Journal of Engineering and Applied Sciences 14 (Special Issue 7): 9995-10009, 2019
ISSN: 1816-949X

Physicochemical Properties and Water Quality Index of Groundwater of Selected Wells in Najaf City Southern Iraq

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Abstract: The area which located along the road area between the cities of Najaf and Karbala areas are very important from hydrogeological used towards the groundwater reservoir which called Dibdibba formation. The reveal part of this sandy formation allows for replenishing and keeping its water by the rainwater penetration and surface flood. Groundwater movement flows through the reservoir from the West to the East and Southeast direction, so, it is unconfined aquifer which means the top surface (water table) is open for permeable materials. This area between the two cities invested for decades due to its importance in addition to the hydrogeological feature of the water reservoirs and hydraulic specifications. Many groundwater wells were drilled in this area to use this water resource for many purposes of farming in particular. There are many water wells in this infiltrated water reservoir upper region represented by the composition Dibdibba formation have been exploited as a sandstone fan or fan-shaped (alluvial fans) according to its sedimentary environment. This water-based reservoir in part on natural nutrition where the rains start this reservoir depletion of stocks over exploited of water in addition to the low levels of nutrition and natural reservoir groundwater and the exposure portion of the formation Dibdibba Sandy helped to renew and sustain its groundwater during the penetration of rainwater and surface water. This water-based reservoir in part on natural nutrition rain then this stock began gradually decreasing and downward due to over exploitation of water in addition to low natural nutrition levels of the groundwater reservoir. Groundwater quality in this reservoir characterized to be higher concentrated with dissolved salts. The results of Water quality index (Wqi) values display that the groundwater of present study location predicted to be severely contaminated and non-suitable for drinking usage at all sites of the wells.

Key words: Water quality index, hydrogeology, groundwater, physicochemical properties, contaminated, particular

INTRODUCTION

Dibdibba formation name which appears in all wells of this aquifer was first utilized by Macfadyen to beds revealed near the city of Basrah in Southern Iraq and Northern Kuwait where about 150 m of locally cross-bedded sands, gravels and carbonate or argillaceous cement sand, clays, sandstones, conglomerates and siltstones are exposed (Fig. 1). Owen and Nasr described the formation from wells of the Zubair field, it comprises gravel and sand containing pebbles of igneous rocks and white quartz, often cemented into a hard grit (Owen and Nasr, 1958). Beds of limestone, marl and silt were reported from wells in Nahr Umr field, Kifl field and at Mussaiyiab field (Elliot *et al*., 1954; Kasim, 1960 and Kasim, 1962).

The formation ungraded and often cross-bedded sequence of gravels and sands accompanied by subordinate intercalated beds or lenses of sandy clay, conglomerate carbonate or evaporite, cemented siltstone and sandstone (Alsharhan and Nairn, 1997).

In the region of Dibdibba formation southern Iraq the water supply is chiefly dependent on the rainfall, fortunately, high porosity of the sandstone and sands, plenty of the water may seep into the ground and be stored or may drain into local surface depressions in which some water gradually transpire into the ground and some evaporates and underground drainage is toward the Euphrates and Shatt al Arab rivers, down both dip and topographic slope (Al-Naqib, 1963). Wqi concept primarily used by Horton (1965), the quality of water from the side of their chemical, physical and biological parameters and ensure its quality is important before it is used for several purposes like potable water, agricultural industrial and recreational, etc. (Sargaonkar and Deshpande, 2003). The common Wqi was advanced

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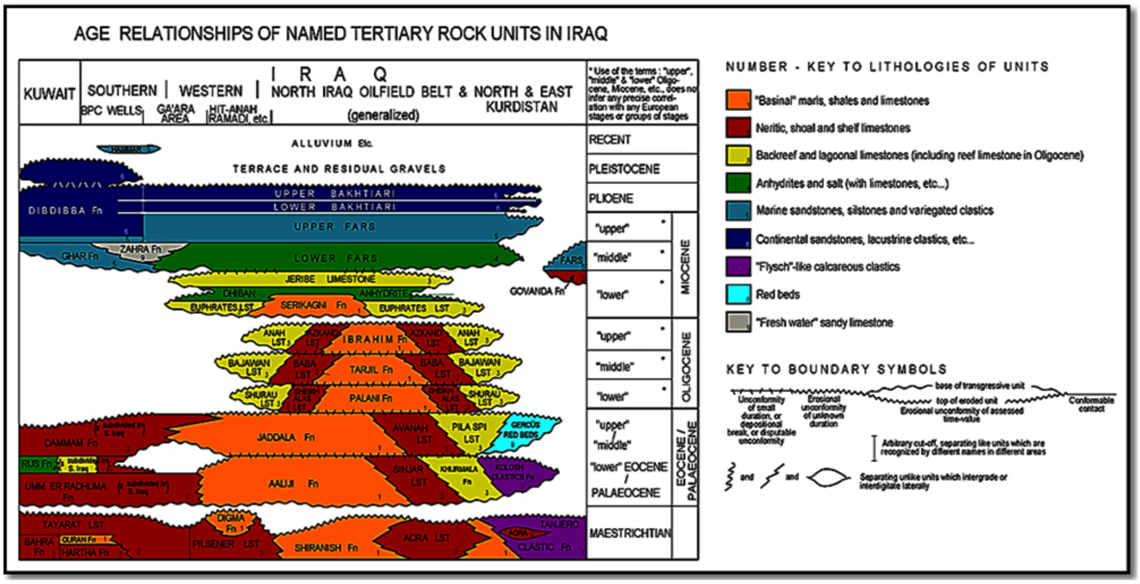

Fig. 1: Age relationships of named tertiary rocks units in Iraq

by Brown *et al*. (1970). Although, the Wqi founded on very serious parameters can show a simple indication of water quality (Yogedra and Puttaiah, 2008). Wqi is a classification shows the composite effect of diversified water quality parameters calculated count on the groundwater suitability for human consumption (Ramakrishnaiah *et al*., 2009).

In this study, the index includes the following eleven parameters: pH: potential Hydrogen ion concentration; EC: Electrical Conductivity; TDS: Total Dissolved Solids, calcium, magnesium, potassium, sodium, chloride, sulfate, bicarbonate and nitrate. In Iraq, many groundwater bodies recharge through vertical downward percolation of precipitation from the surface also indirect vertical seepage, about 100-300 mm of precipitation per year on the Mesopotamian flood plain and Jezira area and over half of Iraq situated within the semi-arid and arid zones (with <150 mm/year rainfall) (Alsam *et al*., 1990).

The goal of this study is to investigate the groundwater quality of Dibdibba aquifer in Najaf city in the South of Iraq to know if it suitable for human consumption by using then the concept of Water quality index (Wqi).

MATERIALS AND METHODS

Study area: This area is situated between longitudes (44°.1840-44°.3320) East and latitudes (32°.3088-32.1180) North in Najaf city South of Iraq about 120 km Southwest of Baghdad (Fig. 2). Variations of recent recharge during dry and wet years have reportedly ranged between 2.2 and 12 mm per year. for the Dibdibba formation in Iraq. From the tectonic side study area located in the Mesopotamian zone within stable shelf and contains the two rivers Tigris and Euphrates within central and South of Iraq also covered with the sediments of quaternary (Fig. 3) (Buday and Jassim, 1987; Al Kadhimi *et al*., 1996; Jassim and Goff, 2006).

