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Groundwater quality assessment using water quality index: A case study of Al Najaf City, Iraq

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ABSTRACT

Water Quality Index (WQI) plays an important role and a powerful tool for analyzing the overall characteristics of water quality. It is considered a common method to replace the data on water quality trends to the general public and policymakers. In the study area, five wells are used at Jazeerat Al Najaf. As stated by the WHO drinking water quality standard, nine physiochemical parameters have been chosen for water quality index determination. The water quality index is used depending on the parameters and calculated utilizing the weighted arithmetic method for assessing the groundwater quality. WQI for pH comes under the excellent category, for electrical conductivity based on water quality classification in the study area is noted under unsuitable for the drinking purpose category. As well, WQI for sulfate and total dissolved solids found under very poor category. Whilst WQI for the calcium, magnesium, sodium, potassium, and chloride came under poor classifications based on the same water quality categorization. Moreover, the overall average result of the WQI classified under poor category (100.206) that influences the socio-economic and health conditions of human beings.

Keywords: Groundwater Quality, Physicochemical parameters, Water Quality Index, Weighted Arithmetic method, Najaf city

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1. Introduction

The Subject of water resources has become more essential in daily life, depending on the production of food stocks in the industry and population growth. A great significant freshwater category on the planet, based on importance and stability, is the groundwater source [1].

Recently, it is most important to save the resources of groundwater against pollutions (anthropogenic or natural sources), which may have harmful impacts on the health of the people [2]. The children die every day about~1.8 million people, especially in developing countries caused by contaminated groundwater [3].

In North Africa apart from Sudan and the Middle East, Iraq and Egypt, groundwater is the major water source in most of these countries. in the Middle East is also known as problems from shortages of water resources, at least twelve countries have severe water scarcity issues [4].

Supplying freshly treated water is necessary to socioeconomic development, political stability, and daily life. For one person, it was noted that 1 m^3 of water may give sufficient water for drinking for one year or when used for irrigation purposes in a dry weather, at the same amount can yield one kilogram of food grain [5].

The water quality is not only necessary for the survival of human beings but also it has linked directly or indirectly with the economy, culture, and human welfare [6]. To determine the drinking water quality for the end-users, the water quality index (WQI) is a significant parameter and one of the best active tools to transfer the details of each water-body to the policymakers. Consequently, WQI becomes an essential parameter for the

management and assessment of groundwater. Therefore, water quality index is considered a mathematical equation utilized to convert a major amount of water quality information into a single digit [7].
The WQI idea is concerning the comparison of respective regulatory standards with the water quality parameter and supplies a single number based on various parameters of water quality that express total water quality at a specific area. The WQI outlined an important mount of water quality information into simple expression, i.e., bad, good, excellent, etc., that are simply usable and understandable by the users [8].
Many researchers analyzed and studied groundwater quality, these studies demonstrated the possibility of utilizing water for human drinking or irrigation purposes [9], [10].
The objective of the present work is to discuss the quality of groundwater at Jazeerat Al Najaf depending on the water quality index calculations.

2. Study area

Al Najaf province is situated in the Iraqi southwestern part and bordered with Saudi Arabia kingdom. The internal boundaries of Najaf are located with the provinces of Babil, Al-Anbar, Karbala, Al-Qadissiya, and Al-Muthanna as shown in Figure 1. It is situated in the south-west of the Iraqi capital center Baghdad where it is far about 161 km.
In terms of climate, Najaf has a dry desert climate. The summer seasons are dry and hot, while precipitation is limited to the winter months and very low. The average amount of Najaf city is only 99mm of rainfall every year. In this study, Jazeera Al Najaf has taken as study area and it is located in the north and northwestern part of the City.

3. Sample collection and methods

In the study area, five wells were utilized (Figure 1). All wells had been carried out by the General Commission of Groundwater of Al-Najaf city. Table 1 presented the boundaries and information for each well (name of sampling site (NSS), date of sampling (DS), well depth (WD), static water level (SWL), dynamic water level (DWL), discharge (D)).
The collected samples were taken to the laboratory of the General Commission of groundwater at Al Najaf city and analyzed chemical and physical parameters within the 48 hours of the collection as stated by WHO standards.

