



Assessment of groundwater quality in Rabia district/Nineveh governorate/Iraq, and Its suitability for irrigation purposes using the Canadian Water Quality Index (CWQI)

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Abstract

The current study involved the evaluation of several chemical and physical characteristics of groundwater from wells located in the Rabia district, northwest of Mosul, and determining their suitability for irrigation purposes. The Canadian Water Quality Index (CWQI) was used to assess the quality of well water within the study area. A total of 15 wells were selected in the center of the district and its surrounding villages for study during the period from 20 September 2024, to 20 February 2025. The depths of these wells ranged from 18 to 330 meters. The electrical conductivity varied between 414 and 5760 microsiemens/cm, depending on the abundance of ions present in the water. The pH values ranged from 6.8 to 8.71, with well number (10) exhibiting a high pH value between 8.5 and 8.71 due to alkalinity caused by carbonates. All water samples studied were classified within the category (S1 - low sodium) according to the Sodium Adsorption Ratio (SAR). The average percentage values of dissolved sodium indicated that approximately 93.3% of the studied well water was of excellent quality for irrigation, while about 6.7% was of good quality for irrigation, indicating suitability for most soil types and crops, except for those highly sensitive to sodium. The results of the current study revealed variability in the Canadian Water Quality Index (CWQI) values among the studied well samples. The measurements ranged between 44 and 83. Data analysis showed that 93.3% of the water samples belonged to the good category, while the remaining 6.7% were classified as marginal.

Keywords: Mosul, SAR, canadian index, irrigation

Introduction

Groundwater can be defined as water that exists in geological layers beneath the earth's surface and is located above an impermeable layer. Groundwater is found within the layers where there are voids and cracks between soil, gravel, and rock particles. The movement of this water is slow compared to the flow of surface rainwater. The sources that recharge groundwater are diverse, including rivers, lakes, rainfall, melting ice, or artificial recharge (Hussein, 2024) [25].

Groundwater sources are among the most important components of life, playing a crucial role in meeting industrial, agricultural, and human needs (Jasim & Abdul Sattar, 2021; Al-Masoudi, 2021) [8]. Groundwater constitutes a significant part of the hydrosphere and is the second largest source of freshwater after glaciers, accounting for approximately 30 percent of freshwater within geological layers on the planet (Amos Agossou *et al.*, 2022) [15]. Therefore, it is considered the largest source of non-frozen freshwater and plays an essential role in the water cycle and supporting plants (Condon *et al.*, 2021) [22].

Groundwater exists in the form of large aquifers beneath the earth and is often protected from pollution sources and climate change (Abdulziz *et al.*, 2019) [2]. However, some aquifers may be exposed to contamination from external sources, such as chemicals released from factories and agricultural fertilizers, or from internal sources represented by the geological layer surrounding the groundwater, which affects the quality and safety of the water, and consequently, human and plant health (Li *et al.*, 2021). Additionally, the increasing rate of groundwater contamination resulting from advancements in life is one of the most dangerous pollution problems affecting on the quality and type of water around the world (Bhutiani *et al.*, 2021; Abood *et al.*, 2021) [9, 19]. Groundwater is also an extremely important natural

resource, as it represents the fundamental basis for agricultural development. Additionally, it is the primary source of drinking water and various domestic, service, and economic uses in the regions of West Nineveh. Due to this significant importance, it requires regular monitoring and continuous studies to assess its condition and protect it from pollution, ensuring its sustainability for future generations (Hussein and Ahmed, 2022) [24]. Technological and scientific advancements have introduced a range of environmental pollutants that are foreign to the natural environment, and the soil is particularly susceptible to pollutants, as it acts as a primary vessel and filter for groundwater (Al-Saleh *et al.*, 2023) [12]. Therefore, it has become essential to study and determine the quality of groundwater to understand its suitability for drinking, agriculture, and industry (Al-Sudani, 2019) [14].

Materials and Methods

Study Location

The Rabia district and its associated villages are located within the Nineveh Governorate in northwestern Iraq. It extends between the latitude lines (42°04'19.102" - 42°25'30.471") east and the longitude lines (36°36'35.135" - 36°56'24.417") north, covering an area of (1679.94) km² and at an elevation of approximately (302) m above sea level (Yahya and Ajena, 2023) [37]. The temperature reaches its peak in the summer months, with an average of (42.9) °C in July, and its lowest in the winter months, particularly in January, with an average of (2.2) °C according to data from the Rabia meteorological station.

