No.31	419176.7	3568476	7.1	3750	2300	10.38	8.805	14.7	0.08
No.32	428529.2	3579159	7.12	4219	2700	10.98	8.311	19.57	0.51
No.33	411760.4	3597393	7.14	4281	2740	11.23	8.64	19.88	0.56
No.34	434751.4	3561441	7.12	10750	6880	30.54	25.1	44.58	2.94
No.35	434491.5	3560535	7.1	6219	3980	16.02	13.25	24.75	1.02
No.36	433361.1	3559880	7.14	6344	4060	16.82	13.99	25.32	1.15
No.37	427756.2	3558388	7.12	4563	2920	9.681	6.418	24.1	1.07
No.38	422941.3	3559033	7.14	4531	2900	9.482	6.254	23.92	1.02
No.40	434901.4	3557899	7.1	9688	6200	27.95	23.04	40.45	2.12
No.41	432963.8	3567522	7.15	4953	3170	11.48	8.64	27.19	1.79
No.42	430851.5	3567087	7.11	3781	2420	8.084	9.875	7.569	0.61
No.43	429156.2	3566803	7.12	4344	2780	10.98	8.64	19.66	0.54
No.44	426788.4	3566564	7.11	4047	2590	9.482	6.336	15.66	0.38
No.45	425288.6	3564774	7.1	3863	2372	7.585	9.052	6.96	0.56
No.50	443766.2	3535652	7.11	6750	4320	16.42	13	24.92	2.48
No.51	446531.1	3534260	7.12	4688	3000	10.43	6.583	26.45	1.48
No.52	414682.7	3582004	7.13	3922	2010	6.837	7.817	6.525	0.51
No.55	420508.9	3558159	7.22	4014	2069	7.036	4.937	13.96	0.38
No.58	450499.8	3531870	7.14	6563	4200	14.97	10.2	29.97	0.13
No.59	439035.9	3538786	7.14	4594	2940	10.38	8.146	18.4	0.22
No.60	432266	3553385	7.61	6139	3929	17.12	17.36	31.36	2.84
No.61	438509	3547715	7.25	4703	3010	15.17	11.19	19.57	0.51
No.62	437011	3542554	7.15	6711	4295	15.77	11.68	20.92	2.61
No.63	408221.4	3589059	7.61	4578	2930	13.67	8.722	18.18	0.41
No.64	406911	3592345	7.15	4359	2790	12.82	10.12	17.83	1.92
						milliequivalent per liter			

Table 6-Chemical analyses and calculated water quality parameters in a wet period to the Dibdibba aquifer.

ID well	CL^-	HCO_3^-	SO_4^{-2}	SAR	Na%	MH	IWQI
No.4	17.54	7.74	23.78	5.52	46.11	43.41	22.75
No.5	15.71	6.69	18.78	8.53	62.03	39.74	20.84
No.6	19.18	7.88	29.15	6.50	48.22	44.19	12.51
No.7	19.86	8.29	31.75	6.45	47.19	44.61	12.25
No.8	19.04	7.87	29.04	6.52	48.38	44.03	12.83
No.9	17.6	7.75	23.82	5.54	46.19	43.49	22.51
No.10	19.15	7.88	31.62	6.37	47.01	44.83	13.00
No.11	18.17	7.70	24.48	6.45	50.01	44.30	18.62
No.12	19.04	7.87	24.98	6.70	50.18	43.54	15.56
No.13	18.22	7.72	24.53	6.43	49.79	44.04	18.49
No.14	7.221	1.11	11.87	2.21	30.45	53.18	65.33
No.15	7.531	1.64	14.22	2.33	31.28	52.80	61.88
No.16	7.503	1.18	12.12	2.31	31.13	52.97	62.42
No.17	7.475	1.18	12.08	2.31	31.05	53.33	62.60
No.18	13.88	7.16	16.49	4.77	41.93	37.68	30.84
No.19	7.672	1.20	12.28	2.37	31.33	52.70	63.16
No.20	13.6	7.13	16.11	4.82	42.76	36.71	31.69
No.21	13.37	7.08	15.86	4.86	44.06	35.22	32.89
No.22	13.17	7.05	15.74	4.90	44.72	34.15	33.44
No.24	9.872	1.64	14.37	2.50	31.53	54.24	53.86
No.25	30.72	12.14	37.93	8.16	48.07	41.39	1.20
No. 26	15.46	7.65	16.97	6.30	50.22	43.87	24.89
No.27	16.22	7.54	12.39	4.83	42.97	45.40	31.23
No.28	16.42	7.60	12.6	4.88	42.92	45.50	31.28
No.29	16.9	8.69	17.99	6.17	48.91	44.98	22.30
No.30	14.95	7.44	12.12	4.75	43.33	46.11	33.50
No.31	14.78	7.41	11.97	4.75	43.51	45.90	33.95
No.32	15.01	7.57	16.66	6.30	51.00	43.08	26.23
No.33	15.23	7.60	16.86	6.31	50.71	43.48	25.65
No.34	37.57	16.06	49.13	8.45	46.06	45.11	1.00
No.35	19.04	8.05	27.98	6.47	46.82	45.27	17.50
No.36	19.46	8.13	28.52	6.45	46.21	45.41	16.46
No.37	15.51	6.72	18.95	8.49	60.99	39.87	22.95
No.38	15.71	6.69	18.78	8.53	61.32	39.74	23.01
No.40	34.41	13.27	45.66	8.01	45.50	45.19	1.10
No.41	16.64	7.08	19.65	8.57	59.02	42.94	15.98
No.42	9.59	1.39	13.03	2.53	31.30	54.99	56.15
No.43	15.23	7.46	16.66	6.28	50.72	44.04	25.86
No.44	12.69	6.23	16.03	5.57	50.35	40.06	33.88
No.45	9.308	1.31	12.99	2.41	31.14	54.41	58.50
No.50	19.18	7.88	29.15	6.50	48.22	44.19	12.44
No.51	15.71	6.75	19.03	9.07	62.15	38.69	17.82
No.52	7.616	1.25	12.37	2.41	32.44	53.34	62.84
No.55	7.362	2.93	14.8	5.71	54.50	41.23	46.23
No.58	25.08	6.52	22.67	8.45	54.46	40.52	4.08
No.59	13.48	7.39	15.03	6.05	50.12	43.97	27.70
No.60	26.74	3.90	37.54	7.55	49.80	50.35	7.79
No.61	17.32	4.26	24.69	5.39	43.24	42.45	28.77
No.62	18.64	8.19	25.19	5.65	46.15	42.55	16.70
No.63	16.56	4.05	22.26	5.43	45.37	38.95	30.95
No.64	14.64	6.88	20.4	5.26	46.26	44.12	29.83
		milliequivalent per liter					

