Contour Maps and Evaluation of Groundwater Quality in Karbala Region

الخرائط الكنتورية مع تقويم نوعية المياه الجوفية في منطقة كربلاء

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Abstract

In the current study, the contour maps of contaminants parameters distribution and the analysis of the chemical quality of groundwater in the Karbala region have been carried out to evaluate the suitability of water for drinking and irrigation purposes. The study based on the observed groundwater data of 155 unconfined wells represented the area. These data have been analyzed and contoured for the hydrogen ion concentration (PH), the concentrations of the major cations Na^{+}, Ca^{+2}, Mg^{+2},$K^{+}$and the anions $SO4^{-2}$, Cl^{-}, $HCO3^{-}$, $NO3^{-}$, the electrical conductivity (EC), the total dissolved solids (TDS) and the total hardness (TH), and they are compared with WHO and Iraqi standards. Only 140 wells were used for contour maps calibration and the remainder 15 wells were used for verification. The results showed good correlation between the observed and estimated data. The water quality index (WQI) was used to evaluate the groundwater for drinking uses. Based on WQI, it is found that 58.7% of the Karbala groundwater is unsuitable for drinking uses. The assessments were also achieved for the important constituents' parameters affecting the water quality for irrigation such as the sodium adsorption ratio (SAR), the sodium percent (% Na), the permeability index (PI) and the magnesium hazard (MH). A correlation matrix was built to evaluate the degree of correlation between any two chemical parameters. Two methods were applied to evaluate the suitability of Karbala groundwater data for irrigation purposes. The first one is the US salinity diagram (1954) and the second one is the Wilcox classification diagram (1955). Based on USSD, 58.7% of the Karbala groundwater data are classified as (very high salinity hazard – medium sodium (alkali) hazard) (C4-S2). Depending on the WCD, 73.5% of the Karbala groundwater data are found unsuitable for irrigation. According to the mean value of PI and MH, the Karbala groundwater data are found permissible for irrigation purposes.

Keywords: Contour map, groundwater quality, Major ions, WHO standards, Karbala.

الخلاصة

في هذه الدراسة، جرى اعداد الخرائط الكنتورية لتوزيع العوامل الملوثة مع تحليل الخصائص الكيميائية للمياه الجوفية في منطقة كربلاء. و كان الغرض من ذلك تقويم درجة ملاءمة الماء لأغراض الشرب و السقي. لقد استندت الدراسة على أساس تحليل البيانات المأخوذة من 155 بئراً غير محصور تمثل منطقة الدراسة. لقد جرت عملية التحليل لهذه البيانات و رسمت لها خرائط كنتورية لدرجة تركيز أيون الهيدروجين (PH)، تراكيز الكاثودات الرئيسة (Na^{+}) ، (Ca^{+2}) ، (Mg^{+2}) ، (K^{+}) و الأنودات ($SO4^{-2}$) ، (Cl^{-}) ، ($HCO3^{-}$) ، ($NO3^{-}$). و بالأسلوب نفسه تم التعامل مع التوصيل الكهربائي (EC)، و المواد الصلبة الذائبة الكلية (TDS) و العسرة الكلية (TH). و قد جرت عملية مقارنة لكل هذه العوامل مع المواصفات القياسية الخاصة بمنظمة الصحة العالمية (WHO) و المواصفات القياسية العراقية. تم اعتماد 140 بئراً لأغراض المعايرة للخرائط الكنتورية، أما الآبار الباقية، و عددها 15 بئراً، فقد أعتمدت لأغراض التحقق من نتائج المعايرة.
أظهرت النتائج ترابطاً جيدا بين البيانات المقيسة و المخمنة. لقد استخدم دليل نوعية المياه (WQI) في عملية تقويم صلاحية المياه الجوفية لغرض الشرب. و استناداً إلى دليل نوعية المياه وجد أن 58.7% من المياه الجوفية في كربلاء غير مناسبة لاغراض الشرب. لقد تم اجراء التقويمات ايضا على العوامل الملوثة المهمة المؤثرة على نوعية المياه لاغراض الري وهي نسبة الصوديوم الممدص (SAR)، النسبة المئوية للصوديوم (الصوديوم المئوي)، (%Na)، دليل النفاذية (PI)، و خطورة المغنيسيوم (MH). انشئت مصفوفة الارتباط لغرض تقويم درجة الارتباط بين أي اثنين من العوامل الملوثة. ثم تم تطبيق طريقتين لتقويم بيانات المياه الجوفية لمنطقة كربلاء لمعرفة مدى صلاحيتها للارواء. الطريقة الاولى هي المخطط الملحي الامريكي (1954)، والطريقة الثانية هي مخطط التصنيف لـ(Wilcox)(1955). استنادا الى USSD فان 58.7% من بيانات

المياه الجوفية لكربلاء تصنف على أنها (عالية الملوحة جدا – متوسطة القلوية) (C4-S2). واستنادا الى WCD وجد ان 73.5% من المياه الجوفية لكربلاء غيرمناسبة للارواء. و اعتماداً على معدل القيم لكل من دليل النفاذية وخطورة المغنيسيوم وجد ان بيانات المياه الجوفية لكربلاء مسموح بها لاغراض الري.

Introduction

One of the commonly used water resources is ground water. The quality of groundwater is as important as its quantity. Water quality concept has been evaluated in the last years owing to greater understanding of water mineralization process and greater concern about its origin **[1]**. Water quality shows water-rock interaction and indicates residence time and recharge zone confirmation **[2]**. The required quality of ground water supply depends on its purposes of use such as drinking, irrigation and industry. The quality properties of groundwater expressed by chemical, physical and biological analysis of a groundwater sample include the obtaining of the constituents concentrations as well as the PH and specific electrical conductance measurements. The physical analysis of groundwater includes temperature, color, turbidity, odor and taste. The Biological investigations include tests to detect the presence of Coliform bacteria, which indicate the sanitary quality of water for human consumption **[3]**. In a chemical analysis of a ground water, concentrations of different ions are determined by weight or by chemical equivalence. Briefly, the concentrations of ions are expressed commonly by weight per volume units. For monitoring concentrations of major ions and nutrients, and values of physical properties of groundwater, twice-yearly sampling should be sufficient **[4]**. The movement of groundwater through the soil tends to develop a chemical equilibrium by chemical reactions with its environment, such as artificial recharge, movement of pollutants and clogging of wells. In order to study the quality of groundwater of large regions, a large number of wells should be constructed to reflect the more reality feature of the groundwater basin for these regions. The chemical quality tests of groundwater are ordinary reported in tables. These tables may be difficult to interpret the groundwater quality for the whole region. Therefore, the quality tests results of groundwater can be represented by a variety of graphic techniques developed to display and detect the major chemical constituents. The contour maps are also useful to show the isograms of equally chemical, biological contaminants concentrations with physical parameters. These isograms help to find the regions of low and high chemical concentrations of groundwater. Therefore, the practical engineer can indicate the better position of low contaminated wells. These facilities will reduce the high costs of refreshing the groundwater for different uses. There are many methods used to draw a contour map such as Kriging method. Al-Mussawi (2008) utilized the Kriging statistical technique to guess the fluctuation of groundwater levels for AL-Dibdiba basin in area of Karbala-Najaf **[5]**. He found that this technique could give a more regular gradient of the groundwater table than other methods. This research studies the distribution of chemical contaminants concentrations in groundwater of Karbala region using contour maps interpretation with some chemical analyses and graphic techniques.

Study area

Karbala is an Iraqi governorate that locates about 100 Km south-west of Baghdad, the capital of Iraq. It locates between latitude 32°06´ to 32°46´ and longitude 43°10´ to 44°19´(estimated by Google earth program) and it covers an area of 5034 Km^2 with a population of 724000 people in 2003 **[6]**.

The city of Karbala province is one of the holiest Islamic cities. The region falls within semi-arid weather of shortage rains .To the west of Karbala, there is a lake known as the Razazah Lake (the lake of salt) located between latitude 32°33´ to 32°60´ and longitude 43°27´ to 43°54´. The Karbala soil type is generally sandy loam soil. The location of Karbala center is at latitude 32°37´ and longitude 44°01´30´´.

Data collection

In the current study, the data of chemical contaminants concentrations for 155 wells were officially taken from The Iraqi General Corporation of Groundwater. These data were observed by this corporation staff for each well once each the middle of three months along the year 2010, and the average of four readings for each well officially adopted to represent the year 2010. The mentioned wells are constructed in unconfined aquifer regions inside and outside the Karbala province boundary. The map of wells locations are drawn using Google Earth program as shown in Fig.(1). The depths of these wells range from 9 m to 330 m. The data include the concentrations of chemical ions like Calcium(Ca^{+2}), Magnesium(Mg^{+2}), Sodium(Na^{+}), Potassium(K^{+}), Bicarbonate($HCO3^{-}$), Chloride(Cl^{-}), Sulfate($SO4^{-2}$), Nitrate($NO3^{-}$) and, the hydrogen number (PH) with the electrical conductivity (EC) and the total dissolved solids (TDS). Also, the data contain the natural ground level of wells, the groundwater level of wells with respect to mean see level and the geographical coordinates of latitude and longitude lines for wells locations.