Geology of the Study Area

Nineveh Governorate, in general, and the Rabia district, in particular, are characterized by diverse geological formations dating back to the Miocene-Quaternary periods.

These extensive formations include the Sirkanji, Al-Fatha, and Anjana formations, which correspond to the lower, middle, and upper Miocene, respectively. The geological composition of the Rabia area is distinguished by the presence of sandstone, claystone, and siltstone (sand, siltstone, and claystone). It also consists of silica gravel, limestone, and dolomite, along with metamorphic and igneous rocks. The gravel is cemented by sandy and silty

materials, with a scarcity of clay materials, and these materials are often rich in gypsum (Sissakian, 1995)^[35]. The sedimentary characteristics indicate that this formation developed in a freshwater environment, with the lower part of the Anjana formation representing a transitional phase between marine evaporitic deposits (Al-Fatha formation) and continental fluvial deposits (Lawa, 1989)^[30], as illustrated in Figure (1).

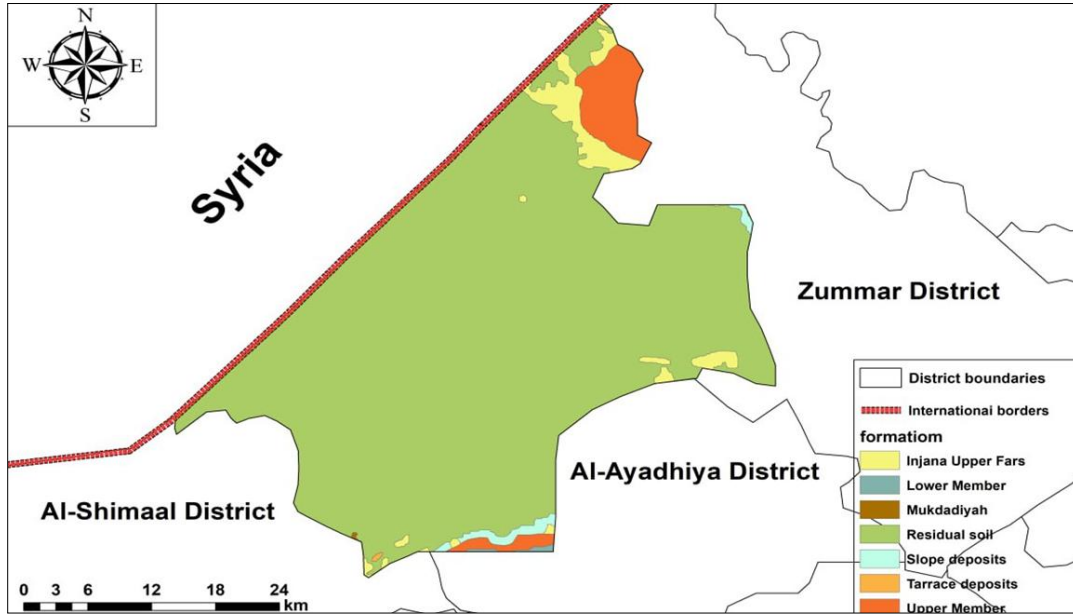


Fig 1: Geological map of the Rabia

Field Work

Water Sample Collection

Water samples were collected from fifteen wells randomly distributed in the center of Rabia District and some of its

associated villages, with one sample taken from each site monthly during the period from September 2024 to February 2025. The studied samples are distributed as shown in Figure (2).

