Application of Water Quality Index for Evaluation of Groundwater Quality for Drinking Purpose in Dibdiba Aquifer, Kerbala City, Iraq

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Abstract

Water quality index (WQI) is a mathematical tool used to transform large quantities of water quality data into single number which represents water quality level. This research is accomplished to evaluate the quality of groundwater in Dibdiba aquifer/Kerbala city-Iraq for the purpose of drinking by using Water Quality Index (WQI). Groundwater samples were collected in April, 2010 from 20 wells. Various physicochemical parameters: pH, total dissolved solids, potassium, bicarbonate, sulphate, total hardness, sodium, calcium, magnesium, and chloride have been calculated in all the water samples. In most of the parameters the concentration observed were found to be above the permissible limits of the Iraqi standard for drinking purpose. The results showed that WQI values for the groundwater of the study area ranged from 432.6 to 184.5, which mean water was found to be severely contaminated and unsuitable for drinking purpose at all sites of the wells. Also this research concluded that further improvement is required to treat the water of Dibdiba aquifer wells for using as drinking purpose.
Keywords: Kerbala, Water Quality Index, groundwater, Iraq.

الخلاصة

ان مؤشر نوعية المياه هو اداة رياضية تستخدم لتحويل عدد من المتغيرات الخاصة بنوعية المياه الى رقم منفرد يعبر عن مستوى نوعية المياه.تم انجاز البحث لتقييم نوعية المياه الجوفية في خزان دبدبة ضمن نطاق مدينة كربلاء المقدسة وتقدير صلاحيتها لغرض الشرب باستخدام مفهوم مؤشر نوعية المياه. جمعت نماذج المياه الجوفية خلال شهر نيسان 2010 من 20 بئر. تم حساب عدد من المتغيرات لكل نموذج وهي درجة التفاعل والاملاح الذائبة الكلية والبوتاسيوم والبيكاربونات والكبريتات والعسرة الدائمية والصوديوم والكالسيوم والمغنيسيوم والكلور .ان التراكيز التي تم الحصول عليها لمعظم المتغيرات هي اكبر من الحدود المسموح بها وفقا للمواصفة العراقية لمياه الشرب. اوضحت الدراسة بان قيم مؤشر نوعية المياه للمياه الجوفية في منطقة الدراسة يتراوح بين 432.6 و 184.5 , وهذا يعني ان مياه جميع الابار ملوثة وغير ملائمة للاستخدام لغرض الشرب.وقد بينت الدراسة بان المياه الجوفية لمنطقة الدراسة تحتاج الى معالجة لاستخدامها لغرض الشرب والاستهلاك البشري.

Introduction

Groundwater is used for domestic and industrial water supply and irrigation all over the world. In the last few decades, there has been a tremendous increase in the demand for fresh water due to rapid growth of population and the accelerated pace of industrialization.

The availability of water in Iraq shows a great deal with spatial and temporal variability. The increase in population and expansion of economic activities undoubtedly leads to increasing demand of water use for various purposes.

Geographically, Iraq is one of the Middle-East countries. Water in this region is inherently scarce as a result of naturally arid climatic conditions (Hamdy A., Trisorio Liuzzi G., 2005).

The Tigris and Euphrates rivers represent the main source of water in Iraq, which are used for various purposes. Turkey, located at the headwaters of the Tigris and Euphrates, controls water flowing downstream through Iraq and to the Arab Gulf. In the mid to late 1990,s, Turkey began to implementation of the great Anatolia project GAP that consists of building 24 dams along the upper Tigris and Euphrates to generate electricity and irrigate a large area of land. The GAP project has effectively reduced water flows in the Euphrates to 1/3 its original annual average.

Karbala city depends mainly on the Euphrates river to meet its water needs for drinking, irrigation, and other purposes. The reducing of the Euphrates flow rate in the future requires researchers to put plans to avert the threat of water scarcity by exploring and classifying other water sources like groundwater as quantity and quality to fulfill water needs of the city for various purposes.

The water quality index WQI method for groundwater quality assessment is widely used around the world due to the capability of fully expression of the water quality information and is one of the most effective tools and important parameters to the evaluation and management of groundwater quality (Wu Jianhua, et al. 2011). WQI is defined as a rating reflecting the composite influence of different water quality parameters (Ramakrishnalah et al., 2009).

The concept of WQI was firstly used by Horton, (1965).The general WQI was developed by Brown et al. (1970) and improved by Deininger for the Scottish Development Department (1975). Over the years, many indices have been calculated for special purposes (Dalkey 1968; Liebman 1969; Prati et al. 1971; O'Connor 1972; Harkins 1974; Walski and Parker 1974; Inhaber 1975; Shaefer and Janardan 1977; Provencher and Lamontagne 1979; Couillard and Lefebvre 1985; House and Ellis 1987). The objective of the present study is to investigate the groundwater quality of Dibdiba Aquifer, Kerbala City, Iraq for human consumption by using a water quality index (WQI).

Methodology

Dibdiba aquifer covers the desert region extending between the two cities Kerbala and Najaf as shown in Fig. (1). The study area is apart of Dibdiba aquifer that located within Kerbala city. Kerbala city is located at central zone of Iraq, about 100 km south of Baghdad, which is the capital city of Iraq. Geologically, Dibdiba formation is unconfined aquifer, it consists of mainly from sandstone with fine gravel, clay siltstone, and silty clay stone and it covered with gypsum and sandy soil layers (Ayob M.S. et al., 1995 and Al-Jiburi H. K., 2002).The climate of the study area is under the condition of the western desert which is characterized by cold winter with low rainfall and hot and dry summer.