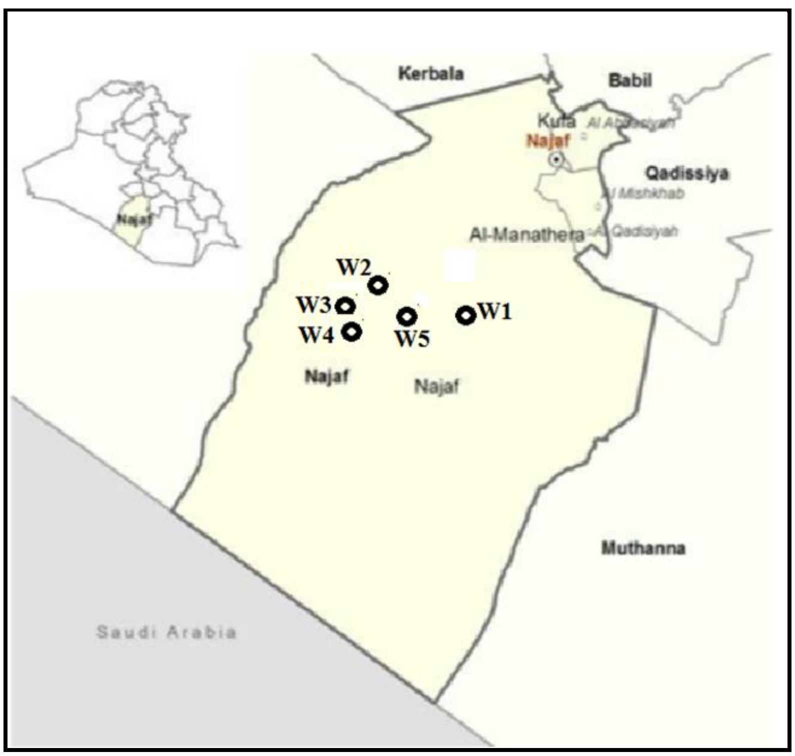

Figure 1. Map of the study area in Iraq and sampling locations

Table 1. Information's of wells in the Study Area

Well (Site No.)	NSS	SD	W.D, m	SWL, m	DWL, m	D, L /s
Site1	Najaf-Karbalaa Road	27/05/2017	42	7	24	7
Site 2	Aboody Farm	23/05/2017	80	5	54	6
Site 3	Hadia Farm	2/08/2017	40	8	32	4
Site 4	Khadija Farm	16/11/2017	50	25.5	42	5
Site 5	Najaf Cemetry	10/03/2017	171	22	45	8

4. Water quality index

The weighted arithmetic index method was utilized depend on the measured values of the physicochemical parameters for estimating the WQI of the sampled well water [11]. In this study, the overall nine physiochemical parameters were chosen for the calculation of water quality index based on the WHO drinking water quality standards. WQI based on the three equations which play an important role in the calculation the index which is referred below.

The quality rating or sub-index (qn) was calculated using the following expression [12]

$$qn = \frac{100[V_n - V_0]}{[S_n - V_0]} \qquad (1)$$

qn is sub-index, V_n is the estimated value, Vi or V_0 is the ideal value and S_n is the standard value

Unit weight (W)

In this step, unit weight (Wi) was obtained using the following formula:

$$W_n = \frac{K}{S_n} \qquad (2)$$

Wn = Unit weight of nth parameter, K is Constant for proportionality, and Sn is the Standard value of the nth parameter.

Total water quality index (WQI) calculated by the following expression.

$$WQI = \frac{\sum q_n W_n}{\sum W_n} \qquad (3)$$

The ideal amount of all physiochemical parameters took as zero except pH value counted 7 [13].

5. Results

The relative existence of dissolved chemicals in water is depending on inputs from anthropogenic activities, and the type of geological rock, and weathering process [14].

In this study, five groundwater samples were taken of wells in the study area, where the sample was collected of each well and analyzed for estimating the quality of groundwater. Values obtained after analyzing were mentioned in Table 2 and includes of the measured values of the parameter with units, and totally observed summary of the physiochemical parameters. The standard limit was mentioned in Table 3, which has specified via WHO. Statistical analysis of each parameter done depends on the minimum, maximum, and average results, details of each measured parameter as illustrated in Table 4. Weighted arithmetic method is used, water quality index (WQI) was calculated, and detailed in Table 5 of the water quality index for each parameter. Water Quality Index (WQI) values and its status for human consumption were illustrated in Table 6.

