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Creating a Drinking Water Quality Index (WQI) Map Using the Geographic Information System (GIS) Technique for Karbala City, Iraq

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Abstract

The geographic information system (GIS) technique is applied in the present study to produce a drinking water quality index map for the Karbala city in Iraq. Ninety-two samples of groundwater were collected from different sites in the study area and analyzed in terms of different chemical parameters affecting the quality of drinking water. The piper diagram is used to estimate the chemical type of groundwater in the study area. Na^{+}-SO_4^{-2} and, Na^{+}-Cl^{-} facies were found to be the dominant major groundwater types. At few locations, the groundwater chemistry belongs to mixed Mg^{2+}-Ca^{2+}-SO_4^{-2} and mixed Mg^{2+}-Ca^{2+}- Cl^{-} facies. Cations and anions were used to create a water quality database in the study area using (GIS) for the purpose of producing a spatial distribution map for each parameter using the Reverse Interpolation Technique (IDW). The results of these determinants were also used to calculate the values of the water quality index and the production of the index map of the quality of drinking water. The analysis of the WQI map results shows that only 1 % of the water samples fall within class II which represents good water quality and 57 % of the available well samples fall under class III which indicates poor water quality, 21% of the water samples fall in class IV which indicates a very poor water quality, and 20 % of the samples indicate unsuitable water. Wilcox and United State Salinity Laboratory (USSL) diagrams are also applied in the current study to evaluate the available water wells in the area, and to determine its suitability for irrigation purposes. To achieve this goal the Electrical Conductivity (EC) has been measured and the sodium percentage (Na %) and sodium Adsorption Ratio (SAR) have been calculated based on the chemical analysis of Ca_2^{2+}, Mg^{2+}, Na^{+}, K^{+}. The results show that only 4 % of the water samples fall under the good to permissible category, and are suitable for irrigation

Keywords: "GIS, Water Quality Index, Karbala, Iraq"

1. Introduction

River water constitutes the main source for drinking water, irrigation and other purposes in Iraq. However, river water has been exposed to many problems in recent years, the most important of which include the scarcity of rainfall, the construction of dams on the Tigris and Euphrates rivers by the neighboring countries, in addition to the fact that rivers have become a dumping ground for industrial waste (Alhadithi, 2016). Therefore, there is an urgent need to find other sources of water to meet people's water needs. Groundwater is one of the most reliable sources of water, which is almost believed to be clean and uncontaminated water (Alhadithi, 2004; Israil, et al., 2006). Hence, there is a general tendency in Iraq to drill more wells to meet the growing water needs for potable water, and water for agricultural purposes and all daily uses.

The current research is conducted to look for other sources of water and to study their suitability for drinking purposes using GIS and the water quality index technique in the Karbala province. These techniques have been used successfully in recent years to assess groundwater quality as they provide an overview of the water quality by incorporating composite data and giving a result that describes the condition of the groundwater. Several researchers around the world have applied the WQI model to evaluate the quality of drinking water. Horton (1965) has been the first to use the WQI concept successfully, which was then developed and improved by Brown et al., (1970). The improvement of WQI for groundwater is described in a number of studies (Backman et al., 1998; Ramakrishnalah et al., 2009; Soltan, 1999; Saeedi et al., 2009; Stigter et al., 2006a; Stigter et al., 2006b). In Iraq, this method has also been used in many studies and for multiple areas (Alhadithi, 2014, 2016; Al-Saadi, 2013; Amal et al., 2013; Khalid, 2011; Rizwan and Gurdeep, 2010). In the current study, the GIS technique has been used to create a water quality database and generate a WQI map to evaluate the groundwater in the Karbala province.

1.1 Study Area

The study area is located in the center of Iraq about 100 km south of Baghdad. It is bounded by latitudes 32° 8' 00" to 32° 51' 00" North and longitude 34° 10' 00" to 44° 17' 00" East (Figure 1). The study area is about 5,043 km^2 and has a population of about 1.067 million according to the census of 2011 (Al-Jiburi, 2002). The climate there is characterized by a cold weather in winter with low precipitation and hot dry summers (Al-Jiburi, 2002). The mean annual values of

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precipitation, temperature and evaporation are 9.9 mm, 23.07 C° and 266.81 mm respectively while the relative humidity has a negative trend compared to the temperature and evaporation (Al-Jiburi, 2002).

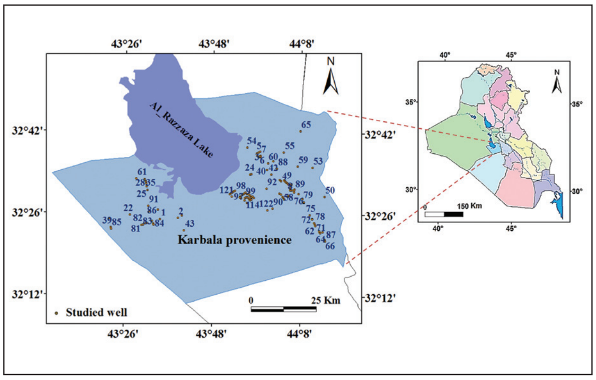

Figure 1. Location map of the study area

1.2 Geology and Hydrology of the Study Area

The geological outcrops in the studied area represent the Dammam, Euphratees, Nfayl, Fatha, Injana, Zahar and Dibdiba Formation as well as the Quaternary deposits which cover 80 % of the studied area. All the geological formations of the study area are described in Table 1. These formations represent part of two structural areas: Salman Zone which belongs to the stable shelf, and the Mesopotamina zone which belongs to the unstable shelf (Al-Jawad et al., 2002).

The study area can be divided into three regions from a topographic point of view, namely, the Mesopotamian plain, the Desert plain, Bahr Al-Najaf, and the Raazaza depression. The main groundwater aquifers in the west of the studied area are Dammam and Umm ErRathuma Formation while the main aquifer within the terregenous deposits of the desert plain is the Injana Formation. Dammam and umm ErRdhuma Formations represent the first and second aquifers within the carbonate rocks respectively.