Groundwater samples were collected in April, 2010 from 20 wells. Coordinates of each well location were identified using GPS as shown in Table (1). Fig (1) shows the Geographical location of the study area and the sites of the wells. Each of the groundwater samples was analyzed for 10 parameters which were pH, total dissolved solids (TDS), total hardness, calcium, magnesium, sodium, potassium, alkalinity, chloride, and sulphate using standard procedures recommended by (APHA: AWWA: WEF, 1998). All the water samples were collected in 3 L plastic bottles which were washed with distilled water before sampling and transporting them to the laboratory. Chemical analysis of the water was carried out at the central laboratory of the Agriculture directorate of Kerbala.

Table (1).Geographical locations of the studied wells in UTM.

Well No.	UTME	UTMN
1	412311	3600481
2	411893	3600553
3	411433	3600657
4	410920	3600753
5	410290	3600774
6	408634	3601664
7	408125	3602027
8	407695	3602313
9	407281	3602586
10	406999	3602789
11	406704	3603010
12	406283	3603288
13	405028	3604175
14	404528	3604529
15	404328	3604729
16	404046	3605133
17	402948	3606893
18	402726	3607128
19	401669	3611241
20	401669	3611657

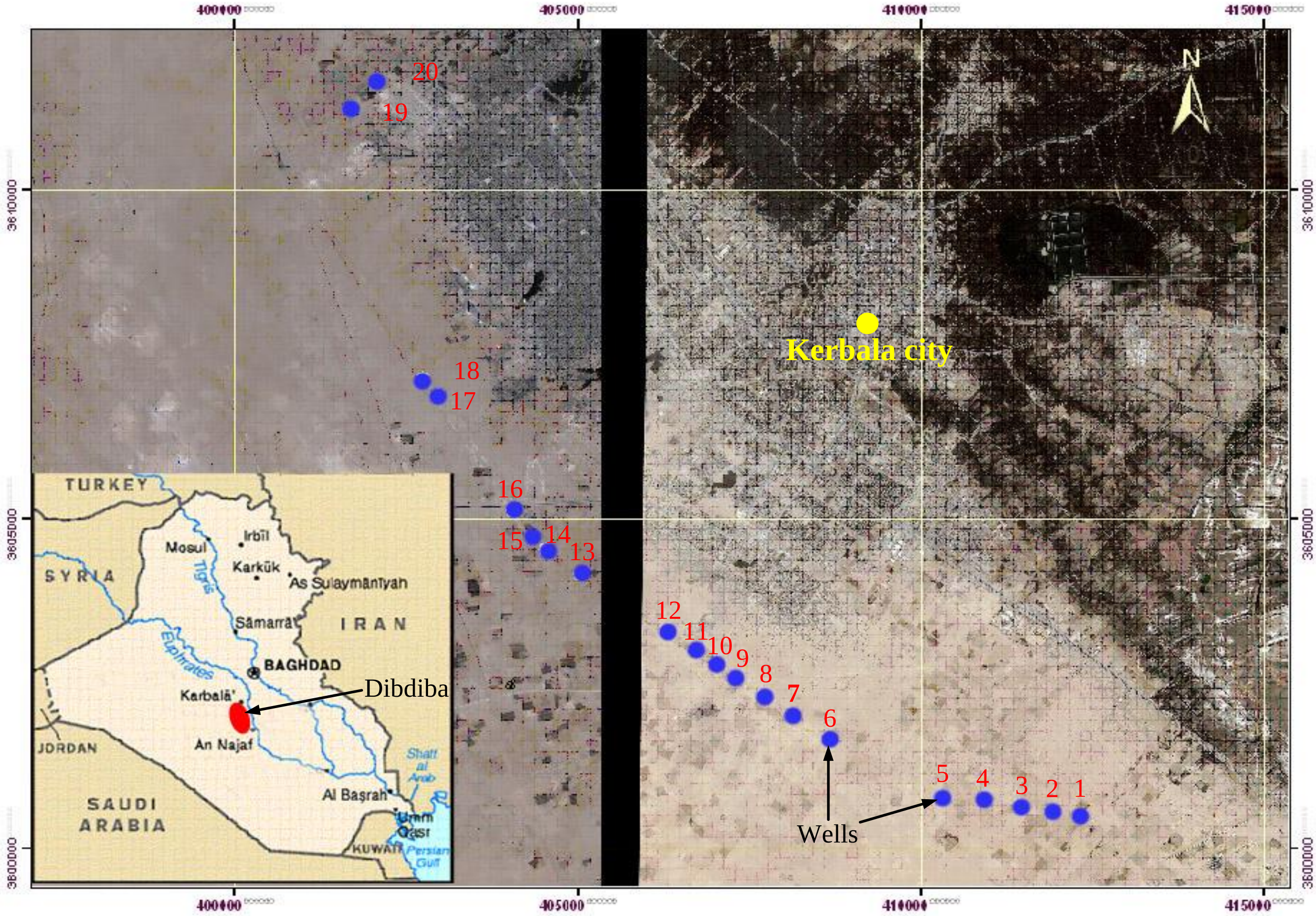

Fig. (1). Groundwater sampling locations.