All observed physiochemical parameters were plotted in Figs (2-10).

Tables 2. Measured Values of the Physiochemical Parameters at Location

	Physiochemical parameters								
	pH	EC	TDS	Ca^{+2}	Mg^{+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{-}
Units	----	ms/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Observed values									
Site1	7.25	4800	3070	245	118	472	10	550	850
Site 2	7.15	3120	1950	129	90	130	13	250	558
Site 3	7.22	2720	1780	113	70	292	13	438	542
Site 4	7.35	5700	3700	132	80	325	20	465	580
Site 5	7.20	4440	2900	124	81	130	10	241	541

Tables 3. Recommended WHO* Standards for drinking water quality

No.	Parameter	Unit	Standard
1	pH	---	6.5-8.5
2	Ec	µs/cm	400
3	TDS	mg/l	1000
4	Ca	mg/l	75
5	Mg	mg/l	50
6	Na^{+}	mg/l	200
7	K^{+}	mg/l	12
8	Cl	mg/l	250
9	SO_4	mg/L	250

*[15], [16], [17]

Table 4. Statistics of groundwater quality parameters

No.	Parameter	Maximum	Minimum	Average
1	PH	7.35	7.15	7.234
2	EC	5700	2720	4156
3	TDS	3700	1780	2680
4	Ca^{+2}	245	113	148.6
5	Mg^{+}	118	70	87.8
6	Na^{+}	472	130	269.8
7	K^{+}	20	10	13.2
8	CL^{-}	550	241	388.8
9	SO_4^{-}	850	541	614.2

Table 5. Calculation of water quality index

Parameters	Observed values (Vn)	Ideal value (Vi/v0)	Standard values (Sn)	Unit Weight (Wn)	Quality Index (Qn)	Wn Qn	Water Quality index (WQI)
PH	7.234	7	7.5	0.133333	46.8	6.24	46.8
EC	4156	0	400	0.0025	1039	2.5975	1039
TDS	2680	0	1000	0.001	268	0.268	268
Ca^{+2}	148.6	0	75	0.013333	198.1333	2.641778	198.1333
Mg^{+}	87.8	0	50	0.02	175.6	3.512	175.6
Na^{+}	269.8	0	200	0.005	134.9	0.6745	134.9
K^{+}	13.2	0	12	0.083333	110	9.166667	110

Parameters	Observed values (Vn)	Ideal value (Vi/v0)	Standard values (Sn)	Unit Weight (Wn)	Quality Index (Qn)	Wn Qn	Water Quality index (WQI)
CL^-	388.8	0	250	0.004	155.52	0.62208	155.52
SO_4^-	614.2	0	250	0.004	245.68	0.98272	245.68
				∑=0.2665		∑=26.705	Av: WQI =100.206

Table 6. Status and (WQI) values for human consumption [18]

No.	WQI	Water type
1	<50	Excellent water
2	50.1 – 100	Good water
3	100.1 – 200	Poor water
4	200.1 – 300	Very poor water
5	> 300.1	Unfit for drinking