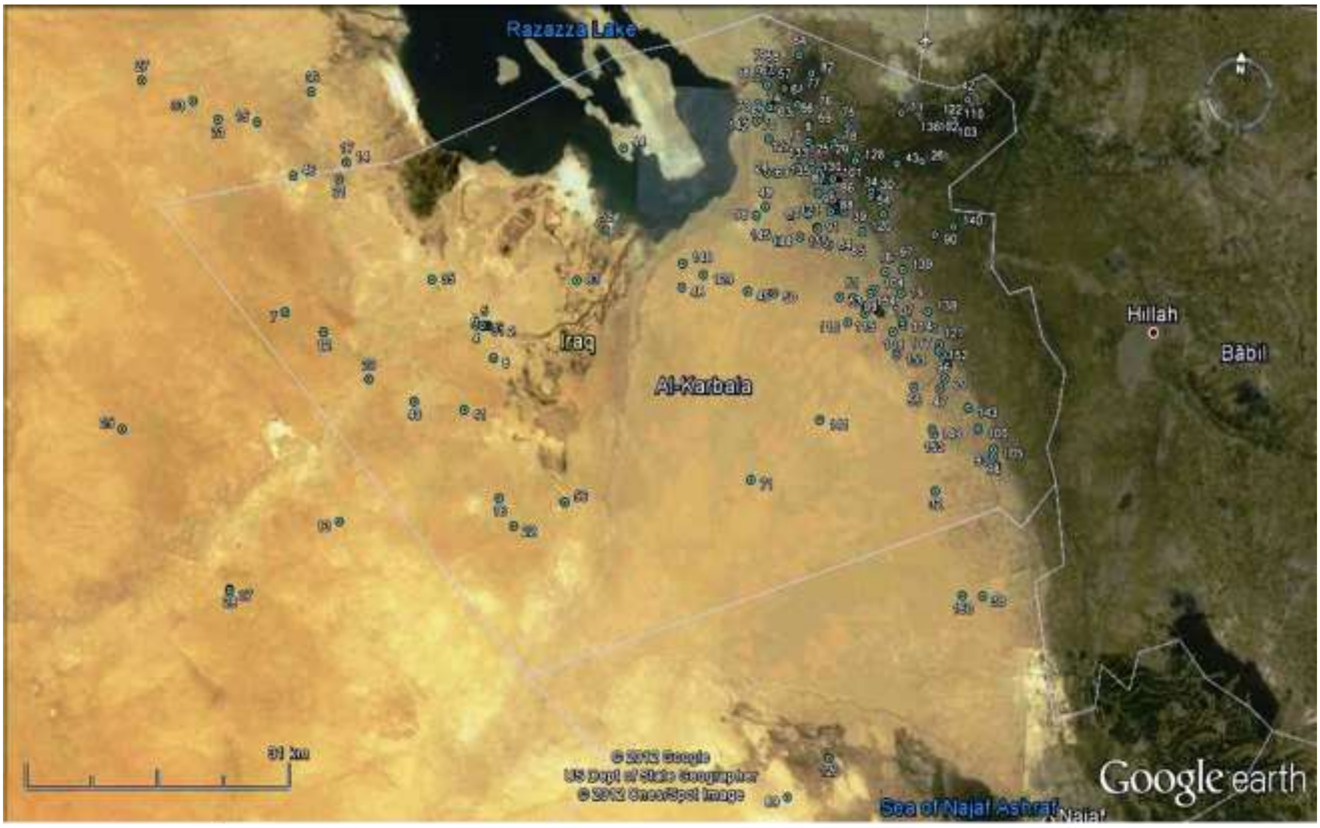

Fig.(1) Google earth map of Karbala wells locations

Chemical analysis of groundwater

For evaluating the suitability of groundwater for different purposes, understanding the chemical composition of groundwater is necessary **[7]**. The contour map of groundwater level of all wells are plotted by using Surfer-2010 software program as shown in Fig.(2). In order to draw the contour maps of contaminants concentrations, the collected data were divided into two parts, the first part includes data of 140 wells Nos.(1-140) used for calibration, and the second part includes 15 wells Nos.(141-155) used for verification. Figures (3) to (13) Show the contour maps of calibrated contaminants' parameters drawn by the mentioned Surfer program. For verification, the latitude and longitude coordinates of 15 wells are projected on these contour maps of each chemical parameter in order to estimate the value of each parameter using the same Surfer program. The estimated parameters are compared with observed data through calculating the correlation coefficient using Excel2007 software program as shown in Figs. (14) to (24).