Table 1. Geological Formations in the studied area

Era	Period	Age	Formation	Description
Cenozoic	Quaternary	Pliocene – Pleistocene	Dibdibba	Sandstone, which is generally white, pink and light grey, well-sorted, fine-coarse grained small pebbles are often reported. Sandstones contain mud balls, occasionally cross bedded. Other rock types are silty clay stone-clayey siltstone.
	Neogene	Late Miocene	Injana (upper fares)	Generally, the formation consists of red, partly greenish silty, sandy calcareous claystone and lenticls of grey, brownish, greenish and yellowish sandstone. Thin beds (0.30 m.) of marly and chalky limestone are occasionally present in the sequence
		MiddleMiocene	Fatha (Lower Fars)	Generally consist of green, partly reddish in places sandy, dolomitic and gypseous marl with interbedded calcareous, partly sandy claystone and fossiliferous limestone
		Middle. Miocene	Nfayil	Lenticular sequence of reddish sandy calcareous claystone and brownish coarse grained sandstone, with limestone intercalations (0.2-2.0 m.)
		Early. Miocene	Euphrates	Basal breccia, limestone and marl. sub rounded, re-crystallized and dolomitized a nummulitic limestone, fragments ranging in size from 1 cm. - 20 cm. cemented by limy material
	Paleogene	Eocene	Dammam	Recrystallized anummulitic limestone, grey, creamy, yellowish and white in color, cavernous and Karstified
		Upper Paleocene	Umm Er Radhuma	Phosphates Limestone/ Dolostone, Dolomite
Mesozoic	Cretaceous	Cretaceous	Tayarat	Dolomitic limestone, silty clay sandstone

The main aquifer in the eastern part of studied area is the Quaternary deposits of the Mesopotamian plain. Figure (2) illustrates the extensions of the Formation of Dammam and its stratigraphical position with other formations along the studied area. The depth of the groundwater varies from one location to another (ranging between 12 and 270), and generally deepens towards the central part of the studied area as shown in Figure (3).

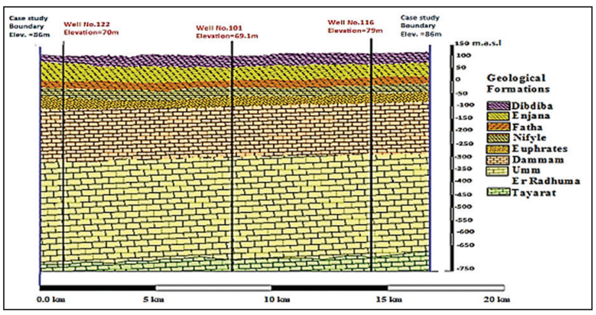

Figure 2. Stratigraphic correlation between the wells in the study area developed from Sissakian (1995) and Consortium-Yugoslavia (1977).

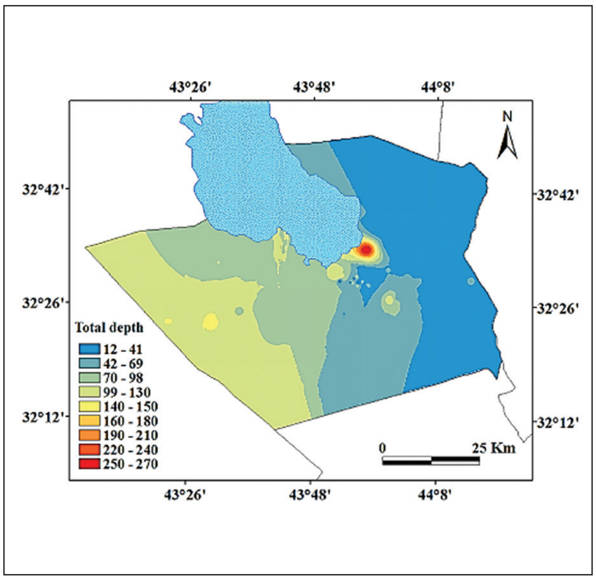

Figure 3. Total depth of groundwater map of the study area

The general direction of the groundwater flow is from west to east and from southwest tonortheast at the western parts of the area,while the groundwater flow is from northwest toward southeast at the Mesopotamian plain with local diversions (Rasul and Waqed, 2015). The most hydrogeological feature in the studied area is the lake of Al-Razzaza.

2. Martial and Methods

Ninety-two samples were collected from ninety-two water wells distributed along the study area; analysis is based on standard roads approved. The locations of these sites are shown in Figure 1. The parameters such as pH, TDS and EC were measured in the field after collecting the samples, while anions and cations were measured in all the groundwater samples in the laboratory. Cations (Ca^{2+}, Na^{+}, and K^{+}) have been analyzed by flame photometer, and Ca^{2+}+Mg^{2+} by the EDTA titration method. Bicarbonate has been analyzed by the H_2SO_4 titration method and chloride has been analyzed by the $AgNO_3$ titration method (Jackso, 1976).

All the measured values were transferred to GIS environment to create a spatial distribution map for each parameter using the Reverse Interpolation Technique (IDW). The results of these determinants were also used to calculate the values of water quality index, sodium percentage (Na %), and the sodium adsorption ratio (SAR).

2.1 Calculating Water Quality Index (WQI)

The groundwater chemical analyses have been used to calculate the water quality index values. The Iraqi drinking water standards for 1992 were taken into consideration also when calculating WQI as shown in Table 2. The weight ***(wi)*** for each chemical parameter has been assigned in the first step depending on its relative importance in the quality of water used for drinking purposes as presented in Table 4. Five is the maximum weight assigned for specific chemical parameters which are believed to be of great importance in the evaluation of water quality and a minimum weight of (2) is given for the chemical parameter that is believed to be not detrimental to the overall quality of water (Table 3).

