Article

Utilizing the Irrigation Water Quality Index (IWQI) to Determine Groundwater Feasibility for Irrigation Purposes, In the Ishaqi Area, Saladin, Northern Iraq

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Abstract: IWQI and distribution maps of the used parameters for irrigation were investigated in the Ishaqi Area. In general, the calculated IWQI values reached from (17.09 -78.8), 19% of samples in the study fell under stringent irrigation regulations, where plants that can withstand saline water can only be grown using groundwater. Of the wells that were examined, a comparatively greater proportion, 76.2% fell under the high restriction category while only 4.8% of them were in the low restriction category and none fell under the unrestricted category. The IWQI reduces from the periphery towards the interior of the study area and rises in the direction of the northeast and southwest; this suggests that the central part of the research area and rises toward the northeast and southwest; this indicates that the study area's core region is polluted and should only be used for crops that can withstand salt. The northeast and southwest regions of the research area are suitable for the cultivation of plants that are moderately to extremely salt resistant. Furthermore, the study area's irrigation water quality variables, including SAR, EC, Na%, and chlorides (Cl-), all indicate that the area's soils may experience issues as a result of the existing irrigation system. When combined with WQI standards and indicators, the geographical distribution maps of the IWQI index can provide a clear picture of the condition of a particular area with regard to groundwater quality for irrigation; they can be very useful and supportive decisions making tool in a process of identifying the areas that suffers from poor ground water availability or contaminated water.

1. Introduction

Water quality evaluation is essential for the evaluation and use of water in the system.

Water quantity alone is not sufficient, that is why it is vital to emphasis that the quality of water is just as important to use in the mentioned above usage, namely irrigation [1]. This is because the groundwater that is used for irrigation, especially in the field crops influences the crops due to dissolved mineral salts in the water. Yet the level of dissolved salts that is assayed, ranges from one type of groundwater to another used in irrigation. With reference to some certain major and minor ions that dissolve in water in different proportions and with these facts putting into consideration and some other factors and determinants, the water can be considered for agricultural and irrigation purposes. Because water is used for agriculture production, there is relatively little data available when examining the physical and chemical characteristics of groundwater quality and contamination indicators [2].

The study area is one of the regions which are well exploited for agriculture due to assured availability of water through Groundwater that it now tapping through several shallow (manual) and deep wells use for irrigation. But as to the adoption of these waters to its maximum and avoiding exhaustion and degradation of their quality there are no clear and efficient plans if these waters should be used for agriculture there are no means of ascertaining the best waters for the purpose in accordance with particular standards [2]; [3]. This is one of the reasons why this study was undertaken/[4] .

The study area is neighbor to the northwest of the city of Samarra at geographic coordinate coordinates of (43° ′50 ″28) and (44° ′06 ″14) E, and the latitudinal coordinates of (33° ′49 ″30) and (34° ′05 ″24) N, with an approximate area of (523) km² The area is aerially productive since people in the region practice agriculture ranging from wheat, barley and corn, they rely on rainwater basis and also do some summer and winter vegetables, irrigated by ground water except the areas close to the Tigris River water that they irrigate their agriculture by from the River water, are shown in Figure (1)
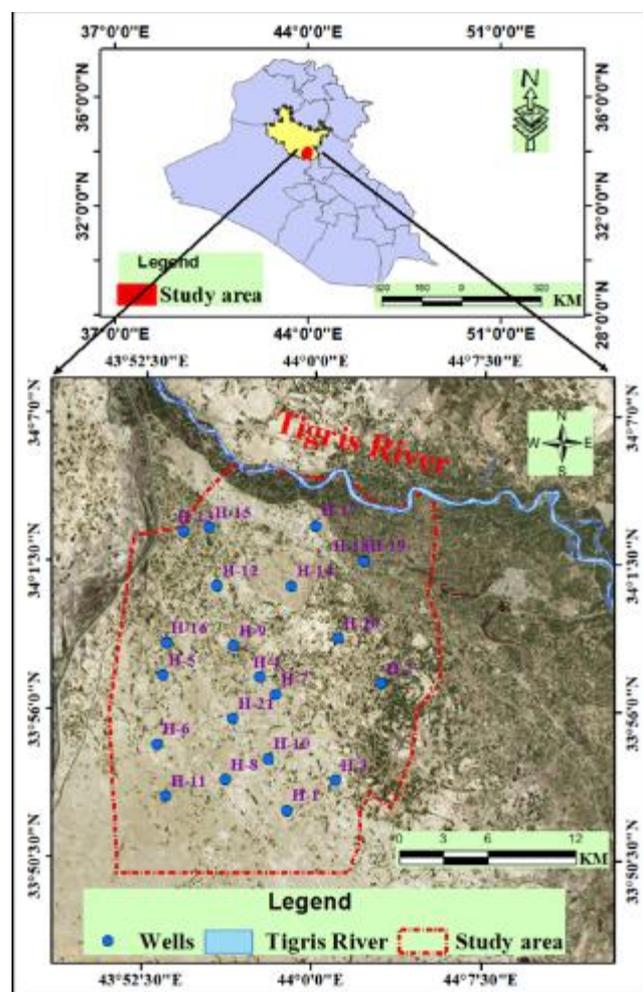
Fig 1. Study area location