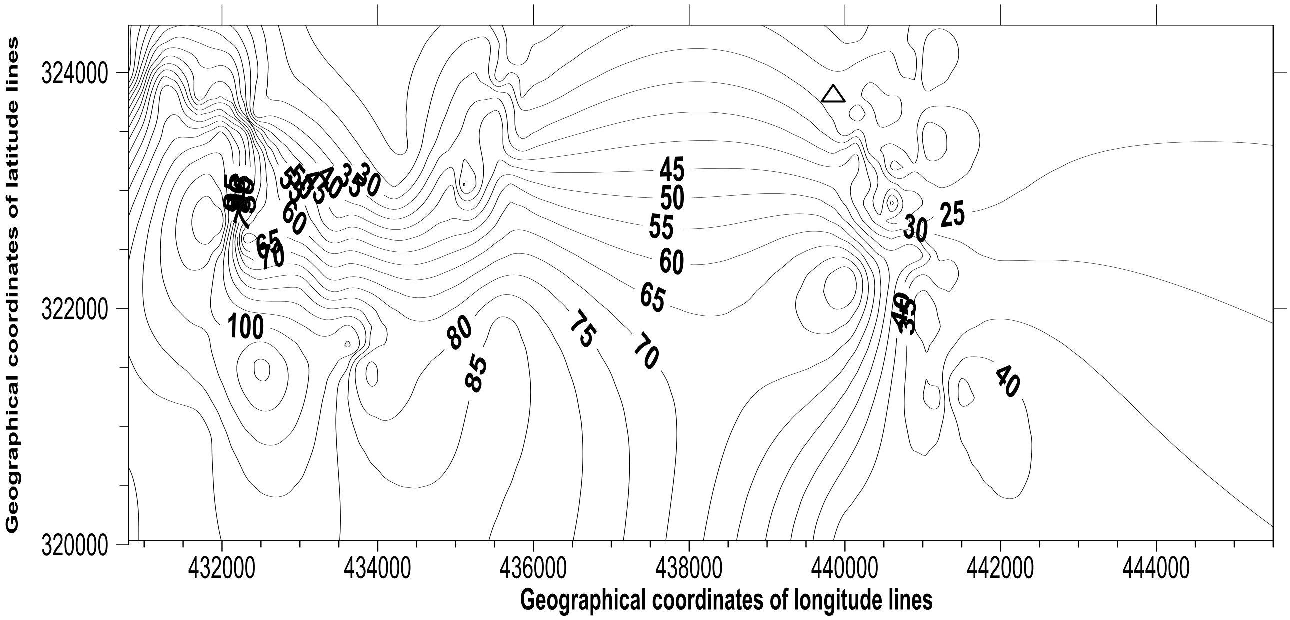

Fig.(2) Contour map of groundwater levels for Karbala region

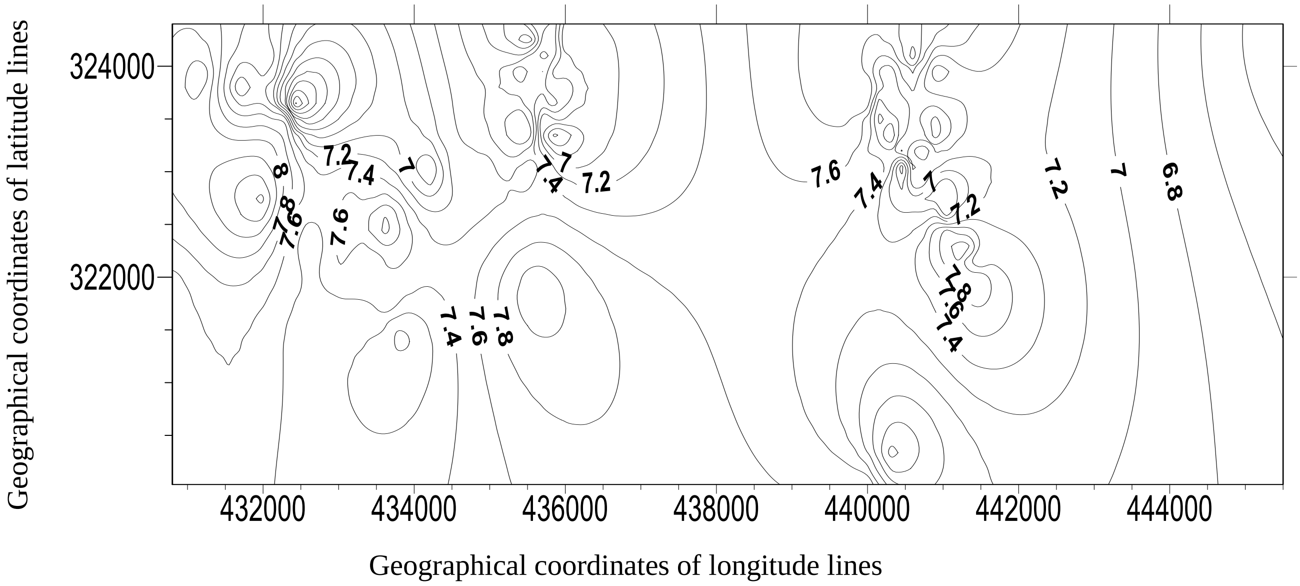

Fig.(3) Contour map of PH value for Karbala groundwater

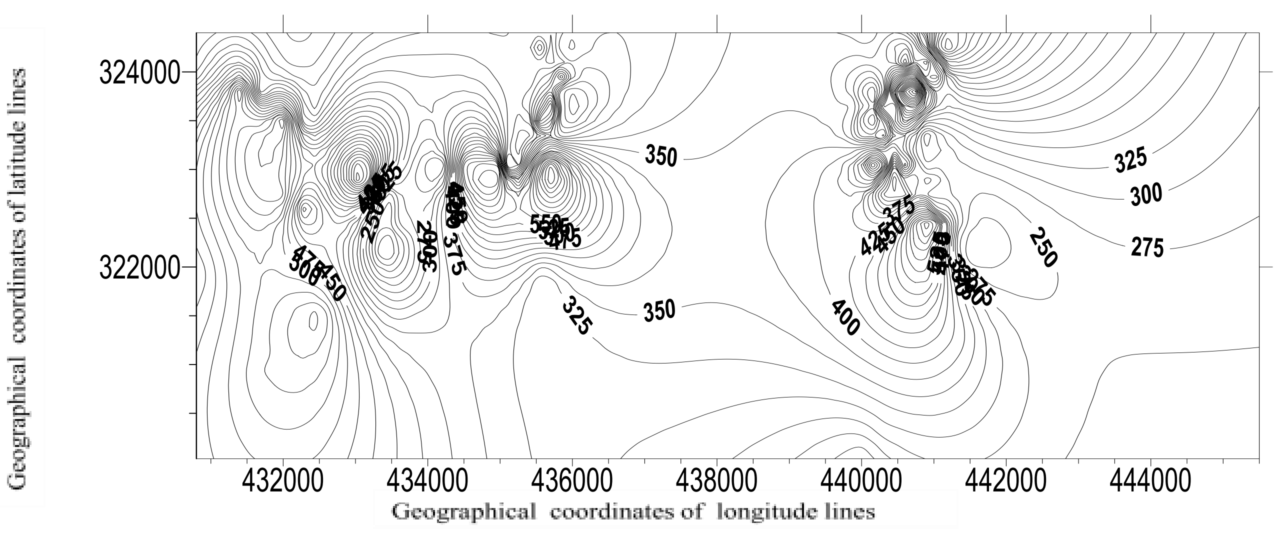

Fig.(4) Contour map of Ca concentration(mg/l) value for Karbala groundwater

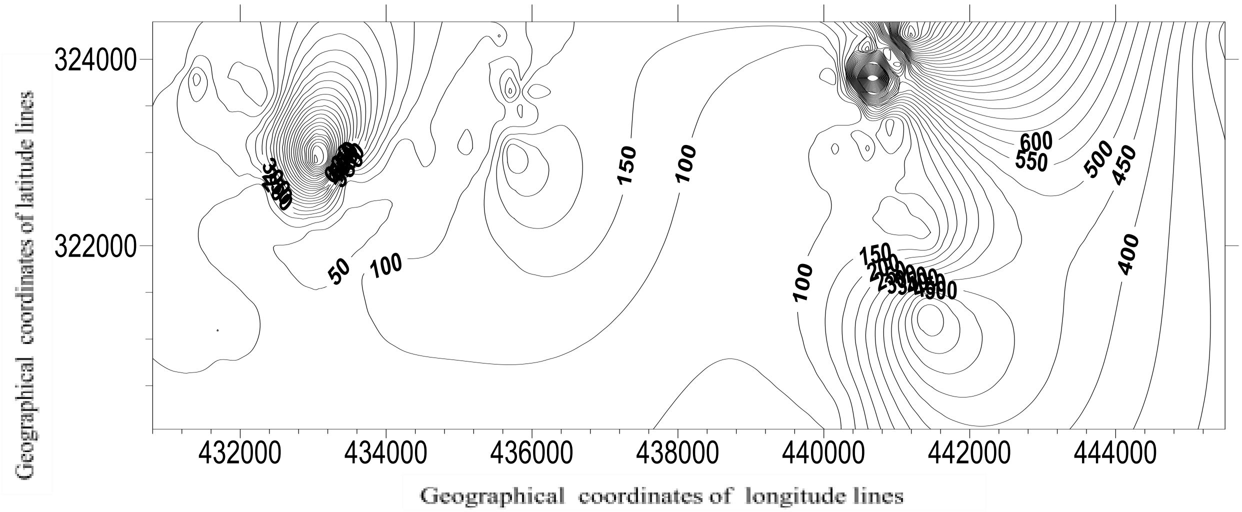

Fig.(5) Contour map of Mg concentration(mg/l) value for Karbala groundwater

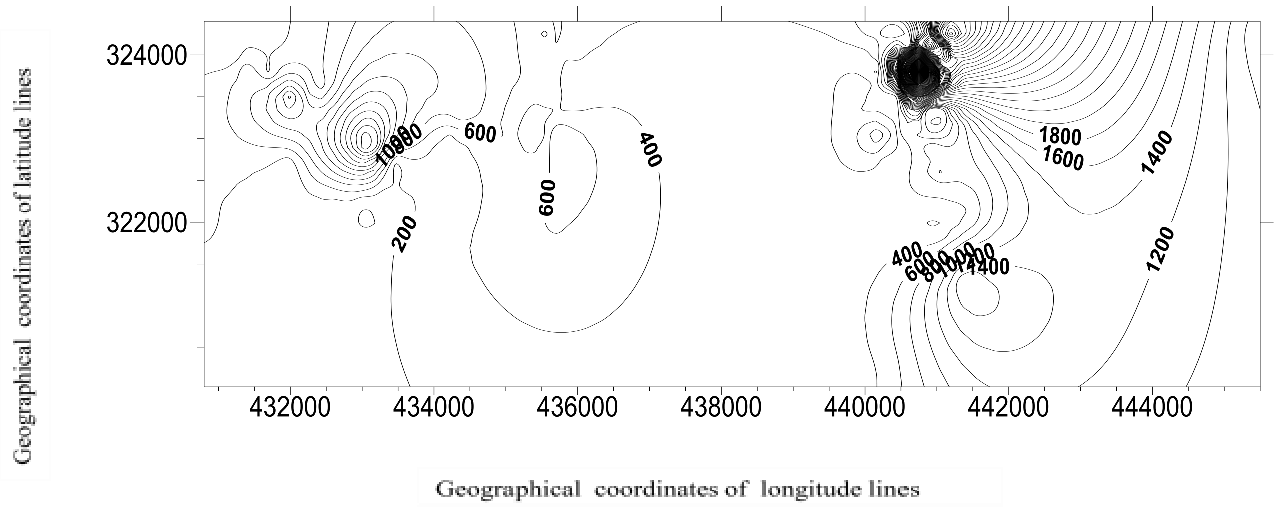

Fig.(6) Contour map of Na concentration(mg/l) value for Karbala groundwater

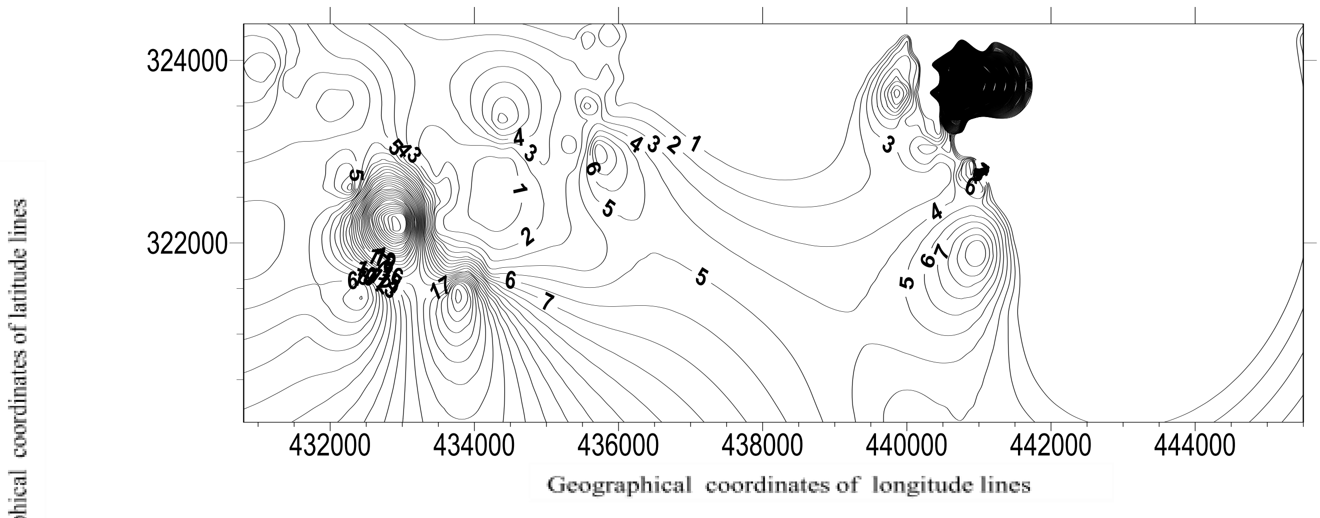

Fig.(7) Contour map of K concentration(mg/l) value for Karbala groundwater

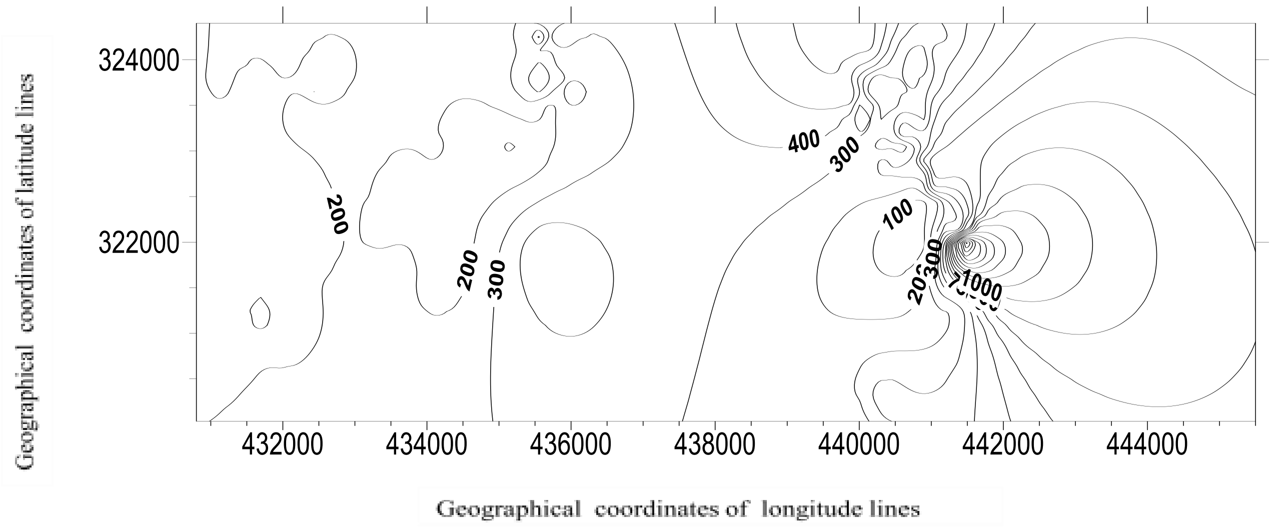

Fig.(8) Contour map of HCO3 concentration(mg/l) value for Karbala groundwater

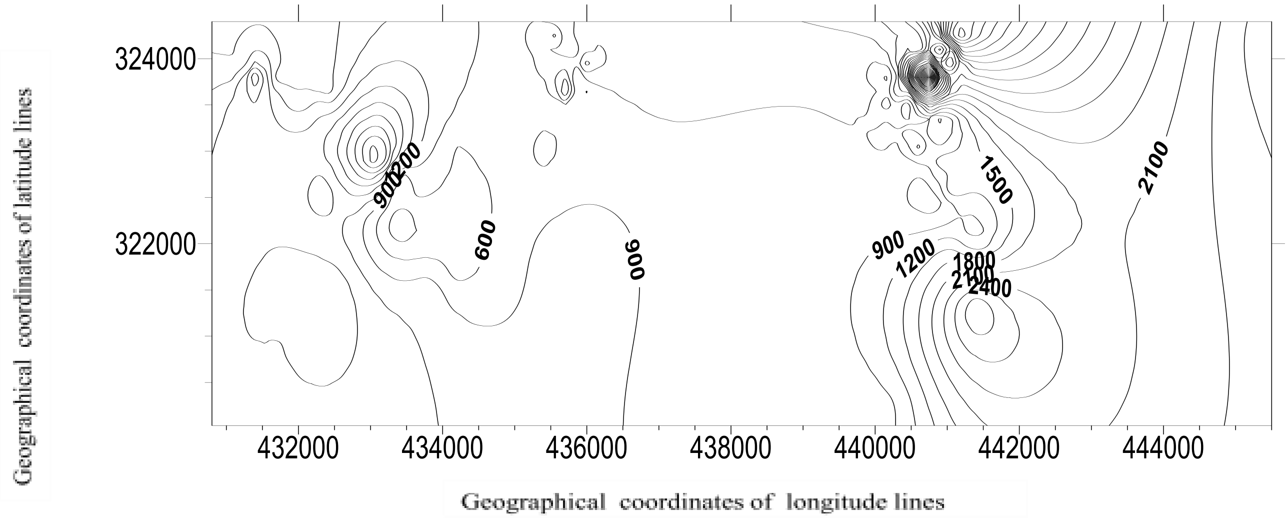

Fig.(9) Contour map of SO4 concentration(mg/l) value for Karbala groundwater

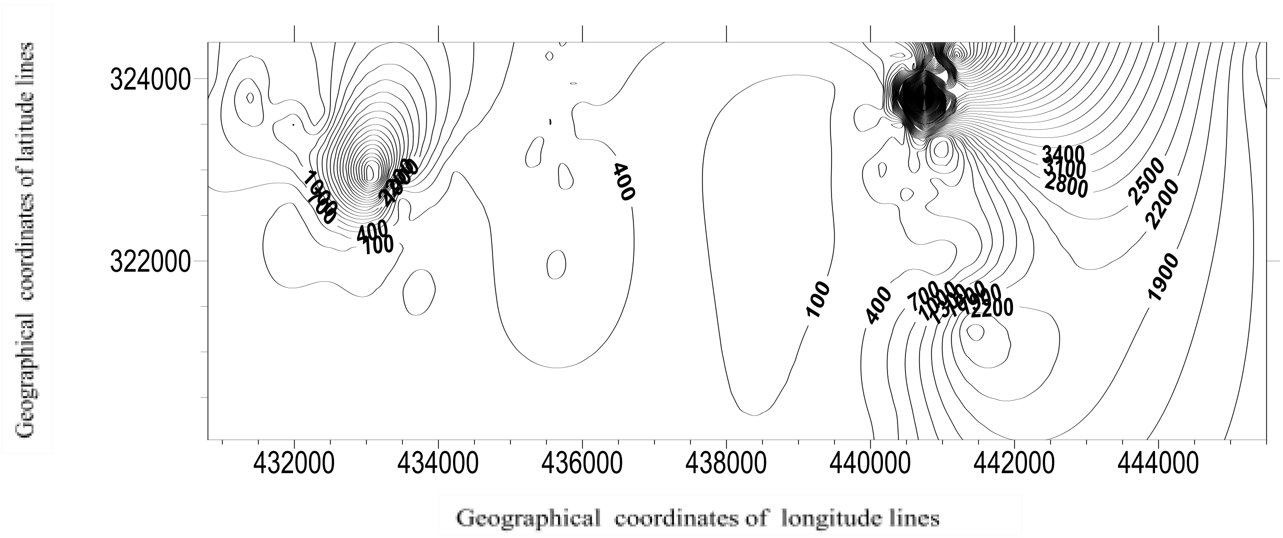

