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# Hydrochemical Assessment and Water Quality Index (WQI) Evaluation of Groundwater in Hawija District, Kirkuk Governorate, Iraq

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## Abstract:

Groundwater plays a significant role in fulfilling drinking water demands and human activities in most regions, especially in cities and villages where there is shortage of surface water.

The purpose of this study is the assessment of chemical and physical characteristics of ten samples of groundwater in the Hawija district of Kirkuk Governorate in January 2025. The results were compared to World Health Organization (WHO) standards and Iraqi specifications.

Several variables were quantified, such as pH, electric conductivity, total dissolved solids, total hardness, turbidity, and major ions (chloride, sulfate, calcium, magnesium, sodium and potassium). A water quality index was also estimated to determine how well the water can be consumed by humans.

The findings revealed that the majority of the measured properties were within acceptable ranges, and some samples were above the standard ranges. This brought about high water quality index of 51-250. The quality of water was between good and very poor, according to the classification, and some of the wells could not be used to drink water as the percentage of dissolved salts was too high. In this paper, the researcher points out the importance of periodically tracking the groundwater in the area and use of suitable treatment methods before it is used as drinking water. It also points out the potential to divert the water to agricultural and industrial use in the event that it goes beyond the acceptable health limits.

**Keywords:** Groundwater, water quality index, Hydrochemical, Hawija.

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## 1. Introduction

Groundwater is a very important resource to human consumption and drinking water. It is also considered to be important to maintain the balance of this ecosystem and to guarantee the health of people. The quality of water accessible to the society has a great influence on human well-being and living standards [1]. Although water is a key biodiversity component and human life, the presence of contaminated water presents a grievous threat of spreading the disease. The increasing levels of heavy metals and other pollutants caused by human activities have increased the quantities of materials produced, the number of people, and volume of wastes, which pose threats to the human populations and aquatic organisms [2, 3, 4].

Water quality monitors need the Water Quality Index (WQI), which assists in assessing the physical and chemical characteristics of water, to track the alterations in the

water system and improve human health and the environment [5]. Water pollution is triggered by a transformation in the chemical, physical and biological characteristics of water i.e. spoilage or destruction of the quality of water, e.g. sewage [6], agricultural pollutants and oil pollutants [7], which are harmful to human health and living organisms [8]. Purification techniques help to get rid of contaminants in general. Total Dissolved Solids (T.D.S.) are common water pollutants which measure the level of positive and negative ions in a water body and are generated as an industrial by-product [9]. The amount of dissolved solids shows how acceptable water is as a drinking source and to some farming [10]. One of the most prevalent contaminants in natural streams is nitrate ion ( $\text{NO}^{-1}$ ), which is brought on by the growing usage of nitrogen fertilizers. High nitrate quantities in water cause some types of cancers [11]. Just like this, the mining activities and the dismantling of the sedimentary rocks are capable of contaminating water with sulfate ions ( $\text{SO}_4^{-2}$ ). It is hazardous to human health and all living things if the concentration in water is more than 400 parts per million [12]. The chloride ion is also employed as a measure of salinity in drinking water as it is a naturally occurring ion and occurs in some concentration and a form of chloride (sodium chloride, calcium chloride etc) [13]. The increase in chloride to an above 50.0 ppm indicates that fresh water sources are contaminated and hence not safe to human consumption and causes numerous human diseases including high blood pressure and kidney failure [14].

The presence of some divalent positive ions ( $\text{Ca}^{+2}$ ,  $\text{Mg}^{+2}$ ) in the water forms total hardness of water upon reaching exceeding the limit of the allowable level of these ions as prescribed by the World Environment Organization. Surface water is not as hard as ground water as the latter is founded on the geological features of the area in which the water flows. The water hardness varies with the resource [15]. Industrial effluent is the major pollutant of rivers, and it is untreated. Because of the importance of this problem and its impacts on the living organisms, several research studies on the chemical, physical and biological of drinking water have been carried out and contrasted against the standard requirements. These investigations contain a series of research that offer information on the overall quality of groundwater throughout Iraq's governorates. Some of the heavy elements were estimated in water and sediment of Tigris River in Nineveh Governorate between 2011 and the year ending 2012 using the atomic absorption technique. The findings reveal that there was a significant increase in copper, zinc, lead and cadmium with a rising water and sediments. These levels were within the environmental limits of Iraq [16]. Some physical and chemical parameters (temperature, pH, electrical conductivity, total dissolved solids, chloride ions and other minerals) of the central drinking water purification plant in Samarra, Salah al-Din Governorate were also studied in September 2020. The results of the analysis of the physical and chemical parameters were within the international and Iraqi drinking water standards [17]. The quality of the ground water was examined in the northeastern region of the Anbar Governorate in western Iraq and (electrical conductivity, dissolved solids, some ions, and pH) were studied. The parameters of electrical conductivity (1599 - 6800)  $075\text{S}/\text{cm}$ , total dissolved solids (1048 - 4446)  $\text{mg}/\text{L}$ , and pH (7-7.9) that were analyzed showed that groundwater cannot be used as drinking water, but the nature of the soil in the area and depth of the groundwater made the water drinkable and usable in agriculture. In order to approximate the water quality index in the summer of 2023, the quality of groundwater in Kirkuk Governorate, which is in the north of Iraq, was determined in the context of research of physical and chemical properties of the groundwater [18]. The outcomes were good and not beyond the acceptable drinking water standard standards of the WHO [19] requirements.

The purpose of the study is to evaluate the quality of ground water in the Al-Hawija District, Kirkuk Governorate, Iraq by measuring the chemical variables of water and comparing them with the WHO standards and the Water Quality Index (WQI) to the same in the year 2025.

