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APPLICATION OF THE LOGARITHMIC WATER QUALITY INDEX (WQI) TO EVALUATE THE WELLS WATER IN AL-RASHIDIYA AREA, NORTH MOSUL FOR DRINKING AND CIVILIAN USES

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Abstract

The current study intends to assess the water quality of the wells in Al-Rashidiya region, located at the north of Mosul city, for drinking and home use, as water samples were collected from ten wells scattered in the study area during the summer, autumn and winter season (seven replicates from each well) for physical, chemical, and bacterial examinations based on International standard methods with the use of the logarithmic model to evaluate the quality of well water using eleven characteristics compared to the international standard limits for drinking water.

The results of the water quality index (WQI) indicated the deterioration of the most studied wells water quality, which was of the water type Unfit water quality for drinking and domestic uses, and this deterioration is due to bacterial contamination (total number of bacteria TPC and faecal coliform) and high concentration of salts, total hardness and sulfate ions. The study recommended the use of the technology of freezing and slow melting or processing of the use of solar radiation to improve the quality of water before it is used for drinking and domestic uses.

Key words : groundwater quality, Al-Rashidiya area, logarithmic water quality index.

Introduction

About a third of the world's population depends on groundwater for drinking, irrigation, livestock and poultry watering. The scenario in Iraq is not very different because groundwater is a major source of water for various purposes in many parts of Iraq. The lack of safe water is a big problem because it causes health problems for humans and livestock and affects their productivity when they contain pollutants, especially bacterial pollution (Shahid *et al.,* 2017). In the past few decades, the need for freshwater has increased. Where about 20% of the world's population lacks safe drinking water and about half of the world's population lacks adequate sanitation, and these acute problems exist in many developing countries. As approximately 95% of urban wastewater is discharged directly to water sources (Abdulwahid, 2013), which leads to the spread of pathogens in the water and thus the transmission of diseases to consumers such as Cholera, Hepatitis, Shigellosis and Typhoid, and diarrheal diseases etc (Al-Saffawi and Al-Assaf, 2018; Al-Saffawi, 2019), which led to high number of people suffering from drinking water pollution problems, especially children, to more than one billion people in each of the societies of Africa, Asia and South America, and that approximately 450 million people in 29 countries suffer from a lack of safe water, as it reaches the number of deaths due to consumption of contaminated water to more than three million deaths, especially diarrheal diseases that kill children in these poor communities (Al-Saffawi, 2018; Talat *et al.,* 2019).

Therefore, it has become necessary to follow the qualitative studies of water using modern scientific techniques to stand in the event of an emergency to take the necessary solutions to limit the exacerbation of environmental problems resulting from that, including studies conducted by (Ramadhan *et al.,* 2018 ; Al-Saffawi and Al-Shuuchi, 2018. Al-Saffawi and Al-Sardar, 2018; Talat *et al.,*2019) on the quality of water sources and their suitability for different uses using water quality

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indices (WQI) models that reflect the interrelated effects of the studied parameters in determining water quality, and it is one of the most effective methods for monitoring water source pollution because it gives one value instead of the huge amount of big data that confuses the reader that is understood by the specialist and non-specialist (Al-Hamdani and Al-Saffawi, 2018a) Therefore, the current study came to evaluate the water quality of wells of Al-Rashidiya area for drinking and civilian uses using the logarithmic water quality index, with some suggestions and recommendations given.

Materials and Methods

Study area

The study was conducted on groundwater in Al-Rashidiya area located to the north of the city from the left side of Mosul city, northern Iraq, which relies on groundwater as a main source of water because it is characterized by agricultural nature and the spread of fields and farms in the study area.

Geology of the study area

Nineveh Governorate is characterized by the widespread formation of Plaspi (middle-upper Eiocene) that contains limestone, marl, and Al-Fatha (middle Miocene) formation consisting of limestone, salty rocks (Halite), gypsum ($CaSO_4.2H_2O$), anhydrite ($CaSO_4$) and marl, and this formation is spread in the northern parts of Iraq and the formation of the Anjana (Upper Miocene) that It consists of succession of clay, sandy rocks and marl, these formations affect the quality of water passing through it (Al-Youzbaky and Eclimes, 2018; Al-Youzbaky *et al.*, 2018).