Table 2. Drinking Water Quality Iraqi Standards (Khalid, 2011)

Parameters	Unit	Iraqi standards for drinking water
TDS	mg/L	500
pH		8.5
Ca^{2+}	mg/L	50
Mg^{2+}	mg/L	125
Na^{+}	mg/L	200
K^{+}	mg/L	12
Cl^{-}	mg/L	200
HCO_3^-	mg/L	200
SO_4^{2-}	mg/L	500
NO_3^-	mg/L	50

According to Ramakrishnalah et al. (1999) a higher weightage is given to nitrite (NO_3^-) parameter than to the others because it plays an important role in the quality of drinking water, while a lesser weight was assigned to other parameters such as magnesium Mg^{2+}, calcium Ca^{2+} and sodium Na^{+} because they are not harmful to the quality of groundwater for drinking purposes. In the second step and in order to assign the relative individual weight of each parameter, standardization was achieved using equation No.1 that is called the relative weight.

Table 3. Relative weight (Wi) values of each groundwater parameter.

Chemical parameters	Unit	Weight (wi)	Relative weight (Wi)
TDS	mg/L	4	0.13
pH		4	0.13
Ca^{2+}	mg/L	2	0.06
Mg^{2+}	mg/L	2	0.06
^{+}Na	mg/L	2	0.06
^{+}K	mg/L	2	0.06
^{-}Cl	mg/L	3	0.10
HCO_3^-	mg/L	3	0.10
SO_4^{2-}	mg/L	4	0.13
NO_3^-	mg/L	5	0.16
		31	1.000

$$Wi = wi / \sum_{i=1}^{n} wi \qquad \ldots\ldots\ldots\ldots 1$$

Where ***Wi*** is relative weight, ***wi*** is the weight of each parameter, and **n** is the number of parameters. In the third step the quality rating scale ***(qi)*** is calculated according to equation number 2 by dividing each chemical parameter concentration (Ci) in each water sample by its respective Iraqi standards for drinking (Si) as shown in Table 5 and the result is multiplied by 100.

$$qi = (Ci / Si) * 100 \qquad \ldots\ldots\ldots\ldots 2$$

In the fourth step, the sub index of the parameter (***SLi***) is calculated for each chemical parameter using the following relationship

$$SLi = Wi . qi \qquad \ldots\ldots\ldots\ldots 3$$

Finally, WQI has been computed using the following relationship:

$$WQI = \sum SLi \qquad \ldots\ldots\ldots\ldots 4$$

The method of calculating the water quality index was explained in detail as an example of well number one in Table 4.

Table 4. Calculating of the water quality index (WQI) of well No. 1

Chemical parameters	Sl	Weight (wi)	Relative weight (Wi)	Ci	qi	SLi	WQI
TDS	500	4	0.13	1945	389.0	50.19	114.7
pH	8.5	4	0.13	7.14	84.0	10.84	
Ca^{2+}	50	2	0.06	130	260.0	16.77	
Mg^{2+}	125	2	0.06	89	71.2	4.59	
Na^{+}	200	2	0.06	140	70.0	4.52	
K^{+}	12	2	0.06	10	83.3	5.38	
Cl^{-}	600	3	0.10	250	41.7	4.03	
HCO_3^{-}	200	3	0.10	63	31.5	3.05	
SO_4^{2-}	500	4	0.13	576	115.2	14.86	
NO_3^{-}	50	5	0.16	1.3	2.6	0.42	
		31	1.00				

2.2 Statistical Analysis

Statistical analysis of chemical parameters of water has been reported from the different divisions of India and other parts of the world (Dewangan et al., 2010; Dhirendra et al., 2009; Navneet and Sinha, 2010; Suhaimi- Othaman et al., 2007 and Antonopouloset al., 2001). A statistical analysis of the chemical parameters of water was carried out using the statistical package for social sciences SPSS, 2009 version 18 to identify the physiochemical parameters that deviate from the Iraqi standards for the quality of drinking water.

The basic statistical test mean, standard deviation and spearman's correlation matrix (assuming $p < 0.01$) are applied as shown in Tables 5 and 6. It can be noted that the mean for all the parameters are more than the limits of Iraqi standards except for the pH values, which fall within the limits. The standard deviation for TDS, Ca^{2+}, Na^{+}, K^{+}, $HCO_3^{-}$and $SO_4^{-2}$is more than the limits, while the remaining parameters are within the limits of Iraqi standards for the quality of drinking water. The degree of a linear association between any two of the water quality parameters measured by the simple correlation coefficient (r) presented in Table 6.

Table 5. Descriptive statistics for all the studied wells

	TDS	pH	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Cl^{-}	HCO_3^{-}	SO_4^{-2}	NO_3
Minimum	1100	7.1	70.0	32.0	81.0	2.0	149.0	63.0	293.0	0.1
Maximum	15200	7.9	1102.0	540.0	2331.0	273.0	3799.0	2013.0	3269.0	9.0
Mean	3342	7.3	262.3	130.5	451.4	41.6	621.5	373.0	999.7	3.0
Std. Deviation	2231	0.2	163.8	79.4	307.9	53.2	489.2	277.1	568.9	2.1
Iraqi St.	500	8.5	50	125	200	12	600	200	500	50

Table 6. Correlation coefficient for a studied well water sample and WQI

	TDS	pH	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Cl^{-}	HCO_3^{-}	SO_4^{-2}	NO_3^{-3}	WQI
TDS	1										
pH	-.084	1									
Ca^{+2}	.950	-.067	1								
Mg^{+2}	.841	-.070	.891	1							
Na^{+}	.946	-.058	.924	.767	1						
K^{+}	.639	-.020	.680	.655	.667	1					
Cl^{-}	.942	-.074	.950	.802	.963	.626	1				
HCO_3^{-}	.910	-.068	.897	.707	.936	.625	.916	1			
SO_4^{-2}	.886	-.062	.919	.926	.870	.772	.836	.766	1		
NO_3^{-3}	-.087	.240	-.106	-.133	-.112	-.266	-.118	-.034	-.182	1	
WQI	.972	-.068	.970	.874	.956	.781	.946	.917	.938	-.136	1

The correlation of the analysis measures the convergence in the relationship between the selected chemical variables. If the correlation coefficient is closer to +1 or -1, it represents the optimal linear relationship between the two chemical variables. The analysis of this method attempts to prepare the nature of the relationship among the drinking water chemical parameters determinants.