## 2. Materials and Methods

Ten groundwater samples were taken from localities in Al-Hawija District, Kirkuk Governorate, Iraq in January 2025, Figure 1 depicts the study site. The wells were selected with care to offer good representation. The well apertures were cleared and water pumped a few minutes after which it was collected. Prior to the collection of the final sample, clean and sterile 1-liter plastic containers were washed using the correct quantity of water. These samples were then stored in chilled boxes at 4 o C until analysis and the location and time of each sample noted. The laboratory results were done at Tikrit university Department of Chemical Engineering laboratory where the pH was measured using Biobass pH meter, electrical conductivity (EC) using a portable conductivity meter made in Singapore and turbidity using MKLAB Benchtop Turbidity Meter and total dissolved solids (TDS) using a HANNA device made in Singapore. Sodium (Na), potassium (K), and calcium (Ca) were measured with a Biobass Flame Photometer. Figure 2 depicts the calibration curves for the alkali metals. Magnesium (Mg) was measured with a Shimadzu AA-6200 atomic absorption spectrometer. Figure 3 depicts the magnesium calibration curve. Sulfate ( $\text{SO}_4^{2-}$ ) was determined using the Turbidity Method by Abbawi and Hassan (1990) [20]. Chloride (Cl) was measured using potassium chromate indicator titration with silver nitrate of known concentration [21]. and total alkalinity (Total Alkalinity) was determined by titration with standard hydrochloric acid (HCl), Total hardness was determined using the titration technique with a known EDTA concentration and Erichromic black T [22] . The water quality index (WQI) was generated for nine criteria using the weighted index method [19].

$$w_i = 1/s_i \text{ --- (1)}$$

$$q_i = c_i/s_i \times 100 \text{ --- (2)}$$

$$WQI = \sum (w_i \times q_i) \text{ --- (3)}$$

$$\text{Overall } WQI = \sum (w_i \times q_i) / (\sum w_i) \text{ --- (4)}$$

Where:

$w_i$ : the proportional importance of every parameter.

$q_i$ : A measure of the quality score for each parameter.

$c_i$ : measured concentration.

$s_i$ : Globally allowed value.

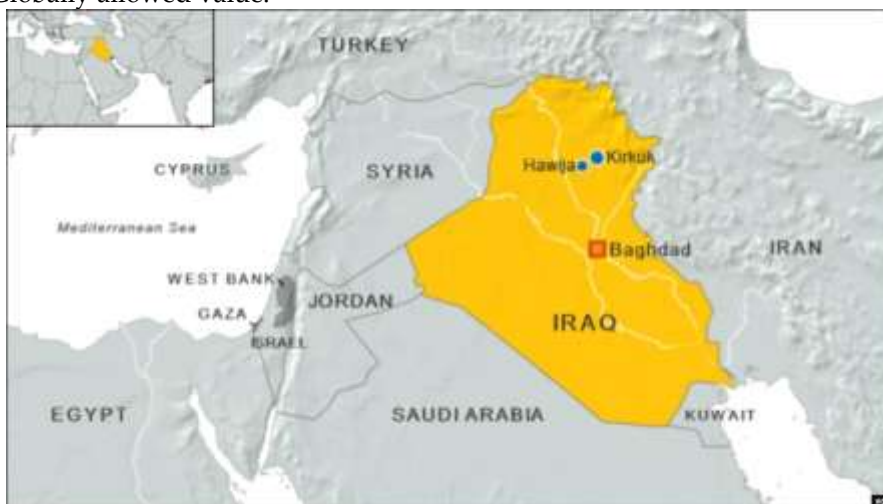


Figure 1. study site.

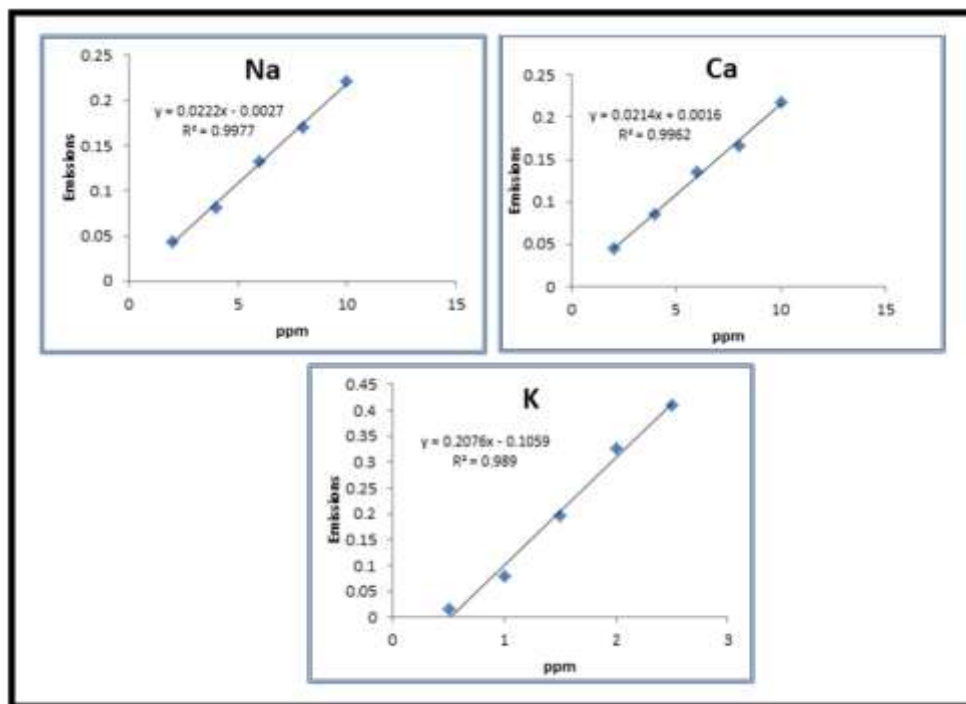


Figure 2. calibration curves for alkali elements.