4.1Electrical conductivity

The electrical conductivity (EC; µS /cm), is usually due to the dissolved mineral content in water (TDS). The groundwater salinity value of the Dibdibba aquifer in the study area and its distribution were shown in the Tables- (5, 6), Dibdibba aquifer is irrigated with groundwater having the highest EC values (class 1500–3000 and class C< 200 or EC ≥3000), Table-2.

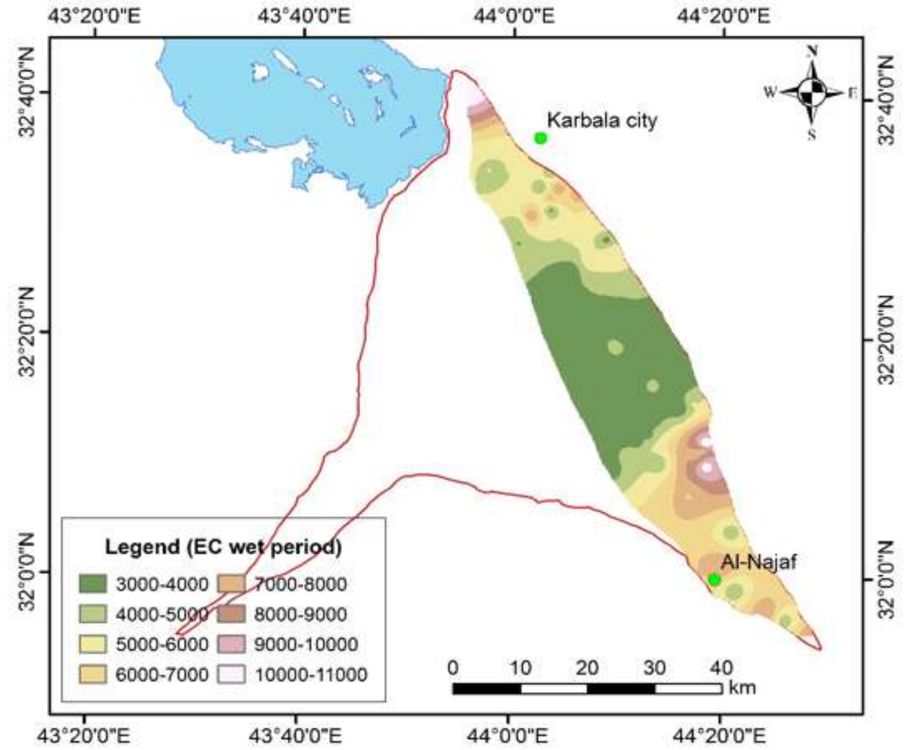

Figure 6-The spatial distribution of EC for the wet period (Dibdibba aquifer).

4.2 Sodium percentage

Sodium excess, in water, often causes changes in soil properties and lowers its permeability [18]. Therefore, the appreciation of percentage Na^+ is needed to decide on water suitability for irrigation. The percentage Na^+ is calculated as follows:

$$Na\% = \frac{(Na^+ + k^+)}{(Ca^{2+} + Mg^{2+} + Na^+ + k^+)} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

where Na^+, K^+, $Ca^{2+,}$ and Mg^{2+} concentrations are expressed in milliequivalents/l. According to the relationship between electrical conductivity and percentage sodium for rating irrigation water quality in the Dibdibba aquifer [19],**(**Figure-7), highlights that groundwater of the Dibdibba aquifer is of unsuitable quality for irrigation in the study area, where the percentage of sodium in water samples varies from 30.4 to 62.1% (average 45.9%) during the wet period Table-(5, 6). The %Na spatial distribution in the study area (Figure-8) showed the groundwater of the Dibdibba aquifer is suitable for irrigation is in the middle of the Dibdibba aquifer area where the (Na %) ratio lies within the good limits and do not exceed 40% according to [20].