In the current study, only NO_3- shows a poor negative correlation with all the ions and a poor positive correlation with pH. PH also indicates a poor negative correlation with all the parameters. All other negative and positive correlations of the pairs are observed as moderate to good correlations. Good correlation indicates chemical weathering and leaching of secondary salts contribution followed by multiple source inputs such as the industrial and agricultural effluents, which exhibit a poor correlation in the groundwater (Udayalaxmi et al., 2010). In addition, good correlation reveals that most of the ions are related in different physiochemical reactions such as the ion exchange in the groundwater pattern.

2.3 Hydrochemical Classification

Hydrochemical facies or hydrochemical zoneation for the present investigation has been carried out by plotting the percentage of the reacting values of major ions in Pipers (1944) trilinear diagrams (Figure 4). It has been observed that 80 % of the water samples fall in the zone of no dominant cation type, and 12 % of the water samples fall in the zone of sodium-potassium type, and that 8 % of the water samples fall in the zone of the calcium type. The alkalis type of water ($Na^+ + K^+$) exceeds the alkaline earth type of water ($Ca^{2+} + Mg^{2+}$) whereas strong acid anions ($Cl^- + SO_4^{2-}$) exceed the weak acids (HCO_3^-) which indicate non-carbonate hardness in all the samples. Na^+- SO_4^{-2} and, Na^+- Cl^- facies, are of a bulk groundwater type in the study area representing 51 % and 31 % from the total water samples respectively.

The dominance of the Na^+- SO_4^{-2} facies reflects the presence of the evaporate minerals, which are the main source of these ions and it is evidence of recharge areas. The Na^+- Cl^- water type reflects the effect of geological formations on the quality of the studied groundwater which comprises halite. At few locations, the groundwater belongs to mixed Mg^{2+}-Ca^{2+}-SO_4^{-2} and mixed Mg^{2+}-Ca^{2+}-Cl. Mixed water types (Ca^{2+} Mg^{2+} Cl^-) suggest the dissolution of rock forming minerals such as halite's and carbonate-bearing minerals and an ion exchange process.

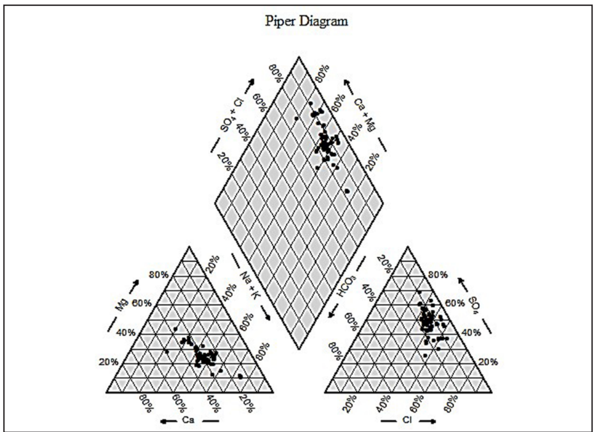

Figure 4. Piper diagram showing the chemical composition of groundwater in the study area

3. Results and Discussion

3.1 Total Dissolved Solid (TDS) and pH

The total dissolved solid (TDS) values for the studied wells ranged from 1200 to more than 14000 (mg/L). A spatial distribution map for TDS using the Reverse Interpolation Technique (IDW) has been prepared as shown in Figure 5a. It can be seen that the water samples show high values of TDS in all the studied wells, being much higher than the Iraqi standards for the quality of drinking water. According to Rao (1986), the high values of TDS may be attributed to the reduction of the osmotic activity of the plants, which interferes with the absorption of water and nutrients from the soil.

The pH values in the studied groundwater ranged from 7.1 to 7.9 as shown in Figure 5b. The pH values of water control the nature and environment of solubility of chemical constituents in the water. The decreasing in the value of pH in the water affects the balance of carbonates and bicarbonate. This results in the release of carbon dioxide and leads to an increase in the water's ability to dissolve increasing the concentration of dissolved salts (Abawi et al., 1990).

3.2 Cations and Anions

In the studied wells, calcium (Ca^{+2}) concentrations ranged from 71 to 1190 mg/L (Figure 5c). All the water samples exceeded the permissible limits of the Iraqi drinking water standards. The increased calcium concentration in the water samples of the studied wells can be ascribed to the geological nature of the area as well as the frequent use of the water wells. Magnesium (Mg^{+2}) values in the studied samplesss ranged from 32 mg/L to 540 mg/L as shown in Figure 5d.

In general, the source of magnesium in groundwater is the minerals containing magnesium; it is washed from rocks and subsequently ends up in water. Magnesium is used for many different purposes and consequently may end up in water through different ways (Deshpande and Aher, 2012). Chemical industries add magnesium to plastics and other materials as a fire protection measure or as filler. It also ends up in the environment from fertilizers' application and from cattle feed. The rock type in the study area is indurate to compacted clastic sediments hence the source of magnesium in the groundwater is clay.