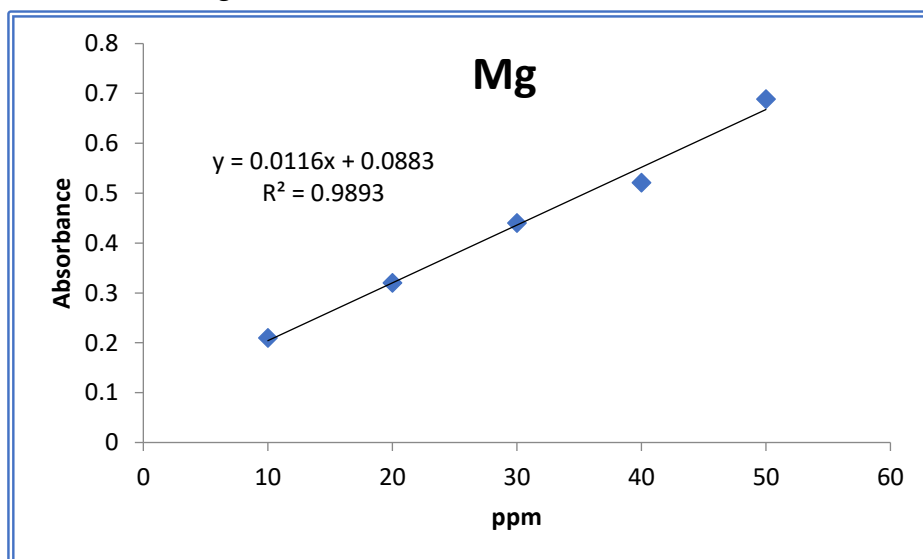


Figure 3. Calibration curve for magnesium.

### 3. Results And Discussion

**Acidity pH:** The pH values as illustrated in Figure 4 and Table 1 were 7.51 to 8.15 thus demonstrating that the water has moderate alkalinity. The pH values of all the samples studied fell within Iraqi standard range and within the acceptable range of the World Health Organization (6.5-8.5) [19]. This alkalinity could be due to the dissolution of carbonate and bicarbonate minerals in the limestone and dolomite rocks to increase the pH value [23]. These findings of the present research are in line with numerous earlier researches, such as the one conducted by Aljuraissy, Amin, and others [17-19].

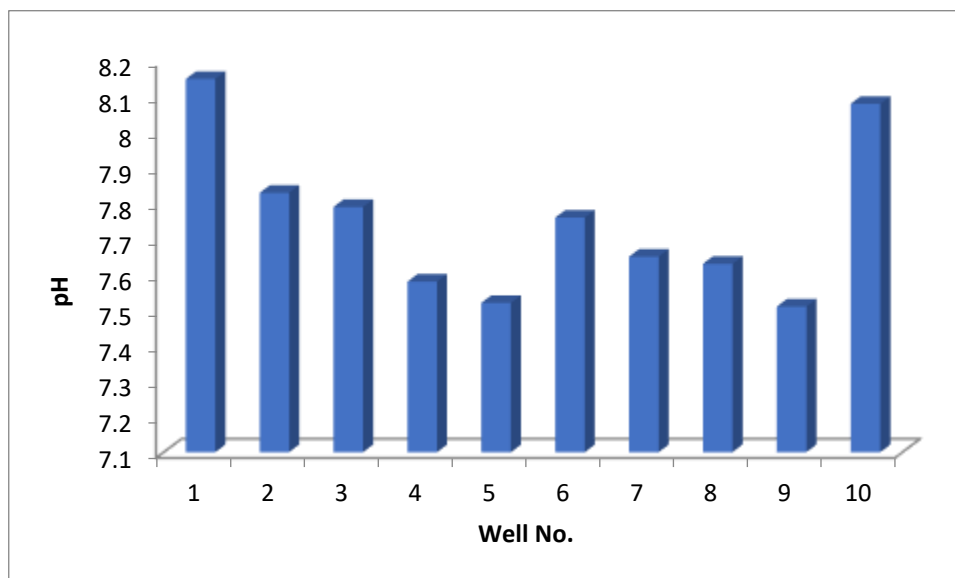


Figure 4. pH values.

Table 1. Parameter values for physical and chemical properties and WQI.

Well No.	pH	EC μs/cm	TDS ppm	Cl ppm	T.H ppm	Turb. NTU	Alka. Ppm	SO <sub>4</sub> ppm	Ca ppm	Na ppm	K ppm	Mg ppm	WQI
W1	8.15	267	130	30.1	134	22	78.6	119	55.7	22.6	2.06	20.2	229
W2	7.83	1370	720	110.5	319.5	21.4	153.3	460	160	89.4	14.1	50.7	250
W3	7.79	1170	640	120	238.7	7.7	117.3	370	119.2	81.3	9.8	48.2	119
W4	7.58	1310	690	108	282	0.3	126.3	405	140.8	84.7	12.5	42.9	59
W5	7.52	1290	670	68.3	271.8	0.08	134.3	495	135.7	96.87	11.4	41	55
W6	7.76	910	450	42.2	226.1	0.1	108.2	362	112.9	68.75	9.74	33.5	51
W7	7.65	1530	860	88.2	362.5	9.44	175.1	545	161.3	133	16.8	57	149
W8	7.63	1350	750	102.4	300.8	6.07	140.3	470	133.6	91.3	13.5	50	112
W9	7.51	920	520	53.1	230.4	0.6	121.3	255	105.2	51.1	9.52	30.7	54
W10	8.08	300	180	22.2	151.3	7.55	72.08	134	61.44	28.6	1.66	18.6	101
Min	7.51	267	130	22.2	134	0.08	72.08	119	55.7	22.6	1.66	18.6	51
Max	8.15	1530	860	120	362.5	22	175.1	545	161.3	133	16.8	57	250
Mean	7.75	1041.7	561	74.5	251.71	7.52	122.69	361.5	118.6	74.77	10.1	39.28	117.9
Std.Dev.	0.21	421.1	230.2	34.2	67.6	7.863	29.8	140.3	34.6	631.	4.67	12.5	68.6

**Electrical conductivity (EC) and total dissolved solids (TDS):** As shown in Figure (5) and Table (1) the values of electrical conductivity ranged between 267 and 1530 microsiemens/cm and was correlated with the increase in dissolved salts.

