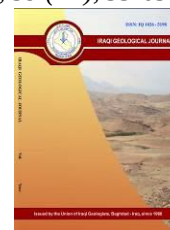




Iraqi Geological Journal

Journal homepage: <https://www.igi-iraq.org>



GIS-Based Evaluation of Groundwater Quality for Drinking Purposes in Selected Areas within Salah al-Din Governorate, Iraq

Salwan S. Al-Hasnawi¹  and Ahmed S. Al-Zubedi^{1*} 
¹ Remote Sensing and Geophysics College, AlKarkh University of Science, Baghdad, Iraq
* Correspondence: AhmedSrdah@yahoo.com

Abstract

Received:
27 February 0026
Accepted:
4 June 2026
Published:
31 July 2026

Groundwater provides is a crucial supply of drinking water in semi-arid regions where surface water is scarce and unreliable. Groundwater quality in the north-central Iraq effected by complex geological and hydrogeological conditions, spatially integrated assessments remain limited. The present study assesses the suitability of groundwater for drinking in the area between Tikrit and Baiji, Salah Al-Din Governorate, through combining hydro-chemical analysis with the Weighted Arithmetic met Water Quality Index and Geographic Information System techniques. Water samples taken from 33 groundwater wells, scattered in the study area, were analyzed to determine the major physical and chemical parameters which then evaluated basedon World Health Organization guidelines for drinking water. The calculated values of WAWQI were used to classify groundwater quality, and Inverse Distance Weighting interpolation was used to examine spatial variability over the study area. The results show that most samples are fall within the poor to unsuitable categories for drinking, largely due to high concentrations of total dissolved solids, namely: sulfate, nitrate and sodium. Spatial patterns of groundwater quality reflect variations in lithology and structurally controlled hydrogeological conditions within the Injana aquifer system. The integrated Weighted Arithmetic Water Quality Index-Geographic Information System approach offers a practical basis for identifying areas of groundwater quality degradation and supports informed groundwater management in semi-arid environments.

Keywords: GIS; Groundwater Quality; Weighted Arithmetic water quality index; Salah al-Din Governorate; Iraq

1. Introduction

In arid and semi-arid regions like the area locates between Tikrit and Baiji within Salah Al-Din Governorate in Iraq, groundwater is a crucial natural water resource, alongside surface water, especially for drinking and other uses. Therefore, the quality of this water is a significant factor impacting public health, economic and social well-being, and sustainable development.

One of the modern methods for assessing water quality by representing it with a single numerical value is the Weighted Arithmetic Water Quality Index (WAWQI), developed by (Brown et al., 1970) and improved by (Chatterjee and Raziuddin, 2002). This method assigns values to each element present in the water based on its degree of impact on water quality, and has therefore proven successful in many studies, such as by (Al-Waeli et al., 2021) in Iraq. These findings highlight the need to understand the tectonic framework to explain the spatial variation in water quality.

Modern trends in water quality studies have focused on integrating geospatial analysis within a Geographic Information System (GIS) environment with water quality indicators. This integration facilitates the visual interpretation of spatial variations in water quality through spatial interpolation methods (Mohamed et al., 2026)

Most studies carried out in the area between Tikrit and Baiji have focused on hydrochemical classification without clarifying the influence of structural and tectonic composition. However, Ahmed et al. (2023) in their study assessed the groundwater quality of the northern region of Salah al-Din Governorate (Bayji as a case study) and the health risks posed by nitrate ions to infants, children, and adults living in villages. Ismail et al. (2023) investigated the hydrochemistry and water quality of shallow groundwater in Tikrit, their conclusion is generally unsuitable for drinking and irrigation. On the other hand, investigated the impact of structural composition on distribution in Salah al-Din Governorate. However, groundwater quality using WAWQI and its interaction with structural composition in the area located between Tikrit and Baiji in Salah Din Governorate has not yet been studied. Therefore, the current research addresses using WAWQI with GIS to assess groundwater quality for drinking purposes in 33 wells distributed in this area, based on the WHO drinking water criteria. The study will also examine the impact of structural composition on the spatial variation of groundwater suitability and integrate hydrochemical analyses, spatial interpolation, and structural composition analysis to represent water quality. The findings of this research can be utilized in the sustainable development of groundwater resources, with a focus on identifying key areas.