Methodology

In the current study, seventy water samples were collected from ten wells scattered in the area (during the autumn and winter season of 2019) as shown in Table 1 and Fig. 1. using polyethene bottles that were cleaned with distilled water, followed by rinsing the sample container with a groundwater before filling it, as well as filling glass containers for dissolved oxygen samples and field fixing it by adding a solution of manganese sulfate and followed by an Alkali-Iodied-Azid solution (Winkler reagent B**).** In addition to filling sterile vials for bacterial examinations (APHA. 1998). Tests were also performed for each of the following characteristics: Temperature, pH, electrical conductivity (EC25), total alkalinity (T. alk.), Total hardness (TH), chloride, sulfate, phosphate, nitrate, total number of bacteria (TPC) and Fecal coliform based on global methods of measurement (APHA, 1998, 2017).

Table 1: Coordinates and characteristics of the studied wells.

Wells	N	E	Depth (m)	Altitude (m)
1	36^0 24'10"	43^0 05'50"	6.0	228
2	36^0 24'01"	43^0 05'43"	7.0	227
3	36^0 23'94"	43^0 05'52"	10	225
4	36^0 24'01"	43^0 05'12"	10	225
5	36^0 23'91"	43^0 05'68"	7.0	226
6	36^0 24'01"	43^0 05'74"	8.0	224
7	36^0 23'91"	43^0 05'72"	10	225
8	36^0 23'97"	43^0 05'79"	12	224
9	36^0 40'52"	43^0 10'16"	10	224
10	36^0 23'92"	43^0 06'12"	4.0	222

Application of water quality index (WQI)

In the current study, eleven important properties were defined for calculating the water quality index WQI, and these different criteria depending on the quality of water use, and for the purpose to determining the water suitability for drinking and civil uses, WQI was calculated using a Weighted Logarithmic water quality index method compared to water quality standards recommended by the (WHO) as shown in table 2.

Table 2: Standard limits (Vs), weight of each parameter for drinking and domestic uses.

Parameters	Vs	Wi
T.°C	25	0.065838473
pH	6.5-8.5	0.219461568
Ec_{25}	1400	0.001175667
T. A	200	0.008229809
T. H	500	0.003291923
DO	5.0	0.329192347
Cl	250	0.006583847
SO_4	400	0.004114804
PO_4	10.0	0.164596163
NO_3	50.0	0.032919236
TPC	10.0	0.164596173
$\sum$		1.000000004

One of the main advantages of the logarithmic models is finding one value that represents the interference between a large number of data for the parameters studied and is easy to understand by all, the WQI value is calculated using (Hossen *et al.,* 2019; Shahid *et al.,* 2017; Devojee *et al.,* 2018) the following eqs:

$$WQI = \text{Anti log}\{\sum Wi \times \text{Log}_{10}\, Qi\}$$

Qi: sub index corresponding to the i^{th} parameter is calculated by using this equation:

$$Qi = \left\{\frac{Va - Vi}{Vs - Vi}\right\} \times 100$$

Where, Va: actual value of each parameter. Vi = the

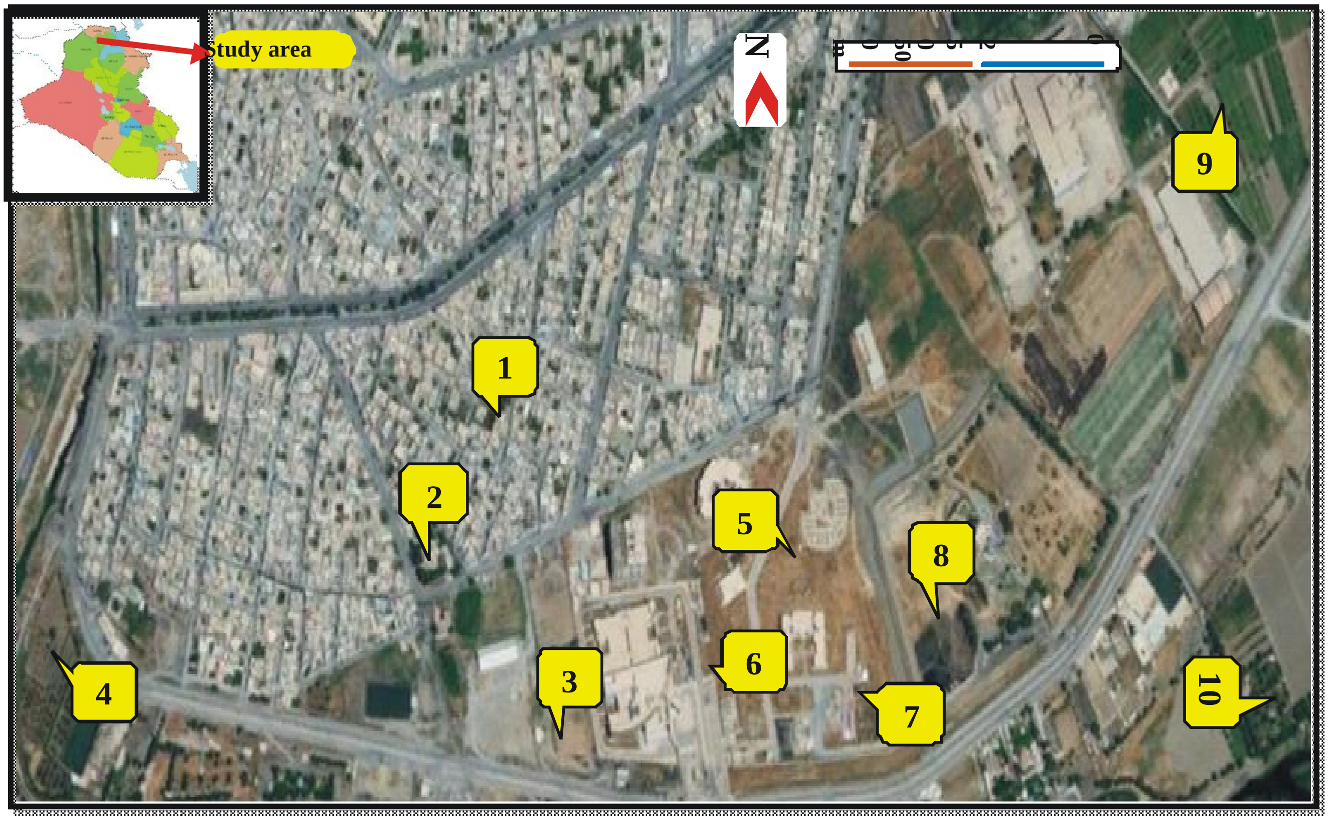

Fig. 1: A map of the Al-Rashidiya area showing the studied wells.

ideal value of each parameter (ideal for pH = 7, DO = 14.6 mg. l-1 while other parameters are equal to zero. Vs = the internationally recommended standard value (Table 2)

Wi = unit weight of the i^th^ parameter which is calculated from the following equation:

$$Wi = \frac{K}{Vs}$$

K = proportion constant which is calculated as follows:

$$K = 1\sum_{i=0}^{n} {}^{1}/_{Vs}$$

After finding an index value, the water quality class and state of the water table is found in the table 3.

Table 3: Water Quality Index (WQI) and Water Quality Status*.

WQI		Water quality status
Value	Class	
0.0 - 25	A	Excellent water
26 - 50	B	Good water
51 - 75	C	Poor water
76 - 100	D	Very poor water
100	E	Unfit quality

* (Lingswamy, and Saxena, 2016).

Results and Discussion

I. Physical properties

Water temperature an important role in influencing the interactions that occur in water and soluble salts from the rocks that pass them as well as micro-organisms activity in the oxidation and reduction processes (Al-Sardar and Al-Saffawi, 2019). The results shown in (Tab. 4) indicate that the changes in the studied water temperatures are very limited, which ranged between (16.7 to 24.0) °C, this is confirmed by previous studies as a result of the presence of water away from the surface of the earth and thus beyond the weather and climate effects (Hamdani and Al-Saffawi, 2018; Al-Saffawi and Al-Sardar, 2018; Al-Sardar and Al-Saffawi, 2019).