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2. Materials and Methods

1-2 Geological and hydrogeological

The study area is covered of Quaternary sediments which are fragmented and moderately cemented material, found in exposed formations comprised of gravely, sandy, silty, and clayey materials arranged in an interbedded or parceled form in an organized way and differentiated in regard with their proportion in each area [1]. Such deposits include Pleistocene and Holocene deposits These are sediments deposited during the

Pleistocene epoch and the Holocene epoch. These sediments have thickness ranging between centimeters to couple of meters as due to the variation in depositional environments, geology of the prepared area, hard and soft components included in the form of morphological structure. These include: Alluvial fan deposits and River terraces deposits.[6]

The type of data collection that has been used in the study was lithological logging data of the 7 wells described in the study area and their representative stratigraphic sections which has been received from the database of the General Authority for Groundwater (Groundwater Department in Salah Al-Din). Part of these sections is depicted in figure 2. According to the previous research studies of the investigated region and with the help of the lithological profile of the wells, the Quaternary aquifer is identified as the most important water-yielding formation within the study area. It is formed of a series of gravels, sand, silt and clay, is described as an unconfined aquifer. This is because it lies on clay and silt layers from below in addition to being restricted from above by the water table[7].
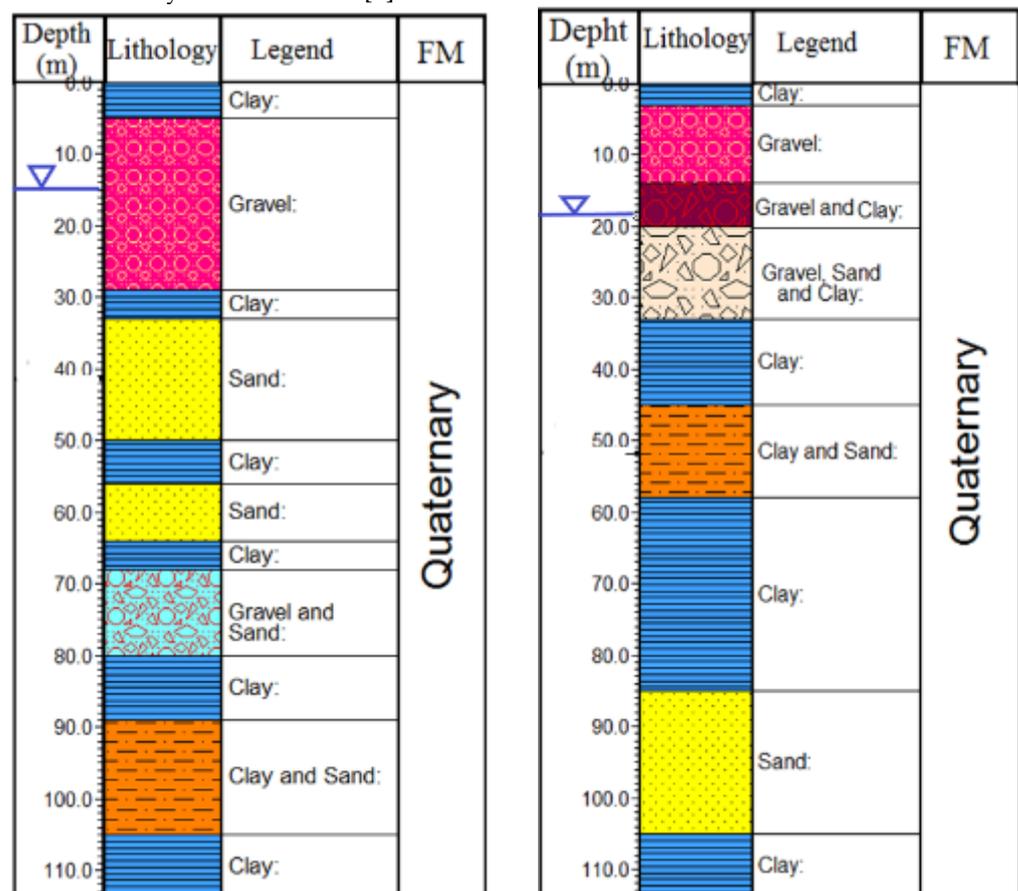