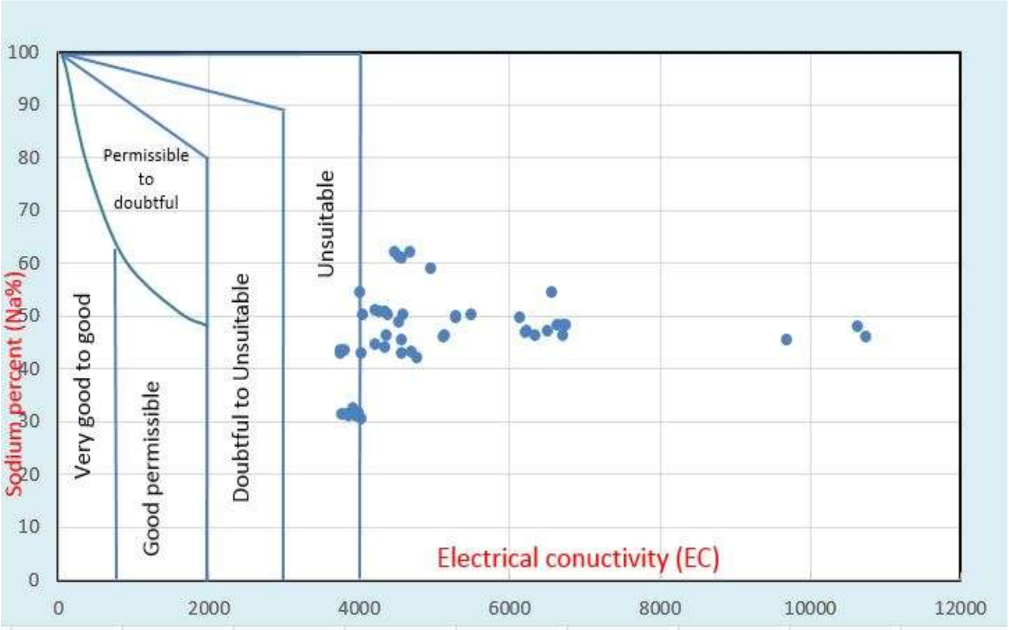

Figure 7- Relationship between electrical conductivity and percentage of sodium for rating irrigation water quality (Wilcox, 1955) in the Dibdibba aquifer.

