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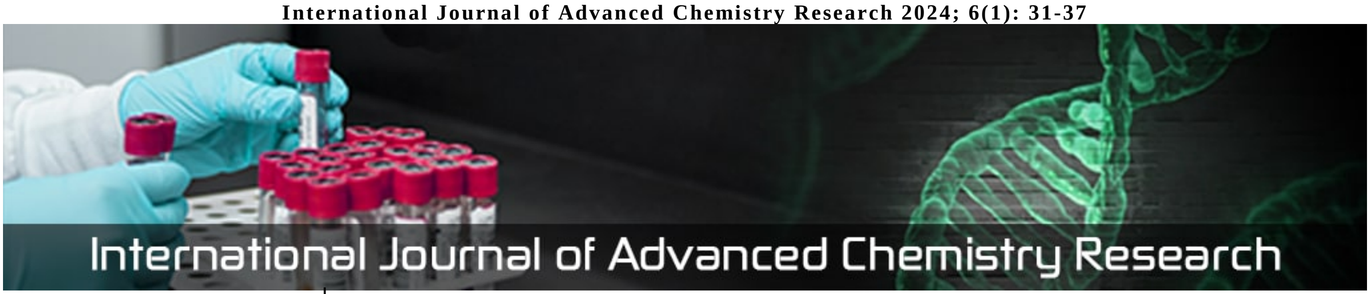

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Application of water quality index (WQI) to assess groundwater quality in Kirkuk governorate, Iraq

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Abstract
This study was conducted to evaluate the quality of groundwater using the water quality index (WQI) in the city of Kirkuk, which is located in northern Iraq and is famous for oil production. The study included areas approximately 20 kilometers away from the city center, which depend mainly on groundwater for human, agricultural and animal use. Nine chemical and physical characteristics of nine wells were determined to estimate the Water Quality Index (WQI) during the summer of 2023. The results showed that most of the chemical and physical parameters of the water samples were within the permissible limits in the standard specifications set by the World Health Organization (WHO) for drinking water. The rates of the studied parameters are (pH = 7.71), (Ec = 805.4), (TDS = 378.67 ppm), (Cl = 85.09 ppm), (NO3 = 40.65 ppm), (SO4 = 138 ppm), (Ca = 93 ppm), (Na=76.3 ppm), (K=3.04 ppm). Regarding the WQI values according to the results of the physical and chemical analyses for each well, they range between (66.6-76.17), as the groundwater in the study area is described as good.

Keywords: WQI, water quality index, groundwater, drinking water

Introduction
The residents of many villages in Kirkuk Governorate in the State of Iraq depend heavily on groundwater due to the severe shortage and increasing need for water for human and agricultural purposes. In general, most groundwater contains higher concentrations of dissolved materials than what is in surface water because it dissolves many minerals during it passes under the surface of the earth in various rock layers, and human activities are the main cause of pollution of groundwater sources [1]. The effect of these pollutants is due to the contamination of these vital resources, which destroys various types of plants and living organisms. In addition, this water becomes unsuitable for drinking and other purposes such as agricultural and industrial use. Thus, the water quality index (WQI is a useful tool in checking the extent of water pollution and thus implementing appropriate measures to reduce pollution of water sources. Water quality is determined by comparing the physical and chemical factors of the water samples subject to study with the permissible limits approved by international organizations. These existing limits are based on approved evidence of scientifically permissible levels of pollution related to the degree of toxicity to human health [2]. The concept of the Water Quality Index (WQI) helps in evaluating the physical, chemical and biological nature of water, especially in relation to human health [3]. The index is basically a mathematical method for calculating one value from the results of multiple tests and is very important for water quality monitors over certain periods of time to detect changes in the aquatic and environmental system. WQI is defined as a rating technique, which shows the effects of individual water quality parameters on the overall water quality. Water quality and suitability for drinking purposes can be tested by determining its quality index [4]. The water quality index can give indications of the health status of water at different monitoring points, and can be used to compare the water quality of one water source with another water source in the same region or in different regions around the world. This study aims to evaluate the quality of groundwater in northern Kirkuk Governorate for drinking purposes by studying some of the physical and chemical properties of this water, giving a picture of the health and safety of drinking water in the region and evaluating its quality using the Water Quality Index (WQI) based on the World Health Organization (WHO) specifications for drinking water.