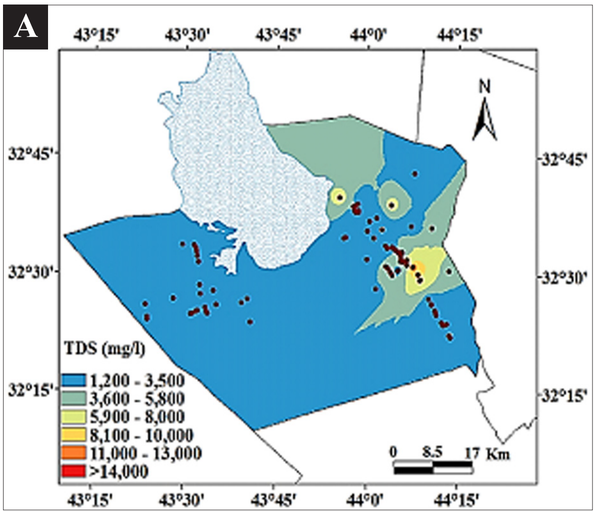

Figure 5.a: Spatial distribution map of TDS

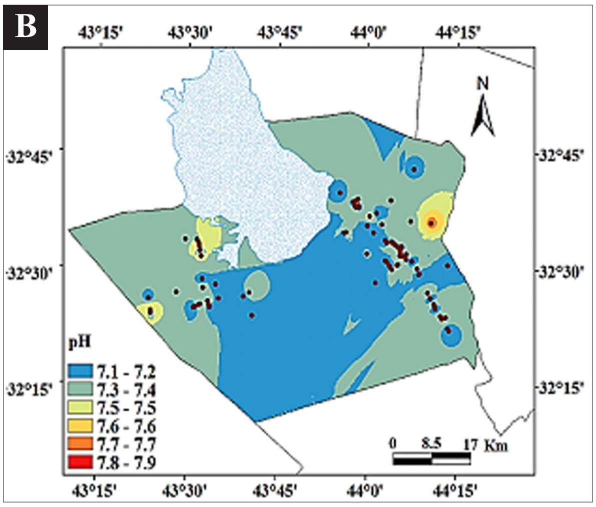

Figure 5.b: Spatial distribution map of pH

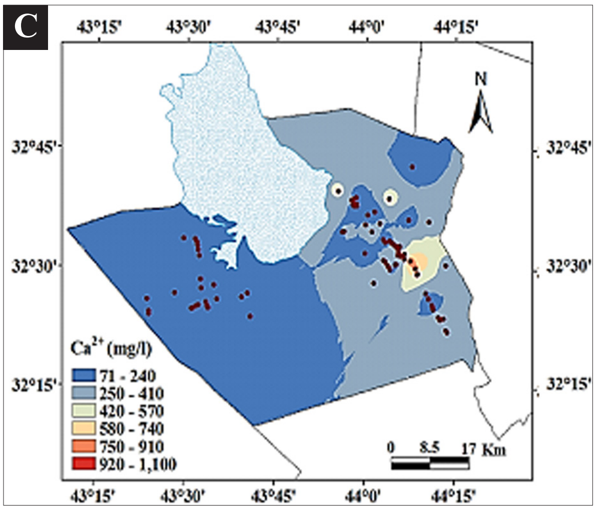

Figure 5.c: Spatial distribution map of Ca^{2+}

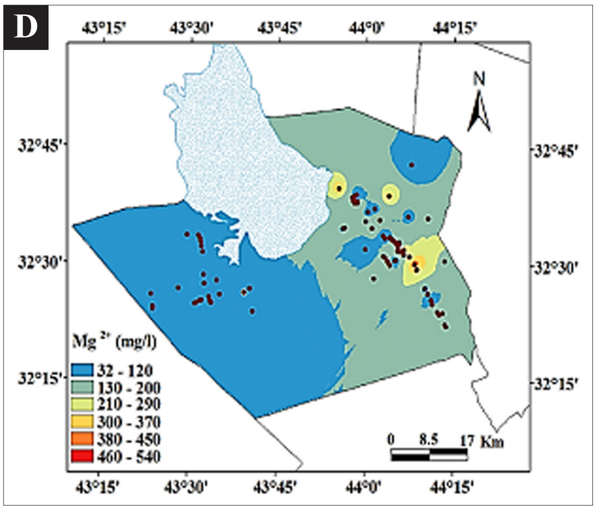

Figure 5.d: Spatial distribution map of Mg^{2+}

Potassium ion (K^+) is found in all the studied wells in higher concentrations than the allowable rates as is evident in Figure 5e. Sodium ion (Na^+) is usually present in groundwater and in high quantities. The upper limit of sodium allowed in drinking water exceeds 200 mg/L according to the Iraqi drinking water quality standards. In general, each groundwater contains some sodium because most of the rocks and soils contain sodium ions, which dissolve easily (Alhadithi, 2014). Accordingly, 80 % of the water samples contain an acceptable sodium content in the south-eastern part of the study area which rises towards the north-eastern part as shown in Figure 5f.