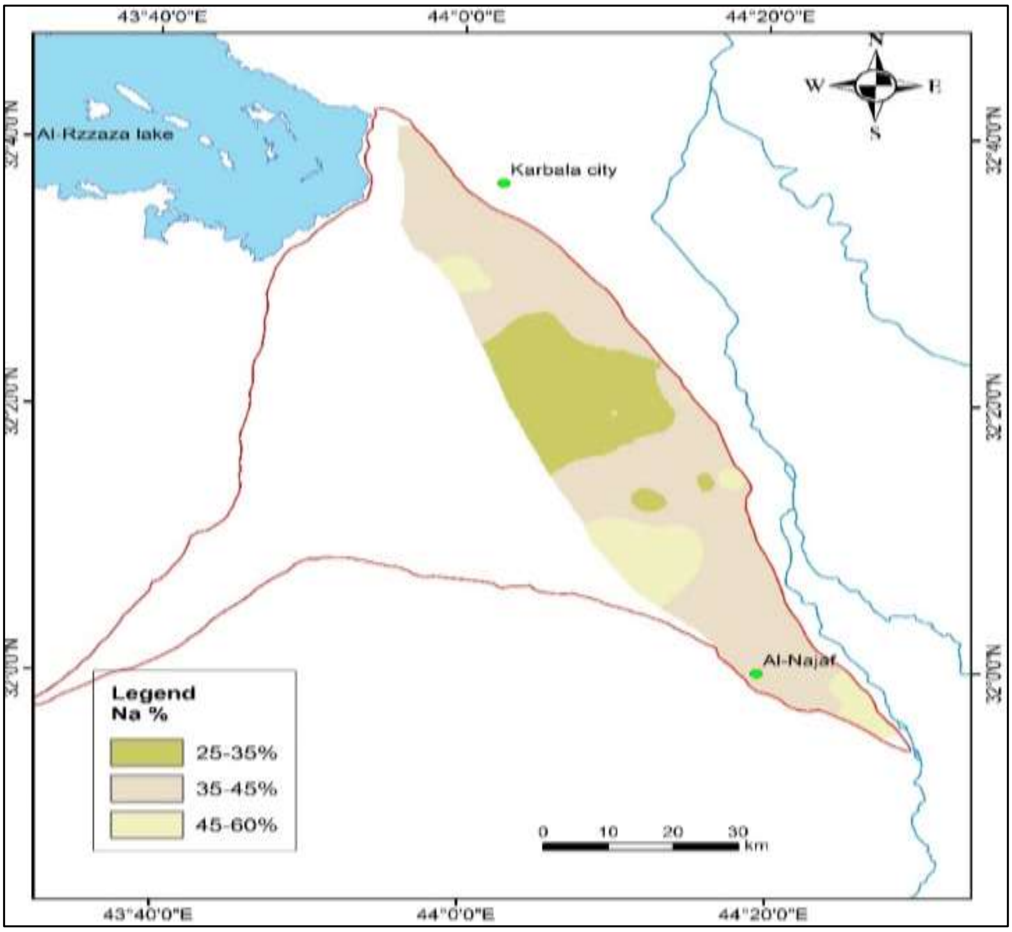

Figure 8- Percentage sodium spatial variation for Dibdibba aquifer in the study area.

4.3 Sodium adsorption ratio

The SAR is essential regarding the prediction of the sodium capacity to accumulate in the soil, which would result from irrigation by sodic water [21]. It gives information about the relative abundance of sodium in water (dispersant cation) compared to flocculants cations (calcium and magnesium) and predicts the extent of sodium and alkaline earth (Ca and Mg) exchange between water and fine particles of the soil. If sodium is high in irrigation water, it provokes the deterioration of soil structure and decreases the infiltration rate [22]. The SAR is commonly used as a test for assessing the alkalizing power of irrigation water [23]، and is expressed as:

$$SAR = \frac{Na^{+}}{\sqrt{Ca^{2+}+Mg^{2+}/2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

where, the concentrations of Na^{+}, Ca^{2+}, and Mg^{2+} are expressed in milliequivalents/l.

The groundwater samples of the Dibdibba aquifer based on SAR values were suitable to doubtful water Table-(5, 6), Figure-12. According to Richards classification system (Figure-9), most groundwater samples fall in the C4-S1, C4-S2 and C4-S3 classes (Low- medium to high of sodium hazard and high EC) indicating that groundwater is a medium suitable for irrigating salt-tolerant crops in soil with good permeability.

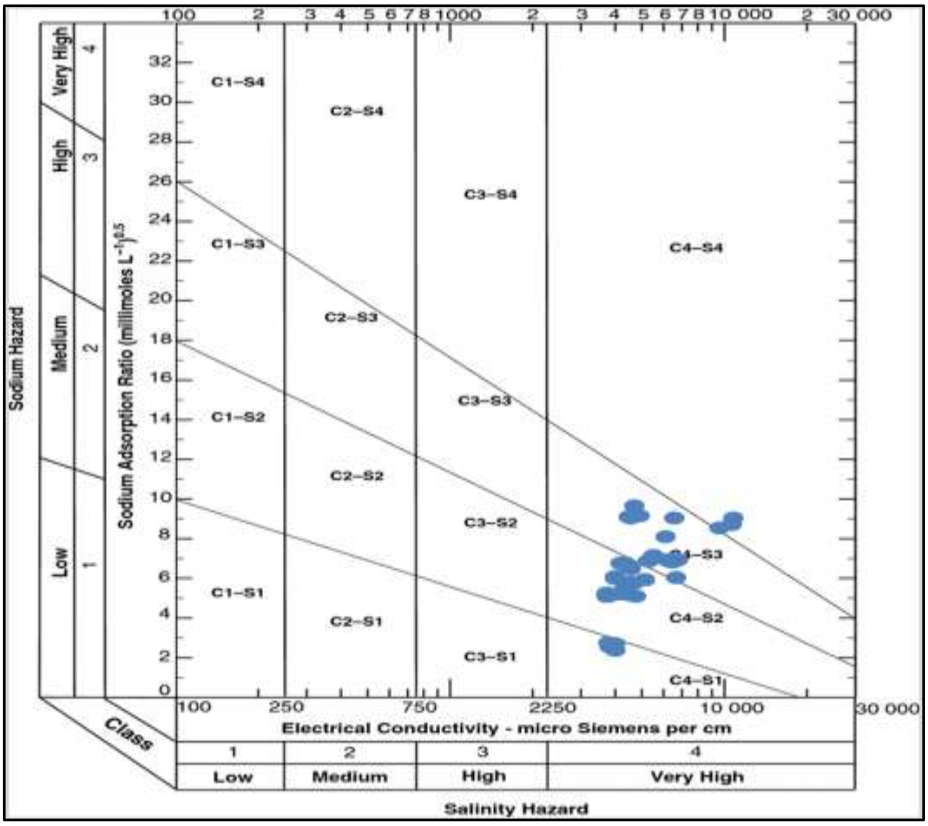

Figure 9-Water quality concerning SAR and EC (Richards 1954) for Dibdibba aquifer in the study area.