Fig. 2. Lithological section of wells (21, 14)

2.3.1 Analysis of physical and chemical parameters

The data of physical and chemical analysis of groundwater samples which have been collected during the present study have been collected from the data bank at the General Authority for Groundwater (Groundwater Department in Saladin) from the data bank of the national program for "Monitoring and Quantitative and Qualitative Analysis of Water Points". Table (1) provides analysis of the data for (21) well located within the study area as listed below.

Table 1: Results of physical and chemical analysis of the groundwater samples

Well No.	TDS	EC (µS/cm)	PH	Ca (ppm)	Na (ppm)	Mg (ppm)	K (ppm)	SO$_4$ (ppm)	HCO$_3$	Cl$^-$)ppm(	NO$_3$ PPm)(
H-1	2475	3500	7.31	244	306	120	4	652	380	438	5.2

H-2	1100	1571	7.14	85	86	96	3.6	440	110	176	2
H-3	2902	3910	7.61	213	340	121	6	861	453	530	2
H-4	4392	6160	7.17	328	570	161	7	1408	490	686	4
H-5	4411	6180	7.6	339	583	139	43	1485	405	681	3
H-6	3674	4980	7.14	109	529	120	3	780	360	781	3
H-7	3063	4250	7.21	257	378	158	8.5	951	262	650	6
H-8	3469	4640	7.12	200	512	80	4	850	265	575	5
H-9	3990	5600	7.19	189	550	71	4	850	358	530	8
H-10	3440	4630	7.2	190	552	75	4.5	865	356	533	8
H-11	3404	5140	7.17	283	530	139	89	1182	479	651	3.5
H-12	2888	3810	7.19	260	410	131	83	1001	448	551	7
H-13	1511	2130	7.51	39	245	20	8.5	306	193	159	5
H-14	2592	3650	7.15	254	212	141	10	791	201	540	6
H-15	2069	3780	7.22	141	321	60	15	711	179	261	2.1
H-16	3450	4790	7.18	214	520	119	7	815	368	676	2.1
H-17	2700	4090	7.13	243	360	130	6.2	806	240	635	7.1
H-18	3512	5300	7.6	350	494	157	65	989	523	697	2
H-19	3512	5300	7.6	350	495	158	66	990	524	698	3
H-20	3512	5300	7.6	350	496	159	67	991	525	699	4
H-21	3246	4360	7.18	207	433	91	3.2	780	449	489	3

2.3.2 Calculation of sodium adsorption ratio (SAR)

The best way to describe soil absorption of sodium is by quantitative indicators, among which SAR is one of the most significant. The amount of water that may be used and made accessible to the crop depends on the ratio of sodium to calcium and magnesium [5]. The following formula (1) is used to compute it, with all ions expressed in epm:

$$SAR = \frac{rNa}{\sqrt{r(Ca+Mg)/2}} \quad ....(1)$$

These results indicate an excellent to good type shown in Table 2:

Table 2. SAR-based proposed well classification and restrictions at groundwater samples

Value Range FAO	Water type	NO. of samples	% of wells
< 6	Excellent type	11	52.38
6-9	Good type	10	47.62
>9	Permissible type	0	0

2.3.3 Calculation of sodium percent (Na%)

The soluble sodium percentage (Na%; also known as SSP) was examined in order to assess the water quality for use in irrigation [8]. It was observed that the higher Na content in the irrigation water has accelerated the direct impacts both the plant growth and/or soil quality [9]. Water salinity levels above Na% 60 may cause build-up of soluble sodium and the likely hood of yielding to poor soil structure, infiltration and aeration[10]. The following formula (2) can be used to calculate the Na%; the results are shown in Table 3.

$$Na^+ \% = \{\frac{Na^+ + K^+}{Ca^{++} + Mg^{++} + Na^+ + K^+}\} * 100 \quad ….. ....(2)$$

Table 3: Water classification based on Na% by [7] in the samples.

Value Range	Water type	NO. of samples	% of wells
<20	Excellent type	0	0
20-40	Good type	3	14.28
40-60	Permissible type	14	66.67
60-80	Doubtful type	4	19.05

>80	Unsuitable type	0	0

2.3.4 Calculation of Irrigation Water Quality Index (IWQI(

The IWQI, as an index of a dimensionless character, is limited to the range of values between 0 to 100 and is estimated on the basis of some parameters (EC), (Na^+), (HCO_3^-) , (Cl^-), and (SAR)[11] , concentration units of the target compounds were converted to (epm) [12]. The Iraqi irrigation water quality indicators and their limits are presented in table (4) proposed by [13] and [14].