The hydrological position of the study area is placed within the Mesopotamian plain aquifer system (Fig. 4) (Jassim and Goff, 2006).This formation is a continental environment originally, fed by rain and floods surface and so, it is natural that the groundwater of it is a continental environment either the quality in a range of calcium, sulfate and sodium chlorides. Total dissolved solids are generally high, it ranges between 2593-4777 mgL^{-1} which not fit for human drinking purposes according to the standards adopted by the food and agriculture organization and Iraqi standards for drinking water (Anonymous, 2001). The soil nature in the area and depth of groundwater qualified this water to agricultural uses because it contains a high percentage of the sand which maintains only 20% of irrigation water to maintain what plants need from elements as though the groundwater depth is major than 5 m which helps to not collect water and salts within zone of plants root (Mohammad, 2012).

The Eastern borders of the reservoir end by the disappearing of the geological formation and its water reservoir then turn into a semi-confined reservoir then confined near the Euphrates river and a ration of the water is discharged into the quaternary sediments above it (Al-Jawad *et al*., 2001). An official survey found that

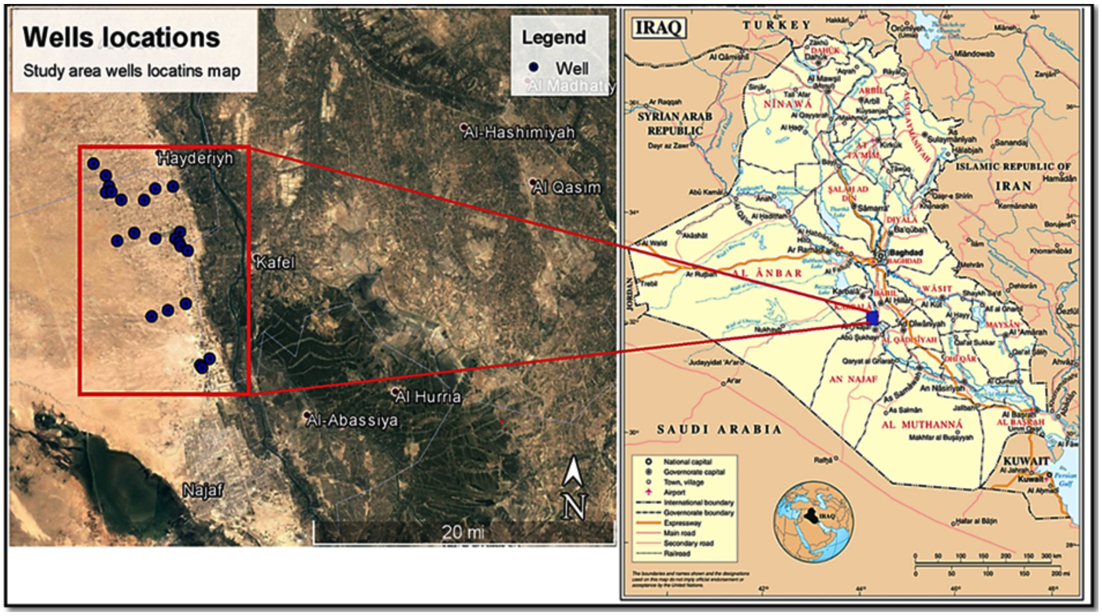

Fig. 2: Study area

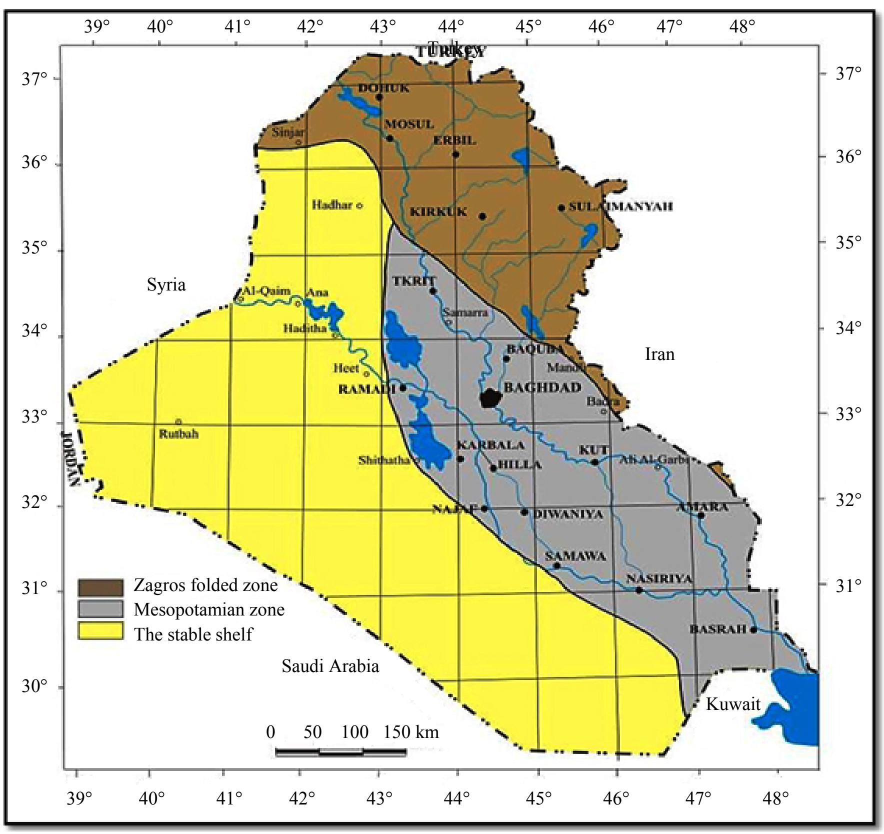

Fig. 3: Tectonic map of Iraq. Buday and Jassim (1987), AlKadhimi *et al*. (1996) and Jassim and Goff (2006)

nearly 5000 wells were in use in this area in 1998; Abstraction for agricultural uses was estimated at around 370 MCM in the 1980s, a substantial side of the extracted water returns back to groundwater through the porous