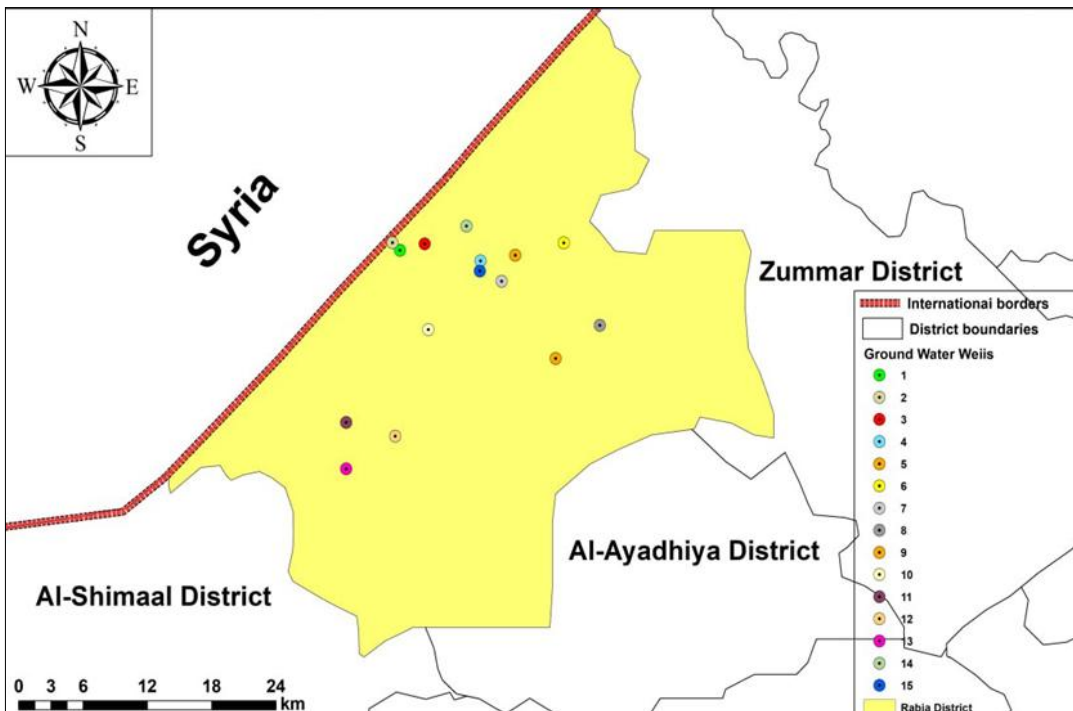


Fig 2: Rabia District – Locations of the studied wells by the researcher From Google Earth

Field measurements were conducted after water was pumped from the well for a sufficient period to ensure that

the sample represents the quality of the groundwater feeding that well. This included measuring the pH (acidity) using a

Water Quality Tester, and electrical conductivity using a Conductivity.TDS.C°meter. Additionally, laboratory measurements were performed, which included chemical analyses to estimate the concentrations of positive and negative ions at the Environmental Laboratory in the College of Science, University of Mosul. Chemical methods were employed for these measurements, where total alkalinity and the concentrations of ions (Na⁺, K⁺) were estimated. The concentrations of sodium and potassium ions in the filtered samples were measured using a Flame Photometer of the type (pFp7), expressed in mg/L. Total hardness and the concentrations of calcium and magnesium ions (Mg²⁺, Ca²⁺) were estimated using the Na₂EDTA Titration method, with the assistance of indicators Erichrom Black-T and Muroxid. The concentration of chloride ions (Cl⁻) was measured using the Mohar method, based on the examinations conducted by Abawi and Hassan (1990)^[1] and APHA (2017)^[17].

The sodium adsorption ratio (SAR), the percentage of sodium dissolved in water (SSP), and the risk of magnesium were calculated using the equations from Paliwal (1972)^[34]. To calculate the water quality index for irrigation purposes, twelve factors were used, which are as follows: pH, electrical conductivity, nitrate, sodium, potassium, calcium, magnesium, chloride, sulfate, the percentage of dissolved sodium (SPP), sodium adsorption ratio (SAR), and magnesium risk (Al-Obaidy *et al.*, 2015)^[10].

Results and Discussion

1. Electrical Conductivity

The results of the study showed a significant variation in the electrical conductivity (EC) values of the well water under investigation during the study period. Well (13) recorded the highest value of 5760 microsiemens/cm in December 2024, while well (6) recorded the lowest value of 414 microsiemens/cm in February 2025. Regarding the averages during the study period, they ranged between 537 and 3908 microsiemens/cm in wells (6 and 13), respectively.

The noticeable variation in the electrical conductivity values of the studied well waters may be attributed to the potential influence of sewage leakage on some wells, as indicated by the study (Chegbeleh *et al.*, 2020)^[21]. This pollution leads to changes in the chemical properties of the water. Additionally, the differences in electrical conductivity values may be due to the geological characteristics of the area, which play an important role in determining the properties of groundwater. The rock layers in the study area contain deposits rich in gypsum, anhydrite, and evaporite materials, which contribute to the high concentration of dissolved salts in the groundwater (Al-Hamdani, 2020)^[5].