As for electrical conductivity, the results indicate that the average value ranged between (2057 to 3712) µS. cm^{-1}, these differences are due to the nature of the geological formations that water passes through. The groundwater passing through the layers rich in evaporation salts is characterized by a high concentration of dissolved salts in them (Al-Saffawi, 2019). These results are similar

Table 4: Range, average and standard deviation of groundwater analysis results for Al-Rashidiya area, ortheast of Mosul (ppm).

Paramet. \ Wells		1	2	3	4	5	6	7	8	9	10
Temp. °C	min	19.2	19.5	19.2	18.7	18.0	16.9	16.7	19.2	18.5	18.4
	max	24.0	24.0	23.0	24.0	24.0	23.0	24.0	23.5	23.0	24.0
	mean	22.1	22.5	22.1	22.0	21.7	21.3	21.7	22.1	21.6	21.8
	± Sd	1.83	1.89	1.73	2.09	2.55	2.27	3.02	1.87	1.84	1.99
pH	min	6.70	6.87	6.86	6.84	6.93	7.01	6.97	6.91	6.91	6.46
	max	6.95	6.99	7.13	7.13	7.02	7.23	7.23	7.05	7.35	7.22
	mean	6.84	6.92	6.95	6.96	6.97	7.11	7.15	7.01	7.10	6.94
	± Sd	0.07	0.04	0.08	0.09	0.03	0.07	0.11	0.12	0.14	0.21
Ec_{25}	min	2250	2146	2057	2240	2530	2681	2611	3200	2611	2680
	max	2971	2622	3232	2561	3256	3510	3063	3712	3480	3249
	mean	2702	2350	2959	2383	2687	2997	2777	3391	2887	2987
	± Sd	206.8	177.8	402	111.1	144.51	288.1	173.9	199.7	276.4	176.0
T. H	min	2040	1340	2260	920	1240	1800	1500	2400	1560	1580
	max	2500	1800	2800	1660	2230	2620	2360	3380	2380	2520
	mean	2216	1616	2514	1440	1976	2310	2117	2826	2051	2137
	± Sd	147.9	162.5	166.9	275.1	345.1	302.1	323.8	354.7	283.8	344.2
T.A	min	328	312	340	360	352	300	368	312	270	296
	max	465	450	485	530	495	490	515	490	465	425
	mean	353	349	375	395	406	369	406	375	363	328
	± Sd	46.2	49.8	45.9	55.8	53.8	54.4	45.8	53.2	61.1	40.8
DO	min	1.6	0.8	0.8	1.2	0.8	1.2	2.0	1.2	1.2	0.8
	max	4.0	2.8	3.6	4.0	2.4	2.4	4.8	4.8	5.2	2.0
	mean	2.8	2.15	2.0	1.9	1.2	1.8	3.4	2.5	2.7	1.5
	± Sd	0.74	0.83	0.9	0.9	0.57	0.36	1.1	1.0	1.3	0.35
Cl	min	170	170	308	152	144	188	192	308	165	182
	max	210	200	395	200	200	260	235	475	372	290
	mean	182	185	369	183	175	235	220	409	230	245
	± Sd	24.8	10.8	26.6	14.5	16.3	25.8	14.4	57.0	63.8	32.5
SO_4	min	983	737	617	686	842	802	990	1097	799	932
	max	1304	1198	1533	951	1121	1462	1258	2006	1363	1790
	mean	1143	945	1304	848	1042	1214	1119	1522	1149	1387
	± Sd	144	142	345	116	129	280	944	309	182	312
PO_4	min	0.12	0.22	0.12	0.16	0.17	0.13	0.25	0.18	0.10	0.10
	max	1.74	0.54	0.39	0.44	0.39	0.49	0.99	0.41	0.39	1.21
	mean	0.51	0.35	0.25	0.26	0.25	0.35	0.46	0.23	0.31	0.54
	± Sd	0.26	0.09	0.09	0.10	0.07	0.12	0.23	0.09	0.10	0.41
NO_3	min	9.30	10.1	10.2	7.43	0.99	1.50	7.75	3.45	7.41	10.4
	max	12.2	12.1	13.0	10.4	3.82	4.94	10.2	11.9	9.55	12.6
	mean	11.0	11.0	11.5	9.42	2.98	3.46	9.02	5.86	8.41	11.4
	± Sd	0.95	0.80	0.91	0.98	1.17	0.98	1.15	2.59	0.70	0.73
TPC*	min	0.93	1.10	0.90	0.43	0.43	1.50	3.00	0.40	2.10	9.30
	max	1016	61.6	85.6	106	53.6	1736	132	568	101	54.4
	mean	164.1	19.0	26.8	48.9	31.5	314	27.8	156	29.1	22.9
	± Sd	349	20.3	28.0	31.0	19.0	637	46.8	206	35.2	15.0
F.C**	min	9.30	0.40	1.50	0.70	0.40	0.90	0.40	2.10	0.09	0.90
	max	110	11.0	9.00	390	15.0	930	110.0	90.0	24.0	110.0
	mean	90.0	4.84	4.25	91.7	3.91	156.9	18.72	17.31	6.478	65.64
	± Sd	36.8	5.03	2.41	129.9	4.77	317.5	40.82	29.83	9.20	51.28