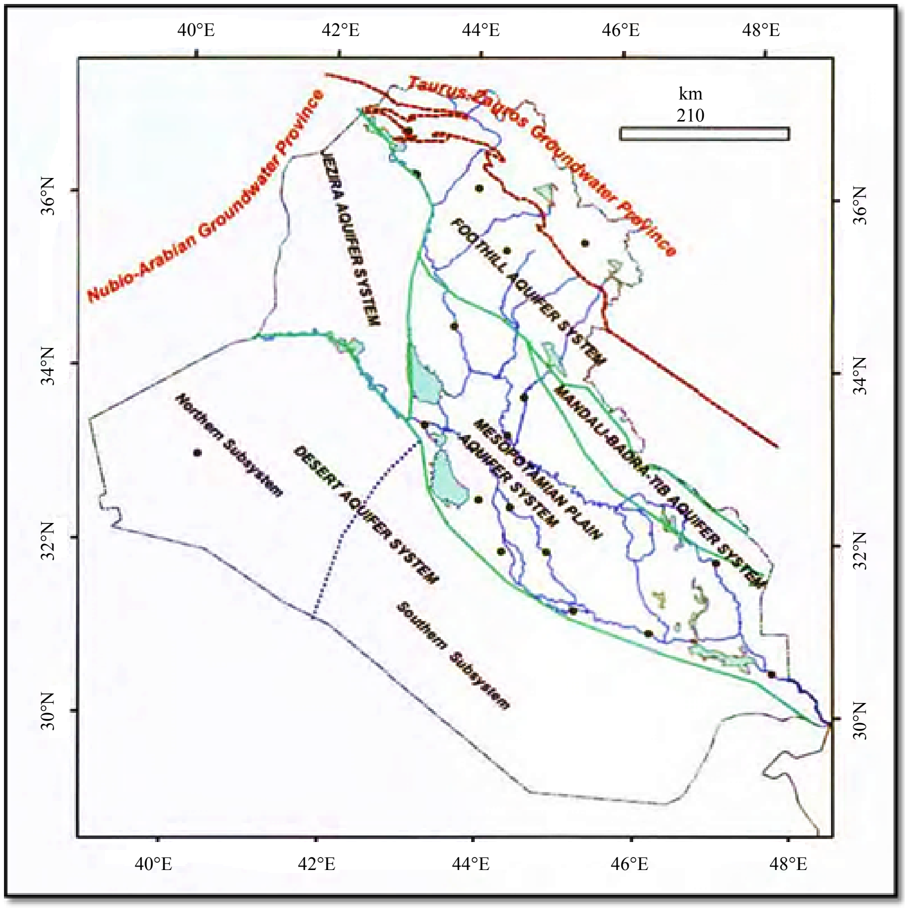

Fig. 4: Major hydrogeological divisions of Iraq. Jassim and Goff (2006)

pebbly sand soils (a return flow of about 84%) (Hassan *et al*., 1989). This formation has become hugely unsaturated in different regions, reversing the downward flow of groundwater from the Neogene to the Paleogene formations in heavy abstraction areas (UN-ESCWA and BGR., 2013).

The physicochemical parameters: Depending on the on a range of drilled water wells in the study area where they penetrated the sandy Dibdibba formation. The samples of groundwater were assembled in October 2013 from 23 wells with depth from (35-52 m). Water samples were obtained in the middle at mid-depth of each well and collected in clear (3 L) pre-sterilized polyethylene bottles which were washed with distilled water before sampling and transported to the laboratory using standard procedures recommended by standard method for the examination of water and wastewater by American Public Health Association (APHA *et al*., 1998).

Chemical analysis of water samples analyzed in the laboratories of the general authority of groundwater in Najaf province in the South of Iraq. Various physicochemical parameters pH, total dissolved solids, EC, magnesium, calcium, potassium, sodium, chloride, sulphate, bicarbonate and nitrate have been calculated for all water samples. Groundwater geochemistry is a (cross-sectional study) of water chemistry for the subsurface environment where the chemical structure of the groundwater is the consequence of the water which enters the groundwater reservoir and interactions with rocks that containing different minerals (Appelo and Postma, 1993). This wide range is the conclusion of the difference in origin (sea, air, birth, etc.) the rate of nutrition and interaction with the atmosphere, rock industrial pollution, temperature and pressure (Stuyfzand, 1999).

Statistical analysis

Water quality index (Wqi): Water quality index is the classification method that provides the combined effect of the individual water quality parameter on the total water quality (Singh *et al*., 2013). For determine Wqi, a weighted arithmetic index process was used in the present study. Microsoft Office Excel was used to

Table 1: Study wells values of parameters samples, all parameters units are in mg/L except for pH

Well No.	pH	Ec	TDS	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Cl^{-1}	SO_4^{-2}	HCO_3^{-1}	NO_3^{-1}
W01	7.50	3870	2675	264	128	420	80	552	1013	460	5.2
W02	7.30	4880	3218	332	157	536	118	716	1296	509	3.0
W03	7.20	5580	3801	309	148	548	96	667	1296	489	1.3
W04	7.23	5490	3734	301	145	542	95	662	1262	485	1.6
W05	7.35	3750	3256	270	130	510	85	639	1104	465	2.3
W06	7.54	5330	2599	258	122.2	402.6	76.3	518	984	421	5.4
W07	7.50	3970	2630	290	140	440	102	869	1089	472	3.0
W08	7.50	3920	2593	280	134	434	95.8	596	1036	469	5.0
W09	7.60	3860	2901	260.5	126.1	410.8	78.8	547	1002	450.7	5.3
W10	7.30	4350	2879	314	148	494	110	667	1214	490	3.0
W11	7.32	4020	2663	295	143	460	106	621	1142	475	3.0
W12	7.28	4630	3058	312	142	510	95	680	1181	480	2.0
W13	7.35	4860	3205	330	156	533	116	714	1286	508	3.0
W14	7.30	4520	2988	300	138	480	85	650	1123	460	2.0
W15	7.40	4460	2949	260	123	440	72	604	960	430	2.0
W16	7.20	5080	3351	340	165	560	120	746	1363	512	2.0
W17	7.12	5710	3754	356	173	580	125	781	1440	514	2.0
W18	7.20	6570	3580	286	139	532	91	651	1190	481	2.1
W19	7.30	4510	2981	298	136	470	83	645	1094	458	2.0
W20	7.12	6930	4665	350	172	586	104	692	1536	508	1.1
W21	7.12	7090	4777	345	170	609	110	705	1844	510	0.8
W22	7.12	6970	4610	350	170	590	104	703	1526	506	1.1
W23	7.18	6980	4617	360	180	612	106	715	1613	508	1.1
Max.	7.60	7090	4777	360	180	612	125	869	1844	514	5.4
Min.	7.12	3750	2593	258	122.2	402.6	72	518	960	421	0.8
Median	7.30	4860	3205	301	143	510	96	667	1190	481	2.0

Table 2: Relative weight for each parameter, all units are in mg/L except for pH

Chemical parameters	pH	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Cl^{-1}	SO_4^{-2}	HCO_3^{-1}	NO_3^{-1}
Highest permitted value for water (Si)	8.5	200	150	200	12	600	400	200	50
1/Si	0.117647	0.005	0.00667	0.005	0.0833	0.00167	0.0025	0.005	0.020
Wi = k/Si	0.475379	0.0202	0.02694	0.0202	0.3367	0.00673	0.0101	0.0202	0.0808

$$K = \frac{1}{\sum_{i=}^{n} \frac{1}{Si}} = 4.04072$$

(Σ1/Si) = 0.247

(ΣWi) = 1

Table 3: The Iraqi standard for drinking purpose

Parameters	pH	TDS	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Cl^{-1}	SO_4^{-2}	HCO_3^{-1}	NO_3^{-1}
Iraqi standard, No. 417	6.5-8.5	1500	200	150	200	12	600	400	200	50

describe statistics of water quality parameters like (median, minimum and maximum) Table 1 and then calculate Wqi for all studied wells.