4.4 Magnesium hazard

Magnesium hazard (MH) represents an excess of Mg^{2+} relative to Ca^{2+}. Generally, Mg^{2+} and Ca^{2+} are in equilibrium in groundwater. Excessive Mg^{2+} affects soil quality by allowing low agricultural yields. Indeed, when the concentration of Ca^{2+} is less than the Mg^{2+}, it behaves in the same manner as Na^{+} and thus degrades the soil structure. The values of MH <50% indicate that water is suitable for irrigation and the soil becomes more alkaline [24]. The ratio proposed by [25] to compute MH is as follows:

$$MH = \frac{Mg^{2+}}{Ca^{+2}+Mg^{2+}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

where the concentrations of Ca^{2+} and Mg^{2+} are in milliequivalents/l Table-(5, 6), Figure-10, highlights that approximately 85% of the samples have an MH value <50% and are therefore suitable for irrigation.

Cation exchange is the chemical reaction frequently cited to explain the high percentage of sodium compared to calcium and magnesium in water from Dibdibba aquifer. Cation exchange is a reaction with flow direction in which the calcium and magnesium in the water are exchanged for sodium that was adsorbed on the aquifer solids such as clay minerals, resulting in higher sodium concentrations and softer water (decreased calcium and magnesium concentrations) [26].

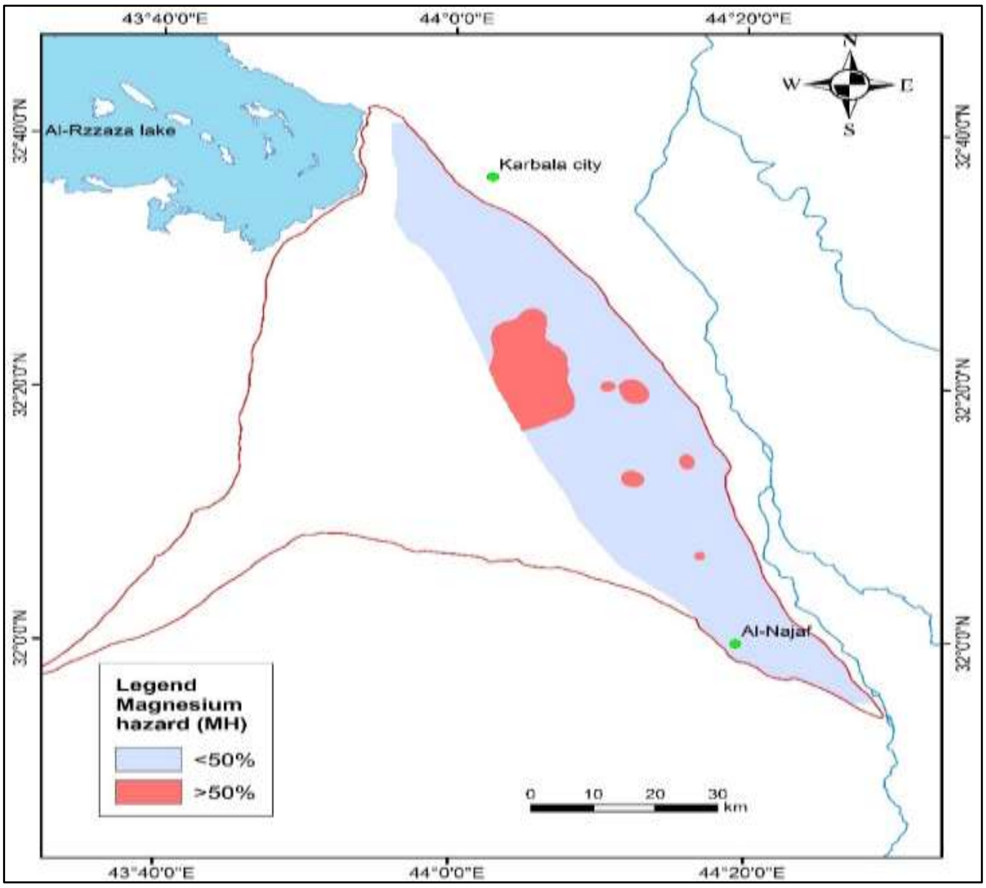

Figure 10-Spatial variation of Magnesium in the study area.

5. IWQI of the Dibdibba aquifer

For assessing the water suitability for irrigation, the IWQI was computed using EC, Na^+, Cl^-, HCO_3^-, and SAR. The *qi* values were ranging between 60 and 35 Tables-(2, 5, 6), the lowest EC values are concentrated in the middle part of the Dibdibba aquifer area and have the best water quality for irrigation regarding the salinity risks. These values are near Al Razzaza Lake and the area near Al-Najaf city (Figure-6). Sodium concentrations located in the class ($6 \leq$ Na < 9 meq L^{-1}) and class (≥ 9 meq L^{-1}). Chloride concentrations ranging between class ($7 \leq Cl < 10$ meq L^{-1}) and class (>10 meq L^{-1}). Chloride concentrations are high in the Dibdibba aquifer area above the standard (7 meq L^{-1}) reflecting the moderate quality of irrigation water [26]. Groundwater has low values of HCO_3^- in the Dibdibba aquifer in the north part of the study area near Al Razzaza lake and area near Al-Najaf city (Figure-12). SAR values are, in general below ten and that represented the suitable water (Table-6).Figures-(11, 12) showed that the frequency distribution and spatial the distribution for the class in the study area according to the quality limit values (Table-2).