Materials and Methods

In this study, nine well water samples were taken in the study area. The samples were collected at varying distances in the study area (figure 1). The depths of the wells ranged between (120-170 meters). For the purpose of conducting various chemical analyses of the water samples, a sample was taken from each well using 1 liter bottles made of polyethylene, covered and sterilized according to scientific methods used in particular. These samples were taken in September 2023. The pH was measured by (pH-meter), conductivity (EC) and total dissolved solids (TDS) were measured using a TDS/EC-meter, and chloride (Cl) was estimated using a titration method using a known silver nitrate (Ag NO3) standard [5]. Sulphates (SO_4) were estimated volumetrically by precipitating dissolved sulphates by adding barium chloride and titrating with EDTA solution [6]. And nitrates (NO_3) were estimated using an (UV-Visible) device. As for the dissolved cations: they are sodium (Na), potassium (K). And calcium (Ca) were determined using a flame photometer. The water quality index (WIQ) was also calculated for nine parameters using the weighted index method [7].

$$wi = 1/si \quad (1)$$

$$qi = ci/si \times 100 \quad (2)$$

$$WQI = \sum (wi \times qi) \quad (3)$$

$$\text{Overall } WQI = \sum (wi \times qi) / (\sum wi) \quad (4)$$

Where:
wi: The relative weight of each parameter.
qi: A measure of the quality score for each parameter.
ci: measured concentration.
si: Globally allowed value.
n: number of bars measured parameters.