Step 1: Calculating the constant of proportionality with Eq. 1 (Table 2) as below:

$$K = \frac{1}{\sum_{i=1}^{n} \frac{1}{Si}} \quad (1)$$

Where:

K : Constant of proportionality
Si : Standard limit for each parameter
n : Number of parameters

Step 2: Calculating relative Weight (Wi) of each parameter by using Eq. 2 as in Table 2:

$$Wi = \frac{K}{Si} \quad (2)$$

Step 3: Calculating quality value scale (qi) for each parameter is allocated by dividing parameter concentration in each sample by its standard value according to Iraqi Standards for drinking purpose by Anonymous (2001) 100 as in Eq. 3:

$$qi = (Ci/Si) \times 100 \quad (3)$$

Where:

qi : Quality rating
Ci : Concentration of a single parameter in each sample (mgL^{-1})
Si : Iraqi standards for drinking purpose (Table 3)

Step 4: To computing Wqi, according to Ramakrishnaiah *et al*. (2009) the (SIi) specified for each parameter as in Eq. 4:

$$Sli = Wi * qi \quad (4)$$

Table 4: Water quality classification based on Wqi values

Water quality	Wqi values
Excellent	<50
Good water	50-100
Poor water	100-200
Very poor water	200-300
Water unsuitable for drinking	>300

Table 5: Wqi for study wells

Well No.	Wqi values	Water quality
01	308.90	Water unsuitable for drinking
02	427.91	Water unsuitable for drinking
03	359.68	Water unsuitable for drinking
04	356.44	Water unsuitable for drinking
05	324.88	Water unsuitable for drinking
06	296.92	Very poor water
07	377.53	Water unsuitable for drinking
08	357.79	Water unsuitable for drinking
09	305.58	Water unsuitable for drinking
10	402.09	Water unsuitable for drinking
11	388.86	Water unsuitable for drinking
12	356.06	Water unsuitable for drinking
13	421.99	Water unsuitable for drinking
14	324.69	Water unsuitable for drinking
15	283.60	Very poor water
16	434.19	Water unsuitable for drinking
17	449.88	Water unsuitable for drinking
18	343.37	Water unsuitable for drinking
19	318.30	Water unsuitable for drinking
20	386.02	Water unsuitable for drinking
21	405.40	Water unsuitable for drinking
22	385.97	Water unsuitable for drinking
23	393.27	Water unsuitable for drinking

SIi is first specified for each chemical parameter. Water quality classification based on Wqi values (Table 4) and to calculate the Wqi as the following Eq. 5:

$$\text{Wqi} = \sum \text{SIi} \tag{5}$$

Water quality criteria for irrigation: Calculating the Sodium Adsorption Ratio (SAR) in groundwater according to Richards (1954) from the following Eq. 6:

$$\text{SAR} = \frac{\text{Na}^{+}}{\sqrt{\frac{\left(\text{Ca}^{+2}+\text{Mg}^{+2}\right)}{2}}} \tag{6}$$

Sodium percentage (Na%) is used also for evaluating the suitability of water quality for irrigation (Wilcox, 1955). As for a following Eq. 7:

$$\text{Na\%} = \frac{(\text{Na+K})}{(\text{Ca+Mg+Na+K})} \times 100 \tag{7}$$

Water quality index (wqi) for all study wells are presented in Table 5.

RESULTS AND DISCUSSION

The potential of Hydrogen (pH): It is the negative logarithm of hydrogen ion activity, a measure of acidity and alkalinity in normal conditions of temperature and pressure (Langmuir, 1997). Solutions with <7 are acidic and if it's >7 become alkaline, pH values of this study are ranged from 7.12-7.6 as shown in Fig. 5. The results present that the groundwater in this study resort to neutralize and partly alkaline.

Electrical Conductivity (EC): EC values of the present study are ranged from 3750-7090 as in Fig. 6. The conductivity of 1 cm of power at 25°C measured in μS/cm where electrical conductivity is dependent on water temperature increasing the water temperature by 1°C causes an increase in electrical conductivity of 2% and also increased by increasing the dissolved salts concentration (Hem, 1985; Detay, 1997).

Total Dissolved Solids (TDS): TDS values are ranged from 2593-4777 mgL^{-1} as a display in (Fig.7), very high values of TDS were measured in all study wells much further Iraqi drinking water standards (Anonymous, 2001). These values considered not suitable for drinking water.

Cations concentrations: The examination of Calcium ions (Ca^{+2}), Magnesium ions (Mg^{+2}), sodium ions (Na^{+}) and potassium (K^{+}), display the range from 258-360, 122.2-180, 402.6-612 and 72-125 mgL^{-1} as in Fig. 8-11.

Anions concentrations: The test range of Chloride ions (Cl^{-1}), Sulfate (SO_4^{-2}), bicarbonate (HCO_3^{-1}) are 518-869, 960-1844 and 421-514 mgL^{-1} as Fig. 12-14.

Nitrate (NO_3^{-1}): Various agricultural activities increase the concentration of nitrates in ground and surface water (Nas and Ali, 2006). The range of nitrate is from (0.8-5.4 mgL^{-1}) as a display in Fig. 15 where its concentration did not exceed the required limit in all samples values for study wells.

Sodium Absorption Ratio (SAR): Groundwater may also classify based on Sodium Absorption Ratio (SAR) as excellent 10, good 10-18, questionable 18-26 and unsuitable (>26) (Richards, 1954). In order to assess the suitability of the wells for irrigation in the study area Fig. 16.

Sodium percentage (Na%): Sodium concentration is an important role in evaluating the irrigational quality of groundwater where the soil of the area study is saline soil according to the high percentage of sodium shows a positive correlation with high salinity soil salinity Fig. 17, the significant positive correlation between soil salinity and the sodium percentage (Lehman *et al*., 2015).