Table 4: The parameters of irrigation water quality and their respective proposed limiting values by [9] and [10].

Qi	EC (µS/cm)	SAR	Na^+ (epm)	HCO_3 (epm)	Cl^- (epm)
85-100	200-750	<3	2-3	1-1.5	<4
60-85	750-1500	3-6	3-6	1.5-4.5	4-7
35-60	1500-3000	6-12	6-9	4.5-8.5	7-10
0-35	<200 or>3000	>12	<2 or>9	<1or>8.5	>10

The Qi values of the water quality parameters by using equation3 and some of the values are given below in table 6 are given by the following formula; the upper limits of the parameters' range En set in table 4 were taken as the In order to test ximap, the upper limits of the parameter range En defined in table 4 were used as the maximum values of the observed samples. The Qi values of the water quality parameters were calculated using equation 3, and some of the values are provided below in table 6.

values of the observed samples in order to test ximap.

Qi = Qmax − ([(Xij − Xinf) × Qimap / Xamp)…. (3)

Xij represents the data points of the parameters displayed in Table 6, and Qmax is the top value of the corresponding class of Qi. (observed value of every parameter), where Xinf denotes the class to which the observed parameter belongs and its lower limit value For qi classes, Qimap denotes the class amplitude, and Ximap is the class amplitude to which the parameter belongs.

Finally, the IWQI was determined using the following relation (4):

IWQI $= \sum_1^n Qi\ Wi$ …. (4)

The value qi in Table 4 represents the optimal weight wi of each parameter provided in Table 5 in accordance with [11], and n is the number of parameters taken into consideration.

Table 5: The weights of the IWQI parameters [11].

Parameters	W_i
Ec	0.211
SAR	0.189
Na^+	0.204
HCO_3^-	0.202
Cl^-	0.194
Total	1. 0

3. Results and Discussion

Thus, the fact that different kinds of water could be used for irrigation is hinged on how the minerals within the water affect the plants and the soil. Salts are known to alter the characteristics of the soil like the arrangement of the particles and influence the level of porosity, factors, which have an influence[15] on plant growth and development indirectly. Before viable groundwater can be utilized for agriculture or for irrigation, several factors must be taken into consideration these include; the kind of crops, the

climate of the region, and the type of soil. Since the water contains salts, the effects include the changes on some of the physical and chemical properties of the soil such as structure, porosity and permeability among others [16]. These changes in the soil may then affect other related cycles and precipitation factors so that the plants which the soil is irrigating may also be affected. Thus, to determine the groundwater irrigation suitability, the interferences of the water chemistry with the soil type and the crop demand needs to be considered. The major areas of consideration in the assessment of these factors include the [17], [18] kind of crops to be grown, climatic factors of the area, and physical characteristics of the soil. Altogether these parameters identified play the role of defining the overall admittance, feasibility and probable effect of use of the ground water for the purpose of irrigation.

In addition to using the metrics (%Na), (SAR), (Cl−), and (EC), the water quality index — which is regarded as the fundamental criteria in this study — was used to evaluate the groundwater quality[19]. The geographical distribution maps for each of these factors were also created using the geographic information system (ArcGIS) tool, as table 6 demonstrates. Your recently added invisible stuff [13]:

Table 6: physical and chemical parameters of wells and IWQI values

Well No.	EC (μS/cm)	SAR	Na%	Na (epm)	Cl (epm)	HCO_3^- (epm)	Qi EC	Qi SAR	Qi Na$^+$	Qi Cl$^-$	Qi HCO_3^-	WQI
H-1	3500	4.01	37.83	13.31	12.36	6.23	6.22	14.47	5.26	5.46	9.94	41.35
H-2	1571	1.04	24.00	3.74	4.96	1.80	12.41	18.70	16.08	14.94	16.67	78.80
H-3	3910	4.61	42.06	14.79	14.95	7.42	5.27	13.53	4.61	4.00	8.43	35.84
H-4	6160	6.44	45.75	24.80	19.35	8.03	0.05	10.99	0.24	1.51	7.66	20.46
H-5	6180	6.74	48.28	25.36	19.21	6.64	0.00	10.76	0.00	1.59	9.42	21.77
H-6	4980	8.32	60.13	23.01	22.03	5.90	2.79	9.51	1.03	0.00	10.35	23.68
H-7	4250	4.58	39.22	16.44	18.34	4.29	4.48	13.58	3.89	2.08	12.47	36.51
H-8	4640	7.74	57.47	22.27	16.22	4.34	3.58	9.97	1.35	3.28	12.39	30.56
H-9	5600	8.66	61.14	23.93	14.95	5.87	1.35	9.25	0.62	4.00	10.39	25.60
H-10	4630	8.58	60.65	24.01	15.04	5.83	3.60	9.31	0.59	3.95	10.44	27.88
H-11	5140	6.45	49.78	23.06	18.36	7.85	2.42	10.99	1.00	2.07	7.89	24.37
H-12	3810	5.18	45.66	17.84	15.54	7.34	5.50	12.63	3.28	3.66	8.53	33.61
H-13	2130	7.95	75.17	10.66	4.49	3.16	10.44	9.80	6.42	6.54	14.38	47.58
H-14	3650	2.65	28.08	9.22	15.23	3.29	6.08	16.42	7.04	3.84	14.21	47.59
H-15	3780	5.71	54.51	13.96	7.36	2.93	5.57	11.80	4.98	11.06	14.76	48.17
H-16	4790	7.07	52.69	22.62	19.07	6.03	3.23	10.50	1.20	1.67	10.19	26.78
H-17	4090	4.64	40.94	15.66	17.91	3.93	4.85	13.48	4.23	2.33	14.16	39.05
H-18	5270	5.51	43.25	21.49	19.66	8.57	2.11	12.11	1.69	1.34	2.12	19.37
H-19	5300	5.52	43.25	21.53	19.69	8.59	2.04	12.10	1.67	1.32	0.71	17.84
H-20	5310	5.52	43.26	21.58	19.72	8.60	2.04	12.10	1.65	1.30	0	17.09
H-21	4360	6.31	51.50	18.84	13.79	7.36	2.02	11.10	2.85	4.65	8.51	29.12

4.1 Sodium Adsorption Ratio (SAR)

overall assessment of quality of irrigation water and fitness of the water for that purpose could be ascertained by using SAR, Na%, EC and Cl-,. The parameters for the present study were thus in accordance to Table 7 displays the (F. A. O.) [20]boundaries for irrigation water quality.. From the concentration of the sodium ion it is seen that as concentration tends to increase so does the pH of the soil increasing it's alkalinity. Here, Sodium ion displaces the Calcium ion that is attached to the soil colloids source [21]. The cations play a major role of displacing sodium with calcium and magnesium leading to dispersion of particles and compaction when it is in a dry condition this making the soil less permeable in texture. This means that the plant roots are unable to get a sufficient amount of this all-important compound[22]. Thus, when the SAR values obtained in the present study from the groundwater samples given in table 6 are compared with the standard values of table

4, it may be concluded that the quality of groundwater for irrigation purpose is excellent to good[23]. Secondly, the GIS based map of SAR values is depicted in the form of Figure 3 it reveals that the SAR values are higher in the western side of the study area and as move towards the east the values get lower. The displacement of calcium and magnesium ions in the soil colloids by sodium ions cause the dispersion of the soil particles and this has a close, tight and heavy structure through which water cannot permeate. This in a way decreases the amount of water which is accessible by the roots of the plants and thus the growth cycle of the crops is altered[24].

Table 7: Classification of groundwater quality for the investigated sites based on IQWI.

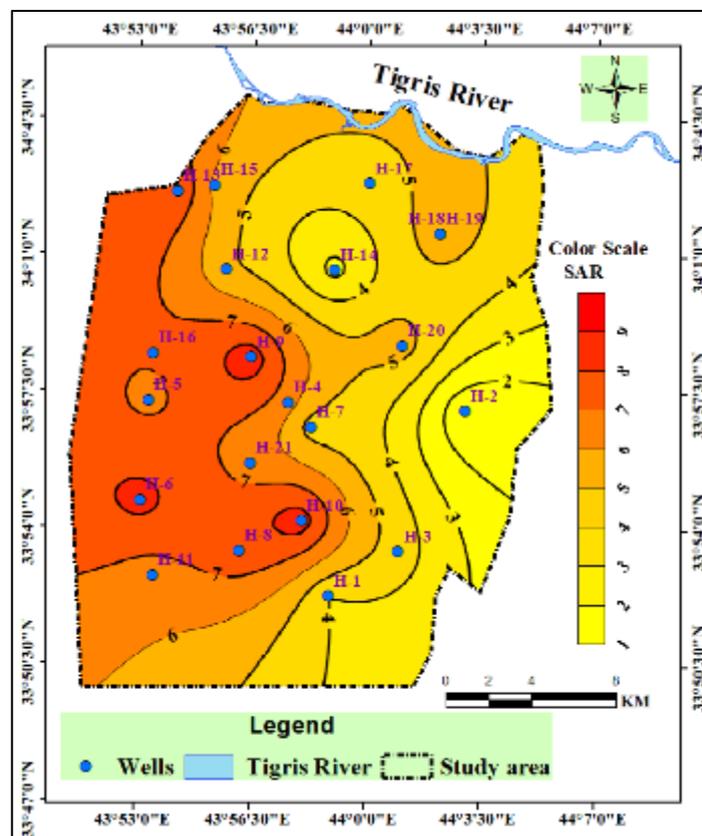| Parameter	Classification of groundwater quality for irrigation		
	Problems unlikely to happen	Increasing Problems	Serious Problems
Ec (µS/cm)	Less than 750	750 to 3000	More than 3000
SAR	Less than 3	3 to 9	More than 9
Cl (ppm)	Less than 70	70 to 300	More than 300