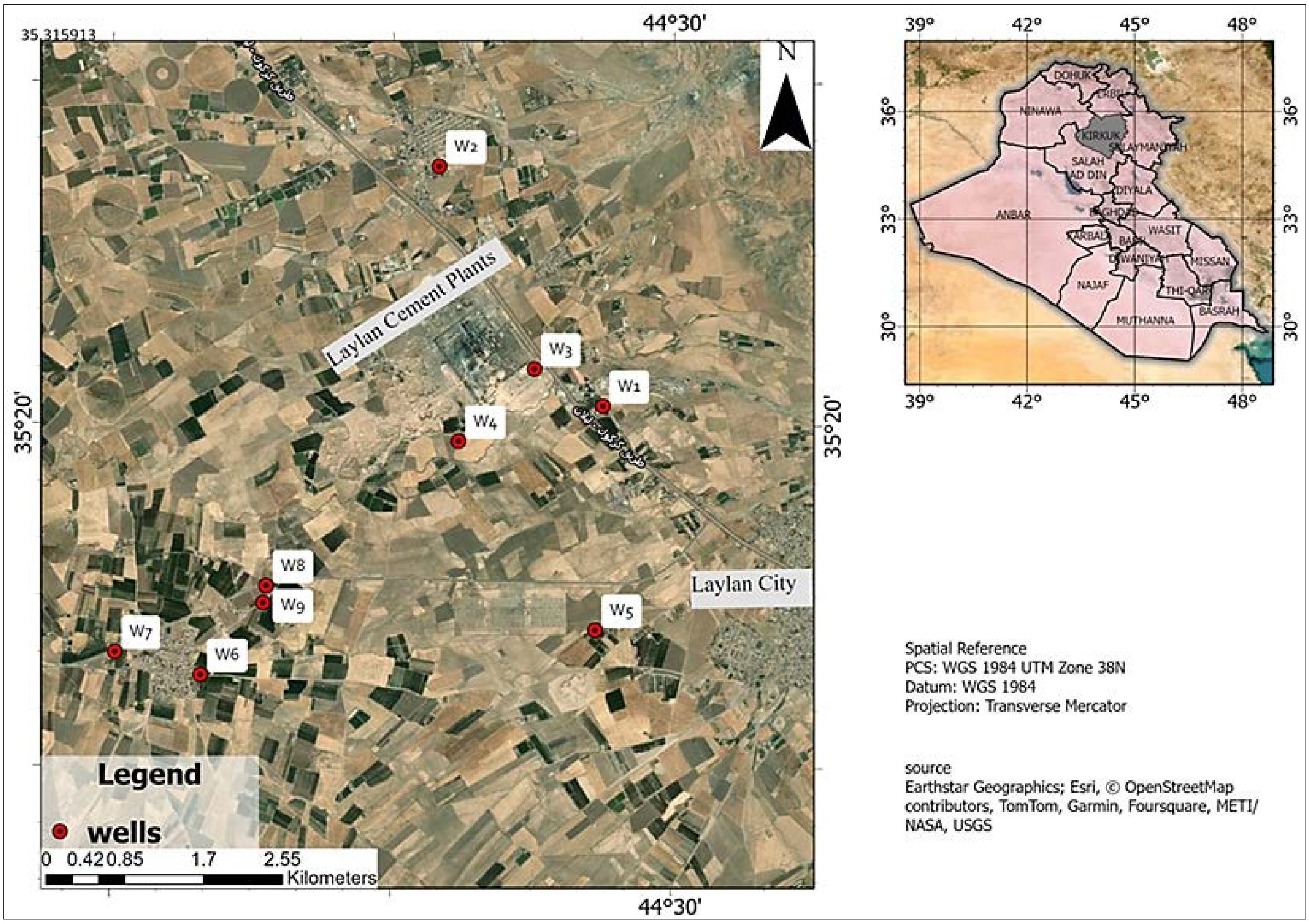

Fig 1: Map of the study location showing sampling points

Results and Discussion

pH

Through the results of chemical analyses of water samples shown in (Table 1), we find that there are no significant differences in the values of (pH) for all samples, where the highest value (7.9) was recorded in well No. (W3, W8) and the lowest value (7.5) in well No. (W5, W9), with an average of (7.7), and when comparing the results of the analyses for pH, we find that there is no significant change. All samples were within the normal range of pH value, which is from (6.5-8.5), as shown in (figure 2).

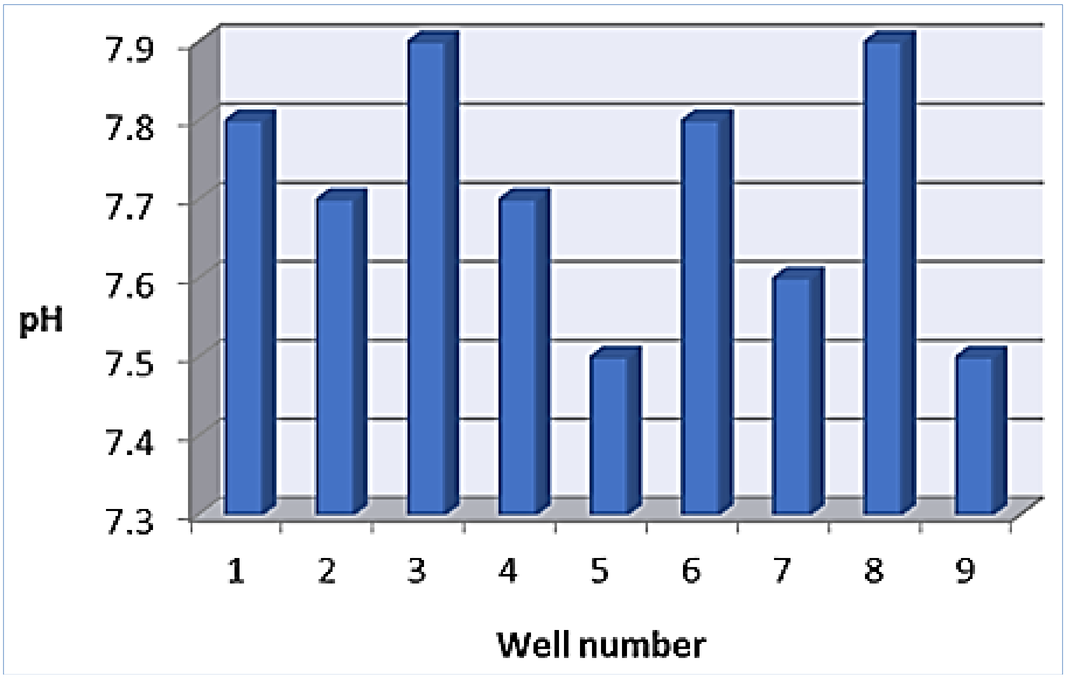

Fig 2: pH values for the studied water models

Electrical conductivity (EC)

In (Table 1) it is shown that the value of (EC) for the wells ranged between (538 µs/cm) for well No. (W1) and (1604 µs/cm) for well No. (W6), where the electrical conductivity values for all wells were within the permissible range, except for the electrical conductivity value for well No. (W6), which was higher than the permissible value which is (1000 µs/cm). As shown in (figure 3), which is likely to increase the concentrations of the ions present. This is indicated by the increase in the percentage of total dissolved solids (TDS) in the water of this well, which is shown in (Table 1).

Total dissolved salts (TDS)

The results in (Table 1) and (figure 4) show that the values of (TDS) were consistent with the electrical conductivity (EC) values in the water of the wells studied, as the highest value was recorded (754 ppm) for well no. (W6), while the lowest value recorded was (254 ppm) for well No. (W1) and the rest of the well water was within the permissible rates. The high TDS indicates high concentrations of calcium, sodium, and magnesium, as the minerals exist naturally and move through the soil and rocks due to surface water and are carried to groundwater [8].