2. Location and Geology of the Study Area

The study area is located within Salah ad-Din Governorate in the north-central part of Iraq which lies between longitudes $43^{\circ}18'39''$ – $43^{\circ}41'21''$ and latitudes $34^{\circ}35'20''$ – $34^{\circ}55'42''$ (Fig. 1).

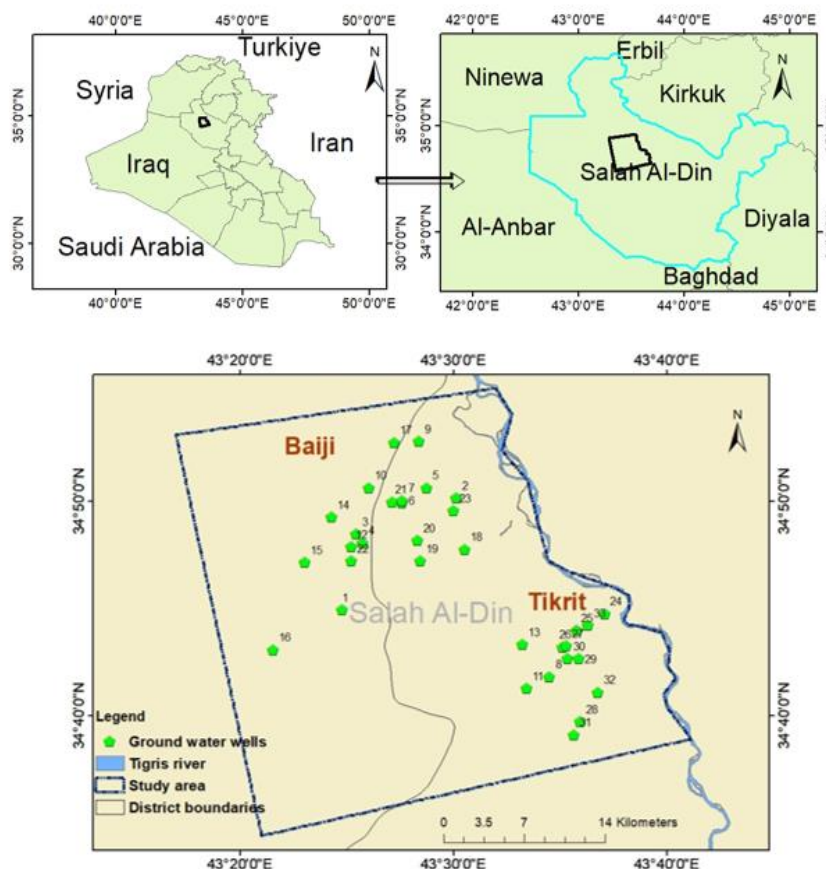


Fig. 1. Map of the study area and its well locations

It is bordered to the northeast by the Tigris River, and to the southwest by the Tikrit subsurface fold, to the southeast by the Shishin Valley in Tikrit, and to the northwest by the sand dunes of Baiji. Ithasa total area of 915 km². The area is generally flat, interspersed with small valleys that flow southeast towards the Tigris River. The elevation is about 160 m above sea level at the western edge of the study area and gradually decreases eastward to 100 m at the Tigris Riverbank.

Tectonically, the study area is located in the Hemrin- Makhul Subzone, also known as the Foothill Zone, which has a thick sediment cover (Jassim and Goff, 2006).

Geologically, the Quaternary sediments and the Injana Formation are the exposed rock in the area of interest. The Sandstone, siltstone and silty claystone with gypsum nodule Midules as thin layers make up the Upper Miocene Injana Formation. Floodplain deposits, river terraces, and the gypsiferous soil that covers the Injana Formation distinguish Quaternary deposits (Pleistocene and Holocene) in some parts of the study area.

