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Ground Water Quality Assessment Using the Water Quality Index, Iraq

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ABSTRACT

Water Quality Index (WQI) has been applying in the present study to assess suitability of groundwater quality for drinking purposes in Amara city, southern Iraq. This was carried out by subjecting twelve groundwater samples, collected from different sites to comprehensive physic-chemical analysis. Ten parameters have been considered for calculating the WQI such as; pH, electrical conductivity, total dissolved solids, sodium, potassium, calcium, magnesium, chloride, sulphate and nitrate. The WQI values shows that 16.66% of water samples falls in good water categories and the others (83.66%) ranged from poor water to unsuitable for drinking purposes under normal conditions and further action for salinity control is required. The high value of WQI at this study has been found to be mainly due to the higher values of EC, TDS, SO_4^{-2}, Ca^{+2}, Mg^{+2} and Cl^- where it was found that there is a very high correlation coefficient between them.

KEYWORDS: Water quality index, ground water, Drinking and irrigation, Iraq.

INTRODUCTION

Water is one of the natural resources necessary for human survival and economic development (Boyd *et al.*, 2019). However, in arid and semi-arid regions, uneven distribution of groundwater and surface water resources has become a contradiction that restricts living standards and economic development (Brhane *et al.*, 2018). Understanding the relationship between groundwater and water demand for agricultural production is important for sustainable agricultural development (Zanotti *et al.*, 2019). Groundwater has become the main source of fresh water for household, agricultural, and industrial uses due to its simple extraction and low cost (Hasan *et al.*, 2017). In agricultural production areas, irrigation water, surface water and groundwater are closely linked, which has changed the hydrodynamic conditions and led to changes in groundwater hydrochemical conditions (Li *et al.*, 2019).

Therefore, understanding the chemical characteristics of groundwater and its influencing factors are critical to the protection and management of groundwater resources and the sustainable use of groundwater (Madlala *et al.*, 2019).

Ground water is a globally important and valuable renewable resource for human life and economic development. It occurs almost everywhere beneath the earth's surface as a multiple-layer aquifer (Shahab *et al.*,2016). Drinking, irrigation, and industrial purposes depend on groundwater resources. Its importance stems from its ability to act as a large reservoir of water that provides "buffer storage" during periods of drought. In rural context, groundwater provides the mainstay for agricultural irrigation and will be the key to providing additional resources for food security.

In urban centers groundwater supplies are important as a source of relatively low cost and generally high quality municipal and private domestic water supply. Due to rapid population growth, urbanization, industrialization, and agriculture, the groundwater is qualitatively and quantitatively under pressure (Nanaini and Suriya, 2020). As per IPCC synthesis report, higher temperature, pollutant loads due to heavy rainfall, and increased pollutant concentrations during drought will degrade the quality of fresh water and endanger drinking water (Jarraud and Steiner, 2012). Surface-groundwater interaction may alter bio-geochemical cycles in soils overlying aquifers (Riedel, 2019). For irrigation and drinking purposes groundwater quality should be monitored continuously to reduce the geochemical contamination risk through appropriate treatment methods (Acharya, 2018).

As of 12 July, 2021 Iraq's population stands at about 42,143,409 (Worldometer, 2022). Iraq is located in the southwest of Asia and to the northeast of the Arab world. It lies between the latitudes 29 and 37 and the longitudes 38° and 48° with a total area of 438317km^2 of which the water body area of the country is 950 km^2 (Elaiwi *et al.*, 2020). The middle and southern part of the country has a continental climate, varying from subtropical, arid and semi-arid, and shifts to the Mediterranean climate in the north and north-eastern mountain regions with an average annual rainfall of about 216mm (Chabuk *et al.*,2020).

Groundwater resources are considered the key to all human activities and their survival race, particularly in arid regions; development projects depend essentially on the ability to manage these resources and to protect their quality and quantity and utilize them such efficiently. Nowadays, Iraq has limited share of Tigris and Euphrates water that are the main sources of surface water, and main recharge source for surrounding aquifers, especially after the construction of the Ilisu Dam in Turkey on the Tigris river (Yousuf *et al.*, 2018). The rapid continuous increase in population in Iraq and the continuous development in irrigation projects become imperative to maintain and protect the available groundwater resources and to sustainably develop its use.

MATERIALS AND METHODOLOGY

Sampling and sample analysis

In this study, groundwater samples were collected from 12 drilled wells with depth of 36 to 100 m from different locations of Ali Al-Garbi in Misan governorate, southern Iraq during January and February 2023(Fig.1). At each of the sites, a GPS was used to get readings of the coordinates of the locations. These wells are mainly used for water supply and irrigation in rural areas.