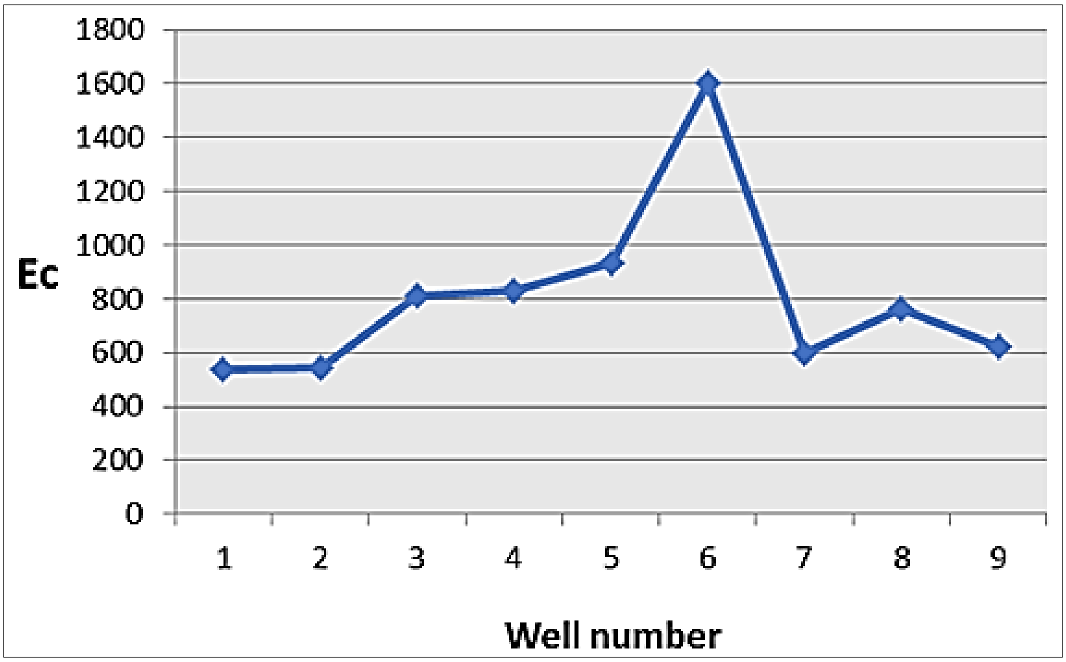

Fig 3: Ec values for the studied water models

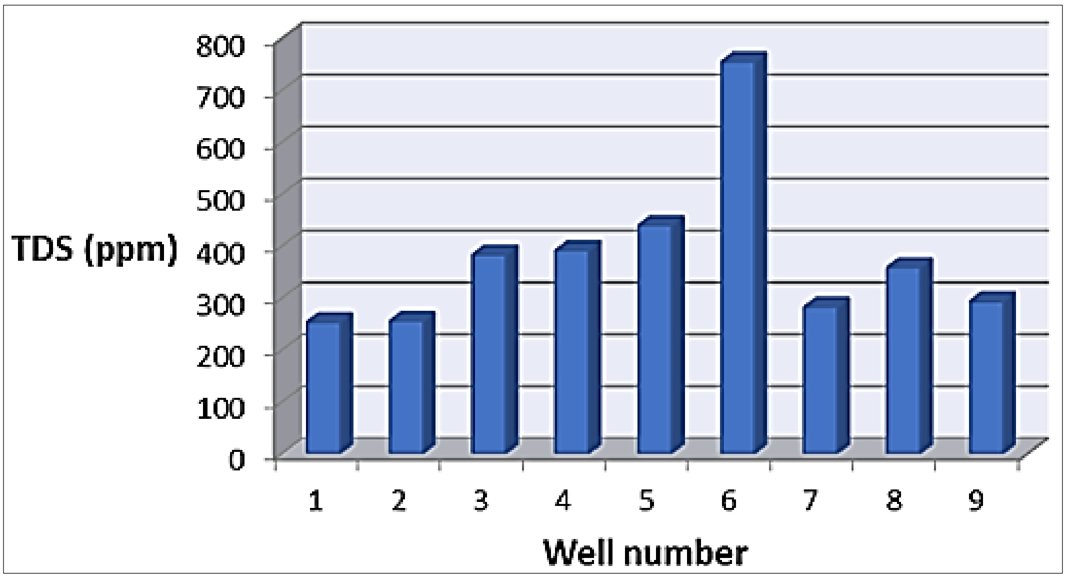

Fig 4: TDS for the studied water models

Chloride (Cl)

The results presented in (Table 1) indicate that the chloride ion concentration values (Cl) were variable, as the highest value (142 ppm) was recorded for well no. (W9) and the highest value was (40.47 ppm) for well No. (W2), although the chloride ion concentration values (Cl) did not exceed the normal limits (250 ppm), but it is important to point out the danger of this ion to human health and crops [9]. (Figure 5) shows the distribution of results among wells in the study area.