2. Ph Value

The results of the current study showed significant variations in the pH values of the studied well waters, with pH values ranging between (6.8-8.71) during the study period. The highest pH value (8.71) was recorded in the water of well number (10) in November 2024, exceeding the permissible limit for irrigation water specifications as shown in Table (16). Meanwhile, the lowest pH value (6.8) was recorded in the water of well number (13) in October 2024, which is within the permissible limit for irrigation water

specifications. The pH averages in the studied well waters ranged between (7.06, 8.60) in wells (3,10) respectively during the study months.

The increase and decrease in pH values may be attributed to the geological composition of the area or the buffering capacity of the well waters, as well as the presence of salts in the soil such as carbonate and bicarbonate ions (Al-Safawi *et al.*, 2018; Al-Hamdani, 2020)^[5, 11].

3. Concentration of Calcium and Magnesium Ions

The values of calcium ions in the studied well water ranged between (2-220) mg/L, with the highest value recorded for calcium ions in well (13) at (220) mg/L, while the lowest value for calcium ions was (2) mg/L. The average calcium concentration during the study period for the examined wells ranged between (2.3-175.5) mg/L in wells (10,13) respectively.

Meanwhile, the concentrations of magnesium ions varied between (4-138) mg/L during the study period, with the highest recorded value for magnesium ions in well (9) at (138) mg/L, while the lowest value for magnesium ions was recorded in well number (10) at (4) mg/L. The average magnesium concentrations ranged from (6-110.6) mg/L in the waters of wells (10,9).

The variation in concentrations of calcium and magnesium ions may be attributed to the geological composition and nature of the rocks in the regions where the studied wells are located, as confirmed by the studies of Ankidawa *et al.* (2017)^[16] and Zhou *et al.* (2020)^[38]. It may also be due to the precipitation of calcite, the dissolution of gypsum, and the dissolution of dolomite in well water, which may increase the total hardness due to the elevated concentrations of Ca²⁺, Mg²⁺, and HCO₃⁻ in the water (Nsabimana *et al.*, 2022)^[33].

4. Chloride Ion

The results of the chloride ion concentration in the studied well waters showed significant differences during the months of the current study. The concentration values of the chloride ion in the well water under investigation ranged between (4-888) mg/L for wells (4,13), respectively. The highest concentration value of the chloride ion (888 mg/L) was recorded in the water of well number (13) during November (2024), while the lowest concentration recorded in the water of the wells under study was (4 mg/L) in the water of well number (4) during October (2024). Meanwhile, the average chloride concentration during the months of the current study ranged between (22.1-725.6) mg/L in the waters of wells (4,13) respectively.

The high concentration of this ion may primarily be due to the geological abundance of evaporite rocks in the studied area, where the salts forming these rocks are characterized by a high solubility in aqueous media (Kannah, 2021)^[28].

5. Nitrate Ion

The current study recorded varying results for nitrate concentrations in the well water under investigation, with values ranging between (3.15- 12.19) mg/L. The highest concentration of nitrate was recorded in the water from well number (13) at (12.19) mg/L, while the lowest recorded concentration was (3.15) mg/L in the water from well

number (5). Additionally, the nitrate concentration levels fluctuated throughout the study months between (3.49 - 11.55) mg/L in wells (10 and 13), respectively, as shown in Table (7). These values fall within the permissible limits for irrigation water standards.

The variation in nitrate concentrations in the studied well water may be attributed to the discharge of household and animal waste or may be due to fertilizers and pesticides used in agriculture (Al-Jubouri, 2020) [6].

6. Sulfate Ion

The concentrations of sulfate ions in the well water under the current study varied, as shown in Table (8). The average sulfate ion concentrations during the study months ranged from (65.6-206.8 mg/L) in wells (6,2), respectively. The recorded concentration values for sulfate ions in the studied well water ranged between (52- 236 mg/L). The lowest concentration of sulfate ions was recorded in the water from well number (5), which was (52 mg/L), while the highest concentration value of sulfate ions (236 mg/L) was recorded in the water from well number (9). The upper and lower values for sulfate ion concentrations did not exceed the permissible limits for irrigation water specifications.

The increase and decrease in sulfate ion concentrations in the well water may be a result of the geological formations in the study areas through which the water from the studied wells flows. The rocks containing gypsum increase the concentration of sulfate ions when they decompose and dissolve in the well water (Kannah and Muhammad, 2022) [29].