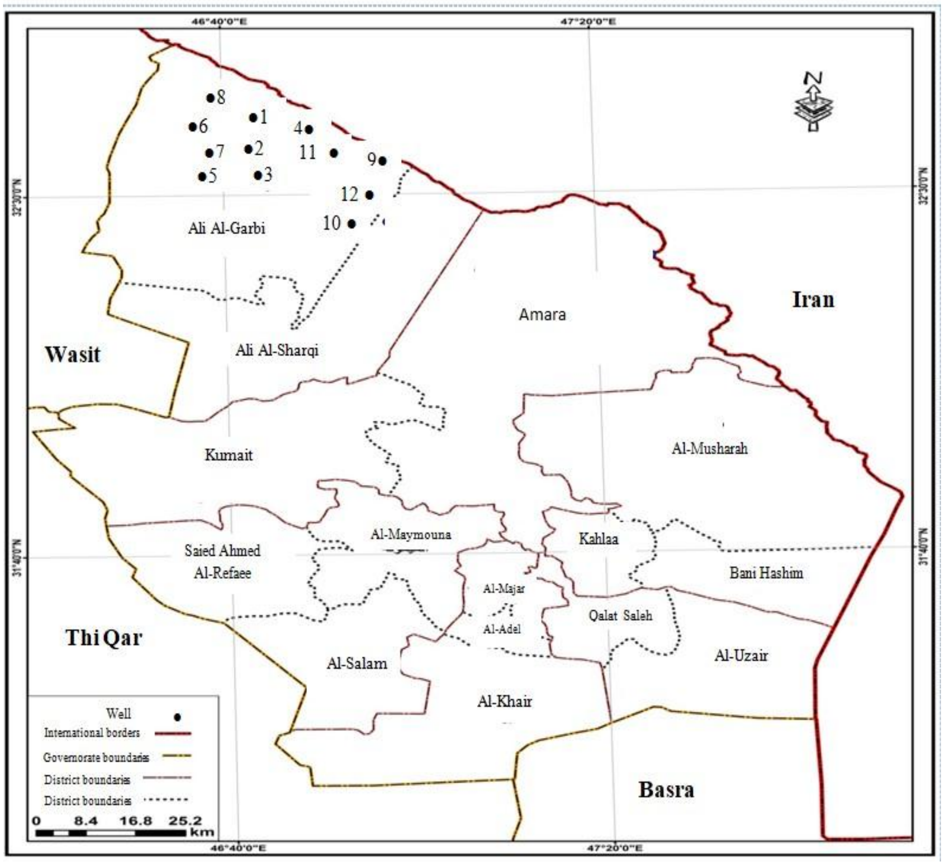

Fig.1: Map of study locations

All water samples were collected in acid washed 200 ml polyethylene bottles (5 liter) to prevent unpredictable changes in characteristic as per standard procedures (APHA, 2017). Ten parameters were analyzed for WQI such as pH, EC, TDS, NO_3^-, SO_4^{2-}, Cl^-, K^+, Na^+, Mg^{2+} and Ca^{2+}, Details of sampling locations along with their latitude and longitude are presented in Table 1. The ground water samples were collected in acid washed plastic container to avoid unpredictable changes in characteristics as per standard procedures (APHA, 2017). The spatial distribution of sampling points is consistent with the distribution of water wells in each village, which can objectively reflect the characteristics of groundwater extraction in the study area.

Table 1. Location and coordinates of studied groundwater samples

Site	Location	Longitude N	Latitude E	Depth (m)
GW1	Al-Jifta - Ali Al-Garbi	46 42 26.8	32 39 27.8	60
GW2	Al-Jifta - Ali Al-Garbi	46 40 51.7	32 37 56.6	70
GW3	Al-Jifta - Ali Al-Garbi	46 40 35.4	32 39 5.3	54
GW4	Al-Jifta - Ali Al-Garbi	46 40 7.1	32 29 52.8	36
GW5	Khazinah - Ali Al-Garbi	46 37 30.4	32 42 40.3	70
GW6	Khazinah - Ali Al-Garbi	46 37 23.2	32 43 50.1	70

GW7	Khazinah - Ali Al-Garbi	46 38 13.9	32 44 18.7	60
GW8	Khazinah - Ali Al-Garbi	46 38 28.1	32 43 52.6	70
GW9	Al-Fakkah - Ali Al-Garbi	46 55 23.4	32 36 5.6	100
GW10	Chlatt - Ali Al-Garbi	46 53 38.9	32 34 41.6	36
GW11	Chlatt - Ali Al-Garbi	46 55 53.7	32 35 55.1	70
GW12	Chlatt Ali Al-Garbi	46 55 58.8	32 35 23.4	87

Calculation of WQI 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. It is calculated from the point of view of human consumption. Water quality and its suitability for drinking purpose can be examined by determining its quality index. The standards for drinking purposes as recommended by WHO (2017) have been considered for the calculation of WQI. In this method, the weight age for various water quality parameters is assumed to be inversely proportional to the recommended standards for the corresponding parameters (Mishra, 2001; Naik and Purohit 2001).