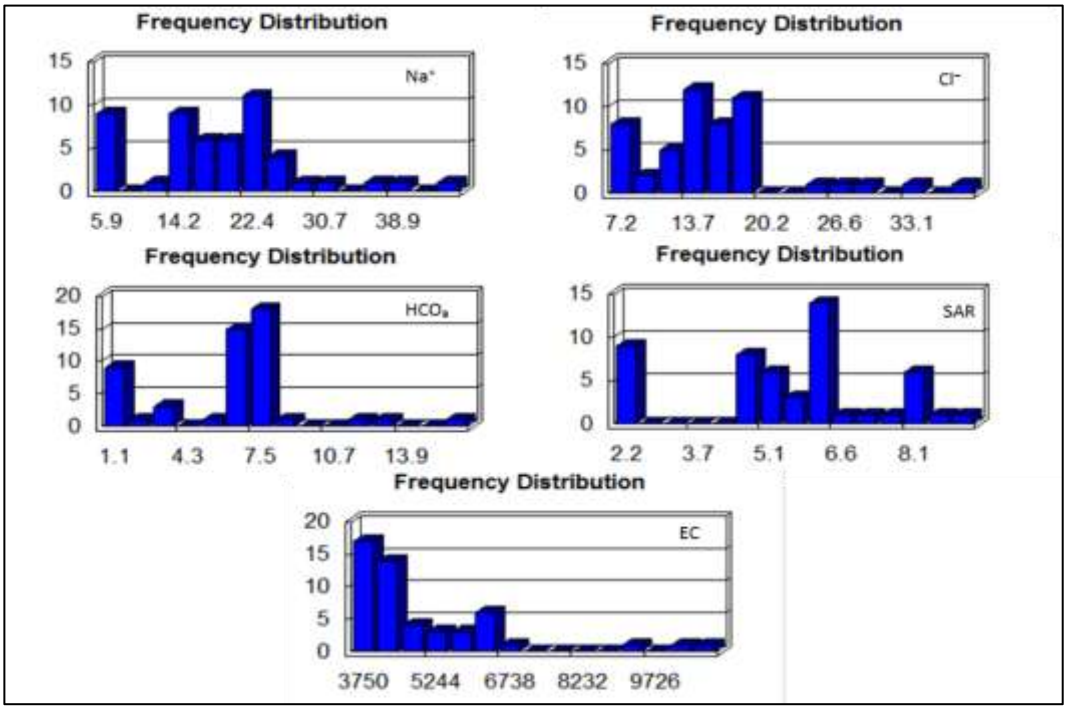

Figure 11-Frequency distribution of IWQI parameter classes for a wet period where the y-axis represents the values of frequency distribution and the x-axis represents the values of IWQI parameters.