Fig.(10) Contour map of Cl concentration(mg/l) value for Karbala groundwater

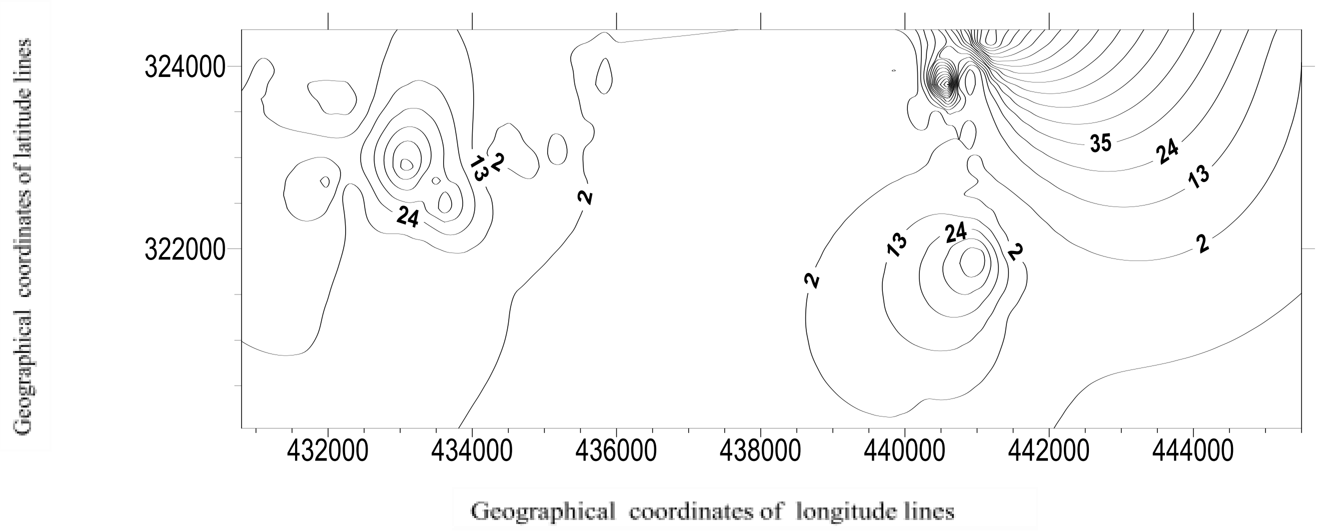

Fig.(11) Contour map of NO3 concentration(mg/l) value for Karbala groundwater

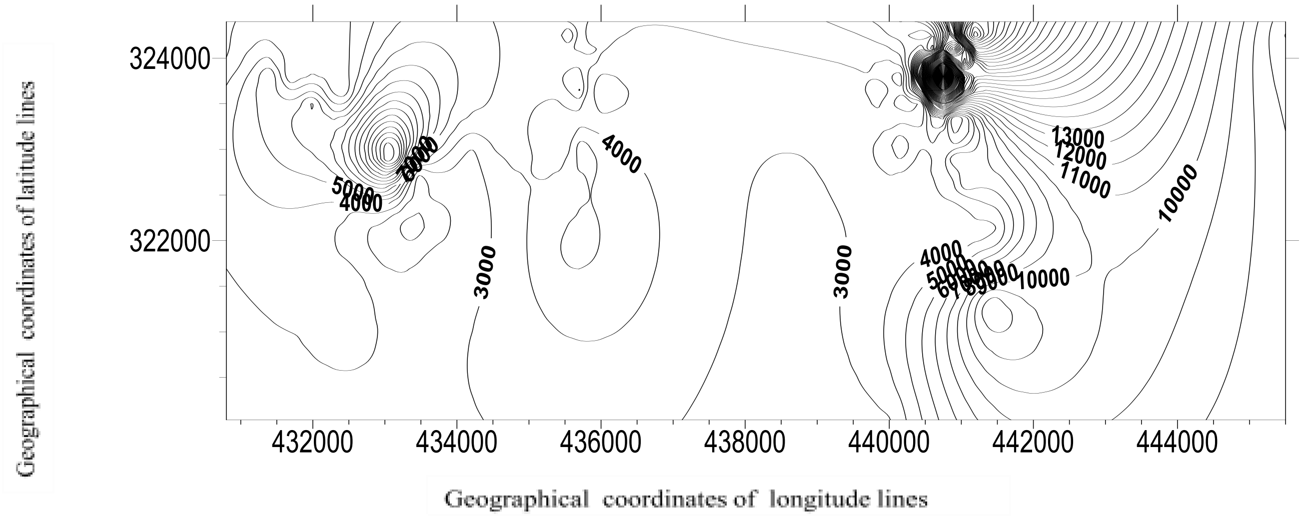

Fig.(12) Contour map of EC concentration(μmhos/cm) value for Karbala groundwater

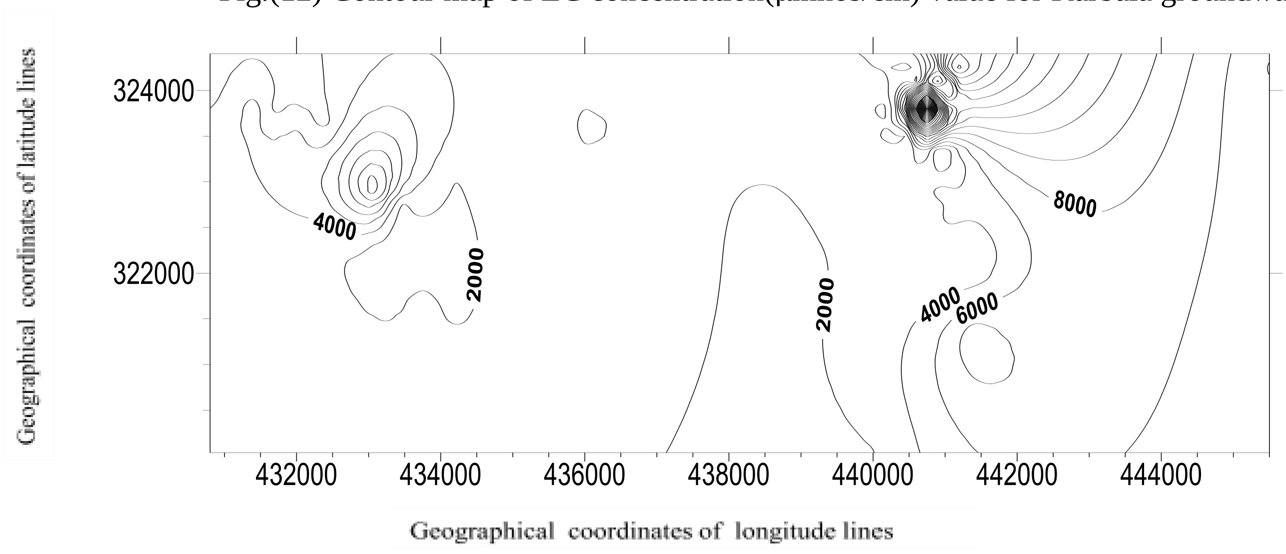

Fig.(13) Contour map of TDS concentration(mg/l) value for Karbala groundwater

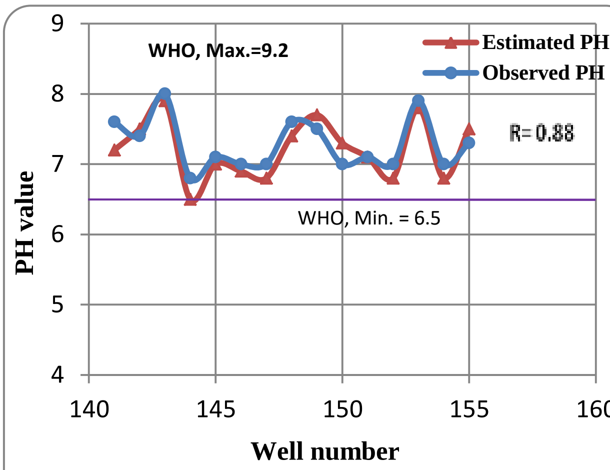

Fig.(14)Observed and estimated values of PH for 15 wells in Karbala region

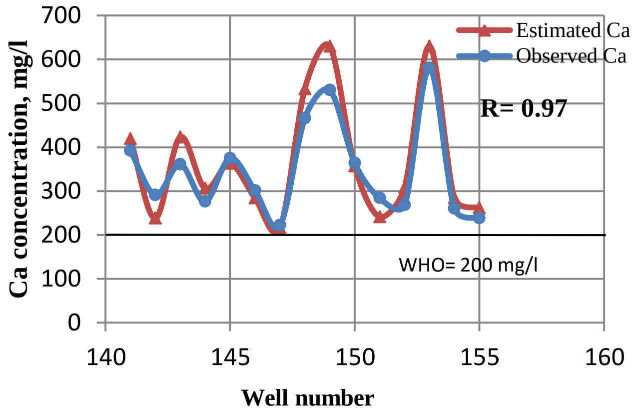

Fig.(15)Observed and estimated concentrations of Ca for 15 wells in Karbala region

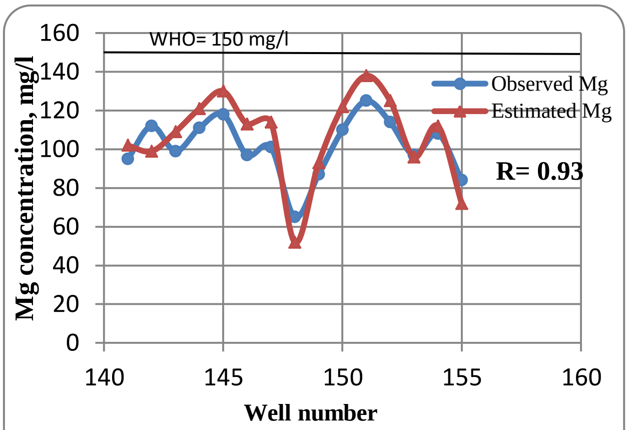

Fig.(16)Observed and estimated concentrations of Mg for 15 wells in Karbala region

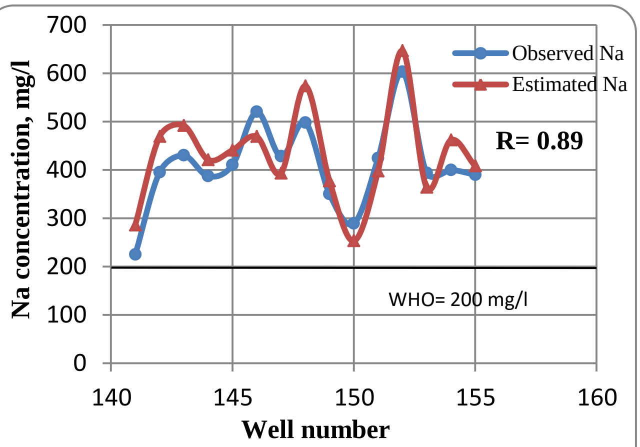

Fig.(17)Observed and estimated concentrations of Na for 15 wells in Karbala region