Fig. 3. Spatial distribution of SAR in the study area

4.2 Sodium percent Na%

High concentration of sodium ions reduces permeability of the soil and increase of this ratio in irrigation water affect either the growth of a plant or a hindrance to plant growth. It also impacts the quality of the soil in any particular region since different plants require different qualities of soil in order to grow and to be productive [21]. 14% of the study area's water samples have high quality[25], 67% are of allowable quality, and 19% are of dubious quality, according to an analysis of the results contained in table 6 above and a comparison with the suggested limit in table 3[23]. A distribution map of (Na%) was also created using a geographic information system, as seen in figure 4. Given that the values increase in the western portion of the research region and drop in the eastern portion, the distribution map and the SAR distribution map agree well[26].
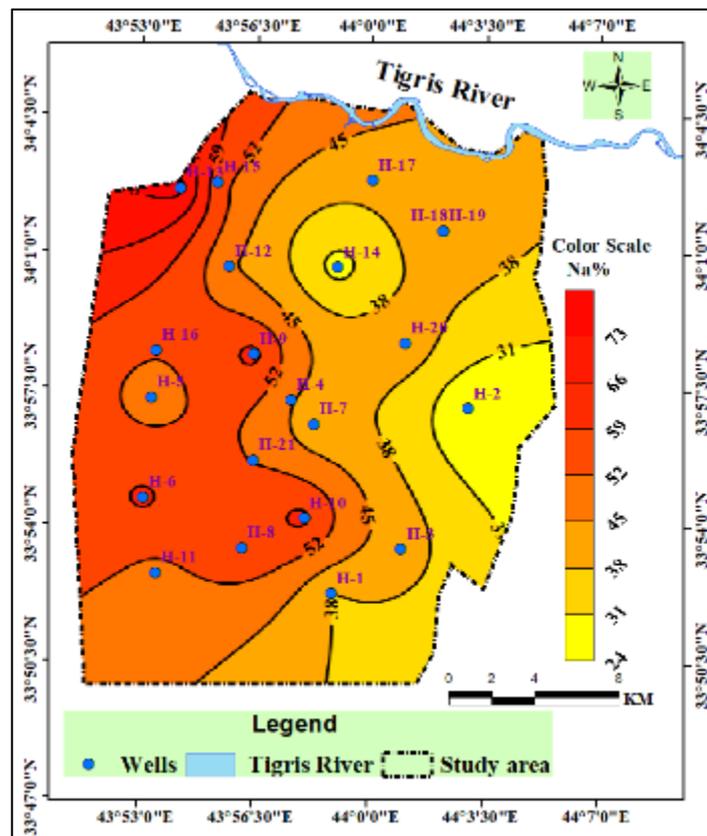
Fig. 4. Spatial distribution of the Percentage of Sodium in the study area