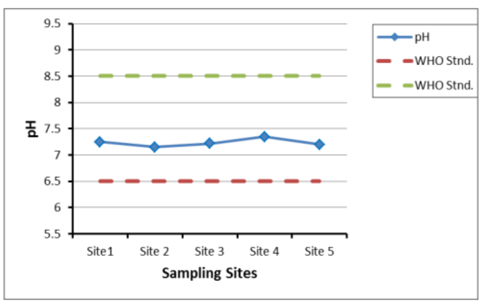

Figure 2. pH analysis of groundwater samples in Jazeerat Al Najaf

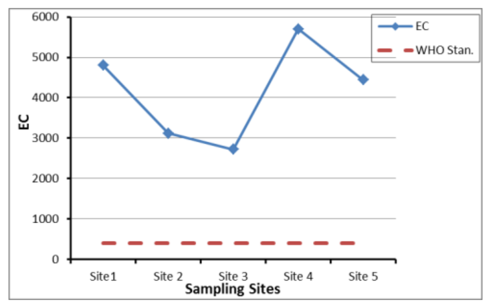

Figure 3. EC analysis of groundwater samples in Jazeerat Al Najaf

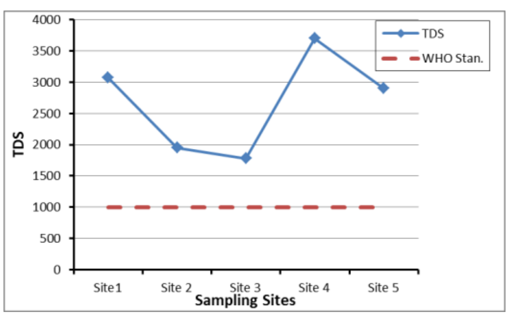

Figure 4. TDS analysis of groundwater samples in Jazeerat Al Najaf

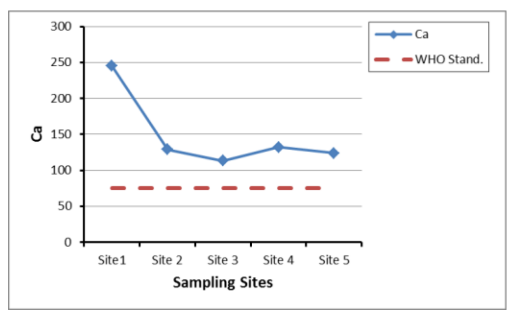

Figure 5. Ca^{+2} analysis of groundwater samples in Jazeerat Al Najaf

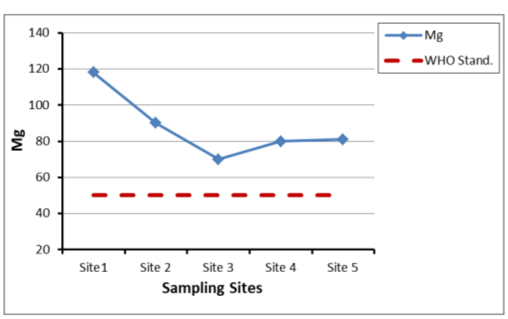

Figure 6. Mg^+ analysis of groundwater samples in Jazeerat Al Najaf

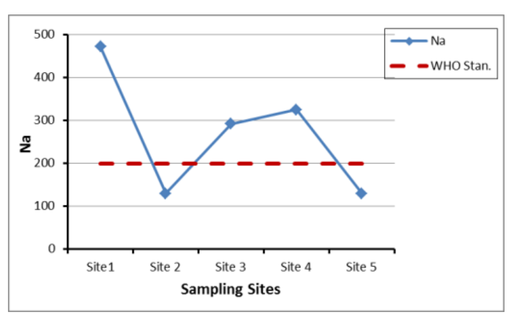

Figure 7. Na^+ analysis of groundwater samples in Jazeerat Al Najaf

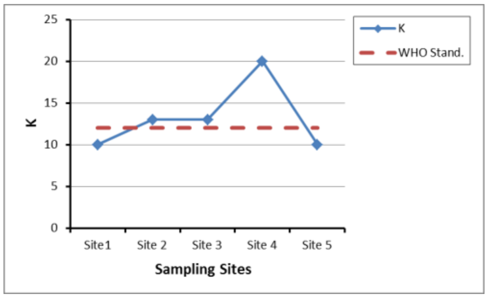

Figure 8. K^+ analysis of groundwater samples in Jazeerat Al Najaf

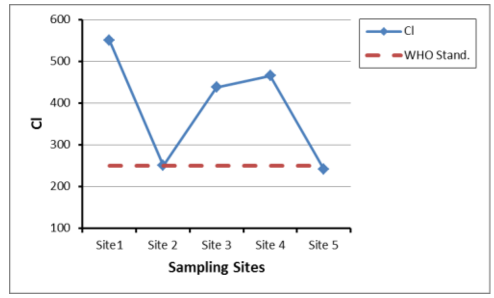

Figure 9. Cl^- analysis of groundwater samples in Jazeerat Al Najaf

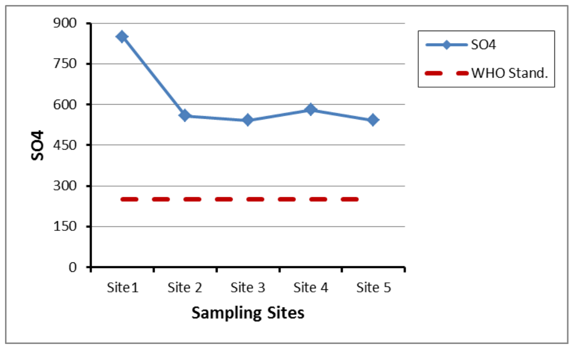

Figure 10. SO_4^- analysis of groundwater samples in Jazeerat Al Najaf

6. Discussions

pH is considered as significant water quality parameter. Value of the pH of the water depends on the alkalinity or acidity. If the pH is below 7.0, a sample is classed to be acidic and it will be classed as alkaline if the pH is higher than 7.0. Acidic water may cause the erosion of the plumping system and metal pipes. Whilst alkaline water will lead to water disinfection [19]. The normal pH of drinking water is ranged between 6.5 and 8.5 as mentioned in the WHO guidelines Table 3. pH values are found in the range between 7.15 and 7.35 (Figure 2.) for all the drinking water samples, while the average pH value is 7.234 and the lowest value is of site 2, and the highest of site 4 as shown in Table 4. The calculated WQI is 46.8, so according to water quality classification, this value comes under an excellent category (Table 6.).