* $\times 10^3$ cell. ml^{-1}., ** $\times 10^2$ cell. 100 ml^{-1}

to the results obtained by Al-Safawi and Al-Sardar (2018) when they studied the groundwater of the of Al-Daraweesh and Abu Jarboua village, Basiqa subdistrict, east of Mosul city, Iraq, which ranged between (2270 to 2920) µS. cm^{-1} and also, with the results reached by Al-Saffawi and Al-Hamdani (2018) for groundwater on the right side of Mosul city, which ranged between (2070 to 3940) µS. cm^{-1} and attributed the reason to the nature of the geological formations and the spread of Alfatha formation (middle miocene) rich in salty rocks, gypsum and anhydrate.

II. Chemical properties

PH affects carbonate balance and water content of mineral elements and the values for groundwater depend on the nature and dissolution of salts and oxides consisting of ground rocks (APHA, 2017(. The results of the study table 4 indicate that the values ranged between (6.46 to 7.23) and that 59 % of water samples are within the normal acidity range. This is due to the high concentration of salts and the dominance of the chloride and sulfur phase at the expense of the bicarbonate phase, which leads to a decrease in the pH value slightly towards acidity (Al-Hamdani and Al-Saffawi, 2018). The decrease in the fluctuation of pH values is due to the Acid Neutralization Capacity (ANC) for the Iraqi water and soil rich in bicarbonate and carbonate salts (Al-Sardar and Al-Saffawi, 2019).

As for the Total Alkalinity, it is due to the presence of bicarbonate ions, because the pH values did not exceed the 8.3 (Al-Saffawi and Al-Hamdani, 2018). The results shown in table 4 indicate the relative height of the Total Alkalinity concentration, which ranged between (328 to 406) ppm. These increase in concentrations are attributed to the reactions that occur with the water containing CO_2 during its movement in the geological layers, which leads to the conversion of insoluble Calcite and Magnesium calcite to the dissolved bicarbonate (Al-Saffawi, 2018_b; Kablan *et al.*, 2018) as in the following equations:

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

$$CaCO_{.3} + 2H_2CO_3 \longrightarrow Ca^{+2} + 2H_2CO_3$$

$$CaMg(CO_3)_2 + 2H_2CO_3 ’! \; Ca^{+2} + Mg^{+2} + 4HCO_3^{\;-1}$$

As for hardness and its causes, it plays a protective role to mitigate the toxic effects of toxic metal elements, and this effect increases with increasing its concentration; toxic elements compete for absorption sites, as well as their inhibition of the mechanics of the effect of some carcinogens on the body of living organisms, but their high concentration has a negative effects on water quality (Al-Saffawi, 2018b). The results indicate that the total hardness concentrations reached (2826) ppm, and generally all samples examined for the study area exceed the internationally allowed maximum limits. This high water hardness is attributed to the previous interactions.