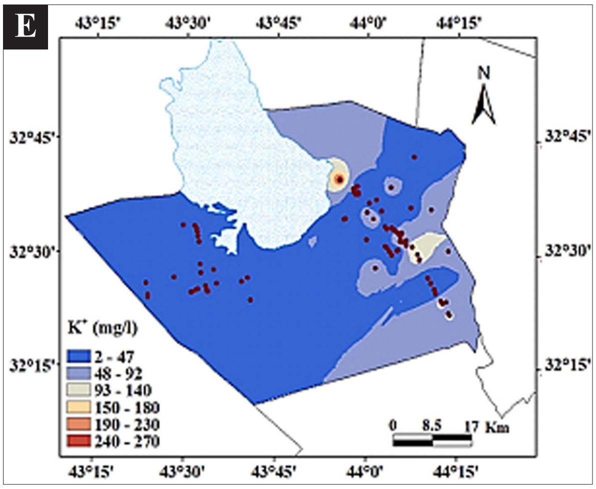

Figure 5.e: Spatial distribution map of K^+

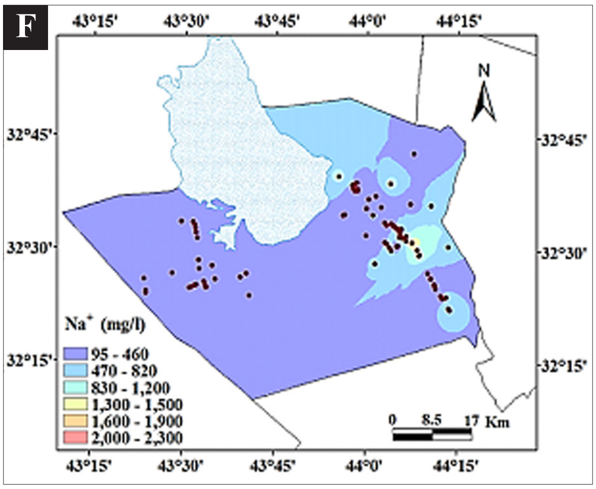

Figure 5.f: Spatial distribution map of Na^+

Bicarbonate (HCO_3^-) contents in the studied wells vary between 65 and 200 mg\L as shown in Figure 5g. Accordingly, 15 % of the studied water samples are within the limits of the Iraqi standards for drinking water quality, whereas the remaining wells have bicarbonate (HCO_3^-) rates higher than the permissible limits. The chloride values were within the limits of Iraqi standards for drinking water quality in 2 % of studied water samples, but the remaining samples showed higher rates than the permissible limits as shown in Figure 5h.

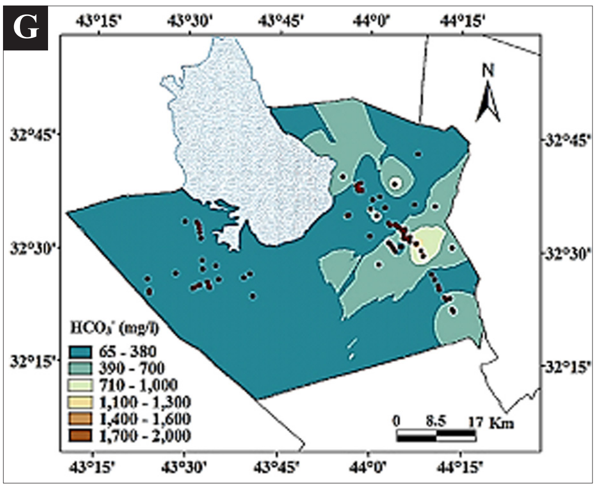

Figure 5.g: Spatial distribution map of HCO_3^-

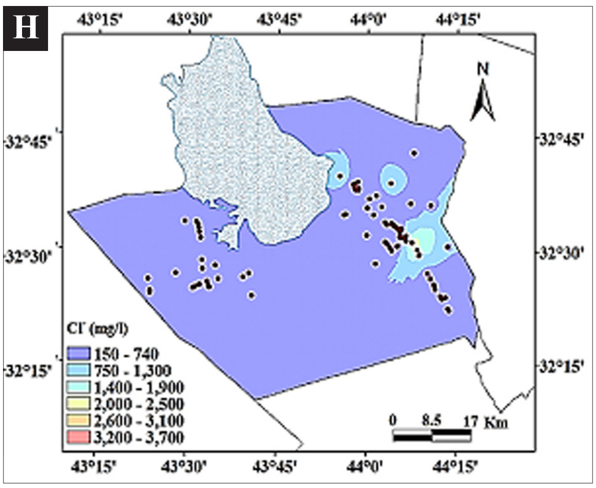

Figure 5.h: Spatial distribution map of Cl^-

Chloride (Cl^-) is a broadly distributed element in all kinds of rocks in different forms. Therefore, it is mostly high in groundwater, where the rainfall is less and the temperature is high (Ramakrishnalah et al., 2009). Some soil characteristics such as porosity and permeability play a key role in building up the chlorides concentration (Chanda, 1999).

The concentration of Nitrate (NO_3^{-3}) ranges between 0.024 and 8.8 mg/L in the studied wells (Figure 5i). The main source of nitrate in the groundwater is either sewage and waste decomposition of organic substances or the excessive use of fertilizers (Karanth, 1987). The values of Sulphate (SO_4^{-2}) vary from 300 to 3300 mg\L in the studied wells as shown in Figure 5j. Accordingly, water samples collected from only 2 % of studied wells have concentration higher than the permissible limits.