The calculation procedure contains three stages, In this study, three steps were obeyed for computing WQI (Varol and Davraz, 2014). Firstly, each of the ten parameters (pH, EC, TDS, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-} and NO_3^-) is assigned a weight (wi) depending on its comparative significance in general water quality and their perceived effects on primary health.

The allotted weight ranges between 1 to 5. The highest weight of five has been given to parameters TDS, EC, Cl^- and SO_4^{2-} because to their major importance in water quality assessment (Boateng, et al., 2016). The least weight of 1 assigned for K^+ because it does not play relevant part in the assessment of water quality. The remaining parameters were assigned a value between 1 to 5 depending on their importance in the whole quality of water for drinking purposes (Boateng, et al., 2016 ; Bouderbala, et al., 2016). Secondly, the computation of the relative weight (Wi) is given in equation below (1):

$$W_i = \frac{w_i}{\sum_n^{i-1} w_i} \qquad (1)$$

where the relative weight is represented by *Wi*, w*i* indicates the individual parameter weight, *n* represents number of groundwater parameters. Thirdly, the computation of quality ranking *qi* for each physiochemical parameter is done through division of its concentration in every water sample with respect to its respective standards suggested by WHO (2017).The result obtained is multiplied by 100 using equation (2):

$$Q_i = \left(\frac{C_i}{S_i}\right) \times 100 \qquad (2)$$

where Q_i represents the quality rating, C_i indicates the concentration of each ground water parameter in every sample (mgl^{-1}), and S_i is groundwater quality standard for each physicochemical parameter based on the national quality standard (WHO, 2017) for groundwater. The WQI model can be defined as below (3):

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$$WQI = \sum_{i=1}^{n} W_i \times Q_i \qquad (3)$$

In this study, the WQI values were divided into five levels “excellent water” to “water unsuitable for drinking”. Table 3 shows water quality classification based on WQI value.

Table 3. Water quality classification based on WQI value

Range (WQI)	Type of groundwater
50<	Excellent water
50≤WQI<100	Good water
100≤WQI<200	Poor water
200≤W<300	Very poor water
300≥	Unsuitable for drinking/Irrigation purpose

Results and Discussion

The groundwater chemistry is mainly affected by both natural and human factors. Natural factors include regional geological conditions, chemical composition of precipitation, hydrogeological conditions, and water-rock interactions (oxidation, reduction). Human factors include pesticide use, fertilizer use, groundwater extraction, groundwater recharge, and biological and microbial effects.

pH

The pH value measures the hydrogen ion concentration in the groundwater. Majority of the representative groundwater sample (Table 2) has pH value of 6.20 to 7.22, at an average rate 7.02. The highest pH value of 7.22 is found at sampling (GW1 & GW8). All samples are within the permissible range (WHO, 2017), except sampling GW10 (pH=6.20), this may be due to the nature of the chemical composition of the soil. Although pH has a less direct impact on water users, it is one of the most critical operational water quality indicators. Higher weights are assigned to pH to determine drinking water quality index (DWQI) which is subjected to change chemically and also, the range of pH is an indicator for heavy metal pollution.

Table 2. Physiochemical properties of groundwater samples in study area

No. of Well	pH	EC µS/cm	TDS mgL^{-1}	NO_3 mgL^{-1}	SO_4 mgL^{-1}	Cl mgL^{-1}	K mgL^{-1}	Na mgL^{-1}	Mg mgL^{-1}	Ca mgL^{-1}
GW1	7.2	2620	1710	1.10	527	416	12	211	80	161
GW2	2	2580	1690	1.40	530	310	4	240	58	173
GW3	7.1	2620	1700	1.10	528	415	12	210	80	160
GW4	8	2840	1840	1.10	446	411	11	264	90	154
GW5	7.2	2320	1520	2.00	520	368	9.8	186	97	148
GW6	1	4930	3190	0.70	849	660	20	447	120	284
GW7	7.1	3570	2310	1.10	570	258	12	147	95	138
GW8	8	4330	2820	0.80	769	590	16	414	105	266
GW9	7.1	8250	5600	19.0	383	1600	33	150	450	640