Figure (6) shows that the total dissolved solids (TSS) ranged between 130 and 860 mg/L and they reflect the degree of saltiness as it increases as the rock salts become more easily dissolved. Slowly moving and deep groundwater can affect high-value zones and enable gradual increase in the concentration of salt. The most important total solid salts [24] are calcium, potassium and sodium salts. The outcomes of this research also point to the fact that the quality of groundwater is superior to that of the studied groundwater in Anbar Governorate since the dissolved salts total and the value of the electrical conductivity of groundwater in Al-Hawija District in Kirkuk Governorate were much lower as compared to the results of the groundwater studied in Anbar Governorate. The results of this study are compared with the results of Al-Sudani's study [18]. It is however consistent with the findings of researchers, Aljuraisy and Iman in their study on the quality of ground water in Kirkuk Governorate [19].

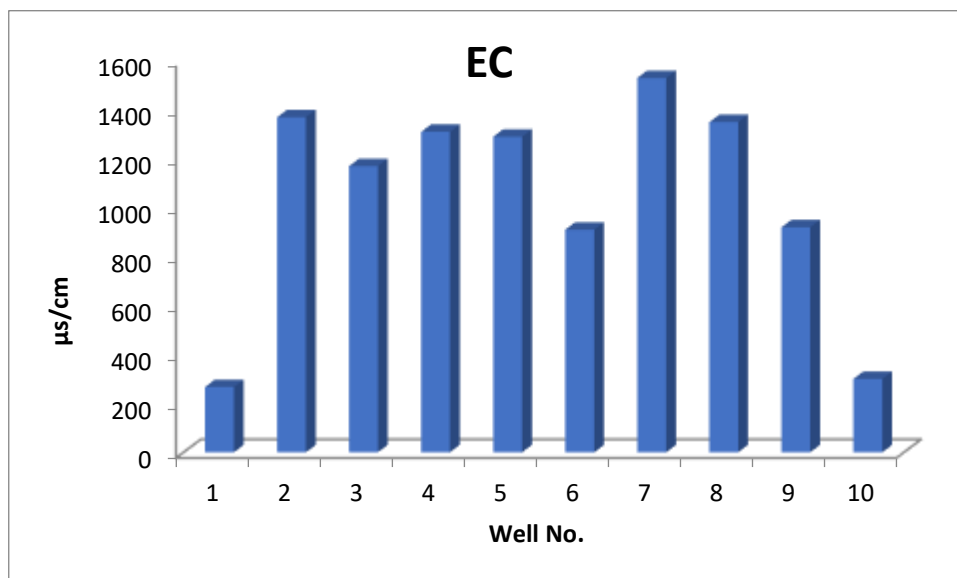


Figure 5. EC values.

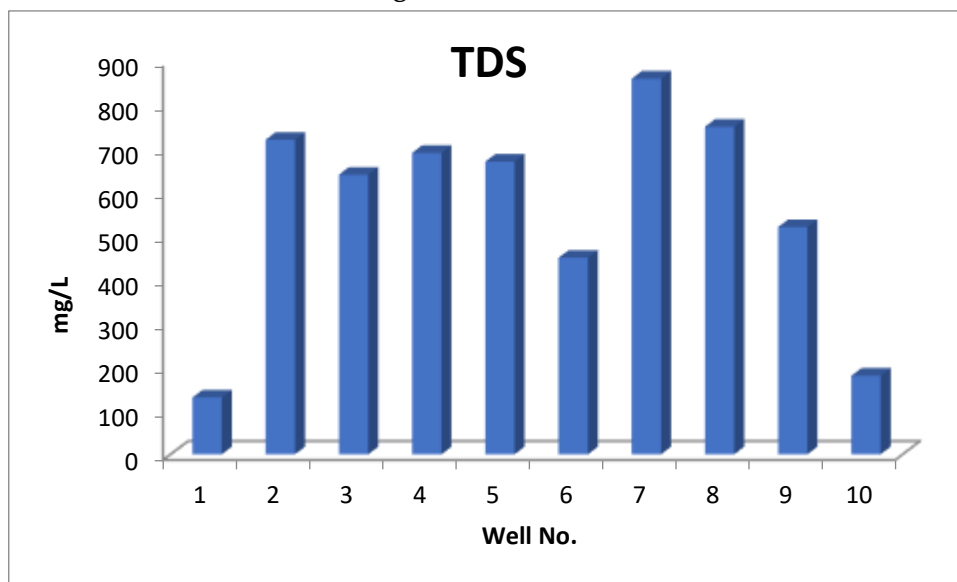


Figure 6. TDS values

**Chloride Cl<sup>-</sup>** : One of the significant inorganic anions present in water and wastewater is chloride, Cl<sup>-</sup>. It happens when sodium chloride salt dissolves. Chloride content is a key measure of the level of salinity in water, ranging from 22.2 to 120 mg/L Figure (7) and Table (1). The disintegration of rocks that contain chloride, like halite, or the influx of salt water from deep groundwater levels could be the cause of high values [25] . Human activities like fertilizer use or the release of agricultural and industrial waste could potentially be the cause [26] . The findings are consistent with the results reached by researchers Aljuraissy and Iman in their study on the assessment of groundwater in Kirkuk Governorate for the year 2024 [19]. However, it differs from the results reached by Al-Sudani regarding the assessment of groundwater in Anbar Governorate, as the chloride content in the groundwater in Al-Hawija District was much lower than its percentage in the groundwater in Anbar [18].