7. Sodium Ion

The study revealed a notable variation in the concentrations of sodium ions (Na⁺) in the groundwater under investigation, with values ranging from 20 mg/L to 150 mg/L during the study period. The highest concentration of sodium ions (150 mg/L) was recorded in water from well number 8, while the lowest concentration was found in the water from wells number 5 and 10, measuring 20 mg/L during the months of the current study. The recorded averages for the ion ranged between 22.6 mg/L and 140.5 mg/L in the waters of wells 5 and 8, respectively.

The relative decrease in sodium ion concentration may be attributed to reverse ion exchange mechanisms in the aquatic system, where higher valence calcium ions (Ca²⁺) and magnesium ions (Mg²⁺) tend to replace sodium ions (Na⁺) on the surfaces of clay minerals and porous media materials. This process leads to a significant reduction in dissolved sodium concentration with an increase in the concentration of divalent ions in the aqueous solution, which aligns with the chemical principles of ionic equilibrium in natural aquatic systems (Egbueri *et al.*, 2019)

[23]. This phenomenon reflects the complex interactions among various ionic components in hydrogeological environments and their impact on the distribution of dissolved elements.

8. Potassium Ion

The results of the current study during the academic period indicated variability in the potassium ion concentrations in the studied well waters. The highest concentration of potassium ion was recorded at (140.8) mg/L in water from well number (8), while the lowest concentration was (3.4) mg/L in water from well number (1). The potassium ion concentration values ranged between (154.2) mg/L, with the lowest recorded concentration (2) mg/L in water from well number (1), and the highest concentration value (154) mg/L in water from well number (8). Both the highest and lowest values were recorded in February (2025).

The variation in potassium ion concentrations may be attributed to different sources within the hydrogeological system, which include rainfall and mineral weathering as primary natural sources, in addition to human contributions resulting from the use of agricultural fertilizers. The distinctive chemical properties of this ion play a critical role in determining its final concentration, as it exhibits high resistance to weathering processes compared to sodium ion. Furthermore, its tendency to adsorb onto soil particle surfaces within geological layers leads to a decrease in its concentration in the aqueous solution (Ibrahim & Nofal, 2020) [26].

9. Sodium Adsorption Ratio

The study results showed a significant variation in the values of the Sodium Adsorption Ratio (SAR) among the studied wells, with rates ranging from (0.896 - 3.578) milli-equivalents/liter in the water of wells (4,8) respectively. Well number (8) recorded the highest value of (3.952) milli-equivalents/liter during November (2024), while the highest value recorded in the water of well number (4) was (0.687) milli-equivalents/liter during February (2025).

The variation in SAR values in the water of the wells under the current study may be attributed to the dominance of concentrations of divalent cations (Mg²⁺, Ca²⁺) over monovalent cations (Na⁺) in this water, which led to a significant decrease in SAR values. This finding is consistent with the results of the study by Al-Shanona *et al.* (2018) [13]. All water samples studied are classified within the category (S1 - Low Sodium) according to the established standards in Table (1), indicating their suitability for irrigating most types of soils and crops, except for those that are highly sensitive to sodium.

Table 1: Classification of Water Based on Sodium Adsorption Ratio (SAR) (Abawi and Hassan, 1990) [1]

Water Class	SAR	Water Suitability Range
S1 - Low Sodium	01-0	Water is suitable for irrigation of most crops and for almost all soil types, except for crops that are very sensitive to sodium
S2 - Medium Sodium	18-10	Water is suitable for coarse-textured soils with good permeability and unsuitable for fine-textured soils, especially when leaching is insufficient and there is a small amount of gypsum in the soil
S3 - High Sodium	26-18	Water is harmful to most soils and requires good drainage and leaching along with the use of gypsum
S4 - Very High Sodium	More than 26	Water is usually unsuitable for irrigation purposes

10. Soluble Sodium Percentage

The results of the study showed a clear variation in the percentages of dissolved sodium (SSP) among the study wells during different months. The measurements ranged from (0.3) % in well (13) during September (2024) to 25.7% in well (8) during February (2025). As for the average values of the sodium percentages, they ranged from 1.09% in well (1) to 23.1% in well (8), indicating spatial and temporal differences in the distribution of sodium concentrations among the studied wells.

The reason for the decrease in the percentage values of dissolved sodium may be attributed to the complex

interaction between geological and hydrological factors affecting the chemical properties of groundwater. The nature of the rock formations and the degree of ion exchange with clay minerals play a crucial role in determining the levels of dissolved sodium, which consequently affects the concentrations of magnesium and calcium ions compared to the concentration of sodium ion (Al-assaf et al.,2020) [3].