GW10 GW11 GW12	7 7.20 7.20 7.22 7.00 6.20 6.50 7.00	5050 906 731	2878 722 568	9 15.05 28.59 19.45	300 221 260	170 80 20	1.6 1.2 0.5	34 42 11.5	50 25 5	600 280 96
Min.	6.20	731	568	0.7	221	20	0.5	11.5	5	96
Max.	7.22	8250	5600	28.59	849	1600	33	447	450	640
Mean	7.02	3395.58	2212.33	7.62	491.91	441.5	11.09	196.37	104.58	258.33

Electrical Conductivity

Electrical conductivity represents all dissolved salts depending on the quantity and quality of dissolved ions and the water temperature (Eaton and Rice, 2017). The results showed (Table 2) an increase in the electrical conductivity values to reach 8250 µS/cm (GW9) and the lowest 731 µS/cm (GW12), at an average rate 3395.58 µS/cm, the high percentage of salts in the groundwater is due to the geological nature of the region or may be due to its filtering from the neighboring lands as well as the washing and dissolution process of the constituent salts of the soil surrounding the groundwater (Mansori *et al.*, 2017).

Total Dissolved Solid

TDS in the investigation area has a maximum value of 5600 mgl^{-1} and a minimum value of 568 mgl^{-1}, with an average value of about 2212.33 mgl^{-1}. All groundwater sampling were exceeded the maximum acceptable limits points are appropriate for drinking or irrigation purposes according to WHO guidelines.

Nitrate

Nitrogen compounds are the most widespread pollutants in subterranean environments, derived mainly from agricultural non-point sources. Therefore, an increase in nitrogen pollution causes a severe threat to public drinking water supplies and human health. The NO_3 concentration varies from 0.7 to 28.59 mg/l, with an average value of about 7.62 mg/l (Table 2). All other representative samples do not exceed the permissible limit of 45 mgl^{-1}.

Sulfate

Sulfate contamination in groundwater can cause human health issues and material damage implications, making the hydrochemical parameter relatively important and are assigned with higher weights. Spatial distribution of sulfate has the minimum and maximum value for groundwater samples and is between 221 and 849 mgl^{-1}. All samples have exceeded the maximum acceptable limits except sampling GW11 according to international standards.

Chloride

Concentration of chloride was ranged between 20 and 1600 mgl^{-1}, with an average value of about 441.5 mgl^{-1}. In the investigation area, all samples have exceeded the maximum acceptable limit (200 mgl^{-1}) according to (WHO, 2017), except samples GW10,GW11 and GW12 they were within the permissible limits. This may be due to the lack of underground drainage systems and poor maintenance.

Sodium and Potassium

Sodium concentration varies from 11.5 to 447 mgl^{-1}, and 25% of the representative sampling points are within the permissible limits. Na is the dominant ion among the cations and occurs in most of the natural waters. Na contributes about 53 to 69% of the total cations, this is primarily due to silicate weathering and dissolution of soil salts stored by the influence of evaporation, human activities, agricultural activities, and poor drainage conditions. K is a naturally occurring element, but its concentration remains lower than Ca, Mg, and Na. The maximum value is found to be 20 & 33 mgl^{-1} (GW6 & GW9) and 83.33% of the sampling points are within the permissible limit, indicating potassium complexes under the conditions investigated.

Calcium and Magnesium

Ca and Mg are directly related to water hardness and abundant elements in surface and ground water. Ca concentration is between 96 and 640 mgl^{-1}, with an average value of about 258.33 mgl^{-1}, and Mg concentration varies from 5 to 450 mgl^{-1}, and an average 104.58 mgl^{-1}. The calcium concentration is permissible in 58.33% of the samples, but 75% of the samples surpass the permissible magnesium limit (WHO, 2017).

Water Quality Index (WQI)

Water quality index is calculated to determine the suitability of water for drinking purpose. Water quality index calculated values for each sample are shown the water quality parameters that were considered in the study using WHO standards as well as their calculated weight (Table 4).