4.3 Electrical Conductivity (EC)

Water quality for irrigation is classified by an Electrical Conductivity (EC) value. It turns out that source waters which may be effectively applied for irrigation have the EC values less than 750 μS/cm. It has been discovered that over 3000 μS/cm is regarded as dangerous for crop growth and development thus, water with EC values below 3000 μS/cm should be used carefully [27]. However, crops may hardly be produced under such highly saline conditions since, besides reducing the controlled typical biological processes essential for healthy crop growth and development, the high salinity levels compromises their economic yields through factors such as stunting and damage. By comparing the findings of the analysed well water samples as shown in table 1 with the guidelines in table 7, it can be realized that the water quality comes under the water quality problematic zone of "Increasing Problems" and "Severe Problems". A distribution map of electrical conductivity (EC) was created with the help of the Geographical Information Systems technique, which is presented in the Figure (5). Just by looking at this map, one can clearly observer that the EC values are high in the middle of the study area and relatively low at the eastern and western parts of the area of interest. There is an increase in dissolved salt concentrations in all the water samples that also translate to high electrical conductivity affecting structure of the soil, water infiltration and physiological processes of plants [28]. This paper identifies the uneven nature of EC through GIS map and implies the importance of water management approach in facing the challenge of salinity in various areas of the study[25].
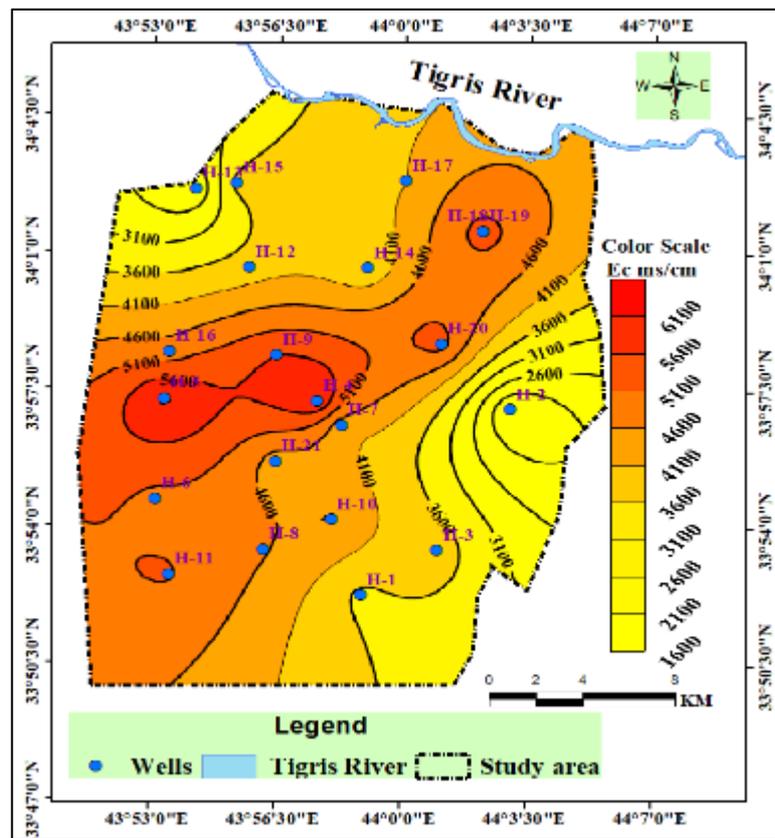
Fig. 5. Spatial distribution of EC in the study area

4.4 Irrigation Water Quality Index (IWQI)

An integrated index called the IWQI is used to assess the water quality for irrigation applications in agriculture. This index considers a number of important variables that have an impact on whether water is suitable for irrigation and divides them into groups based on how appropriate the water is. Among these are: (EC) gauges the salinity of water and how it affects plants' ability to absorb nutrients and water, (SAR) Measures the sodium hazard on soil fertility and its effect on water permeability, Chloride (Cl⁻) Measures the water content of chloride, which can be toxic to plants at high concentrations and Na% Affects soil permeability and plant growth [29].There are several indices used to determine water quality for irrigation purposes, and in this study, the IWQI was utilized. Based on these factors, the IWQI value is calculated, which ranges from 0 to 100. Water is classified into different categories from unsuitable to excellent based on this value. This index provides a comprehensive assessment of water quality and its suitability for agricultural irrigation, as shown in the table 8.

Table 8: Revised IWQI index categorization schema.

IWQI Value Range	Type of restriction	Type of field crops	Percentage of wells	Type of Soil
85 to100	No restriction	no toxicity	0%	Groundwater can be used for all types of soil as low risk of soil salinity and sodicity is prevailed
70 to 85	Low restriction	avoid the use of salt sensitive	4.8%	Groundwater can be used for light soil texture with high sand content, moderate to high permeability
55 to 70	Moderate restriction	moderate salt tolerance plants	0%	Groundwater can be used for moderate to high permeable soil taking in consideration moderate soil leaching processes
40 to 55	High restriction	moderate to high salt	19%	Groundwater can be used for permeable soil without compact layers and taking in consideration the high frequency of the