Electrical Conductivity (EC), is the ability of any medium, like water, to carry an electric current. Through previous studies, conductivity appears good correlation with ten parameters like pH value, temperature, total hardness, alkalinity, total solids, calcium, chemical oxygen demand, iron chloride concentration of water, and total dissolved solids [20]. In Figure 3, the measured conductivity values of all sites are drawn based on the WHO standard limit, the maximum allowable range of conductivity is 400 μS/cm. The outcomes showed that the average conductivity value is 4156 μS/cm (Table 4.), and the measured conductivity of all water samples ranges from 2720 μS/cm (site 3) to 5700 μS/cm (site 4), which this shows that all values of EC have exceeded the allowable WHO limits. Calculated WQI was noted in 1039 which is unsuitable for drinking purposes according to water quality classification.

Total dissolved solids (TDS), solids indicate to substance dissolved or suspended in wastewater or water. Also, solids could influence in a number of ways on water or effluent quality adversely. Generally, high dissolved solids in waters are of lower palatability and could be caused lack negative physiological reactions [21]. Greatest TDS showed in site four with a value of the 3700 mg/l, regarding the result of TDS, whereas, in site 3, the minimum TDS value was about 1780 mg/l (Table 4. and Figure 4.). The permissible limit for TDS is 1000 mg/L as stated in WHO guidelines, where all the values found of the water samples have exceeded the permissible limits and the result of the WQI within 268 that classify under very poor category based on water quality classification. Water is not pleasant as potable water when it including more than 1000 mg/l of TDS.