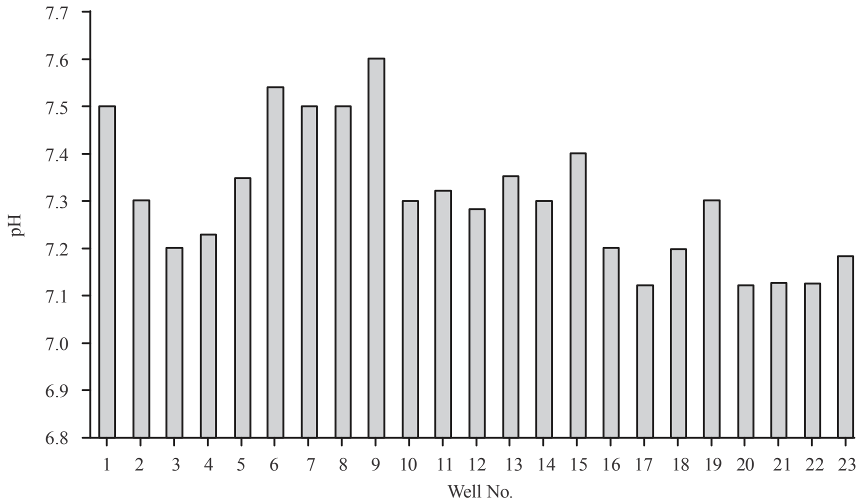

Fig. 5: pH values for all study wells

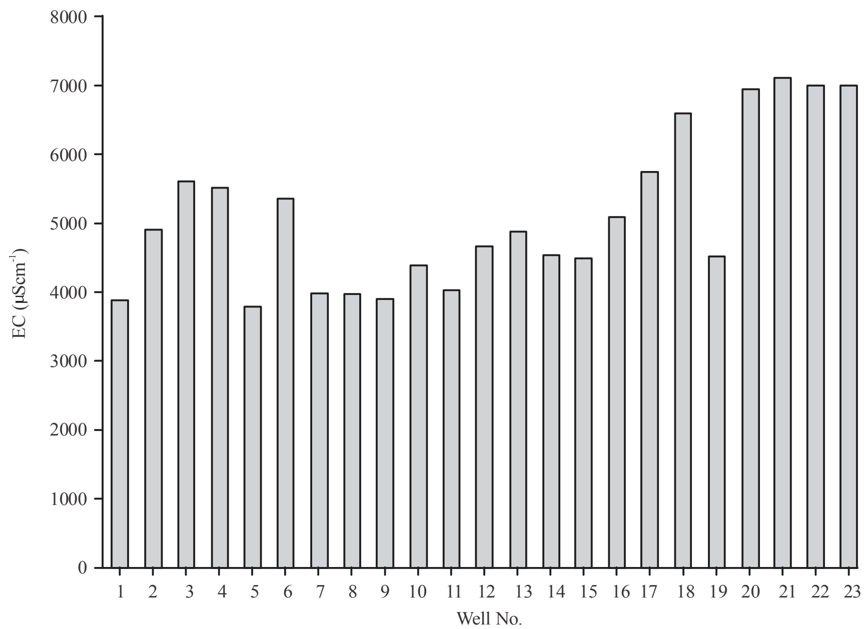

Fig. 6: EC values for all study wells

The aquifer is essentially recharged from rainfall, since, it is located in an arid environment where rainfall is rare and restricted within slight Winter months, so, the aquifer is not fully saturated and many of its large parts are lacking sufficient groundwater, however, the saturated thickness is growing to the West. The aquifer is usually unconfined in its Western parts and moved towards the East, therefore, the clay and marl lenses inside the formation retain water in isolated sandy lenses.

The previous studies on this aquifer specified that the Western parts of it are nearly dry and therefore inappropriate for exploitation projects where the Eastern parts are more promising (Joshi *et al*., 2009; Al-Ani, 2004). The irregular investment of groundwater of this aquifer is very chancy where different parts of the aquifer set positive and negative productivity of water use together (Buxton and Smolensky, 1999; Leijnse and Hassanizadeh, 1994). The results are shown by the physical and chemical values of parameters of the study wells samples as agreeing with the Iraqi drinking water standards (Anonymous, 2001).

The pH observed values 7.12-7.6 are consistent with the Iraqi drinking water standards with ranges from 6.5-8.5 and showed that the groundwater head for neutralizing or slightly alkaline. The massive rates of TDS concentration due to the gypsum, sand and silty clay in

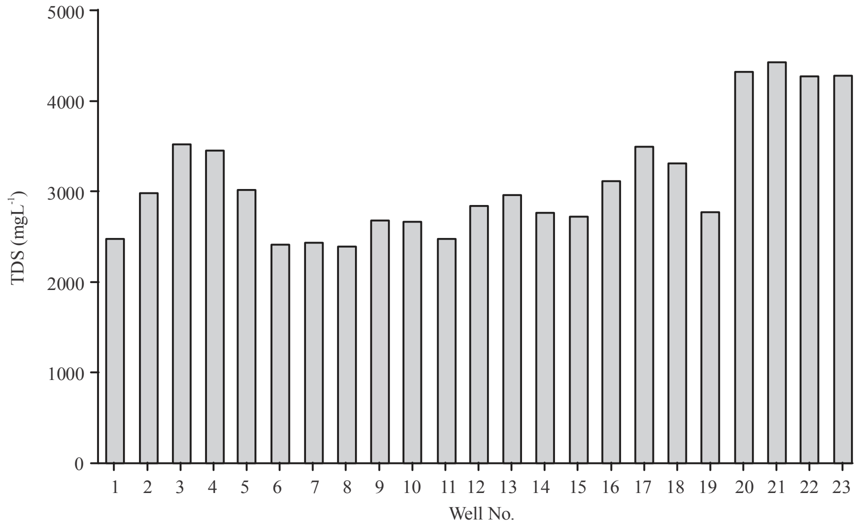

Fig. 7: TDS values for all study wells

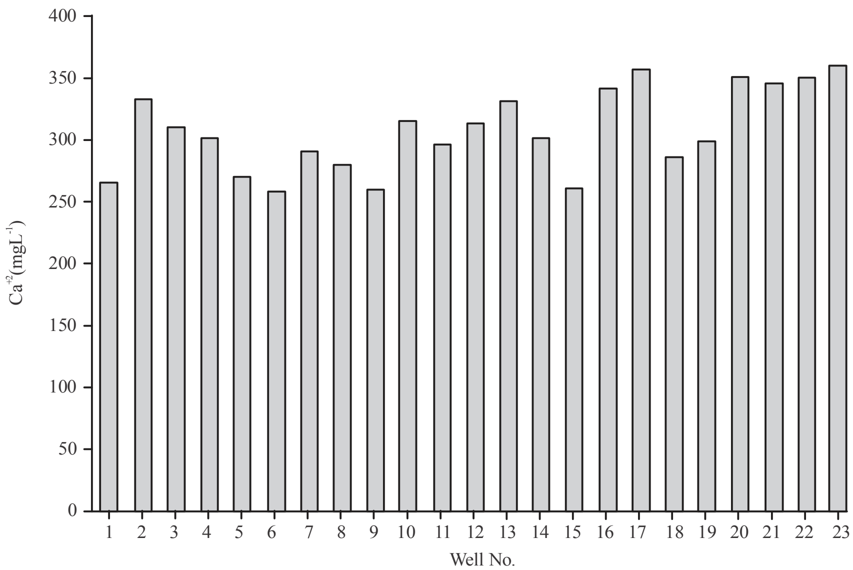

Fig. 8: Ca^{+2} values for all study wells

the chemical composition of the formation. The geological nature of this formation reflects the high and low concentration of calcium. The values of magnesium are within acceptable and permissible limits by comparing them to specifications Iraqi drinking water standards. Sodium is present in the groundwater due to the ease of melting of sodium salts in water (Desonie, 2008). The study showed high rates of potassium and these high concentrations minimizes plant uptake of calcium (Ayers and Westcot, 1985). High chloride concentration in dry areas due to its spread in all rocks and crust sediments where the chlorides are spread on the surface of the earth in the form of sodium and potassium chlorides the most important elements of water and the sense of salt taste of water depends on the positive side of chlorides and high concentration of chloride ion is often shaped as sodium chloride and gives the taste of salt (Berkowitz *et al*., 2008), this high concentration of chloride points out there is a high percentage of organic pollution can occur near sewage and waste of factories, results water distasteful and unsuitable for drinking and watering cattle (Chapman, 1998). High values of sulfate due to the presence of large amounts of gypsum materials where the sodium sulfate the main source of sulfate in groundwater and the high concentration of it causes a difference in the taste of water. All study wells tend to alkalinity due to the presence of hydroxide, carbonates and bicarbonates ions