As for the concentration of dissolved oxygen in water, it is one of the important criteria for determining the quality of water, the degree of its pollution, and its role in preventing the formation of harmful compounds and bad odours (Al-Saffawi, 2018a). The results of the study shown in table 4 indicate that the concentration of dissolved oxygen was between (0.50-5.20) ppm and 99% of water samples measured exceed the permissible limits for drinking (WHO, 2004) and the reason for this decrease is the lack of friction with the atmospheric air, as well as the relative rise in the temperature of the wells water will lead to an increase in the activity of microorganisms and thus reduce the dissolved oxygen in the water, which will create anaerobic conditions, change the paths of reactions, and create unpleasant odours and products harmful to the aquatic environment (Al-Sardar and Al-Saffawi, 2019), as in the following eqs:

$$2\{CH_2O) + SO_4^{=} \xrightarrow{\text{Anoxic Bact}} 2CO_2 + 2H_2O + S^{=}$$

$$S^{=} + 2H^{+} \longrightarrow H_2S$$

High levels of sulfate (> 400 ppm), It is likely to cause negative effects on consumers such as a laxative effect, irritation of the gastro-intestinal tract and the human catharsis system with excess magnesium ions in the groundwater (Talat *et al.*, 2019). All water samples (100%) exceeded the values specified by the WHO.

Excess chloride concentrations increase the corrosion processes of metals, this leads to the possibility of an increased concentration of metals in drinking water, despite the need for small amounts of chlorides for the normal functions of the organisms cells (Al-Saffawi *et al.*, 2008). It was found that the chloride content (73% of samples) in the study area were within acceptable levels according to WHO standards. The reason for the relatively high levels of chloride due to the dissolution and weathering of rocks containing chloride salts as water passes through them.

It is also noticed from table 4 the significant decrease in the concentrations of phosphate ions in water, which ranged from (0.10 to 1.74) ppm, this decrease is due to the reactions that occur in water with some cations such as calcium ions to form insoluble calcium phosphate in the water as well as its ability to adsorb on the surfaces of colloidal and clay particles, which makes its concentration lower compared to other anions (Al-Saffawi and Al-Assaf, 2018).

Increased concentrations of nitrate ions (45ppm) have serious effects in humans such as "Blue Baby Syndrome", stomach, intestine and rectal cancer, abortion of pregnant women, and sudden death of births (Al-Saffawi, 2018b). The nitrate content in the studied water samples ranged from (0.99 to 12.2) ppm, the source of nitrate ions in the groundwater is caused by anthropogenic pollution. Fortunately, these values have not exceeded the allowable limit according to the WHO,

III. Bacteriological properties

Bacteriological contamination indicators are the most important tests that give a clear picture of the extent of water contamination with microorganisms and the health problems resulting from it, as the faecal coliform and *E. coli* bacteria are very necessary to give a picture of the occurrence of fecal pollution and thus the possibility of existence types of pathogens (Al-Maathidi *et al.*, 2018), the results are shown in table 4 indicate that the most common ranged between (53.6 to 1610) x 10^3 cells. ml^{-1} and (4.25 to 156.9) x 10^2 cells. 100 ml $^{-1}$, respectively. Unfortunately, all water samples do not conform with the standard specifications for the bacterial contamination indicators, and this gives evidence of the presence of fecal contamination, therefore an increase in the possibility of pathogens in the studied water and thus its serious effects on the health of consumers (Al-Saffawi *et al.*, 2018).

These results are consistent with the results obtained by (Al-Saffawi and Al-Sardar; Talat *et al.*, 2019; Al-Hamdani and Al-Saffawi, 2018; Kablan *et al.*, 2018) in their studies of groundwater for different areas at Nineveh Governorate.

Assessment of water quality for drinking and civilian uses

After applying the logarithmic model to evaluate wells water for drinking and civil use purposes, the results are shown in table 5 indicate that the values of WQI ranged between (113 to 285); the highest value was in the water samples studied for well 6 and the lowest values in the well 4 and when comparing the results in the table 3 to classify the water quality, we note that all the groundwater for the study area was Unfit water quality for drinking

Table 5: Results of calculating Logarithmic water quality index values (WQI). $*\times10^3$.