Water Quality Index

Water quality index (WQI) is defined as a technique of rating that provides the composite influence of individual water quality parameter on the overall quality of water. WQI has been calculated to evaluate the suitability of groundwater quality of Dibdiba aquifer (Kerbala city) for drinking purposes. The WQI was calculated for each well by using ten parameters, namely TDS, Ca^{+2}, Mg^{+2}, Na^{+1}, K^{+1}, SO_4^{-2}, CL^{-1}, HCO_3^{-1}, TH, pH according to Iraqi drinking water standards for each chemical parameter illustrate in Table (2).For calculating WQI, a weighted arithmetic index method was used as below (Brown RM et.al, 1972 and Dhirendra M. J. et al., 2009):

1- Calculating the constant of proportionality by using Eq. (1) as shown in Table (3):

$$k = \frac{1}{\sum_{i=1}^{n} \frac{1}{Si}} \qquad \text{.......................... (1)}$$

in which

k= constant of proportionality

Si=permissible limit for the i^{th} parameter

n= number of parameters.

2- Calculating of weightage of i^{th} parameter (relative weight) Wi by using Eq.(2) as shown in Table (3):

$$Wi = \frac{k}{Si} \qquad \text{.......................... (2)}$$

3- Calculating sub index of i^{th} parameter Qi by the expression:

$$Qi = \frac{100Vi}{Si} \qquad \text{.......................... (3)}$$

in which Vi is the monitored value of the i^{th} parameter.
4-Calculating water quality index WQI as follows:

$$WQI = \frac{\Sigma_{i=1}^{n} QiWi}{\Sigma_{i=1}^{n} Wi} \qquad \text{.......................... (4)}$$

On the basis of the WQI, the quality of the water is categorized into five statuses from unfit for drinking purpose to excellent (Mishra and Patel, 2001) as shown in Table (4).

Table (2). The Iraqi standard for drinking purpose.

Parameters	pH	TH	Ca^{+2}	Mg^{+2}	HCO_3^-	CL^-	TDS	K^+	Na^+	SO_4^{-2}
Iraqi Standards, No. 417	6.5-8.5	500	200	150	200	600	1500	12	200	400

Table (3). Relative weight for each parameter.

Chemical parameters	Highest permitted value for water(Si)	1/Si	k	Wi
pH	8.5	0.117647	4.357671	0.512667
Hardness	500	0.002		0.008715
Calcium	200	0.005		0.021788
Magnesium	150	0.006667		0.029051
Bicarbonate	200	0.005		0.021788
Chloride	600	0.001667		0.007263
TDS	1500	0.000667		0.002905
Potassium	12	0.083333		0.363139
Sodium	200	0.005		0.021788
Sulphate	400	0.0025		0.010894
Total		0.22948		1.0

Table (4). Status of water quality based on WQI (Mishra and Patel, 2001).

WQI value	0-25	26-50	51-75	76-100	>100
Water quality statuses	Excellent	Good	Poor	Very poor	Unfit for drinking purpose

Results and Discussion

The physicochemical parameters concentrations in the groundwater samples of the study area were presented in Table (5).

Table (5). Values of some water quality parameters of Dibdiba aquifer.

well No.	PH	T.D.S mg/L	TH mg/L	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	CL mg/L	SO4 mg/L	HCO3 mg/L
1	7.32	3748	2527	618.8	91.74	57	595	978.4	2038	67.4
2	7.12	4320	2545	628.4	90.76	74.2	839	1227	1513	63.5
3	7.25	3962	2236	634.8	54.65	69.4	657	1049	1977	59.5
4	7.37	4320	2342	609.2	74.17	75.3	696	1985	2178	79.3
5	7.35	3605	2183	641.2	46.84	69.3	499	850.8	1958	59.5
6	7.4	3962	2166	593.1	59.53	64.9	472	779.9	1965	51.6
7	7.45	2887	2043	657.3	26.35	65.4	447	602.7	1840	39.7
8	7.35	2888	1955	471.3	73.2	57.6	442	623.9	2113	59.5
9	7.46	2760	2157	705.4	24.4	53	429	588.5	1406	71.4
10	7.25	2825	2175	737.4	16.59	60.1	463	850.8	2009	63.5
11	7.35	2887	2228	657.3	64.84	52.9	363	687.7	1830	47.6
12	7.15	2379	1955	474.5	72.22	63.7	338	609.7	1769	67.4
13	7.35	2569	2104	474.5	88.81	53	381	765.7	1890	43.6
14	7.23	2315	2087	522.6	67.34	39.7	341	673.6	1682	55.5
15	7.2	2728	2016	529.1	62.46	45.3	296	623.9	1720	47.6
16	7.23	2932	2113	481	87.84	50	226	531.8	1704	39.7
17	7.26	2728	1189	401	20	72.4	219.6	851	1769	0
18	7.37	2931	1160	348.7	47.6	79.7	268.2	716.5	1852	0
19	7.36	4320	1755	456.8	80.76	119.7	668.9	1146	2182	83.3
20	7.48	3533	1698	403.5	80	107.4	366.3	882.7	2008	67.4

In this study EXCEL is used to describe statistics of water quality parameters (median, standard deviation, minimum and maximum) for all studied wells as shown in Table (6).

Table (6). Summary of basic statistics for different water quality parameters (units are in mg/L except for pH which has no units).