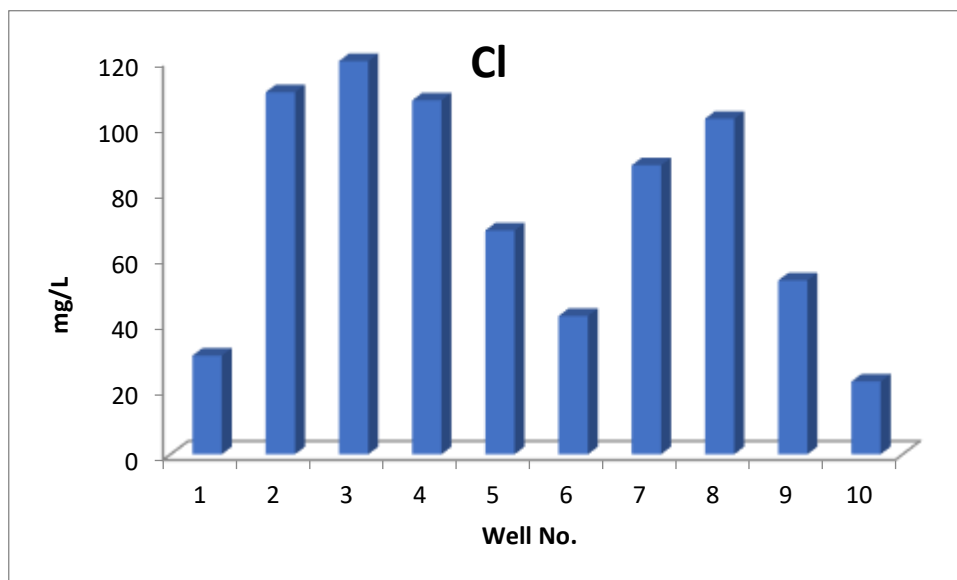


Figure 7. Chloride values.

**Total hardness (T.H.), calcium (Ca), and magnesium (Mg):** As indicated in Figure (8) and Table (1), the total hardness ranges between 134 and 362.5 mg/L, which means that there are changes in the origin of dissolved minerals. While magnesium ( $Mg^{2+}$ ) ranges from 18.6 to 57 mg/L Figure (9), calcium ( $Ca^{2+}$ ) ranges from 55.7 to 161.3 mg/L Figure (10). Hard water is formed as the deposits of chalk and limestone which are largely made up of calcium and magnesium carbonates filter water, making the water to be of high hardness [27] because the carbonate minerals (limestone and dolomite) are highly soluble. Part of the decomposition of rocks could result in reduced readings. The calcium level were near to those obtained by the researchers Aljuraisy and Iman [19]. But it is not as great as the Al-Sudani have accomplished [18]. Moreover, the lowest magnesium concentration was the lowest Al-Sudani had achieved in his work on assessment of ground water in Anbar [18]. This could be due to the geological composition of Anbar that is mineral rich than Hawija District hence directly affecting the contents of the ground water in the areas.

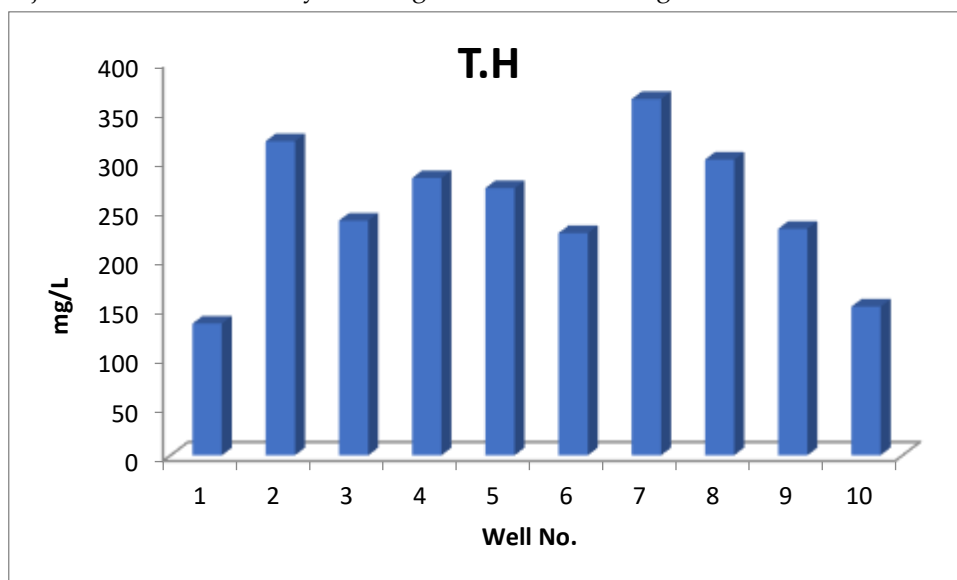


Figure 8. Total Hardness values.