The rates of dissolved sodium percentage values indicated that approximately 93.3% of the studied well waters were of excellent quality for irrigation, while about 6.7% were of good quality for irrigation, as shown in Table (2)

Table 2: Classification of Water Based on the Percentage of Dissolved Sodium (SSP) (Al-Hadidi, 2018) [4]

Water Suitability for Irrigation	Percentage of Dissolved Sodium
Excellent	Less than 20
Good	20-40
Permissible	40-60
Doubtful	60-80
Unsuitable	More than 80

11. Magnesium Hazard

The values of magnesium risk rates in the current study ranged between (41.06-0.980) % in wells (10 and 13), respectively. Meanwhile, the percentage values for magnesium risk ranged from (30.7-88.1) %, with the lowest

value being (30.7) % in the water of well (11) during December (2024), compared to the highest percentage in the water of well (10), which was (88.1) % during September (2024).

Table 3: Standard Parameters for Irrigation Water

Physical and Chemical characters	Range
pH	8.4-6.5 €
E.C μ s/cm	2250 **
SO ₄ ⁻² mg/L	920 €
Cl ⁻ mg/L	100 ***
Ca ⁺² mg/L	400 €
Mg ⁺² mg/L	61 €
Mg Hazard	50 €
NO ₃ ⁻¹ mg/L	45 €
K ⁺ mg/L	78 €
Na ⁺ mg/L	100 €
SAR	18**
Na%	40**

CCME (2017) *** Ayers and Westcot (1994) [18] € US Salinity Laboratory (1954) [36] **

Water Quality Guidelines for Irrigation

The results of the current study revealed a variation in the Canadian Water Quality Index values in the analyzed well samples, with measurements ranging from 44 to 83. Data analysis showed that 93.3% of the water samples fell into the good category, while the remaining 6.7% were classified as marginal, as detailed in Table (5).

The values of Sodium Adsorption Ratio (SAR), Sodium Saturation Percentage (SSP), and magnesium hazard were calculated using the equations below:

Sodium Adsorption Ratio (SAR)

was calculated according to the following equation and expressed in milliequivalents per liter:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}}$$

Sodium Saturation Percentage (SSP)

was calculated according to the following equation and expressed in milliequivalents per liter:

$$\% Na = \frac{Na^+}{[Ca^{+2} + Mg^{+2} + Na^+ + K^+]} \times 100$$

magnesium hazard

was calculated according to the following equation (Paliwal,1972) [34]

$$\% Mg = \frac{Mg^{+2}}{Ca^{+2} + Mg^{+2}} \times 100$$

The condition of the water sample is expressed by linking the value of the index to a numerical scale as shown in Table (4).

Table 4: Water Quality Index Values (Lumb *et al.*, 2006) ^[32].

Grade	Water Quality Index	Assessment	Description
1	Excellent	95-100	Water quality is protected, assuming the absence of pollution sources, and the water condition is very close to clean levels
2	Good	80-94	Water quality is protected but may be weak or slightly threatened, and the water condition rarely deviates from the desired or required level
3	Moderate	60-79	Water quality is often protected, but may be weak or threatened occasionally, with the water condition frequently deviating from the desired or required level
4	Questionable	45-59	Water quality is often weak or threatened, with the water condition frequently deviating from the desired or required level
5	Poor	0-44	Water quality is always weak or threatened, with the water condition continuously deviating from the desired or required level

Table 5: Canadian Water Quality Inde (WQI) Values for Studied Sites

Site	Irrigation WQI	
	WQI	Category
1	88	Good
2	87	Good
3	89	Good
4	94	Good
5	93	Good
6	93	Good
7	90	Good
8	72	Moderate
9	61	Moderate
10	86	Good
11	65	Moderate
12	77	Moderate
13	67	Moderate
14	89	Good
15	89	Good

Conclusions

All water from the study wells was classified within category (S1) based on sodium adsorption ratios, indicating that the water is suitable for irrigating most crops and nearly all soils, except for crops that are very sensitive to sodium. Most well waters were classified as excellent for irrigation based on the percentage of dissolved sodium, except for well number (8), which was classified as good.

Recommendations

1. Conduct an extensive environmental study on groundwater that includes most areas of Rabiah District and western Nineveh, in addition to other districts and sub-districts of the governorate.
2. Conduct a study on the presence of heavy metals in the water of the studied wells.
3. Conduct a study on the use of one of the treatment methods to achieve high-quality water purity.
4. Apply other water quality indicators such as the weighted mathematical model and the National Health Institute model.
5. Conduct a study of groundwater in Rabiah District that includes broader chemical and physical examinations.