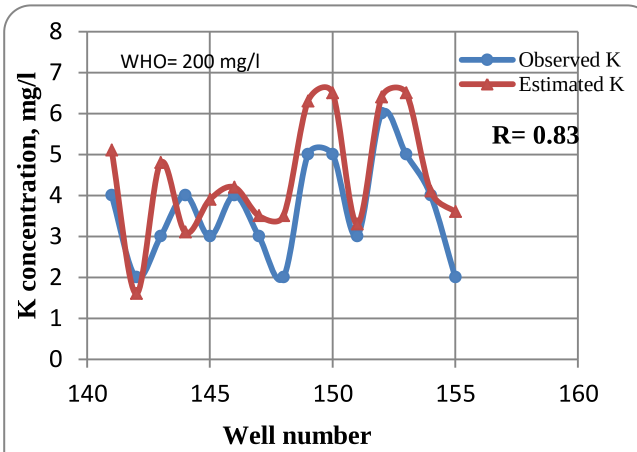

Fig.(18)Observed and estimated concentrations of K for 15 wells in Karbala region

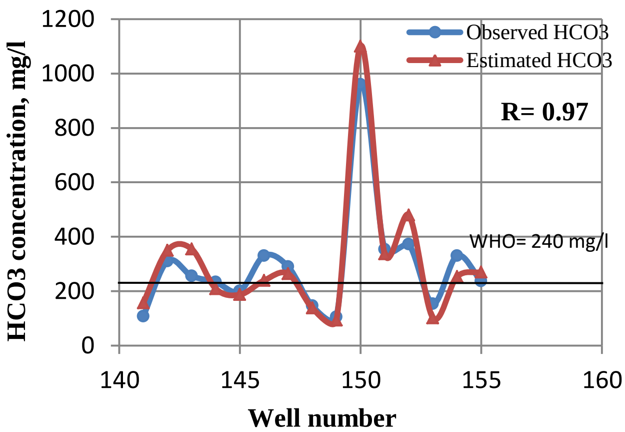

Fig.(19) Observed and estimated concentrations of HCO3 for 15 wells in Karbala region

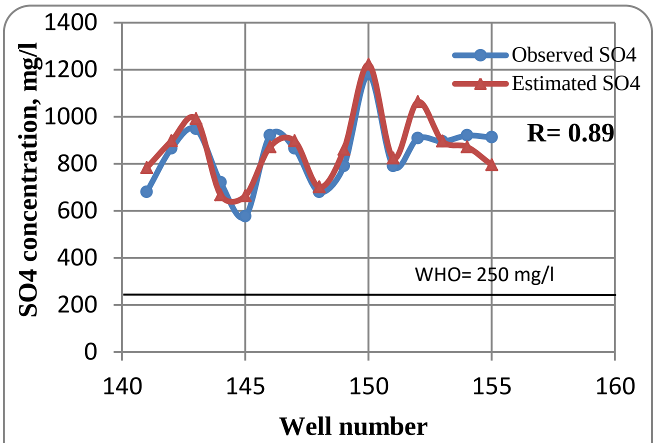

Fig.(20) Observed and estimated concentrations of SO4 for 15 wells in Karbala region

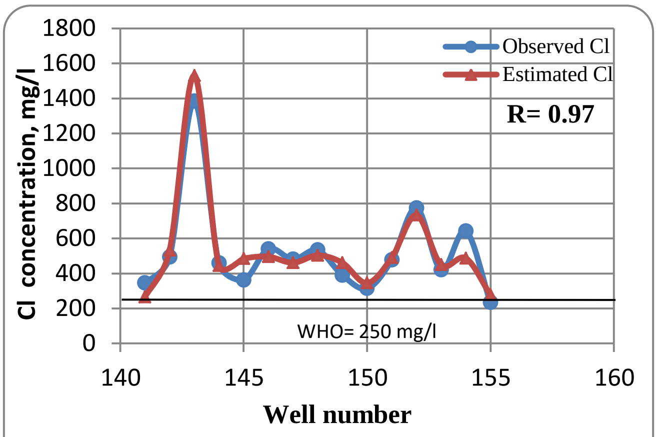

Fig.(21)Observed and estimated concentrations of Cl for 15 wells in Karbala region

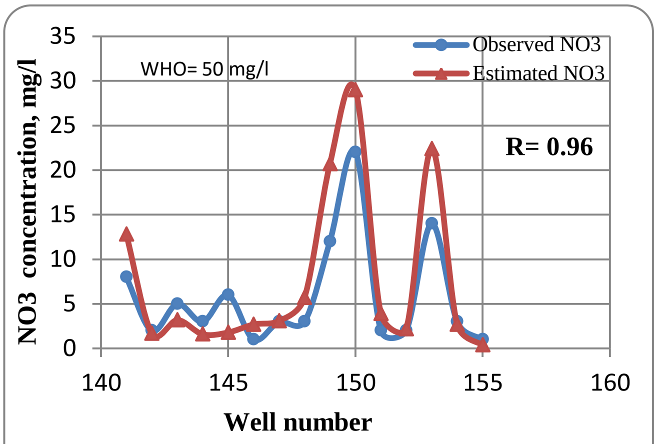

Fig.(22)Observed and estimated concentrations of NO3 for 15 wells in Karbala region

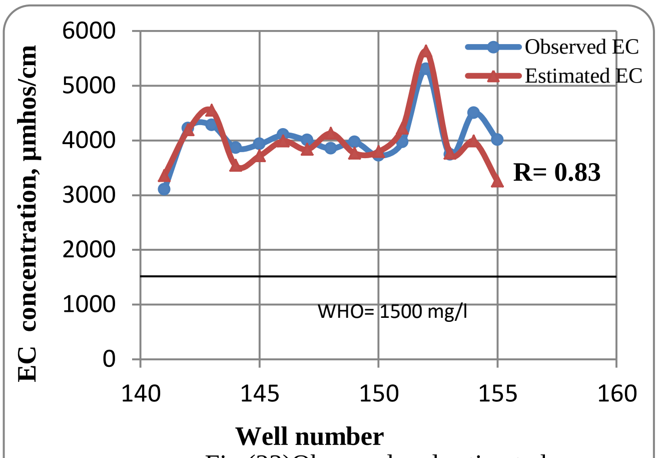

Fig.(23)Observed and estimated concentrations of EC for 15 wells in Karbala region

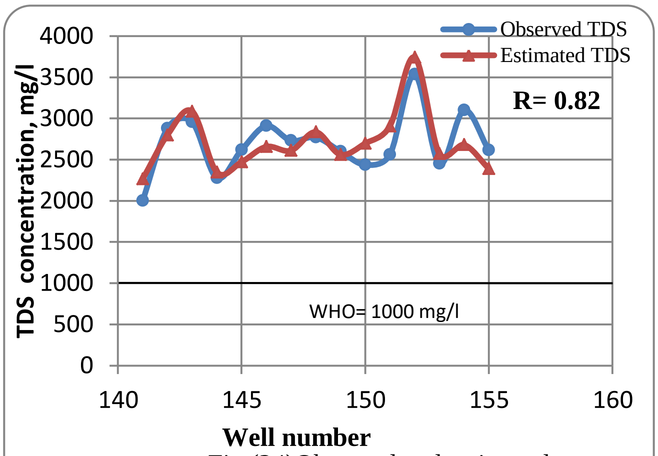

Fig.(24)Observed and estimated concentrations of TDS for 15 wells in Karbala region

In addition, the following parameters were determined:

1. ***The sodium adsorption ratio*** **(SAR):** The US salinity laboratory (1954) of the U.S. department of Agriculture recommends this ratio because of its direct relation to the adsorption of sodium by soil. It is defined by**[8]**:

$$\mathbf{SAR} = \frac{\mathbf{Na}}{\sqrt{(\mathbf{Ca}+\mathbf{Mg})/2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(1)}$$

Where the concentration of the constituents are expressed in milli-equivalents/liter (meq/l).

2. ***Permeability index*** **(PI) :** is a parameter computed to evaluate irrigation water quality and is expressed by Doneen (1964) as **[9]**:

$$\mathbf{PI} = \frac{\mathbf{Na}+\sqrt{\mathbf{HCO3}}}{\mathbf{Ca}+\mathbf{Mg}+\mathbf{Na}} \times \mathbf{100} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(2)}$$

Where all ions are in (meq/l) .

3. ***Percent Sodium*** **(%Na):** Sodium concentration is important in classifying an irrigation water because sodium reacts to soil to reduce its permeability. Sodium content is usually expressed in terms of percent sodium also known as soluble-sodium percentage, defined by **[3]**:

$$\%\mathbf{Na} = \frac{\mathbf{Na}+\mathbf{K}}{\mathbf{Ca}+\mathbf{Mg}+\mathbf{Na}+\mathbf{K}} \times \mathbf{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(3)}$$

Where all ionic concentrations are expressed in (meq/l).

4. ***Magnesium hazard*** **(MH):** It is a useful indicator to specify the magnesium hazard which is proposed by Szabolcs and Darab (1964) for irrigation water as follows **[10]**:

$$\mathbf{MH} = \frac{\mathbf{Mg}}{\mathbf{Mg}+\mathbf{Ca}} \times \mathbf{100} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(4)}$$

Where Ca and Mg are measured in milligram/liter (mg/l).

5. ***Total hardness*** **(TH):** It is an important property used to indicate the quality of groundwater ordinary expressed as the equivalent of calcium carbonate (CaCO3). It is primary defined by calcium and magnesium cations expressed as **[3]**:

TH = 2.5 Ca + 4.1 Mg ……………………..(5)

Where TH, Ca and Mg are measured in (mg/l).

6. ***Water quality index*** **(WQI):** WQI is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers **[11]**. It is used to estimate the quality of drinking water. The WQI was determined utilizing weighted arithmetic method as follows **[12]**:

$$\mathbf{Qi} = \frac{(\mathbf{Mi}-\mathbf{li})}{(\mathbf{Si}-\mathbf{li})} \times \mathbf{100}$$

The unit weight of the parameter, $\mathbf{Wi} = \frac{\mathbf{K}}{\mathbf{S_i}}$

$$\mathbf{K} = \frac{\mathbf{1}}{\left(\frac{1}{S_1}\right)+\left(\frac{1}{S_2}\right)+\cdots+\left(\frac{1}{S_i}\right)}$$

Where: S_i = standards values of various parameters from 1 to i.

M_i = Estimated value of the i^{th} parameter in the laboratory

l_i = Ideal value of the i^{th} parameter

l_i =0 for all the parameters except PH, which is 7.0

$$\mathbf{WQI} = \frac{\sum_{i=1}^{n} Q_i W_i}{\sum_{i=1}^{n} W_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(6)}$$

The contour maps of all above six parameters are drawn as shown in Figs.(25) to (30).