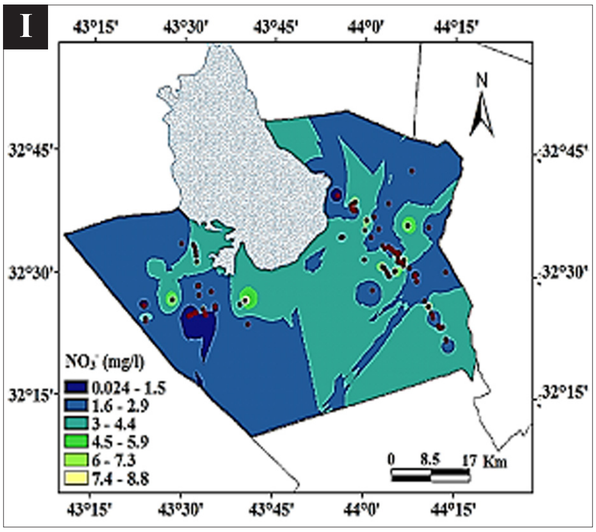

Figure 5.i: Spatial distribution map of NO_3^-

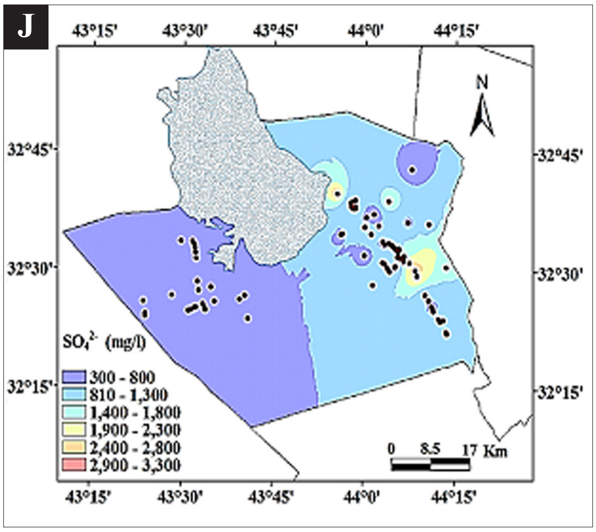

Figure 5.j: Spatial distribution map of SO_4^{2-}

The spatial distribution maps of the constituents with the chemical analysis discussed above were made to evaluate the quality of Karbala groundwater for drinking uses depending on the data of ninety-two wells representing Karbala region. It is found that the tendency of the Karbala groundwater flow is in the north and northeast direction. The spatial distribution maps of the concentrations of the contaminants in Karbala groundwater give acceptable presentation of groundwater quality distribution due to the good correlation between the observed and estimated values of these concentrations. Therefore, these maps can be approximately used to estimate the suitable locations of new wells containing minimum harmful contaminants.

The analyses reveal that the major cation Na^+ in the Karbala groundwater generally has dominant representation at an average of 59 % of all the cations. The major anions SO_4^{-2} and Cl^- are also dominant at the average of 44 % and 43%, respectively of all the anions. Na_2SO_4 and NaCl components are mainly found in Karbala groundwater, therefore, it tends to have permanent hardness. The average concentration of all major ions in the Karbala groundwater is found in the order $SO_4^{-2}>Cl^->Na^+>HCO_3^->Ca^{+2}>Mg^{+2}>K^+>NO_3^-$. According to the average TDS value of 3342 mg/l, the Karbala groundwater is too unsuitable for drinking uses.

3.3 Generation of Water Quality Index (WQI) Map

According to Ramakrishnalah et al. (2009), the computed WQI values have been classified into five types, namely excellent water to unsuitable for drinking as indicated in Table 7. Based on the classification, only 1% of water samples fall within class II which represents a good water quality, and 57 % of the available water wells fall under class III which indicates a poor water quality, 21% of the water samples fall in class IV which indicates a very poor water quality and 20 % of the samples are unsuitable water.

Table 7. Percentages of studied water well samples based on WQI values

WQI value	Class	Water quality	Percentage of studied water sample
<50	I	Excellent	Nil
50-100	II	good water	1%
100-200	III	poor water	57%
200-300	IV	very poor water	21%
>300	V	Unsuitable water	20%

All calculated WQI values have been transferred to GIS environment to create a spatial distribution map of WQI. It has been produced using then reverse interpolation technique (IDW) which can be considered as a general suited map for providing information and observation data visually about drinking water in the study area represented by the spatial distribution of the index of the quality of water used for drinking. This map enabled decision-makers to evaluate water for drinking purposes easily and for large areas because it shows the spatial distribution of groundwater quality as an index value. Figure (6) shows the spatial distribution map of WQI which has shown that the water in the study area is unstable for drinking purposes.

The reasons behind this could be the excessive depletion of groundwater and the cultivation of crops which consume a lot of water such as grass, in addition to not using modern irrigation methods. Another reason could be the mixing of Al-Razaza Lake waters with the groundwater.

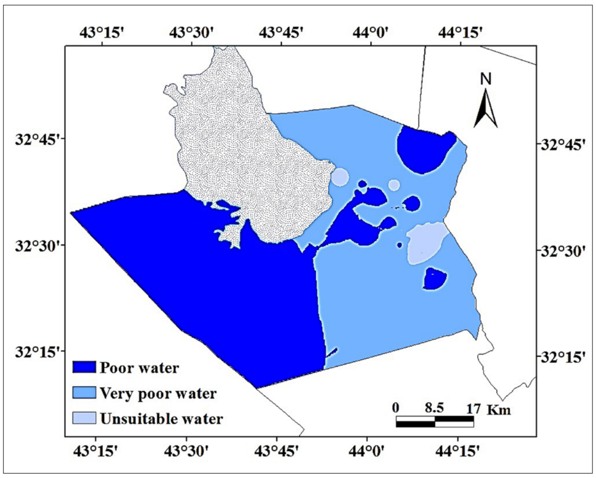

Figure 6. Spatial distribution map of WQI

3.4 Water Quality for Irrigation Purposes

Since most groundwater in the studied wells is not suitable as drinking water the outcome of the current study can be discussed further in attempting to provide water for purposes, other than the drinking purposes, such as irrigation in the city of Karbala. A standard diagram (Wilcox, 1955 and USSL, 1954) has been used to assess the suitability of water for irrigation purposes in the study area. Accordingly, the Electrical Conductivity (EC) has been measured in the field and the sodium percentage (Na %) and Sodium Adsorption Ratio (SAR) have been calculated based on the chemical analysis of Ca_2^{2+}, Mg^{2+}, Na^+, K^+ using the following equations:

$$Na\% = \left(Na^+ + K^+\right)*100 / Ca^{2+} + Mg^{2+} + Na^+ + K^+ \quad ... 5$$

$$SAR = Na^+ / \sqrt{(Ca^{2+} + Mg^{2+})/2)} \quad ...... 6$$

The percentages of sodium (Na %) ranging between 20 % and 76 % were plotted against specific conductance in the Wilcox diagram as shown in Figure 7. It shows that the groundwater of the study area is in bad condition. It is unsuitable in 34 % of the water samples, and is of a doubtful to unsuitable quality in 28 % of the samples. Only 2% of the samples are of a good to permissible quality (Table 8). It is noted that 36 % of the water samples are out of the limits of the diagram because of the high value of the EC which can be considered or added to the proportion of unsuitable water quality.