References

1. Abawi, Suad Abdul and Hassan Mohammed Suleiman Practical engineering for the environment - Water tests. Ministry of Higher Education and Scientific Research, University of Mosul, Ira, 1990
2. Abdulaziz, Abdulrazak Misbah, Al-Amari, Khairy Mohammed, Saber, Ali Khair Assessment of groundwater quality for drinking purposes using the Water Quality Index in the city of Sorman - Libya, Libyan Journal of Environmental Sciences and Technology, 2019:2:7-11.
3. Al-Assaf AY, Talat RA, Al-Saffawi AY, T. Suitability of water for irrigation and livestock watering purpose using IWQI Model: The case study, groundwater quality of some quarters of Mosul city, Iraq. Plant Archives, 2020:20(1):1797-1802.
4. Al-Hadidi, Amina Faris Farhan Assessment of the water quality of the Tigris River in the area between the Mosul Dam and Qayyarah for various uses. Master's thesis, College of Environmental Sciences Technology, University of Mosul, Iraq, 2018 .
5. Al-Hamdani, Noor Ahmad Sadoun Application of water quality indicators to assess the quality of water

- from several wells in the left bank of Mosul City, Iraq. Master's thesis, College of Environmental Sciences and Technology, University of Mosul, Iraq, 2020.
6. Al-Jubouri, Burhan Sheet Mohammed Response of the plant *Vigna unguiculata* L. and *Phaseolus vulgaris* L. to water from some wells in southern Nineveh Governorate. Master's thesis, College of Science, Tikrit University, Iraq, 2020.
 7. Al-Khatooni, Mohammed Issa Khidr Rural settlement in Tal Afar district (A study in rural geography). Doctoral dissertation, College of Education for Humanities, Tikrit University, Iraq, 2021.
 8. Al-Masoudi, Istabraq Kazem Shbout Quantitative qualitative variation of groundwater characteristics in the Al-Dujaili district. *Journal of the College of Education, Wasit University*, 2021:1(42):144-166.
 9. Abood R, Mustafa A, Al Somaydai J. Assessment of groundwater quality at selected location of three wells Al-Warrar Canal, Ramadi City, Iraq. *Iraqi Journal of Civil Engineering*, 2021:15(2):1- 7.
 10. Al-Obaidy AM, J, Al- Janabi ZZ, Shakir E. Assessment of water quality of Tigris river within Baghdad city. *Mesopotamia Environ. J*, 2015:3(1):90- 98.
 11. Al-Safawi, Abdul Aziz Younis, Al-Shanouna, Reem Adnan Abdul Razak, Maysar, Noor Assessment of water quality characteristics and calculation of the Water Quality Index (WQI) for some water sources in Abu Maria village, Tal Afar district, Nineveh Governorate. *Journal of Education Science*, 2018:27(3):81-98 .
 12. Al-Saleh AM, Khalaefa N, Mahid HH. Environmental Consequences of Soil Heavy Metal Contamination in Gharyan Regions, Libya: A Comprehensive Study. *Rafidain Journal of Science*, 2023:32(4):10-24.
 13. Al-Shanona RA, A, Al-Sardar NM, S, Al-Saffawi AY, T. Water quality assessment for irrigation and livestock drinking in Abu Maria village/district of Tall-Afar-Iraq. *Accepted for publication in J.En. st (JES)*, 2018:18:9-14.
 14. Al-Sudani HI, Z. Hydrochemistry of Groundwater in northeast part of Anbar Governorate–West of Iraq. *Baghdad Science Journal*, 2019:16(1):88-96.
 15. Amos Agossou, jeongSeok Boem lee. Evaluation of Potential Seawater intrusion in the Coastal Aquifers System of Benin And Effect of Countermeasures considering future sea level rise. *Water*, 2022:14:4001.
 16. Ankidawa BA, Ishaku JM, Bello Y. Hydrogeochemistry and Groundwater Quality Index in Hong Environs, Adamawa State, North Eastern Nigeria. *International Journal of Integrated Engineering*, 2017:9(3):58-71.
 17. APHA AWWA WCDE Standard Methods for The Examination of Water and Waste Water". 23rd. Ed. Washington DC. USA, 2017, 1-55.
 18. Ayers RS, Westcot DW, Water Quality for Agriculture Irrigation and Drainage. Paper Rev.1. FAO, Rome, 1994, 29.