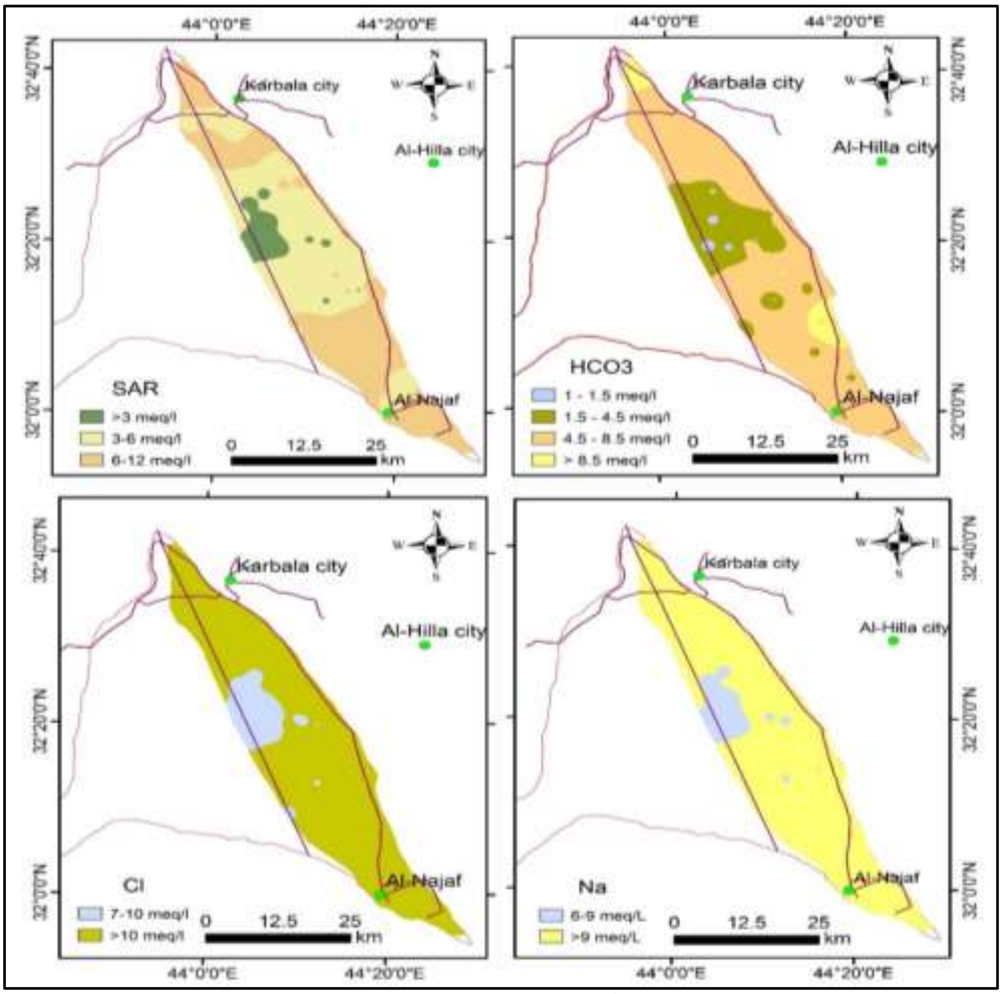

Figure 12-The spatial distribution of IWQI parameters (Na$^+$, Cl$^-$, HCO3$^-$, and SAR according to the quality limit values of Meireles et al. (2010).

Based on IWQI limits, three categories of irrigation groundwater quality were observed in the Dibdibba aquifer. These were very moderate ($55 \leq IWQI < 70$), harmful ($40 \leq IWQI < 55$), and Severe harmful ($IWQI < 40$) classes . These results confirmed that the groundwater quality of the Dibdibba aquifer should be used with caution for irrigation in the study area (Table-4).

The IWQI calculation using the model of Meireles et al. (2010), highlights that almost all samples in wet period are considered as “Severe restriction (SR)” (80%), “High restriction (HR)” (4%), and “Moderate restriction (MR)”(16%), (Figure-13). The obtained suitability map from IWQI values (Figure-14) is evaluated according to five categories (Table-3). Index values are between (55 - 70) may be used in soils with moderate to high permeability values being suggested for moderate leaching of salts (Plants with moderate tolerance to salts may be grown). The index values that are between (40 - 55) may be used in soils with high permeability without compact layers (Plants with moderate to high tolerance to salts with special salinity control practices, except water with low Na^+, Cl^-, and HCO_3^- values). Water with Severe restriction represents the most significant part of the study area with index values are low 40 should be avoided its use for irrigation under normal conditions.

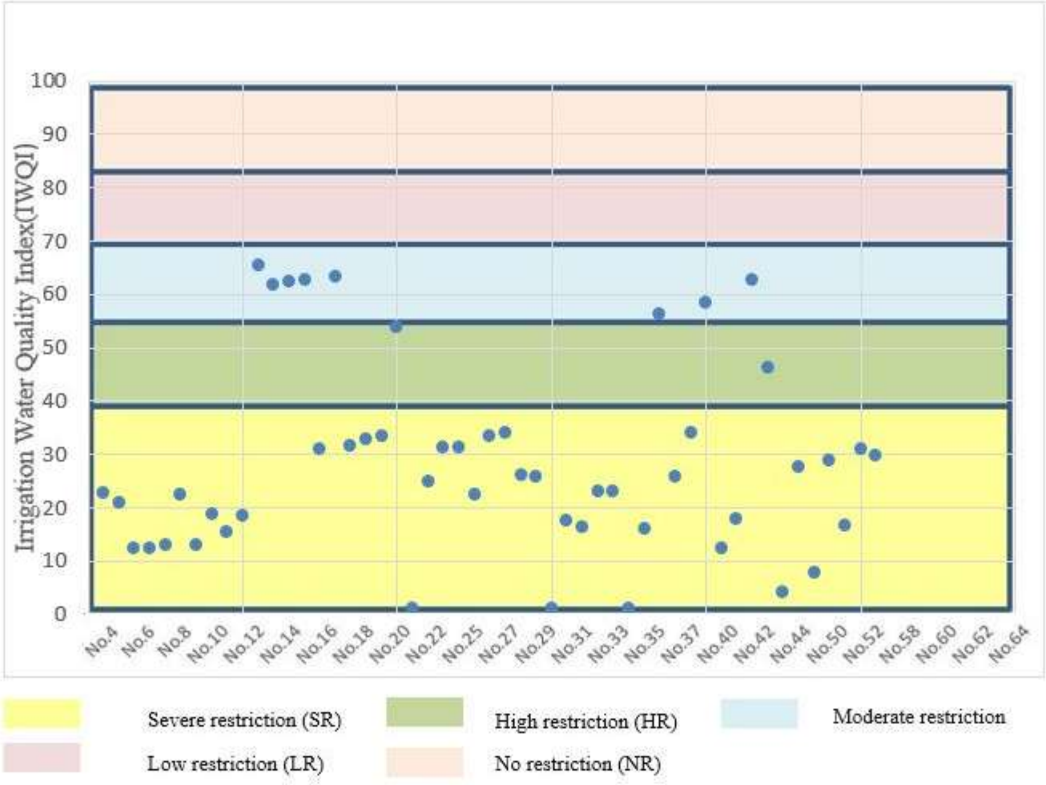

Figure 13-IWQI spatiotemporal variation diagram, where x-axis represented wells in the study area.