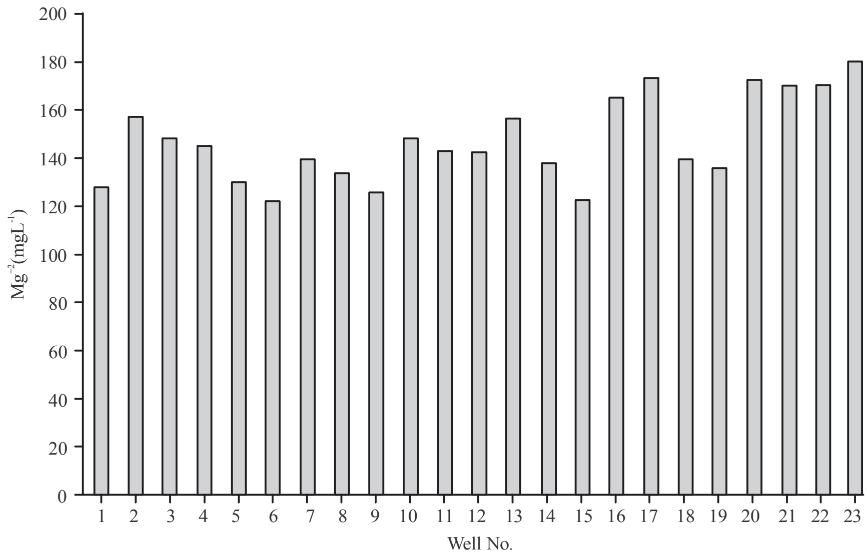

Fig. 9: Mg^{+2} values for all study wells

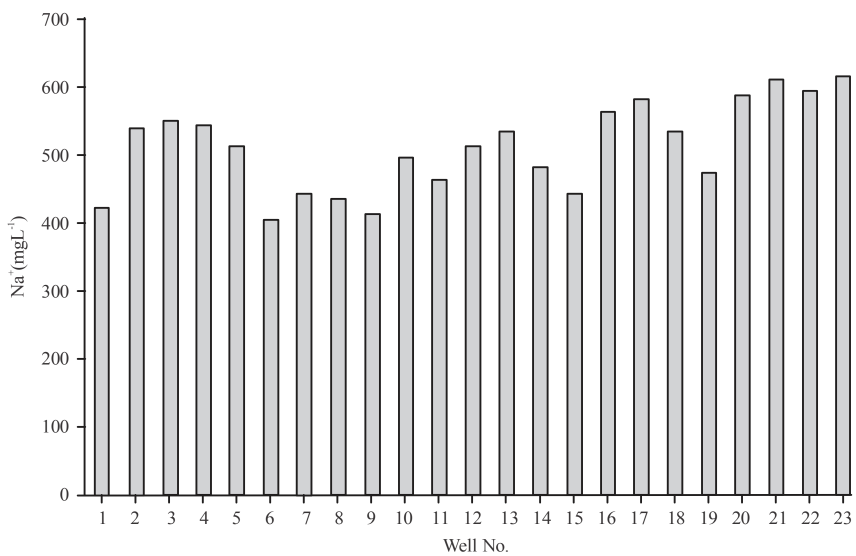

Fig. 10: Na^{+}values for all study wells

in water (Merkel and Planer-Friedrich, 2008). Nitrate concentration is very low in all study wells which is below the Iraqi drinking water standards (Anonymous, 2001). The previous studies from the state company of geological survey and mining in Iraq presented that the groundwater flow direction of the study area is from west to East and from the Southwest to the Northeast (Ayob *et al*., 1995; Al-Jiburi, 2002).

This activity increased groundwater contamination due to dissolved rocks in different chemical composition through the distance traveled up to reach locations of selected wells. The other cause for the high values of wqi is a persistent emptying of agricultural flow. When comparing the positive and negative ion concentrations and the total salinity of the groundwater samples, there are no wells within the permissible limits for use for drinking purposes. Groundwater validity for irrigation purposes depends on the ion concentrations in the water mainly taking into consideration the salt content expressed by electrical conductivity (Ayers and Westcot, 1985) (Fig. 18 and 19).

Increased Na% in water leads to reduced soil permeability due to the exchange of calcium ion and magnesium with sodium in the soil (Rasul, 2000). Therefore, it a risk and causes problems for irrigation, groundwater cannot be used for human consumption as a result of the high concentration of salinity and major ions in the wells. When using the (Richards, 1954)