Chemical parameters	Mean	Median	Std. Deviation	Minimum	Maximum
pH	7.32	7.35	0.1	7.12	7.48
Hardness	2031.7	2108.5	358.9	1160	2545
Calcium	522.25	561.1	110.1	348.7	737.4
Magnesium	61.55	66.09	24.27	16.59	91.74
Bicarbonate	53.34	59.48	21.81	0	83.28
Chloride	851.23	772.8	328.73	531.8	1985
TDS	3229.95	2909.5	670.99	2315	4320
Potassium	66.5	64.3	19.3	39.7	119.7
Sodium	450.35	435.5	167.17	219.6	839
Sulphate	1870.15	1871	204.92	1406	2182

Parameters

1.Total Dissolved Solids (TDS)

The groundwater is gaining various compositions from feeding area and access to discharge area due to exposure to multiple processes cause a change in chemical composition, such as evaporation, increase the concentration of elements and conveyed through the percolating water, and mixing processes and mitigation.

The concentration of TDS ranged from (2315) mg/L to (4320) mg/L as shown in Fig. (2). Increasing in TDS concentration may be attributed to the geological formation for Dibdiba aquifer (Gypsum soil, sandstone, and silty clay stone). Al-Jiburi H. K., (2002) also reported high concentration of TDS for the study area.

Very high values of TDS were recorded at all the wells much beyond permissible Iraqi drinking water standards limit. According to the Iraqi standard for drinking purpose, water containing more than 1500 mg/L of TDS is not considered desirable for drinking water supply.

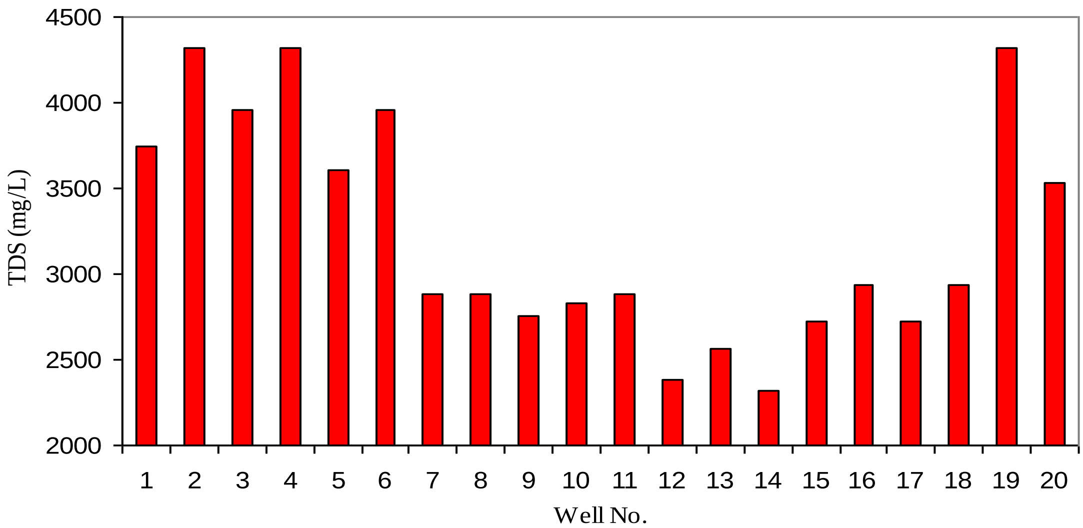

Fig. (2).TDS values for all wells.

2. Cations Concentrations

The ranges of Ca^{+2}, Mg^{+2}, Na^{+}, and K^{+} were (348.7 to 737.4) mg/L, (16.59 to 91.74) mg/L, (219.6 to 839) mg/L, and (39.7 to 119.7) mg/L respectively as shown in Figures (3), (4), (5), and (6). High and Low concentrations of calcium ion are observed in Wells (10) and (18) respectively due to geological formation of the study area. Fig.(4) shows that the concentration of magnesium ion is low according to the Iraqi standard for drinking purpose that refer to nature of geological layers in this region formation from (claystone) (Al-Jiburi H. K.,2002). Sodium ions (Na^{+1}) was observed in lower concentration in the groundwater through the wells (16 and 17) lies in the east part of Dibdiba formation as shown in Fig. (5). Sodium ion concentrations are exceeded limits the Iraqi standard for drinking purpose. This result agreed with the results of previous studies of Jiburi H. K., 2002**.** Potassium ions (K^{+1}) are results from the dissolve of the minerals which are available in rocks and the using of chemical fertilizers near the study area. Potassium ions were observed greater than the allowable concentration in all wells as shown in Fig. (6).