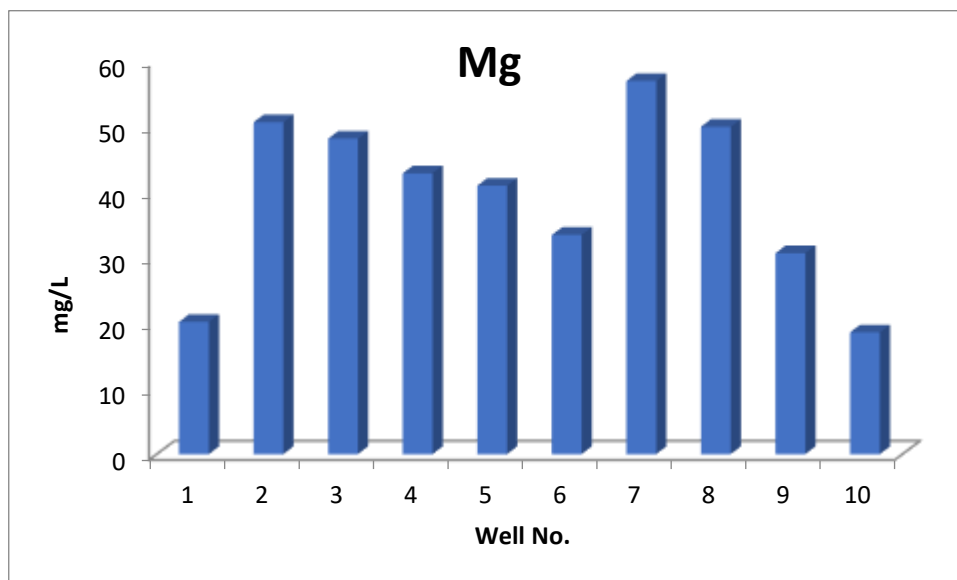


Figure 9. Magnesium values.

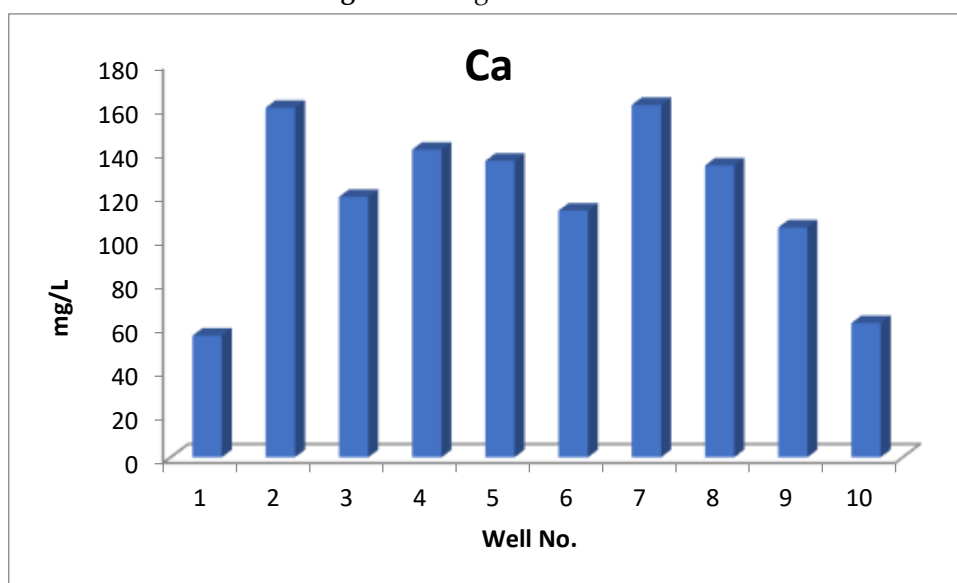


Figure 10. Calcium values.

**Alkalinity and Sulfates ( $\text{SO}_4^{2-}$ ):** The range of alkalinity is 72.08–175.1 mg/L Figure (11). It is a sign that bicarbonates and carbonates, which are involved in pH regulation, are present. The amount of dissolved alkali in water is expressed as total alkalinity. Carbonates, bicarbonates, hydroxides, borates, phosphates, and silica are the sources of alkalinity in water [28].

The range of sulfates ( $\text{SO}_4^{2-}$ ) is (119–545) mg/L Figure (12). They could be caused by the minerals anhydrite and gypsum dissolving in geological layers. In certain places, elevated sulfate levels in water could be a sign of industrial or agricultural contamination [29]. The results of the present study differ from the results reached by researchers Aljuraisy and Iman, as they were higher in terms of sulfate ion content [19]. However, it is less than what Al-Sudani reached in his research on the evaluation of groundwater in Anbar Governorate [18].

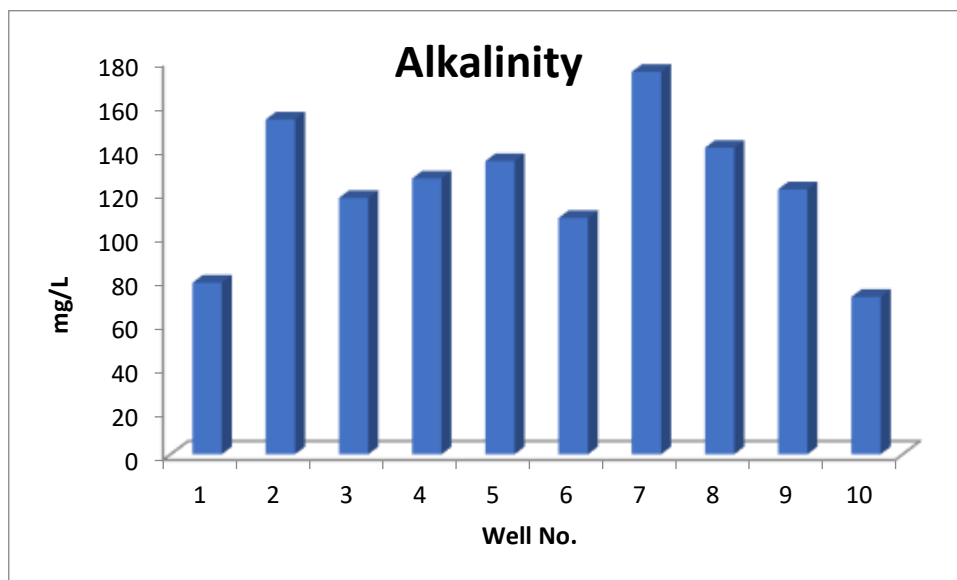


Figure 11. Alkalinity values.