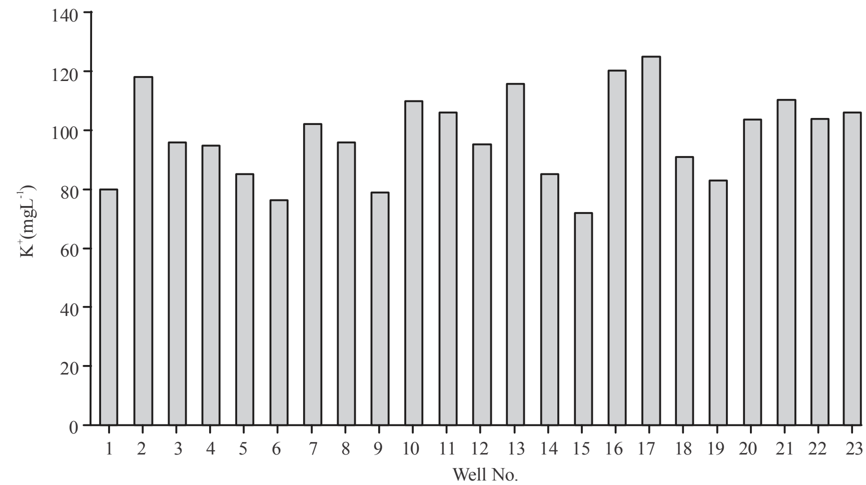

Fig. 11: K^{+1} values for all study wells

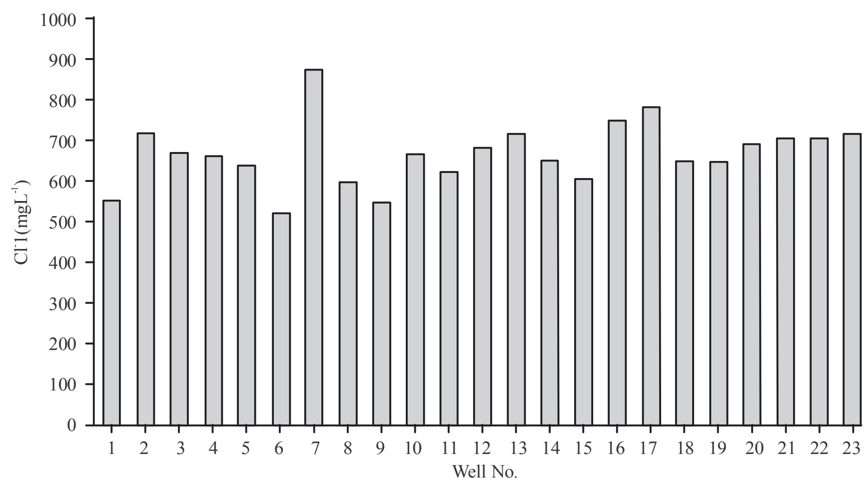

Fig. 12: Cl^{-1} values for all study wells

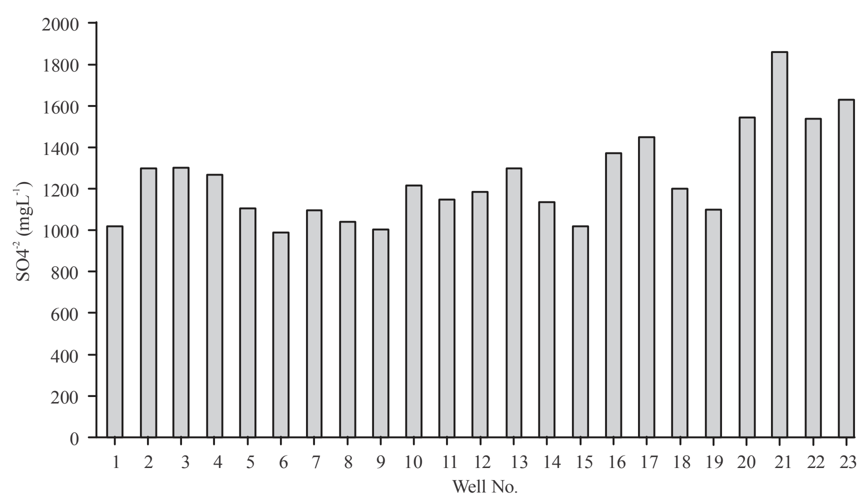

Fig. 13: SO_4^{-2} values for all study wells

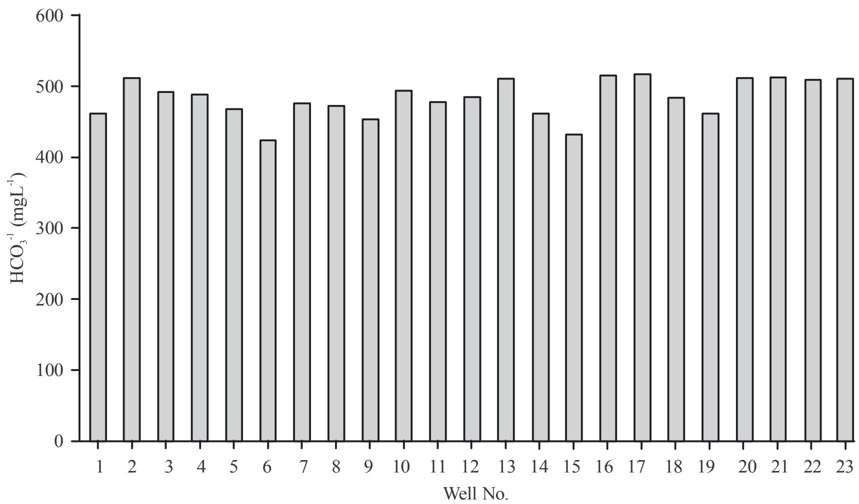

Fig. 14: HCO_3^{-1} values for all study wells

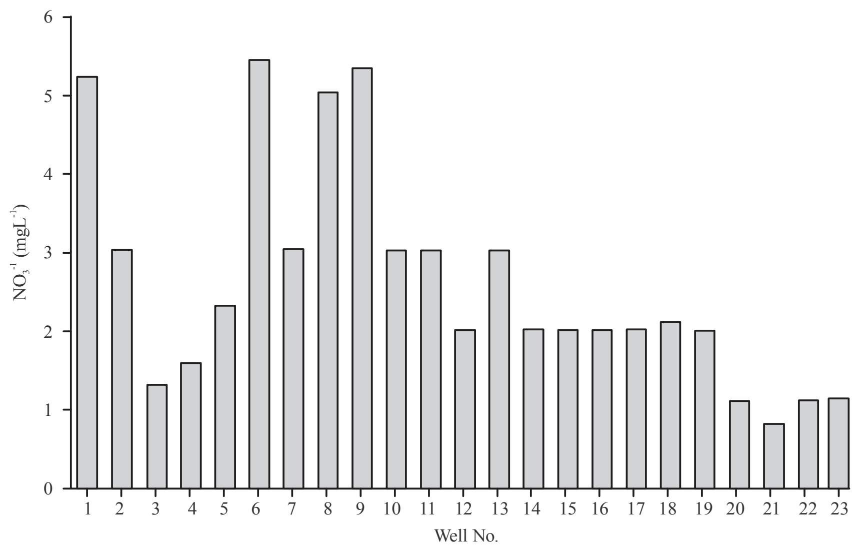

Fig. 15: NO_3^{-1} values for all study wells

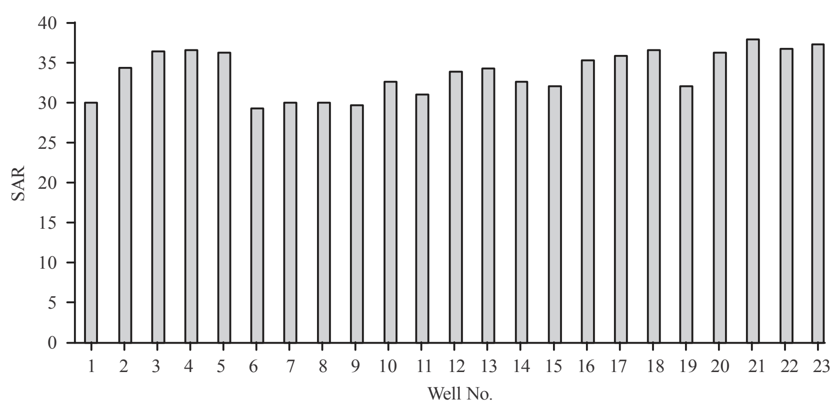

Fig. 16: Sodium Absorption Ratio (SAR) for all study wells

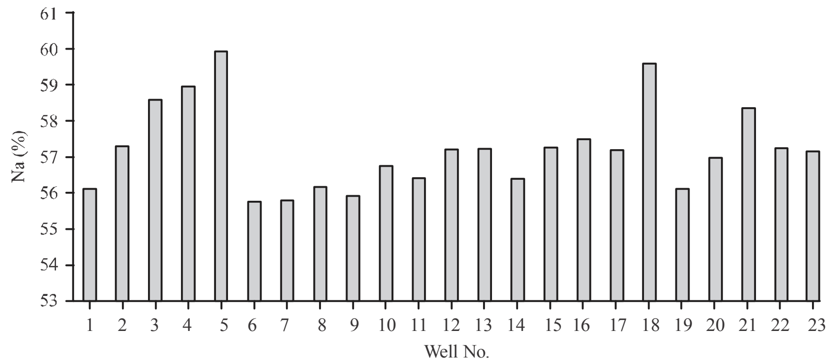

Fig. 17: Sodium percentage (Na%) for all study wells

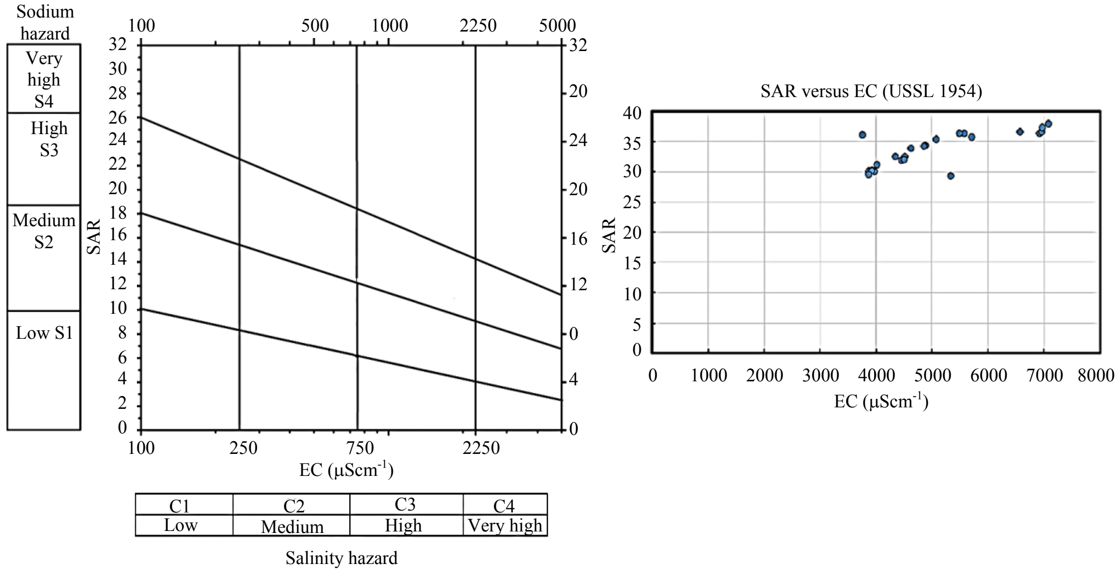

Fig. 18: Classification of groundwater based on SAR and EC for irrigation purposes (after the US Salinity laboratory, Richards (1954)

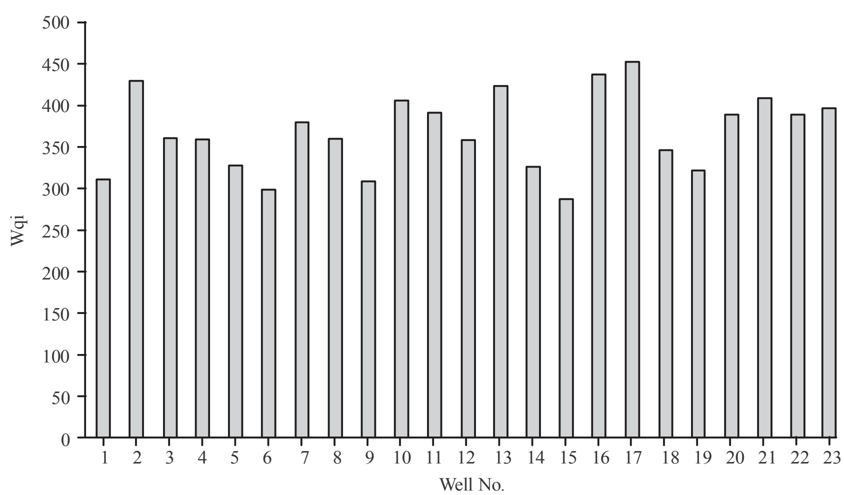

Fig. 19: Wqi for all wells samples

classification which is based on the relationship between Sodium Adsorption (SAR) and Electrical Conductivity (EC) as in Fig. 18 and 19, it is not admissible for irrigation purposes.

It is necessary to place the wells in the study area under a periodic monitoring plan for the underground levels to ensure the safe and non-invasive exploitation of reservoirs of the underground reservoirs by devising a calculated plan for the number and areas of spread of the observation wells that can be drilled and to use them in determining the levels of fluctuation in the underground levels and calculating the natural recharge of the reservoirs and the limits of their variation and the circumstances affecting on it Fig. 19.

CONCLUSION

The Wqi for 23 samples ranges from 283.60-449.88 two wells samples show values between 283.60-296.92 which are very poor quality for drinking water and twenty-one wells samples display values between 305.58-449.88 and that is mean the water is unsuitable for drinking.

From Wqi values, it is very important to suggest further improvement is required to treat the wells for using for drinking purpose. The looseness of groundwater quality because of the high concentration of TDS and Sulfate SO_4^{-2}. The analysis offers that study area groundwater needs good processing and protection from the contamination before any consumption. Wqi values at all wells are much above 300 indicating unfit for drinking purpose.