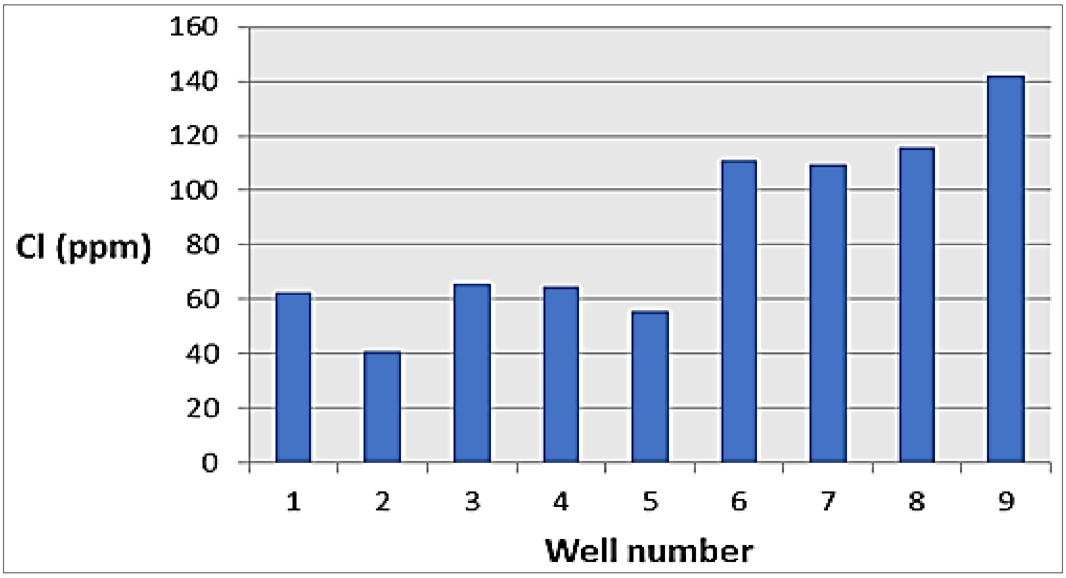

Fig 5: Chloride (Cl) for the studied water models

Table 1: Parameter values for physical and chemical properties and WQI for wells used for drinking and agriculture in the Area

Well No.	pH	EC µs/cm	TDS ppm	Cl ppm	NO_3 ppm	SO_4 ppm	Ca ppm	Na ppm	K ppm	WQI
W1	7.8	538	253	62.48	27	134	98	38.8	3.2	70.19
W2	7.7	542	255	40.47	28.2	132	92	34	2.6	67.84
W3	7.9	814	383	65.32	23	144	97	98	3.3	71.2
W4	7.7	831	391	64.61	29.1	139	107	44.2	2.9	69.48
W5	7.5	934	439	55.4	30	144	102	52	3.1	69.28
W6	7.8	1604	754	110.8	45.8	170	123	133	3.47	76.17
W7	7.6	600	282	109.4	49.66	121	88	72	2.5	66.6
W8	7.9	762	358	115.4	60.94	135	70.4	97	3.08	71.31
W9	7.5	624	293	142	72.2	127	60.2	118	3.41	70.273
Min	7.5	538	253	40.47	27	121	60.2	34	2.5	66.6
Max	7.9	1604	754	142	72.2	170	123	133	3.47	76.17
Mean	7.71	805.4	378.67	85.09	40.65	138	93.06	76.33	3.04	70.274
Std. Dev.	0.15	330.3	155.27	34.64	17.37	13.9	18.81	36.55	0.33	2.68

Nitrates (NO_3)

From the results shown in (Table 1) and (figure 6), there is an increase in the nitrate ion concentration for some wells, where the highest value was recorded (72.2 ppm) in well no. (W9). This may explain the high concentration of nitrate ions due to agricultural activities in the studied area, as wells with high concentrations of nitrates are located in agricultural areas. In general, the largest portion of the studied drinking water samples did not exceed the permissible limits. It is (50 ppm).