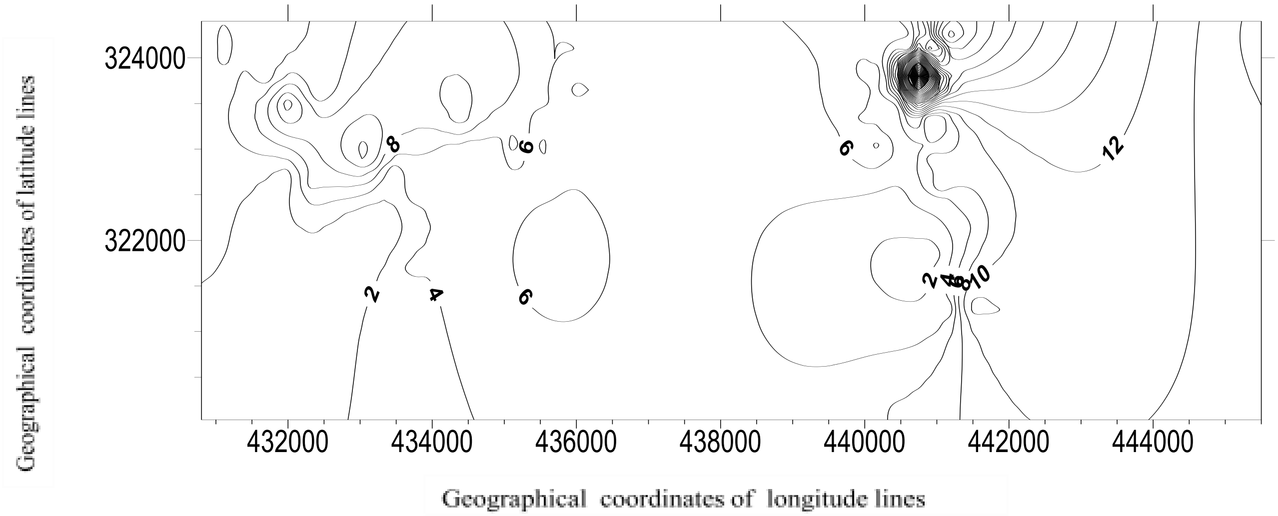

Fig.(25) Contour map of sodium adsorption ratio (SAR)(meq/l) for Karbala groundwater

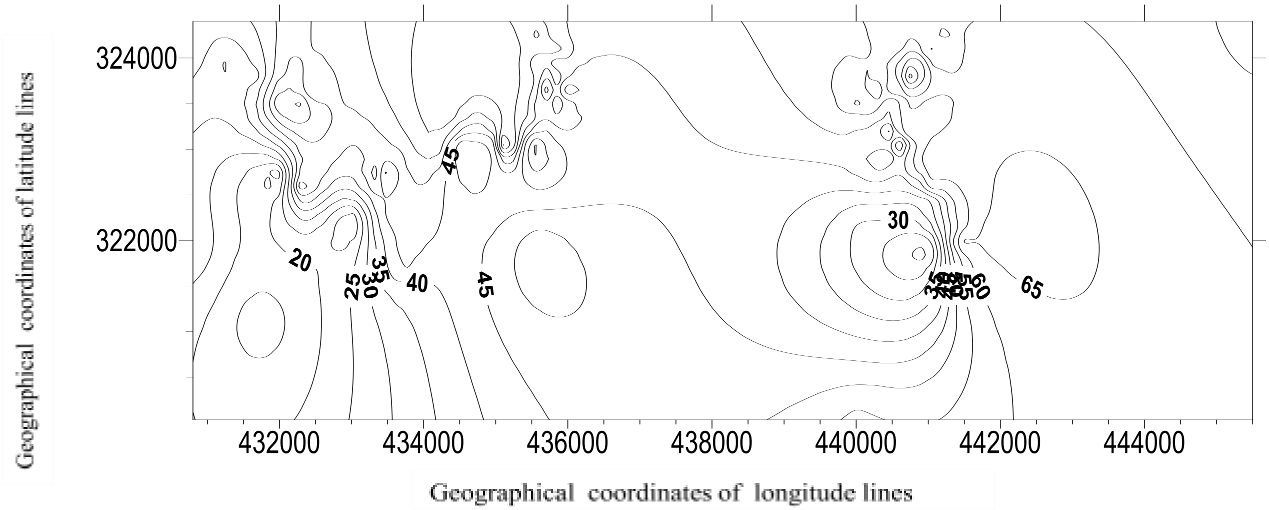

Fig.(26) Contour map of permeability index (PI%) for Karbala groundwater

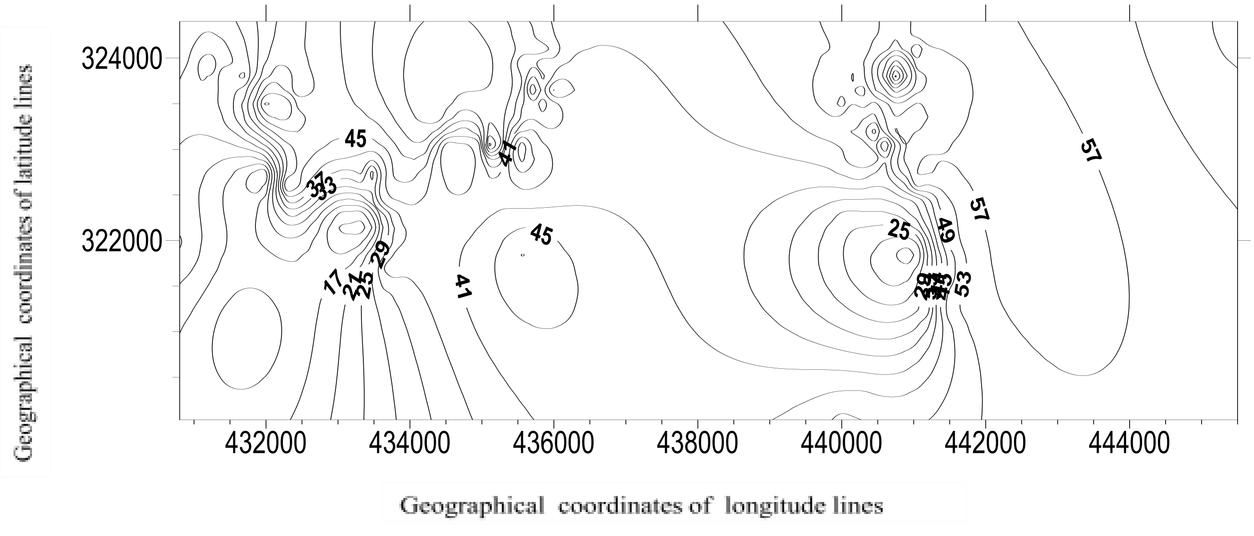

Fig.(27) Contour map of soluble-sodium percentage (%Na) for Karbala groundwater

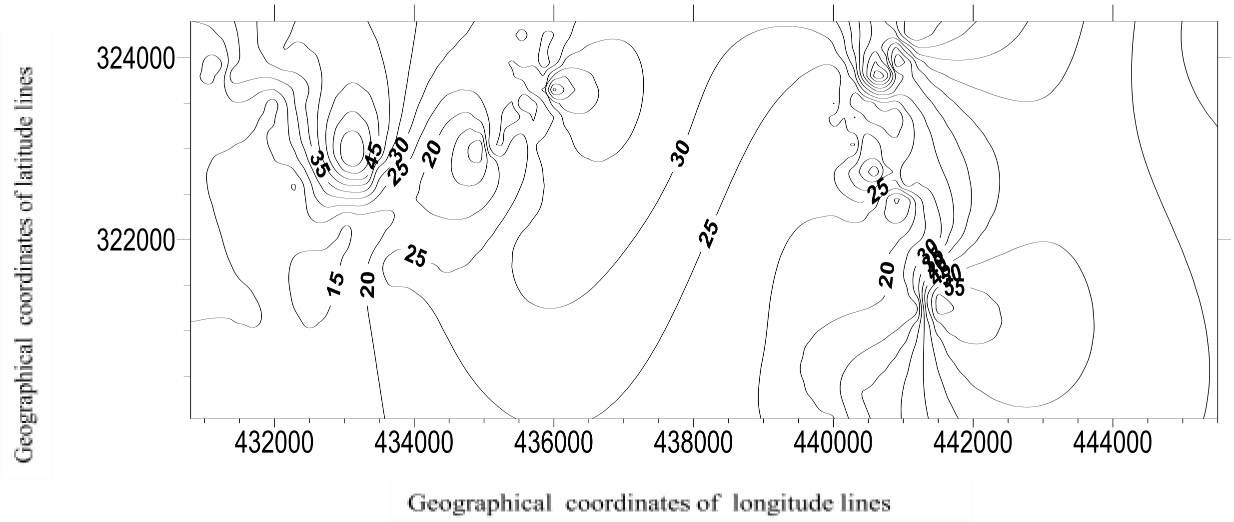

Fig.(28) Contour map of magnesium hazard(MH%) for Karbala groundwater

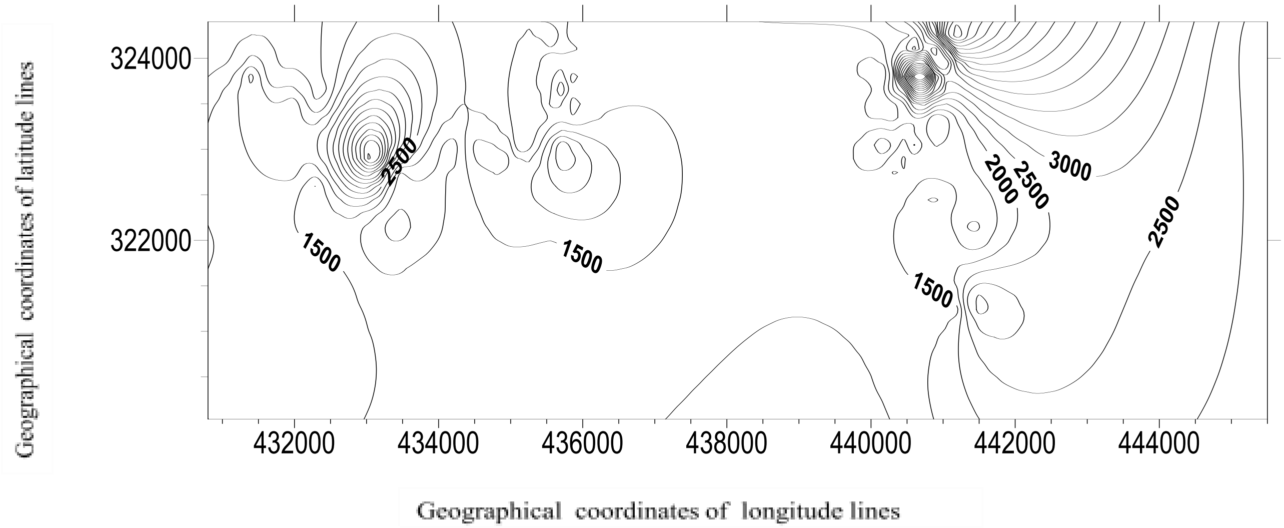

Fig.(29) Contour map of total hardness (TH)(mg/l) for Karbala groundwater

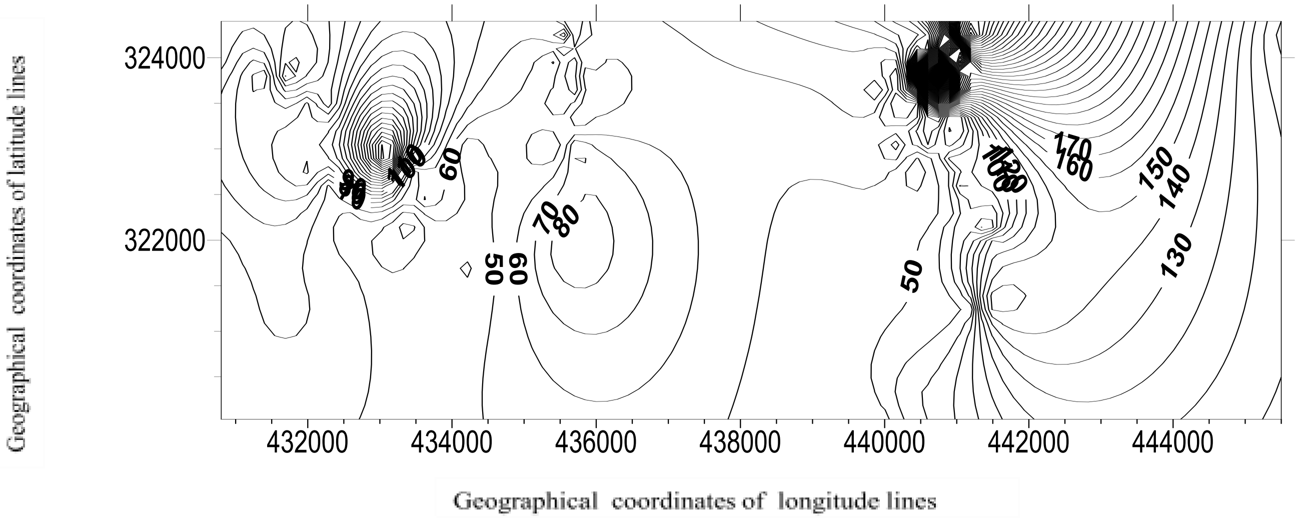

Fig.(30) Contour map of groundwater quality index (WQI) for Karbala groundwater

The statistical values listed in Table(1) as minimum, maximum and mean of measured chemical parameters are determined and compared with standards of the World Health Organization (WHO) in 2004**[13]** and Iraqi standards in 2001**[14]**. In order to test the relation between chemical parameters, the degree of correlation between these parameters was calculated and arranged in matrix as shown in Table(2).