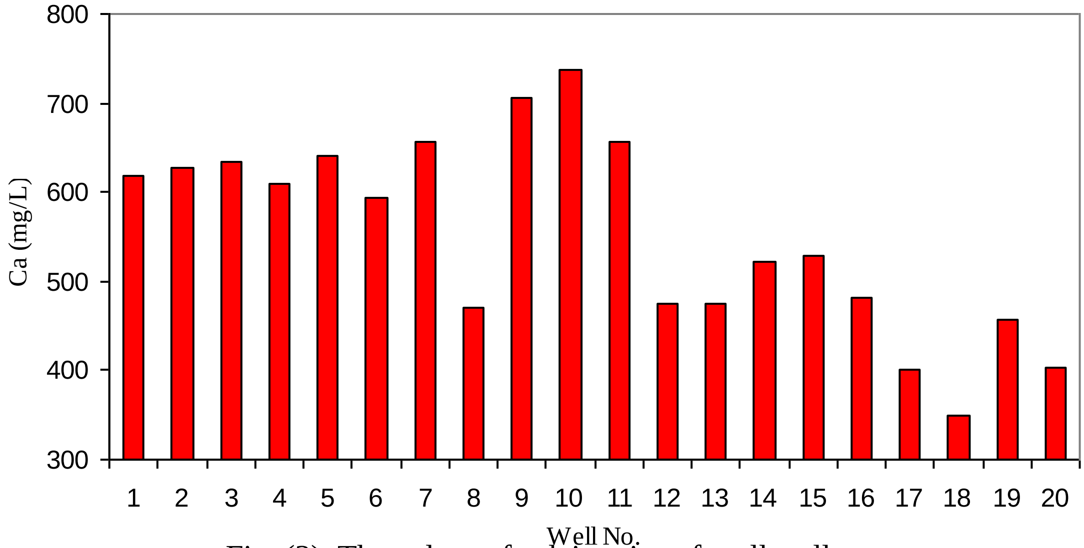

Fig. (3). The values of calcium ions for all wells.

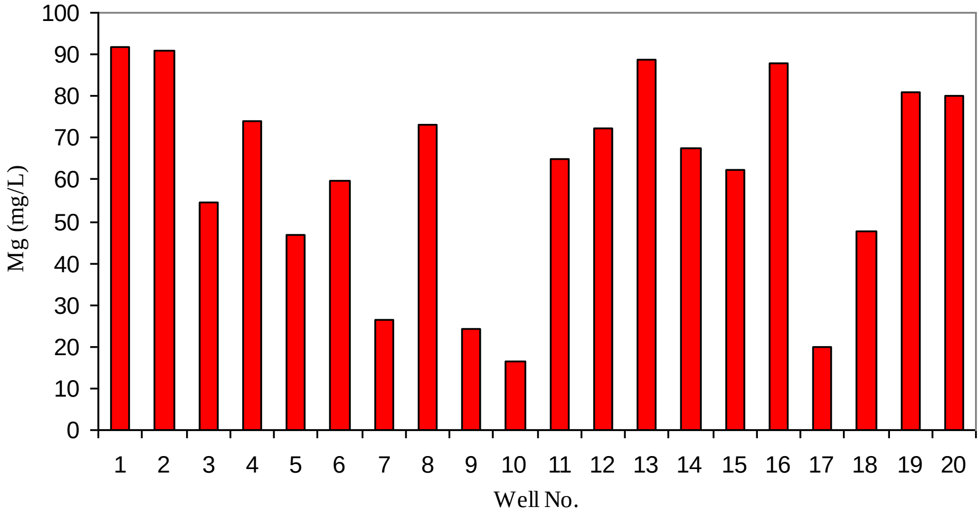

Fig. (4). The values of magnesium ions for all wells.

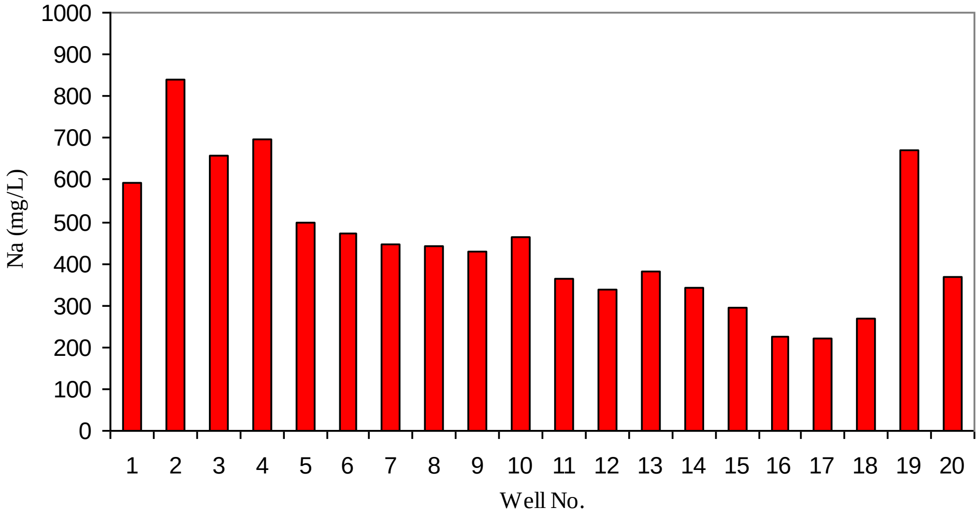

Fig. (5). The values of sodium ions for all wells.