According to Ramakrishnaiah *et al*. (2009), the main causes of quality degradation of groundwater are the high concentration of TDS and sulfate in study wells. The stratigraphic sequence of Dibidibba formation consists of several layers of sand permeated by clay and gravel deposits making it a good layer to contain the water and passes through it but the water storage of this reservoir began depletion as a result of the digging large number of short depth wells in addition to low levels of natural recharge of the rain and surface torrents as well as the limited deployment of the reservoir and its surface effects have another negative effect to not relying on this reservoir in the future but explore and study other formations located below it within the stratigraphic column of the area.

The elevation of alkalinity is due to presence hydroxide ions and bicarbonates in water as groundwater contains a small percentage of soluble matter and this indicates the presence of some organic substances soluble in water like calcium salts, magnesium, sodium, potassium, chloride, sulfates, nitrates and due to calcium, magnesium and their salts are the most common elements in the Earth's crust.

The study concluded that geological formation is contributed as main determinants of groundwater quality, since, the existence of each of sulfate and chloride in the solubility of sulfur salts such as gypsum, anhydrite and halite which are commonly found in the majority of the study area. As for the use of irrigation, must be it treated very cautiously also it requires a series of irrigation measures and improve quality.

ACKNOWLEDGEMENT

First of all, we are grateful to the general authority of groundwater in Najaf province in Iraq for allowing us to perform all our field experiments, chemical analysis of wells in the study area. Thanks to the Ministry of Higher Education and Scientific Research in Iraq for their financial aid. We also express our gratitude to Laboratoire Chrono-Environment (UMR 6249-CNRS), Universite de Franche-Comte (Besancon, France) for the precious help during all work steps.

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