In order to classify the groundwater of the study area for irrigation use, two graphic techniques are applied. The first one is the US salinity diagram (1954)**[8]** and the second one is the Wilcox classification diagram (1955)**[15]** as shown in Figs.(31) and (32), respectively. In US salinity diagram, electrical conductivity (EC) is considered as salinity hazard and sodium adsorption ratio (SAR) as Sodium (alkali) hazard. The Wilcox diagram deals with EC and sodium percent (%Na).

Table (1) Statistical values of the observed chemical parameters data for 155 unconfined wells inside and outside the boundary of the study area with standards comparison.

Parameter	Minimum value	Maximum value	Mean value	WHO International Standards,2004	Iraqi Standards,2001
PH	5.2	9.4	7.4	6.5 - 9.2	6.5 - 8.5
Ca^{+2}(mg/l)	43	960	324	200	50
Mg^{+2}(mg/l)	12	2050	157	150	50
Na^{+}(mg/l)	4	23000	697	200	200
K^{+}(mg/l)	1	1658	15	200	---
$HCO3^{-}$(mg/l)	64	2257	279	240	---
$SO4^{-2}$(mg/l)	10	9600	1048	250	250
Cl^{-}(mg/l)	14	36788	1032	250	250
$NO3^{-}$(mg/l)	1	217	9	50	50
EC(µmhos/cm)	395	86200	5085	1500	1000
TDS(mg/l)	222	74015	3709	1000	1000
TH(mg/l)	199	10505	1451	500	500
SAR	0.12	99	7	---	---
% Na	5	84	44	---	---
PI (%)	10	83	50	---	---
MH (%)	4	74	28	---	---
WQI	22	968	72	---	---

Table(2) Correlation matrix of chemical parameters for Karbala groundwater

	PH	EC	TDS	TH	Ca	Mg	Na	K	HCO3	SO4	Cl	NO3
PH	1											
EC	0.05	1										
TDS	0.05	0.997	1									
TH	0.11	0.85	0.83	1								
Ca	0.12	0.52	0.51	0.75	1							
Mg	0.06	0.87	0.85	0.96	0.56	1						
Na	0.03	0.98	0.99	0.76	0.44	0.78	1					
K	0.01	0.83	0.85	0.48	0.28	0.49	0.91	1				
HCO3	0.01	0.03	0.01	0.02	-0.05	-0.01	-0.01	-0.04	1			
SO4	0.09	0.93	0.93	0.89	0.61	0.9	0.87	0.68	0.04	1		
Cl	0.05	0.99	0.995	0.81	0.46	0.84	0.99	0.87	-0.03	0.89	1	
NO3	0.17	0.45	0.43	0.67	0.33	0.72	0.35	0.01	-0.1	0.53	0.43	1
		C1	**C2**	**C3**			**C4**					

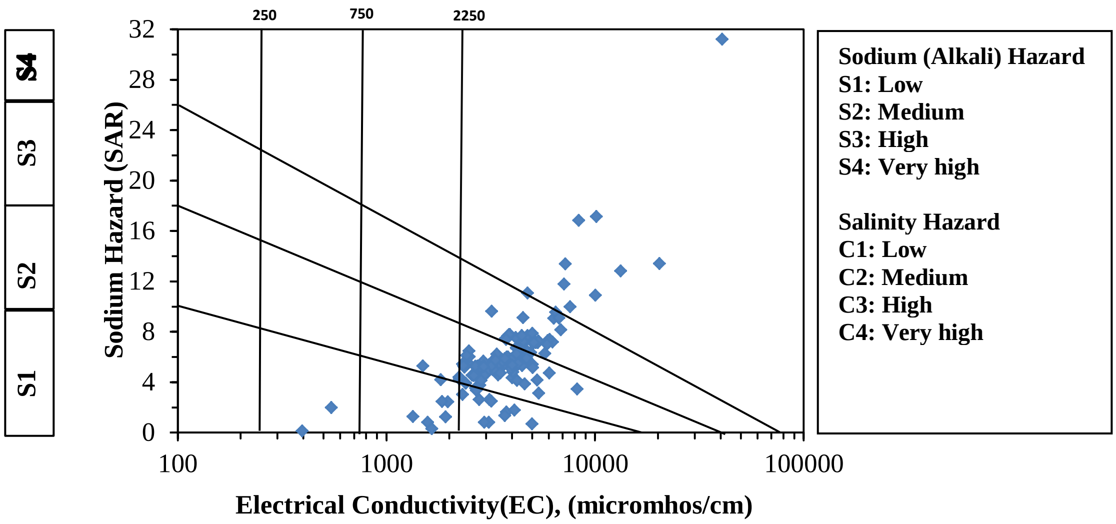

Fig.(31)Salinity Diagram for Classification of Irrigation Water (Based on Richards 1954[8])

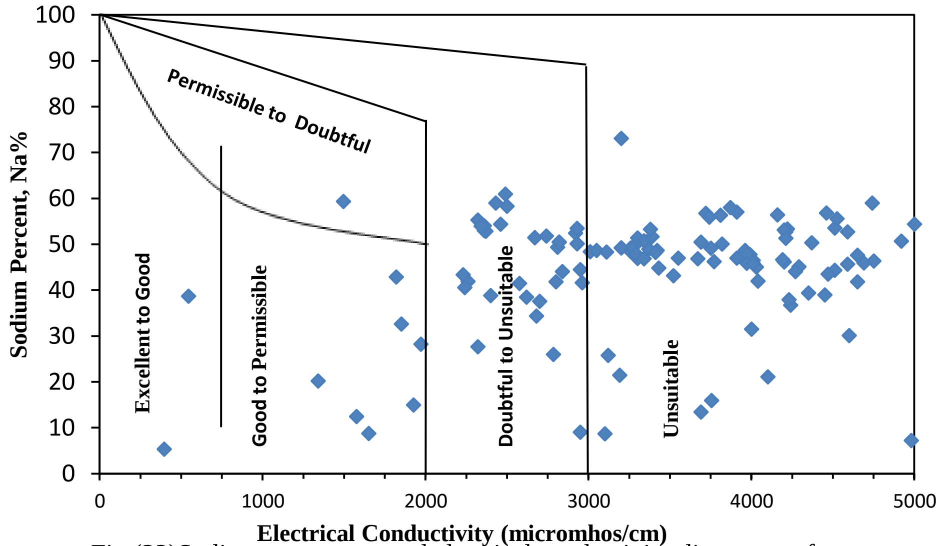

Fig.(32)Sodium percentage and electrical conductivity diagram for classification of irrigation water(Based on Wilcox 1955)

Results Discussion

Contour maps evaluation of groundwater parameters

Al-Jiburi and Al-Basrawi (2007) found that the general trend of groundwater flow through Iraqi western desert including Karbala region is towards northeast, following the discharge zone along the right bank of Euphrates River**[16]**. Locally, different directions of flow may occur throughout the region, depending on the geological setting of water-bearing horizons and nature of structure and topography **[16]**. In the current study, Fig.(2) shows the trending of groundwater flow towards north and northeast nearly the same as in Al-Jiburi study.

The primary goals following the chemical analysis of groundwater is to find groundwater quality and suitability to multiple uses based on different chemical indices. The contour maps, Figs.(3) to (13) show that the high contaminants concentrations of Karbala groundwater are generally located between longitude(44°00´- 44°20´),(43°20´ - 43°40´) N and latitude (32°10´ - 32°40´) E. The verification of contour maps shown in Figs.(4) to (24) gives good relation between observed and estimated data according to the correlation coefficient(R)ranged 0.82 to 0.97.

Evaluation of groundwater quality for drinking

As groundwater moves along its flow paths in the saturated zone, increases of TDS and the major ions normally occur **[17]**. Figs.(3) to (13) and Figs.(25) to (30) show this increasing phenomena of TDS, EC and the ions named Ca^{2+}, Mg^{2+} , Na^{+}, $HCO3^{-}$, $SO4^{2}$, Cl^{-}, $NO3^{-}$, also the parameters SAR, PI, NA%, MH ,TH, WQI, except the value of PH and the concentration of K^+ cation decreased in flow direction. This exception may refer to the acidity action along flow direction for PH and the increasing distance from the recharge sources for K^+ cation.

. It is found that 0.7%, 7.1% and 92.2% of observed groundwater data have values of PH less than the minimum WHO limit of 6.5, greater than the maximum WHO limit of 9.2 and between 6.5-9.2, respectively. Table (1) shows that the PH values vary from 5.2 to 9.4 with mean of 7.3, indicating acidic to alkaline nature of groundwater and tending to alkaline activity at average value. The mean value of PH is within the WHO and Iraqi standards.

Among major cations, Na^+ was generally dominant **[7]**. A higher sodium intake may cause hypertension, congenial heart diseases and kidney problems **[18]**. Referring to Table (1), the mean value of Na^+ represents 58.4% of the all cations. Calcium and magnesium ions were of secondary importance, represented in averages 27.2% and 13.2% of the all cations, respectively. Potassium ion fairly occurs at low concentrations in groundwater **[19]**. K^+ represents 1.2% of the all cations. Cations, Na^+, Ca^+ and Mg^+ have the means 697, 324 and 157 mg/l, respectively above the WHO and Iraqi standard limits. While the mean concentration of K^+ (15mg/l) is immensely below the WHO limit of 200 mg/l. The primary anions, sulfate($SO4^-$), chloride(Cl^-) and bicarbonate($HCO3^-$) have percentages 44.3%, 43.3% and 11.8% of the all anions, respectively. These anions have mean concentrations (1048, 1032 and 279 mg/l, respectively) above the WHO and Iraqi limits. While the concentration of nitrate ($NO3^-$) anion varies from 1 to 217 mg/l, with a mean value of 9 mg/l below the WHO and Iraqi limits of 50 mg/l.