Calcium (Ca^{+2}), is considered as the richest ions in freshwater, besides, it is significant in the precipitation of lime in a plant, bone building, and shell construction [22]. Calcium values ranging between 113 (site 3) to 245 (site1) mg/l, and the average calcium value is148.6 mg/l, all values of the samples exceed the WHO standard allowable limit (75 mg/l) (Figure 5.), and the calculated result of the WQI is found 198.13 that classify under the poor category as stated by the classification of water quality.
Magnesium (Mg^{+}), is considered as alkali earth metal and is the reason for water hardness. Mg^{+} is washed from all the rocks and successive ends up in the water bodies [23]. Magnesium result changing of 70 (site 3) to 118 (site1) mg/l, while the average magnesium value is about 87.8, all values of the samples higher the WHO standard limit (50 mg/l) (Figure 6.). Calculated WQI was found 175.6 and it is classified under poor category depending on water quality classification.
Sodium (Na^{+}) can be defined as a natural constituent of untreated water, almost its concentration is raised through pollution sources like precipitation runoff, rock salt, detergent, and soapy solution. As well the presence of a high concentration of sodium may give to the water a bitter taste [24]. In the study area, the concentrations of sodium ranged from130 (site 2&5) to 472 (site 1) mg/l, In Table 3, which is a site (2&5) within the allowable limits (200 mg/l), while samples (3, 4 &1) and the average sodium value of 269.8 mg/l were exceeded the permissible limit (Figure 7.). In contrast, WQI was noticed 134.9 which classify under poor category based on water quality classification.
Potassium (K^{+}), Clay minerals, feldspar, and some micas, are considered the major natural source of potassium in groundwater. Potassium may cause a disagreeable taste and pipes corrosion in spite of no negative health effects have been notified to be caused by potassium intake by residents [25].
In this study, the concentration of potassium ranged from the 10 (site 1&5) to 20 mg/l (site 4) in the water samples. Site sampling (2, 3, &4) and the average Potassium value 13.2 have exceeded the allowable limit (12 mg/L) (Figure 8.). Further, WQI was noticed 110 that comes under the poor category as stated by water quality classification.
Chloride (Cl^{-}), is broadly noticed in nature in the salts form of sodium (NaCl), calcium ($CaCl_2$), and potassium (KCl), as well as one of the significant water quality indicators. In addition, there are many anthropogenic activities and natural factors which add chloride elements in groundwater, leaching from rocks, including geological weathering, domestic effluent, agricultural use, irrigation discharge [26]. The values of chloride in the present investigation ranged from 241(site 5) to 550 (site 1) mg/l. It is observed there is a chloride amount in sampling sites (1, 3, &4) and the average chloride value of 388.8 mg/l exceeds the allowable limit (250 mg/l) (Figure 9.). Furthermore, WQI was observed 155.52 that classify under poor category based on water quality classification.

Sulfate ($SO4^{-}$) is an important chemical factor for water quality and has an effect on the odor and taste of water consumption (Bouslah, Djemili, and Houichi, 2017). Upper values of sulfate with water may have a clear taste and maybe lead to laxative outcomes in the unusual water consumer [28]. In the aquifer system, sulfate is derived foremost through weathering of two main forms of sulfate-containing rocks, namely gypsum and pyrite, besides the add concentrations from many anthropogenic practices [29]. Sulfate values of the sampled water differed between 541 to 850 mg/l. the highest values were noticed at (site 1). while the lowest values of sulfate were noticed at site 5. All measured values and the average sulfate value 614.2 mg/l are exceeded the allowable limit (250 mg/l) (Figure 10.). The WQI result found 245.68 that classify under very poor category depending on water quality classification.
The total average WQI result was observed in a poor category (100.206) which influences the socioeconomic and the health status of the residents. The metals and upper values of physicochemical parameters in groundwater could cause numerous diseases. Water qualities of groundwater sources in the study area were not appropriate for domestic and drinking purposes. For that reason, awareness could be led to the public not to utilize the water like this quality, the highest priority has to be given to the periodic water quality monitoring, and proper technologies must be used to make treated water more appropriate for drinking purposes.

7. Conclusion

Generally, the results demonstrated that the WQIs can decrease the extent of major data of parameters into a single value to make the information in a simplified form. The WQIs results could utilize to estimate the efficiency of the groundwater quality of end-users. The water quality indices (WQI) differed which ranged 46.8 to 1039. Based on the outcomes aforementioned, it was summarized to the following:

- WQI For pH was 46.8 which come under excellent category according to water quality classification in the study area.
- Calculated WQI for electrical conductivity was found in 1039 which is unsuitable for drinking purposes according to water quality classification.
- The result of the WQI for total dissolved solids and sulfate found 268 and 245.68, respectively, which comes under very poor category according to water quality classification, water containing more than 1000 mg/L of TDS is disagreeable as drinking water.
- The calculated WQI for the calcium, magnesium, sodium, potassium, and chloride found 198.13, 175.6, 134.9, 110, and 155.52, respectively, which come under poor category according to water quality classification.
- The overall average result of the WQI was found in a poor category (100.206) which affects the health and socio-economic conditions of the inhabitants.
- Water qualities of sampling sites were not suitable for drinking purposes.
- The highest priority should be given to periodic well water monitoring, also proper technologies must be used to make treated water more appropriate for drinking purposes.

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