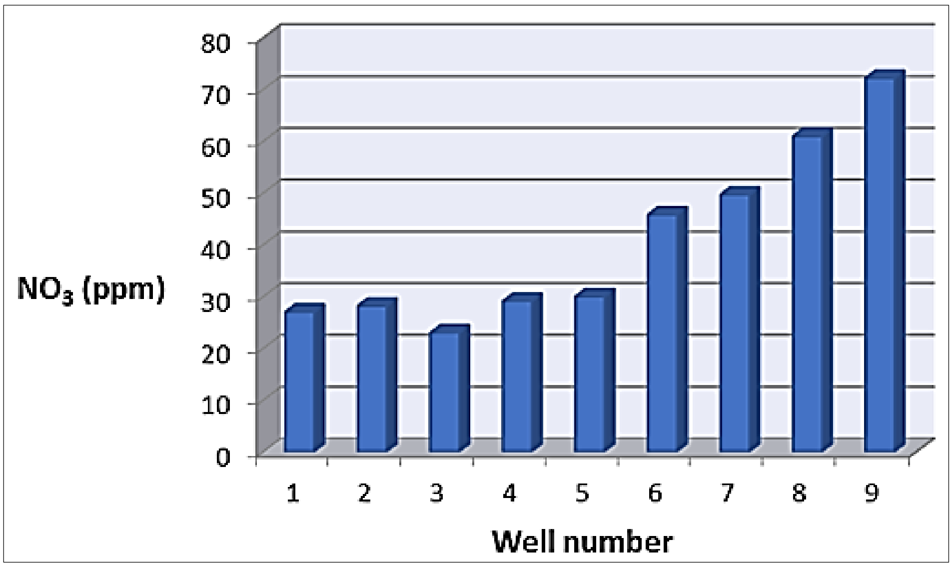

Fig 6: Nitrates (NO_3^-) for the studied water models

Sulfates (SO_4)

It is dissolved and filtered from rocks containing gypsum, iron sulfide and other sulfur-bearing compounds [8]. In this study, the sulfate concentration values range between (121 ppm) and (170 ppm) as shown in (Table 1) and (figure 7). It is within the acceptable limit (250 ppm).

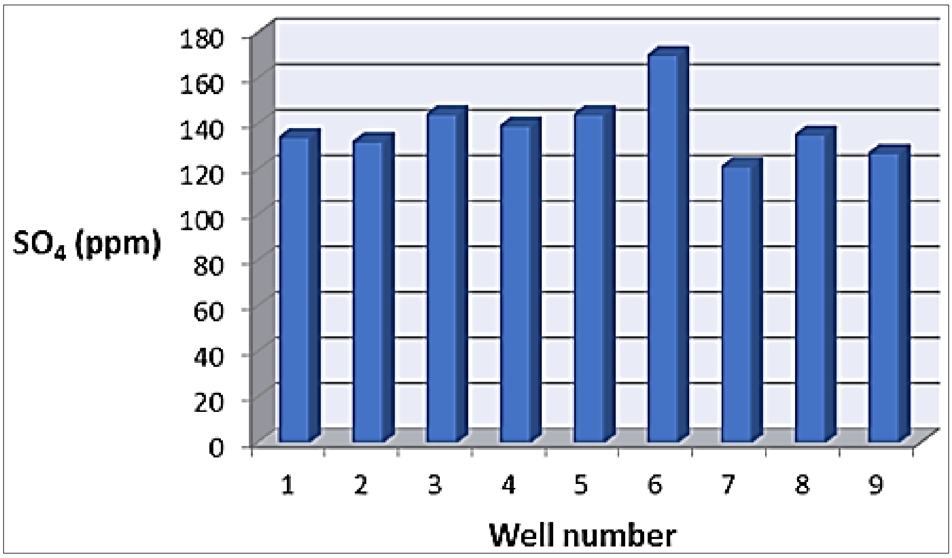

Fig 7: Sulfates (SO_4) for the studied water models

Calcium (Ca)

It enters the groundwater system via filtration of calcium-bearing minerals. In the study area, calcium concentration ranges from (60.2 ppm) for well No. (W9) to (123 ppm) for well no. (W6) As shown in (Table 1) and (figure 8). Note that the permissible limit is (75-200 ppm).

Sodium (Na)

It is a highly reactive alkali metal [10]. It is present in most groundwater [11]. So many rocks and soils contain sodium compounds, which dissolve easily to release sodium into groundwater [8]. Results shown in (Table 1) and (figure 9) indicate that the sodium ion distribution values (Na) increase with varying values in the region, and it is clear that the sodium concentration ranged between (34 ppm) for well No. (W2) and (133 ppm) for well No. (W8) and was within permissible limits.