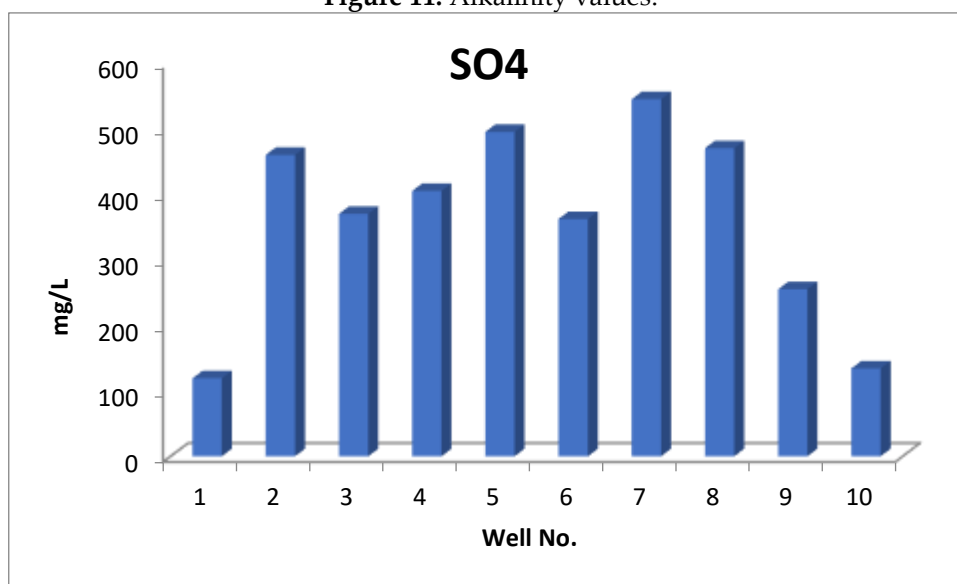


Figure 12. Sulphate values.

**Sodium (Na<sup>+</sup>) and Potassium (K<sup>+</sup>):** The range of sodium concentrations is 22.6–133 mg/L Figure (13) Table (1). It is very important in the determination of the quality of groundwater. High sodium concentrations may occur as a result of seepage of sodium salts into areas near salt deposits or ion exchange between sodium and calcium/magnesium [30].

The range of potassium is 1.66 to 16.8 mg/L Figure (14). It is less soluble than calcium and sodium and hence it is less concentrated. The level of sodium obtained in this experiment is similar to researchers Aljuraissy and Iman; however, the potassium level was higher than that of their findings had shown [19]. However, the results of sodium and potassium were significantly worse than those that Al-Sudani had in his study in the Governorate of Anbar [18].

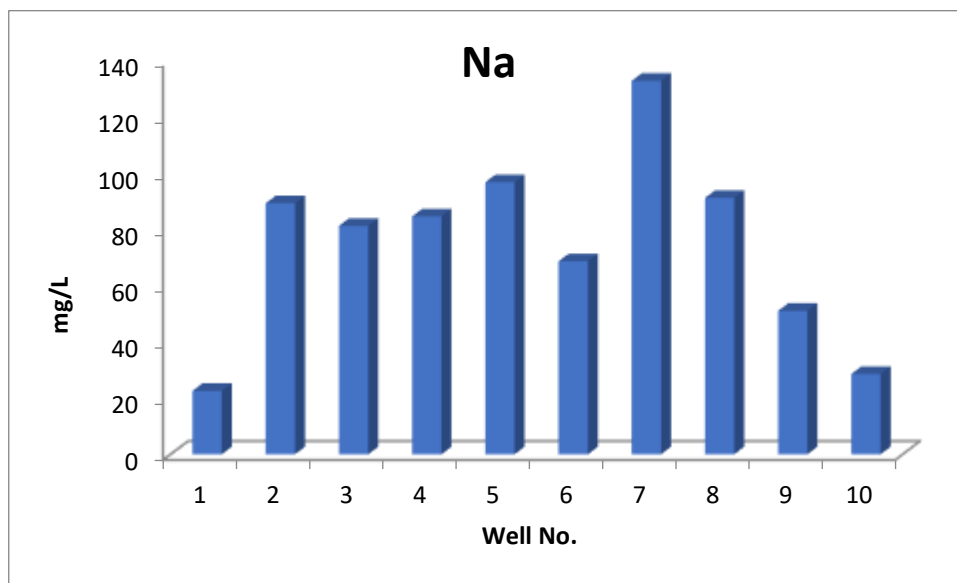


Figure 13. Sodium values

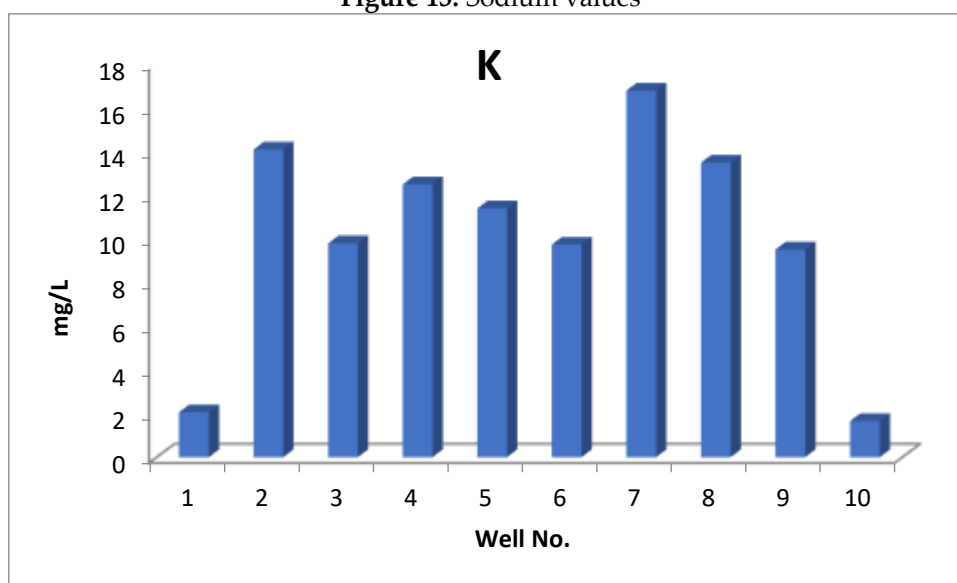


Figure 14. Potassium values

**Turbidity:** Turbidity is one of the most important physical indicators of water quality, as it expresses the extent to which water contains insoluble suspended particles, such as silt, clay, decomposed organic matter, microorganisms, or impurities resulting from various human activities [31]. Turbidity values in the waters of the study area range between (0.08 to 22 NTU) Figure (15), which reflect clear variations between wells.