Table 4. An example Calculation of WQI for the sample 1 (GW1)

Parameter	Observed value	WQ standard value (Si)	Weight (w_i)	Relative weight (W_i)	Quality Rating (Qi)	WiQi
pH	7.22	6.5-8.5	3	0.081	96.26	7.797
EC	2620	1000	5	0.135	262	35.37
TDS	1710	500	5	0.135	342	46.17
NO_3	1.10	45	5	0.135	2.44	0.329
SO_4	527	250	5	0.135	210.8	28.458
Cl	416	200	4	0.108	208	22.464
K	12	12	1	0.027	100	2.7
Na	211	75	3	0.081	281.33	22.787

Mg Ca	80 161	50 250	2 4	0.054 0.108	160 64.6	8.64 6.976
			∑ wi =37	∑ Wi = 1		∑ WiQi = 181.691

WQI values of wells were ranged from 59.757 to 482.815 (Table 5) and therefore, can be categorized into four types “good water” to “water unsuitable for drinking”. According to the results only two samples were placed in ‘‘Good water’’ classification and the rest fall below this range. Table 6 shows the percentage of water quality index of samples that falls under different quality. Accordingly 16.66% of wells water falls in class (II) (good water), 41.66% falls in class (III) (poor water), 25% falls in class (VI) and 16.66% falls in class (V). This means that near 83.33 % of the samples are not in good conditions and are unsuitable for drinking purposes.

Table 5. Classification of Water quality index (WQI) for samples

No. of well	WQI values	Classification type
GW1	181.691	Poor water
GW2	145.929	Poor water
GW3	212.456	Very poor (bad) water
GW4	189.739	Poor water
GW5	167.815	Poor water
GW6	320.159	Unsuitable (unfit) for drinking
GW7	198.179	Poor water
GW8	287.158	Very poor (bad) water
GW9	482.815	Unsuitable (unfit) for drinking
GW10	217.820	Very poor (bad) water
GW11	83.176	Good water
GW12	59.757	Good water

Table 6. Water quality classification based on WQI value

WQI value	**Water quality index (WQI)**	**Well identity**	**Percentage of water samples**
< 50	Excellent	--	00
50-100	Good water	W11, W12	16.66
100-200	Poor water	W1, W2, W4,W5, W7	41.66
200-300	Very poor (bad) water	W3, W8, W10	25.00

> 300	Unsuitable for drinking	W6, W9	16.66

The reason of increasing WQI is considered this region as a drainage system for a groundwater from north toward south. In this study, the groundwater quality may improve due to inflow of freshwater of good quality during rainy season. The high value of WQI at this study has been found to be mainly due to the higher values of EC, TDS, sulphate, chloride, calcium and magnesium where it was found that there is a very high correlation coefficient between them (Table 7).

Table 7: Correlation coefficient matrix of water quality parameter and WQI

Parameters	pH	EC	TDS	NO_3	SO_4	Cl	K	Na	Mg	Ca	WQI
pH	1										
EC	-0.040	1									
TDS	0.013	0.994**	1								
NO_3	-0.734*	-0.040	-0.015	1							
SO_4	0.664*	0.276	0.272	-0.794**	1						
Cl	0.184	0.739**	0.788**	0.072	0.005	1					
K	0.431	0.806**	0.853**	-0.209	0.466	0.805**	1				
Na	0.643*	0.285	0.292	-0.723**	0.935**	0.099	0.503	1			
Mg	0.150	0.844**	0.892**	0.113	0.082	0.937**	0.89**	0.142	1		
Ca	-0.609*	0.796**	0.772**	0.462	-0.220	0.547	0.404	-0.166	0.625*	1	
WQI	0.160	0.958**	0.973**	-0.124	0.404	0.793**	0.929**	0.440	0.890**	0.669*	1

The degree of a liner association between any two of the water quality parameters, and water quality parameters with WQI as measured by the simple correlation coefficient (r) is presented in Table 7. Correlation analysis measures the closeness of the relationship between chosen variables. If the correlation is nearer to +1 or -1, it shows the perfect linear relationship between the two variables. This way analysis attempts to establish the nature of the relationship between the water quality parameters and WQI. It is observed that the EC variations are mainly controlled by total dissolved solids (r=0.994**), chloride (r=0.739**), potassium (r=0.806**), magnesium (r=0.844**) and calcium (r=0.796**). Calculated WQI also show that the highly significant interrelated with the values of EC (r=0.958**), TDS (r=0.973**), Cl (r=0.793**), K (r= 0.929**), Mg (r=0.890**) and Ca (r=0.669*).

CONCLUSIONS

In the present study water quality index has been computed to assess suitability of groundwater quality for drinking purposes in Amara city. Twelve groundwater samples were collected to comprehensive physic-chemical analysis. For calculating the WQI ten parameters have been considered such as: pH, electrical conductivity, total dissolved solids, sodium, potassium, calcium, magnesium, chloride, sulphate and nitrate. The results shows that only 16.66% of water samples falls in good water categories and another samples of WQI exceeded the upper limit for drinking water. The high value of WQI at this study has been found to be mainly from the higher values of electrical conductivity, sulphate, chloride, calcium, magnesium and total dissolved solids in the groundwater.

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