Paramet. \ Wells		1	2	3	4	5	6	7	8	9	10
T.°C	Qi	90.00	90.00	88.40	88.00	86.80	85.20	86.80	88.40	86.40	87.20
	Wi×logQi	0.129	0.129	0.128	0.128	0.128	0.127	0.128	0.129	0.128	0.128
pH	Qi	60.00	16.00	10.00	8.000	6.000	22.00	30.00	2.000	20.00	12.00
	Wi×logQi	0.390	0.264	0.219	0.198	0.170	0.294	0323	0.066	0.285	0.236
EC_{25}	Qi	193.0	167.9	211.4	170.1	191.9	214.1	198.4	242.2	206.2	213.4
	Wi×logQi	0.003	0.004	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
T. A	Qi	177.0	323.2	175.0	197.5	203.0	184.5	203.0	187.5	181.5	164.0
	Wi×logQi	0.019	0.021	0.018	0.024	0.019	0.019	0.019	0.019	0.019	0.018
T. H	Qi	443.0	176.5	503.0	288.0	395.2	462.0	529.3	565.2	410.2	427.4
	Wi×logQi	0.008	0.007	0.009	0.008	0.009	0.008	0.009	0.009	0.009	0.087
DO	Qi	123.0	129.7	131.3	132.3	142.6	133.3	116.7	126.0	124.0	136.5
	Wi×logQi	0.688	0.695	0.697	0.698	0.709	0.699	0.680	0.691	0.689	0.702
Cl	Qi	72.80	74.00	147.6	73.20	70.00	94.00	88.00	163.6	92.00	98.00
	Wi×logQi	0.012	0.012	0.014	0.012	0.012	0.013	0.013	0.015	0.013	0.013
SO_4	Qi	286.0	236.3	326.0	212.0	260.5	303.5	279.8	380.5	287.3	346.8
	Wi×logQi	0.010	0.097	0.103	0.095	0.100	0.102	0.100	0.106	0.101	0.101
PO_4	Qi	5.100	3.500	2.500	2.600	2.500	3.500	4.600	2.300	3.100	5.400
	Wi×logQi	0.116	0.090	0.066	0.069	0.066	0.090	0.109	0.060	0.081	0.121
NO_3	Qi	22.00	22.00	23.00	18.84	5.960	6.920	18.04	11.72	16.82	22.80
	Wi×logQi	0.042	0.044	0.225	0.042	0.026	0.028	0.041	0.035	0.040	0.045
TPC	Qi*	164.1	1900	268.0	49.00	315.0	3140	278.0	1560	291.0	656.4
	Wi×logQi	0.860	0.706	0.896	0.774	0.907	1.072	0.898	1.022	0.902	0.960
$\sum$ Wi × log Qi		2.137	2.069	2.378	2.051	2.149	2.455	2.323	2.145	2.270	2.417
WQI. value		137	117	239	113	141	285	210	140	186	261
Water status		Unfit	Unfit	Unfit	Unfit	Unfit	Unfit	Unfit	Unfit	Unfit	Unfit

and domestic uses.

This deterioration in the quality of well's water is due to the high concentrations of most studied properties above the permissible upper limits for drinking and domestic uses, as well as to bacterial contamination. As for the high rise in the value of the water quality factor for the well 6, it is mainly due to the rise in the total number of bacteria TPC as the value of the quality rate (Qi) reached to (3140) which reflected on the value of (Wi × log Qi) to reach (1.072), and then come the effects of most of the characteristics of the wells studied, such as the effect of water temperature, pH, the concentration dissolved oxygen, sulfates and nitrates. The same reasons apply for the deterioration of the water quality of the rest wells.

Conclusions and Recommendations

The studied wells water was characterized by high most studied parameters, especially the values of electrical conductivity, total hardness, total alkalinity, chloride ions, total number of bacteria (TPC) and faecal coliform bacteria (F. C) with low concentration of dissolved oxygen in water, which led to the deterioration of the water quality of the wells for drinking and civilian purposes, As all the values of water quality index (WQI) of the studied water from the class unfit for drinking and domestic uses. Therefore, we recommend periodic monitoring of these water sources with the use of some simple and easy techniques by consumers when needed and at the lowest cost to remove pollutants from wells water and eliminating the number of bacteria and make them suitable for use as a technology of freezing and slow thawing or the technique of solar radiation treatment (Al-Hamdani and Al-Saffawi, 2018; Al-Saffawi and Talaat, 2018).

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