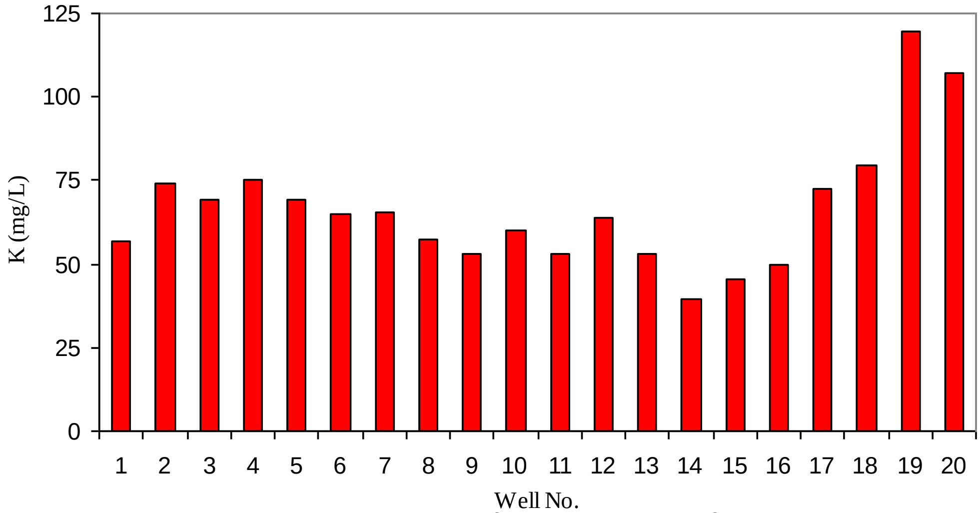

Fig. (6). The values of potassium ions for all wells.

3. Anions Concentrations

The ranges of anions concentration in the study area groundwater for sulphate (SO_4^{-2}), chloride (Cl^-), and (HCO_3^-) were (1406 to 2182), (531.8 to 1985), and (0 to 83.28) mg/L respectively as shown in Figures (7), (8), and (9). The sulphate concentration in groundwater is attributed to the dissolving of the gypsum by surface water which is seeping to the groundwater and also due to dissolving the sulfur oxides by rainwater. Fig. (7) showed the high values of SO_4^{-2} were recorded at all the wells much beyond permissible Iraqi drinking water standards limit, water for all wells containing more than 400 mg/L of SO_4^{-2}. This result agrees with the results of Al-Jiburi H. K., 2002. Fig. (8) shows that chlorides ions concentrations are greater than the allowable concentration in most wells. That is because various sedimentary nature for geological layers in this region. Dibdiba aquifer was observed low concentration of bicarbonate as shown in Fig. (9), this may be attributed to the nature of geological layer for this formation. Bicarbonate ions were observed lower than the allowable concentration in all wells.

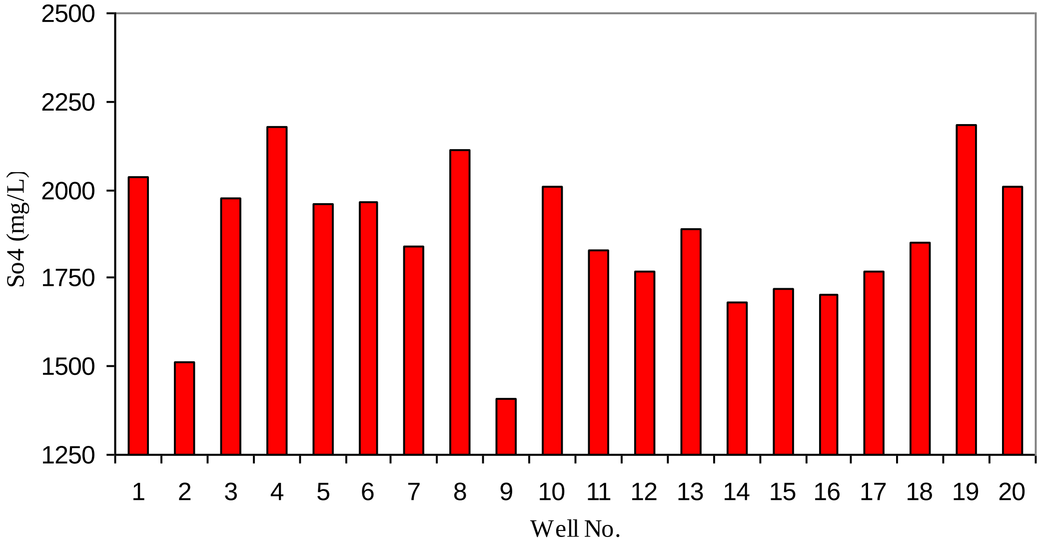

Fig. (7). The values of sulphate ions for all wells

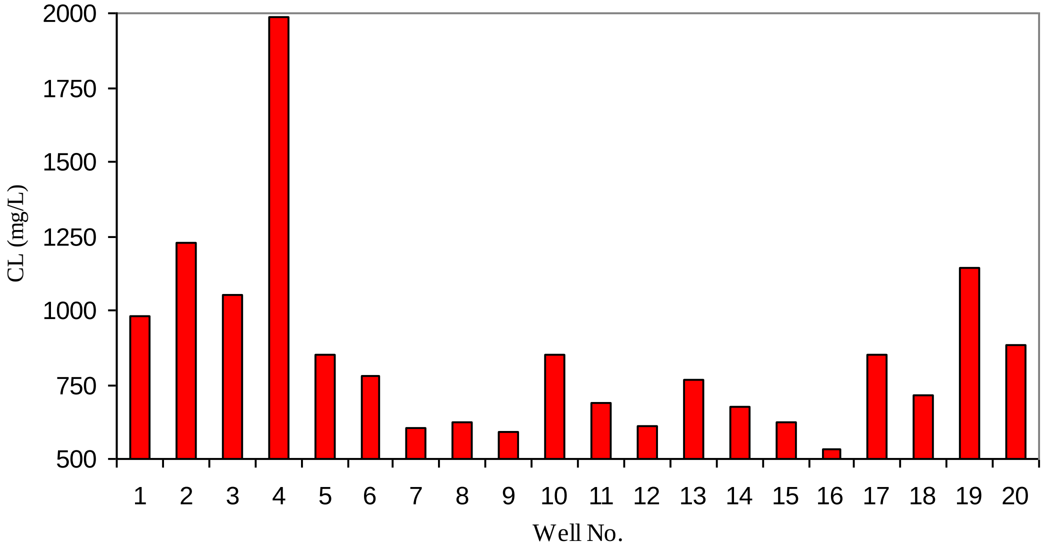

Fig. (8). The values of chloride ions for all wells.