The GIS-based IWQI and thematic maps discussed earlier could be used to prevent (1) soil and water deterioration. (2) Vital problems in agricultural production. Therefore, it could help the sustainable management of natural resources in the Dibdibba aquifer in the study area.

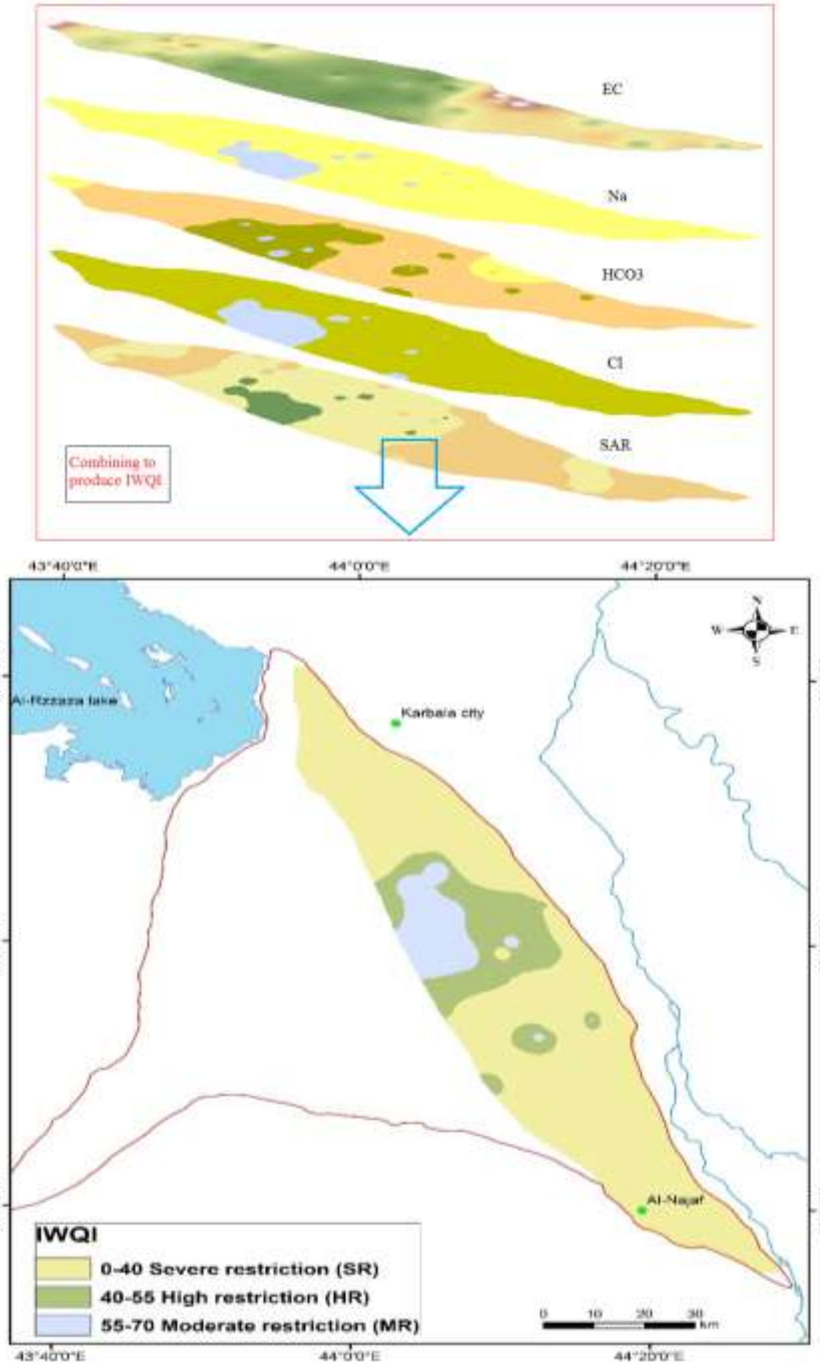

Figure 14-IWQI spatial variation map in Dibdibba aquifer.

6. Conclusion

The assessment of water quality for irrigation is of great importance due to several factors, such as the growing demand for farming development and the arid climate conditions. Most groundwater samples fall in the C4-S1, C4-S2 and C4-S3 classes (Low- medium to high of sodium hazard and high EC) indicating that groundwater is medium suitable for irrigating salt-tolerant crops in soil with good permeability. The IWQI calculation highlights that almost all samples in the wet period are considered as “Severe restriction (SR)” (80%), “High restriction (HR)” (4%), and “Moderate restriction (MR)”(16%). The obtained suitability map from IWQI values is evaluated according to five categories. Index values are between (55 - 70) may be used in soils with moderate to high permeability values being suggested for moderate leaching of salts (Plants with moderate tolerance to salts may be grown). The index values that are between (40 - 55) may be used in soils with high permeability without compact layers (Plants with moderate to high tolerance to salts with special salinity control practices, except water with low Na^+, Cl^-, and HCO_3^- values). Water with Severe restriction represents the most significant part of the study area with index values are low 40 should be avoided its use for irrigation under normal conditions.

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