 19. Bhutiani R, Ahamad F, Ram K. Quality assessment of groundwater at laksar block, Haridwar in uttarakhand, India using water quality index: A case study. *Journal of Applied and Natural Science*, 2021:13(1):197-203.
 20. Canadian Council of Ministers of the Environment (CCME). Canadian Water Quality Guidelines for the Protection of Aquatic Life: CCME Water Quality Index, User's Manual—2017 Update. In *Canadian Environmental Quality Guidelines, 1999*; Canadian Council of Ministers of the Environment: Winnipeg, MB, Canada, 2017. Available online: <https://ccme.ca/en/res/wqimanualen.pdf> (access ed on 10 January 2022).
 21. Chegbeleh, L. P., Akurugu, B. A., and Yidana, S. M. (2020). Assessment of groundwater quality in the Talensi District, Northern Ghana. *The Scientific World Journal*, 2020:8450860: 1-24.
 22. Condon LE, Kollet S, Bierkens MF, Fogg GE, Maxwell RM, Hill MC. *et al.* Global groundwater modeling and monitoring: Opportunities challenges. *Water Resources Research*, 2021:57(12):2020029500.
 23. Egbueri JC, Mgbenu CN, Chukwu CN, Investigating the hydrogeochemical processes quality of water resources in Ojoto environs using integrated classical methods. *Modeling Earth Systems Environment*, 2019:5(4):1443-1461.
 24. Hussein, Ahmad Hussein. Groundwater pollution due to karst system effects in the Sinjar area. *Journal of Arts College Research, Menoufia University*, 2022, 130, 23.
 25. Hussein AL, ZN. Identifying areas with high potential for groundwater availability in Najaf Governorate. *Nasaq*, 2024, 43(10).
 26. Ibrahim LA, Nofal ER. Quality hydrogeochemistry appraisal for groundwater in Tenth of Ramadan Area, Egypt. *Water Science*, 2020:34(1):50-64.
 27. Jassim, Qadisiyah Hussein Abdul Sattar, Ahmad Spatial analysis of groundwater characteristics in the southeast of Al-Yusufiyah district. *Al-Mustansiriya Journal for Arab International Studies*, 2021:18(74):134-152.
 28. Kannah A. The suitability of groundwater in Mosul city for various civilizational uses. *Journal of Education and Science*, 2021:30(4),54-0.
 29. Kannah AM, Muhammad QT. Assessment the Quality Number of Well Water on the Left Side of the City of Mosul/Iraq and its Suitability for Drinking Using the Canadian Water Quality Index. *Rafidain journal of science*, 2022, 31(4).
 30. Lawa FA. Biostratigraphy depositional environment of the Oligocene–Miocene sediments in the Mosul–Qaiyara area, North Iraq. *GEOSURV, int. rep*, 1989, 1801.
 31. Li P, Karunanidhi D, Subramani T, Srinivasamoorthy, K. Sources consequences of groundwater contamination. *Archives of environmental contamination and toxicology*, 2021:80:1-10.
 32. Lumb A, Doug H, Tribeni S. Application of CCME water quality index to monitor water quality: A case of the Mackenzie river Baisn, Canada. *Environ. Mon. Asses*, 2006:113:411- 429.
 33. Nsabimana A, Li P, Wang Y, Alam SK. Variation and multi-time series prediction of total hardness in groundwater of the Guanzhong Plain (China) using grey Markov model. *Environmental Monitoring Assessment*, 2022:194(12):899.
 34. Paliwal KV. Irrigation with Saline Water IA, RA, *Monograph (2) (New Series)*, New Delhi, 1972, 198

35. Sissakian VK. State Establishment of Geological Survey Mining (GEGSURV). January, Baghdad printing dept. Baghdad Iraq, 1995, 352.
36. US Salinity Lab oratory Diagnosis Improvement of saline and alkaline soils. Department of Agriculture, Hand book,1954:60:160.
37. Yahya M, Qusai AK, Ajena A. Hydrogeological Characteristics of Rabia Sub-Basin Northwest, Iraq. *Iraqi Bulletin of Geology Mining*,2023:19(1):77-97.
38. Zhou Y, Li, P, Xue L, Dong Z, Li, D. Solute geochemistry and groundwater quality for drinking irrigation purposes: a case study in Xinle City, North China. *Geochemistry*,2020:80(4):125609.