0 to 40	Severe restriction	high salt tolerance plants		irrigation schedule for irrigation water with EC > 2000 µS/cm and SAR>7
0 to 40	Severe restriction	high salt tolerance plants only	76.2%	Groundwater can't be used to irrigate soil under normal conditions

when comparing the calculated IWQI results in the well waters shown in Table 6 with table 8 Since Out of the above calculated wells, more that 76.2% of the total wells analyzed fell inside the severe range which restricts the use of the groundwater to only the high salt tolerance plants, and under no condition it should be used for irrigation purposes. Nonetheless, 19% of the total investigated wells were found to fall within the high restriction category that allows the use caution of the irrigation Out of the investigated wells only 4.8% Were classified in the low restriction category that avoids the salt sensitive plants and is mindful of the irrigated soil texture, permeability and soil sodicity problems. In conclusion, none of the wells had no restriction range at all.

For development of the map of the IWQI (Irrigation Water Quality Index) for the study area, Geographic Information Systems (GIS) were applied which is described in figure (6). The map also shows that the trend of the IWQI is low at the middle of the study area and high at the northeastern and south western zones of the study area. This map can be interpreted as follows: the regions marked in yellow are treated as polluted and not suitable for agricultural practices, nevertheless plants that are salt sensitive can be grown here. To grow moderately to highly salt tolerant plants, the areas highlighted in red or orange can be utilized.

Spatial location data gathered mentioned that GIS based maps may be employed to describe areas with overexploitation of the groundwater and infested areas as well as areas conducive to farming. Thus, these maps can give the chiefs elaborate trends that would facilitate the recommendations on how to manage the water resources in a sustainable manner, and the districts where agricultural wells can be drilled.
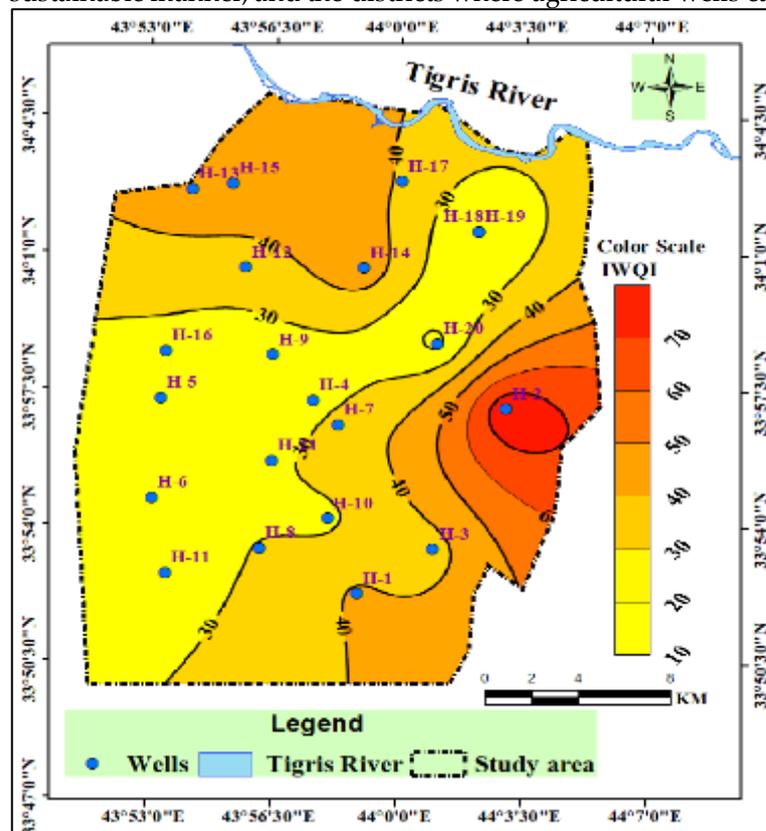

Fig. 6. Spatial distribution of IWQI in the study area

4. Conclusion

The Irrigation "Water Quality Index (IWQI)" was developed to answer the demand for an evaluation tool and was intended to determine if the ground water resources in the research region were suitable for irrigation. The spatial distribution of the irrigation water quality norms—SAR, EC, Na%, and Cl⁻—is depicted using IWQI and GIS mapping. To clear up any doubts regarding the quality of groundwater and its potential use, including irrigation, in the research area. IWQI reported that 4.8% of the analyzed wells were determined to be under low and moderate limitations, while 95.2% of the investigated wells operate within upland water limits, falling into the category of severe restrictions that hinder its usage for irrigation. Additionally, the investigation showed that, according to IWQI, 95.2% of irrigation fell into the bad category. As a result, residents in the study region are less aware of the risk of ground water pollution, even though risk education about the issue may encourage them to refrain from using such contaminated water for irrigation or to remediate it before use.

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