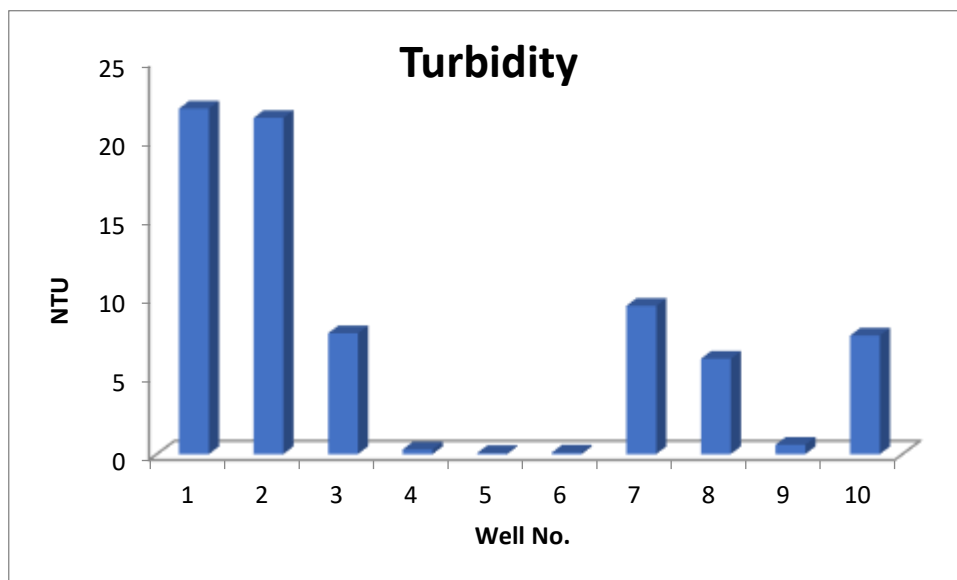


Figure 15. Turbidity values.

**Water Quality Index (WQI):** The Water Quality Index (WQI) was determined using the weighted mathematical index method [31], and 12 parameters to measure the quality, description, and human use of the water of ten wells in the study area. The WQI values were compared to the normal standards provided by the world health organization and they were found to be 51-250 (Figure 16). Increased readings will mean worsened water quality, contamination, and salinity levels.

High WQI areas can be contaminated by dissolved salts, agricultural contamination, and contact with rocks of groundwater. Lower values (<100) indicate better water quality that is suitable for human consumption [32]. Table (2) uses the weighted computation technique to categorize the Water Quality Index [19].

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

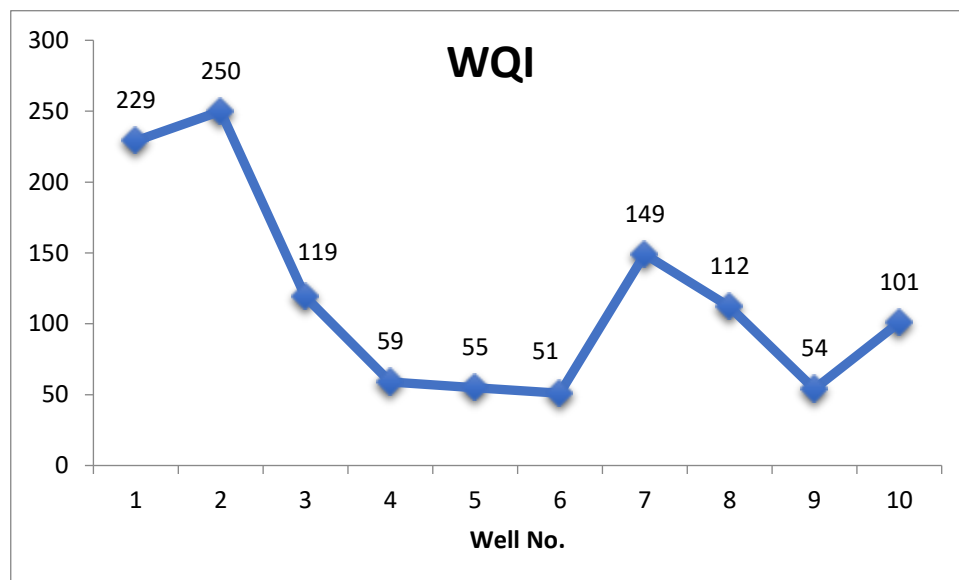


Figure 16. The WQI value for each well.

#### 4. Conclusion

The ground water of Al-Hawija District has been chemically tested and the findings indicate that it is of either ordinary or poor quality. Some of the wells contained high levels of dissolved salts thus rendering them inappropriate to be consumed by humans. The chemical properties were mostly defined by the geological formations, the process of breaking down gypsum and limestone rocks, which caused the increase of the level of calcium, magnesium and sulfates. Besides the possibility of industrial or agricultural pollution, high electrical conductivity and total dissolved solids are indicative of the influence of natural geochemical processes. Also, the variation of sodium and chloride indicates the presence of ion exchange or saltwater intrusion of deep aquifers, and therefore, water quality needs continuous monitoring and treatment as needed.

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