Based on the average values of major cations and anions in the groundwater of Karbala region, the distribution pattern of these ions is as $Na^+ > Ca^{+2} > Mg^{+2} >> K^+$ and $SO4^{-2} > Cl^- > HCO3^- >> NO3^-$, respectively. Generally, the distribution pattern of all the major ions can be decreasingly arranged $SO4^{-2} > Cl^- > Na^+ > Ca^{+2} > HCO3^- > Mg^{+2} >> K^+ > NO3^-$.

The electrical conductivity (EC) depends upon temperature, ionic concentration and types of ions present in the water **[20]**. Thus, the EC gives a qualitative picture of the quality of groundwater **[12]**. 97.4% of the observed groundwater data have EC values greater than the WHO limit. The EC in this paper varies from 395 to 86200 µmhos/cm. Its mean of 5085 µmhos/cm highly exceeds the maximum permissible limits (1500 and 1000 µmhos/cm) of both WHO and Iraqi standards, respectively.

The total dissolved solids (TDS) are a measure of total inorganic substances dissolved in water **(23)**. The TDS is used as a factor defining general groundwater salinity **[22]**. 98.1% of the observed groundwater data have TDS values greater than the WHO limit. The TDS values vary from 222 to 74015 mg/l with its mean of 3709 mg/l, which too more exceeds the WHO and Iraqi standards limits of 1000 mg/l. Increasing levels of TDS in an aquifer are indication that the aquifer is contaminated **[23]**. Therefore, the groundwater of Karbala region is highly contaminated.

Basically, the total hardness (TH) is the soap-consuming property of water **[24]**. It is found that 95% of the observed groundwater data have TH values greater than the WHO and Iraqi limits. In the study area, the observed values of TH as in Table (1) vary from 199 to 10505 mg/l with its average of 1451 mg/l exceeds the WHO and Iraqi limits of 500 mg/l.

Commonly, the water quality index (WQI) is used for drinking water evaluation. The maximum permissible limit of WQI is 100 **[12]**. In this study, WQI values range between 18 and 968 with a mean value of 72. Table (3) shows the WQI categories established by Brown (1970)**[25]**. Based on Table (3), the observed groundwater data are evaluated as 2.6%-excellent, 38.7%-good, 32.9%-poor, 18.1%-very poor and 7.7%-unfit to drinking. Overall, about 58.7% of the observed data are considered unsuitable for drinking uses and 41.3 % of these data are suitable for drinking.

Table (3) Water quality index categories based on Brown (1970) [26]

Water Quality Index (WQI)	Description
0 - 25	Excellent
26 – 50	good
51 – 75	poor
76 - 100	Very poor
> 100	Unfit to drinking

Evaluation of groundwater quality for irrigation

According to the US Salinity hazard Laboratory classification (1954) shown in Fig. (31), about 92.9% of Karbala groundwater data are classified as very high salinity hazard class (C4). Only 1.3% and 5.8% of studied groundwater data have the classification of medium class (C2) and high class (C3) salinity hazard, respectively. Groundwater that falls in the medium salinity hazard class (C2) can be used in most cases without any special practices for salinity control **[7]**. Groundwater lies in the high salinity hazard category (C3) may cause damage to the sensitive plants and a negative impact on many crops. The salinity hazard category (C4) is not recommend for irrigation in normal cases, but it can be used to irrigate the salt tolerant plant in permeable soils under good management. The primary effect of high EC reduces the osmotic activity of plants and thus interferes with the absorption of water and nutrients from the soil **[27]**. According to Wilcox classification (1955) shown in Fig.(32), about 73.5% of the Karbala groundwater data are classified as unsuitable for irrigation. While the percentages 1.3%, 4.5%, 0.7% and 20% of the studied data are respectively classified as excellent to good, good to permissible, permissible to doubtful, doubtful to unsuitable.

The calculated values of SAR using eq.(1) range from 0.12 to 99 with a mean value of 7. Essentially, the high sodium content (SAR) tends to develop alkaline in the soil. Practically, the continuous use of irrigation water contained high SAR value will damage the physical structure of the soil due to the dispersion of soil clay by the excessive colloidal amounts of absorbed sodium that causes soil to be hard and compact. According to the US Salinity hazard Laboratory classification (1954) shown in Fig. (31), about 12.3% of the Karbala groundwater data are classified as low sodium (alkali) hazard class(S1), whereas the percentages 60%, 20.6% and 7.1% of observed groundwater data are respectively classified as medium(S2), high(S3) and very high(S4) sodium hazard. Clearly, the dominant class of Karbala groundwater is S2. The water of this class may be used on coarse-textured or organic soils with good permeability **[8]**. Based on the mean value of SAR, the groundwater of this study is within low alkali category (S1).

Obviously, according to the US Salinity diagram as in Fig.(31) , the percentages 58.7%, 20.6%, 7.1%, 6.5% and 4.5% of the observed data of Karbala groundwater are classified within class C4-S2, C4-S3, C4-S4, C4-S1 and C3-S1 respectively while the classes C2-S1 and C3-S2 have the same percentage 1.3% of these data.

The computed values of percent sodium (%Na) range from 5% to 84% with the mean value of 44%. High percentage of Na^+ with respect to (Ca^{2+} Mg^{2+} Na^+) in irrigation water, causes deflocculating and impairing of soil permeability **[18]**. Table (4) represents the quality classification of irrigation water after Wilcox (1955). According to this table, the percentages (5.8%, 18.7%, 70.3%, 4.5% and 0.7%) of the observed groundwater data have %Na values within the limits of <20, (20-40), (40-60), (60-80) and >80, respectively. It is clearly concluded that the most amount of the studied groundwater subjected to class of permissible water.

Table (4) Quality classification of water for irrigation (after Wilcox) [3]

Water Class	Percent Sodium (%Na)
Excellent	< 20
Good	20 - 40
Permissible	40 - 60
Doubtful	60 - 80
Unsuitable	> 80

Environmentally, a high permeability index (PI) with subsurface structural profiles would widely indicate the common contaminants of groundwater. Doneen (1964) classified PI into three classes, class I (PI>75%), class II (25%≤PI≤75%) and class III (PI<25%)**[9]**. Waters of class I and class II are categorized as good for irrigation with 75% or more of maximum permeability. Waters of class III are unsuitable with 25% of maximum permeability. In the study area, 1.3%, 92.2% and 6.5% of the observed groundwater data are within class I, class II and class III, respectively. The PI values vary from 10% to 83% with the average value of 50% as in Table (1). According to average value of PI,the Karbala groundwater data are classified under class II.Therefore,the water is permissible for irrigation.

The magnesium content in water is one of the most essential parameters in evaluating the quality of water of irrigation. The major source of magnesium in the groundwater is due to ion exchange of minerals in rocks and soils by water **[28]**. Generally, calcium and magnesium maintain a state of equilibrium in most waters **[29]**. Water contains calcium and magnesium concentration higher than 200 mg/l cannot be used in agriculture **[7]**. In the current study, the average concentration of calcium exceeds 200 mg/l whereas that of magnesium is less than this limit as in Table (1). The magnesium hazard (MH) greater than 50 is harmful and unsuitable for irrigation use. In this study, the MH values of observed groundwater data range between 4% and 74% with the average value of 28% (Table 1). Only 5.2 % of the groundwater data have MH values over 50. According to the previous percentage and the mean value of MH, the Karbala groundwater can be classified as safe and permissible for irrigation use.

Correlation Matrix

A correlation matrix is a technical method used to establish the degree of correlation between two variables of the different chemical parameters affecting the quality of groundwater. This matrix has been designed as in Table (2). The correlation coefficient (R) is computed using Xcel-2007 software program. A positive R corresponds to an increasing while a negative R corresponds to a decreasing monotonic trend between two water quality parameters **[30]**. A high correlation coefficient (near 1 or -1) means a good relationship between two variables and its value near 0 means no relation between them **[31]**. In the study area, $HCO3^-$ shows poor negative correlation with all the ions and poor positive correlation with PH, EC and TDS. PH indicates poor positive correlation with all parameters. Good correlations are found between pairs of parameters like (EC with TDS, TH, Cl, Mg, Na, K, and SO4), (TDS with TH, Cl, Mg, Na, K and SO4), (TH with Cl, Mg, Ca, Na and SO4), (Cl with SO4, Mg, K and Na), (SO4 with Mg and Na), (Mg with Na and NO3), (Na with K). The very high positive correlation is found between TDS and EC because conductivity increases due to the increasing concentration of all dissolved constituents. All other negative and positive correlations of pairs are observed as poor to moderate correlations. Good correlation indicates chemical weathering and leaching of secondary salts contribution followed by multiple source inputs like industrial and agricultural effluents, which exhibit poor correlation in groundwater **[12]**. In addition, good correlation reveals that most of the ions are related in different physiochemical reactions like ion exchange in the groundwater pattern. A good correlation of TH with anions Cl^- and $SO4^{-2}$ can interpret that the hardness of Karbala groundwater is tend to be permanent. Briefly, the wide change in the correlation coefficients of constituent ions pairs subjects to spatial variation of groundwater pollution through the specified zone and helps in limiting polluted pattern under different levels.

Conclusions

The contour maps of constituents with chemical analysis were made to evaluate the Karbala groundwater quality for drinking water and irrigation use depending on the data of 155 unconfined wells represented Karbala region. The conclusions of this study are as follows:

1. It is found that the tendency of Karbala groundwater flow is in the north and northeast direction.
2. The contour maps of concentrations of the contaminants in Karbala groundwater give acceptable presentation of groundwater quality distribution due to the good correlation between 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.
3. The analyses reveal that the major cation Na^+ in the Karbala groundwater has generally dominant representation as average of 58.4% of all the cations. The major anions $SO4^{-2}$ and Cl^- are also dominant on the average of 44.3% and 43.3%, respectively of all the anions. Expectedly, Na_2SO4 and NaCl components may be mainly found in Karbala groundwater. Therefore, the Karbala groundwater tends to have permanent hardness.

4. The average concentration of all major ions in the Karbala groundwater is found in the order $SO4^{-2}>Cl^{-}>Na^{+}>Ca^{+2}>HCO3^{-}>Mg^{+2}>>K^{+}>NO3^{-}$. According to the average TDS value of 3709 mg/l, the Karbala groundwater is too unsuitable for drinking uses.
5. According to the water quality index (WQI), 58.7% and 41.3% of the Karbala groundwater data are unsuitable and suitable for drinking purposes, respectively.
6. According to US Salinity hazard Laboratory classification (1954), the dominant percentage 58.7% of the Karbala groundwater data are categorized within (very high salinity hazard - medium sodium (alkali) hazard), class (C4-S2).
7. According to Wilcox specification (1955), the dominant percentage 73.5% of the Karbala groundwater data are unsuitable for irrigation use.
8. The quality classification of irrigation water, after Wilcox (1955), shows that 70.3% of observed groundwater data are within the class of permissible water.
9. According to the classification of permeability index (PI), by Doneen (1964), 92.2% of the observed groundwater data within class II which is permissible for irrigation.
10. It is found that 94.8% of the groundwater in the study area is safe from magnesium hazard (MH) and permissible for irrigation purposes.
11. The analyses indicate that 95% of observed groundwater data have total hardness greater than the WHO and Iraqi standards. The correlation matrix of contaminant parameters in the study area shows a good correlation of TH with anions Cl^{-} and $SO4^{-2}$ referring to permanent hardness of Karbala groundwater.

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