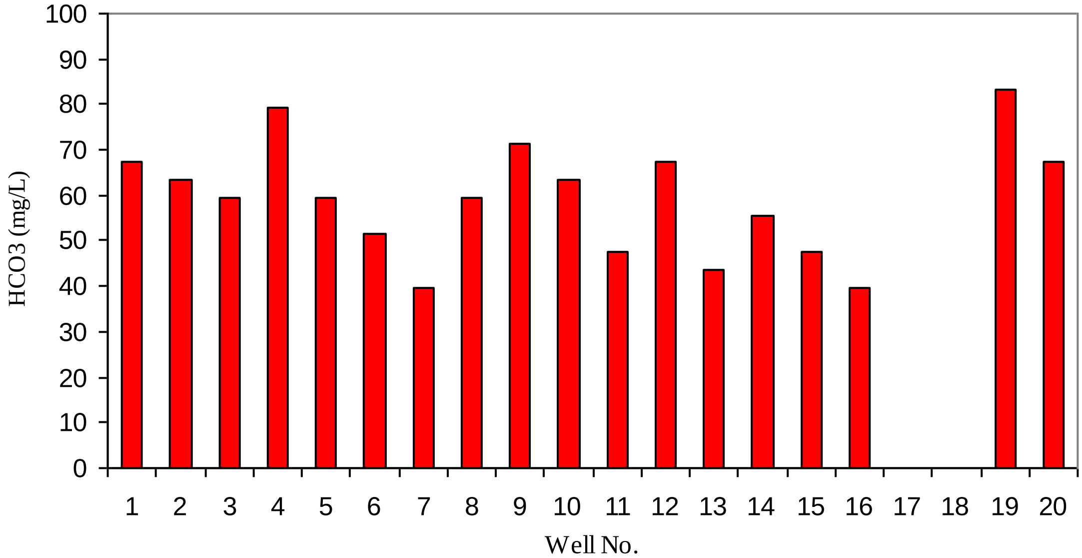

Fig. (9). The values of bicarbonate ions for all wells.

4. Hardness

The range of Hardness concentration was (1160) mg/L in well (18) to (2545) mg/L in well (2) as shown in Fig. (10). The hardness is attributed to the effects of the two ions, calcium and magnesium. Therefore, the geological formation (Gypsum, Claystone) in study area was the main causes for rising in hardness concentration.

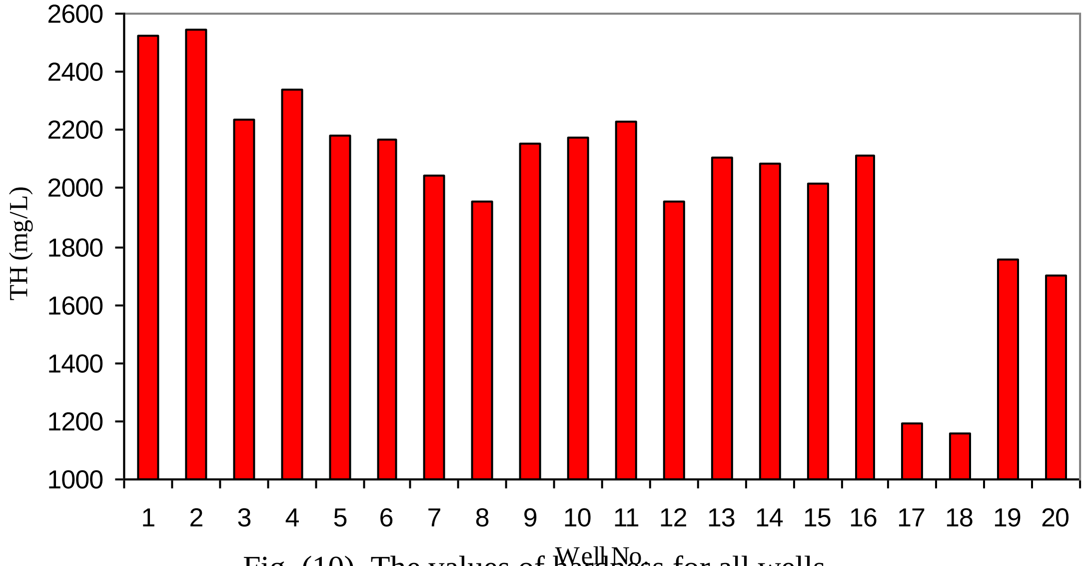

Fig. (10). The values of hardness for all wells.

5. pH

The pH is one of the most important factors that serve as an index for the pollution. The pH values of the study area groundwater ranged from (7.12 to 7.48) as shown in Fig. (11). The results showed that the groundwater tend to be neutralized or little alkaline.