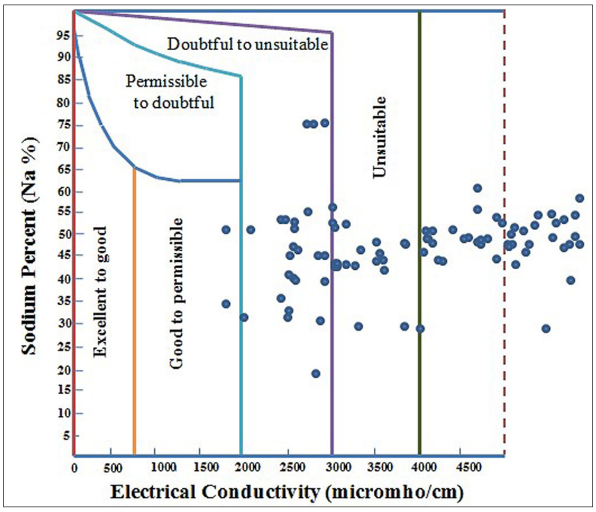

Figure 7. Diagram of the quality of irrigation water classification (Wilcox, 1955)

The calculated values of SAR in the study area varied from 4 to 16 meq which have been plotted on the US salinity. It is taken as an alkalinity hazard and the electrical conductivity (EC) is taken as a salinity hazard which is summarized in Table (8) and is shown in Figure (8). As is clear, only 4 % of samples fall in the C3-S1 fields, indicating a medium to high salinity and low alkalinity water; this means that this water can be used for irrigation, where a moderate amount of leaching and a moderate permeability with the leaching soil occur. Furthermore 96 % of the water samples fall in C4-S1, C4-S2, C4-S3 and C4-S4 field, is indicating a very high salinity and a low to medium sodium hazard. This water is not suitable for irrigation under normal conditions and further action of salinity control is required in the remediation of such problem.

Table 8. Classification of groundwater for irrigation in the study area

Wilcox, 1948	Well No	% of sample	USLL 1954	Well No	% of sample
Excellent	Nil	0	C3-S1	86,84,71,69	4
Good to permissible	71,84	2			
Doubtful to unsuitable	1,2,6,18,20,25,28,33,35,36,42,43,59,61,65,68,69,70,73,80,81,83,85,86,91,92	28	C4-S1	1,2,3,18, 42,59,70, 88	9
Permissible to Doubtful	Nil	0	C4-S2	4,6,7,8,9,10,11,12,13,19,22,24,26,28,30,31,33,35,36,37,38,39,40,41,44,45,46,47,48,49,50, 52,53,57,60,61,62,63,65,66,67,68,72,73,74,75,77,78,81,82,83,85,87,90,91,92.	62
Unsuitable	3,4,5,9,10,11,12,13,14,19,22,24,26,30,38,39,40,52,60,62,66,67,72, 74,75,77,78,82,87,88,7,8,15,16,17, 21,23,27,29,31,32,34,37,41,45,46,47,48,49,50,51,53,54,55,56,57,58,63,64,76,79,89,90.	70	C4-S3	5,14,15,16,17,20,21,23,25,32, 34,43,51,56,58,64,89	18
			C4-S4	27,29,54,55,76,79	7

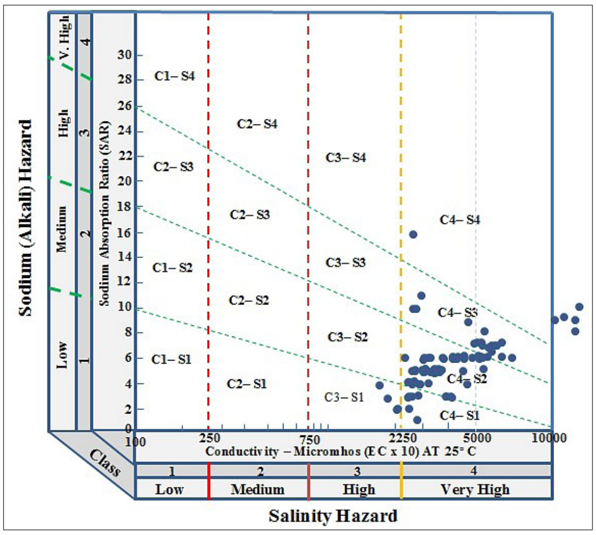

Figure 8. Diagram for irrigation water quality classification (USSL, 1954)

4. Conclusions

The GIS technique has been applied in the present study to create a water quality index map to evaluate the quality of groundwater in the Karbala province used for drinking purposes in a precise manner. Chemical parameters of the water samples including cations and anions have been considered to calculate WQI. It has been observed that the water samples fall in the poor water to unsuitable water categories. More detailed analyses have been conducted by plotting analytical data on USSL and Wilcox diagrams to assess the suitability of well water for irrigation purposes.

The results show that only 1 % of the studied groundwater samples can be used for drinking purposes, and 4 % can be used for irrigation purposes. Also, the current study has clearly shown that the techniques of GIS and water quality index are efficient, economic, fast, and easy means to evaluate the quality of groundwater for drinking purpose.

Recommendation

Conducting hydrogeological studies and detailed examinations of the water- bearing formations, including the exposed ones along with studies and interpretations of the subsurface geology from the lithologs data along with selected subsurface geological sections.

The use of modern irrigation methods instead of the traditional ones.

The construction of dams which recharge the aquifer to prevent the circulation of the Al-Razzaza Lake waters with groundwater.

Preventing the cultivation of crops which consume large quantities of water.

Monitoring the amounts of water pumped out of wells.

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