Potassium (K)

It is found in many minerals and most rocks, since many of these rocks are relatively soluble and release potassium, the concentration of which increases over time in groundwater. The results in (Table 1) and (figure 10) show that the potassium concentration values ranged between (3.47 ppm) for well No. (W6) And (2.5 ppm) for well No. (W7) The irregular distribution of potassium may be explained by the quantity and quality of fertilisers used to fertilise farms in this region

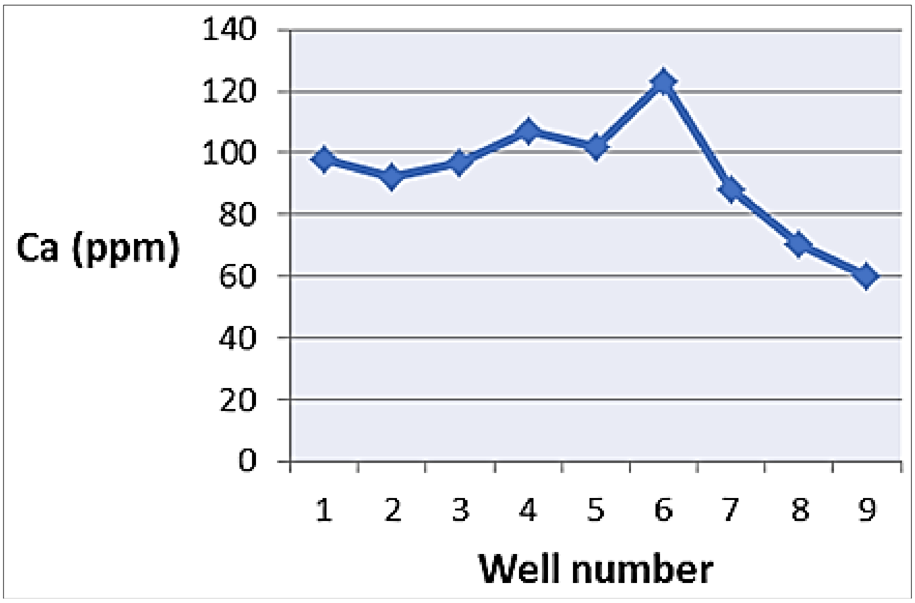

Fig 8: Calcium concentration (Ca)

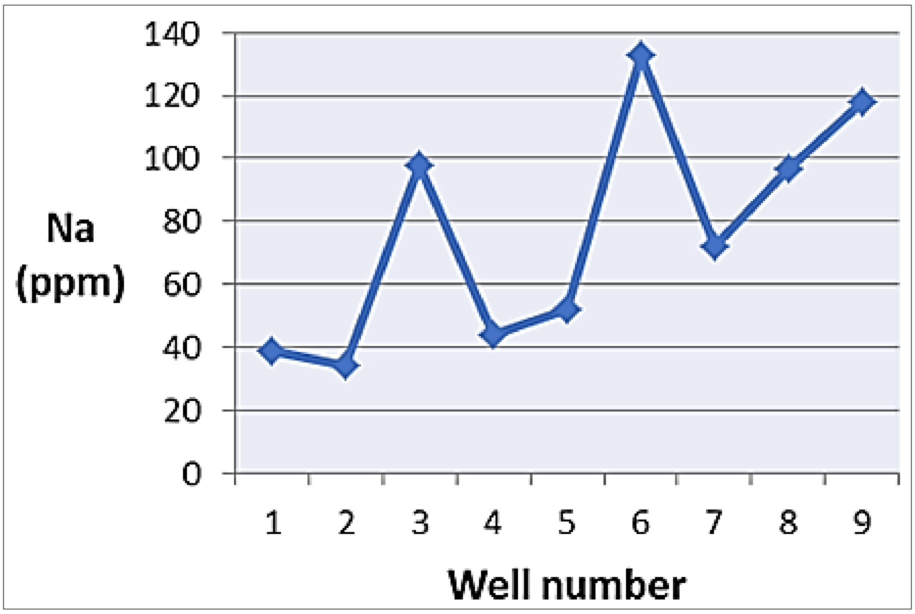

Fig 9: Sodium concentration (Na)