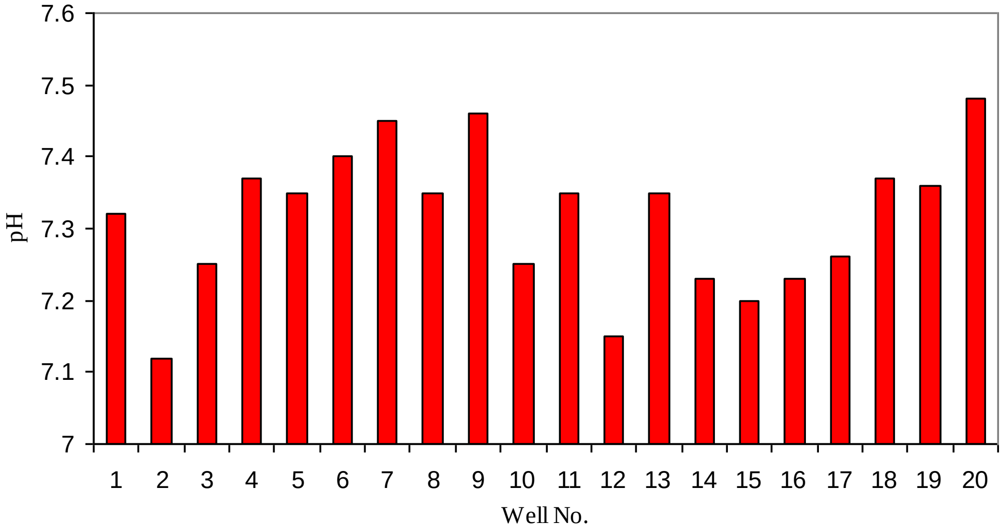

Fig. (11). The values of pH for all wells.

Water Quality Index

The results of groundwater classification for 20 wells in the study area using WQI model are shown Fig. (12). WQI values at all wells are much above 100 indicating unsuitability of wells water for drinking purpose. According to Mishra and

Patel (2001) index value more than 100 or above is unsuitable for drinking and propagation of wildlife and fish culture.

WQI values for the study area ranged from 432.6 for well (19) to 184.5 for well (14). The prime causes of deterioration groundwater quality are increasing in concentration of TDS, Hardness, and SO_4^{-2} in water of wells.

Pervious studies of state company of geological survey and mining showed that the movement direction of groundwater flow to the study area is from west to east and from southwest to northeast (Ayob M.S. et al., 1995 and Al-Jiburi H. K., 2002). This movement leads to increased pollution of groundwater due to dissolution of rocks with various chemical composition during the distance traveled until reaching to the locations of the selected wells. The other reason for high WQI values were continuous discharge of agricultural runoff.

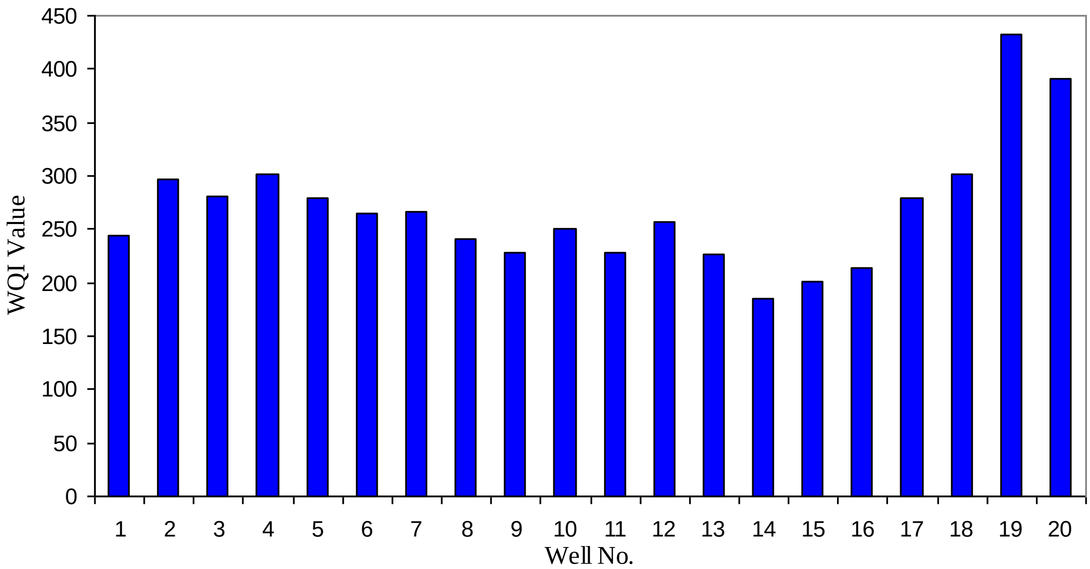

Fig. (12). The WQI values and their classifications.

Conclusions

According to the results of the WQI values, the following conclusions were found:

1. The WQI for the groundwater samples of Dibdiba aquifer (Kerbala city) ranges from 432.6 mg/L to 184.5 mg/L.
2. WQI values at all wells are much above 100 indicating unsuitability of wells water for drinking purpose.
3. From WQI values, it is suggested that further improvement is required to treat the Dibdiba aquifer wells for using as drinking purpose.
4. The prime causes of deterioration groundwater quality are TDS, hardness, and sulphate SO_4.

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