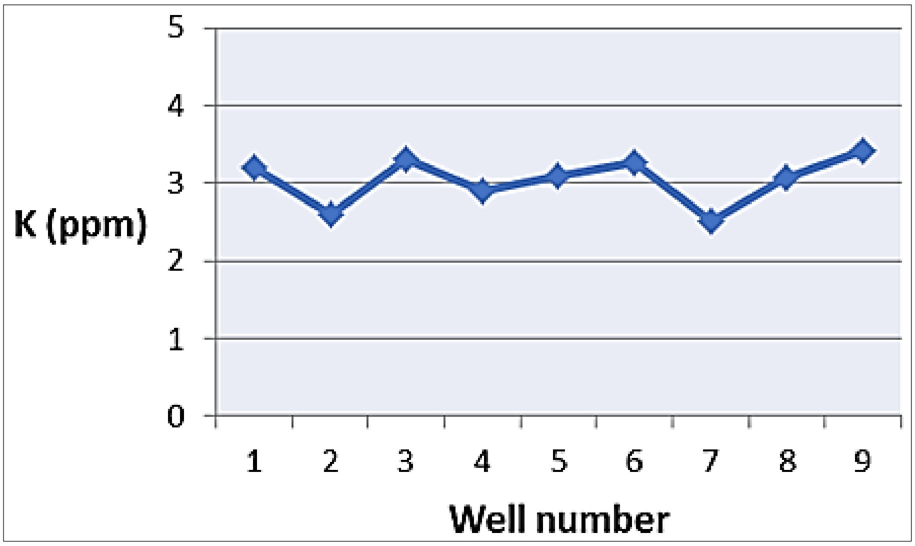

Fig 10: Potassium concentration (K)

Water quality index (WQI)

After calculating the water quality index using the weighted mathematical index method, using nine parameters for well water in the study area to determine its quality, description, and suitability for drinking or not, and in comparison with the standard specifications set by the World Health Organization WHO [12]. The WQI value was according to the results of the physical and chemical analyses for each well, and as shown in (figure11) it ranges between (66.6-76.17), as the groundwater in the study area is described as good. (Table 2) shows the classification of the water quality index based on a weighted calculation method [13].

Table 2: Water quality index classification (WQI)

The condition	WQI
Excellent water	>50
Good water	50-100
Bad water	100.1-200
Very poor water	100.1-200
Not suitable for drinking purposes	>300

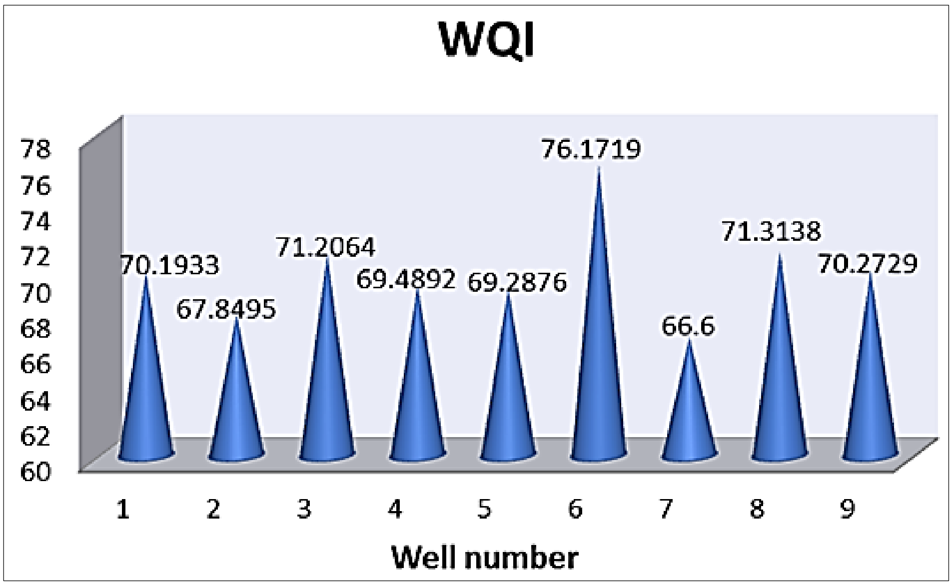

Fig 11: The WQI value for each well

Conclusion

There is a discrepancy between the results of well water parameters for the studied area, as they differ slightly between them. In general, the groundwater of the studied area is classified within the permissible specifications for drinking water. The quality of this studied water is according to the values of the quality index (WQI) for each well was rated good. The results of the study recommend the necessity of continuing to conduct periodic analyses of the levels of physical and chemical characteristics to identify any unhealthy condition, educating citizens in various segments of society and by all means not to over-consume the rates of withdrawal from these wells, and rationalizing water consumption and preserving it so that it is not a cause of water depletion and exposure to salinity.

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