From a hydrogeological point of view, the area contains two aquifers: one belongs to the Quaternary deposits, which has shallow wells, unconfined type whereas the other is Injana Formation, which has deep wells, confined type, as stated in Ahmed et al. (2023).

3. Materials and Methods

3.1. Sampling of Groundwater Hydrochemical Data

In this study, groundwater Hydro-Chemical and GIS data for the study area were used to assess water quality for drinking purposes. The comprehensive spatial representation of the study area was achieved through the randomly in sampling locations within the study area.

Water samples were taken through the fieldwork in which carried out from 33 groundwater wells distributed throughout the study area (Fig. 1) above, in the summer of 2025. Two liters dry plastic bottles were used to collect the samples, which then these samples were chemically analyzed according to the standard methods for testing water and wastewater (APHA, 2017) to obtain conductivity data for total dissolved solids (TDS), pH and elements Na⁺, Mg²⁺, Ca²⁺, SO₄²⁻, HCO₃⁻, CO₃²⁻, and NO₃⁻, which represent the hydrochemical data. This data was used to calculate the WAWQL.

The water quality standards of WHO (2022) have been adopted for assessing groundwater quality for drinking purposes (Table 1).

Table 1. Guidelines for drinking-water quality (WHO, 2022)

Parameter	WHO guideline (mg/L or range) (Standard (Si))	Ideal Value (Vi)
EC	400	0
TDS	1000	0
Na ⁺	200	0
K ⁺	12	0
Mg ²⁺	50	0
Ca ²⁺	75	0
SO ₄ ²⁻	250	0
Cl ⁻	250	0
HCO ₃ ⁻	500	0
(μS/cm)		

ArcGIS 10.8.2 software from ESRI was used for the purpose of processing and geospatial analysis, as well as for mapping the distribution of groundwater well locations. In addition, Microsoft Excel

software was used for the purpose of managing the well databases and WAWQI calculations, also was used for the purpose of classifying water quality for well sampling sites.

The current study employs an integrated geochemical-hydro-chemical approach to evaluate the drinking water quality of 33 wells within the study area. The geospatial analysis also performed with WAWQI values to cover all study area. The methodology consists of many stages, which is detailed below.

3.2. Data Pre-processing

The initial data of hydro-chemical analyses for total dissolved solids (TDS), pH, and elements Na^+ , Mg^{2+} , Ca^{2+} , SO_4^{2-} , HCO_3^- , CO_3^{2-} , and NO_3^- , results from groundwater samples is verified and standardized using Microsoft Excel to confirm analytical accuracy and consistency. The verification process involved the following:

- Unit format (ml/l or um/l)
- Verifying anomalous inductions and extreme values through descriptive suggestion

Ideal value (VI) and the maximum allowable limit (Si) for each parameter was then determined based on WHO (2022). The weighted water quality index WAWQI for the hydro-chemical data was then analyzed by calculating the quality rating (Qi) and the unit weight (Wi) for each parameter based on Brown et al. (1970).

3.3. Weighted Arithmeticwater Quality Index Calculation

In order to combine the values of all hydro-chemical analysis parameters into a single composite value representing the quality of groundwater, both techniques by Brown et al. (1970) and Tyagi et al. (2013) were used. The Water Quality Index calculation WAWQI method was performed for all hydro-chemical parameters in order to assess the groundwater quality for drinking purposes. Applying this indicator involves several steps. First, rating the quality by using the equation:

$$Q_i = (S_i - V_i / C_i - V_i) * 100, \quad (1)$$

Whereas: C_i : Measured concentration of coefficient I, S_i : Maximum limit allowed according to WHO (2022), V_i : Ideal Value

Then, assign weights (W_i) for all hydro-chemical parameters using the equation:

$$W_i = 1/S_i, \quad (2)$$

The weight of each coefficient is inversely proportional to the maximum allowed value according to WHO (2022). This highlights the importance of coefficients with strict limitations given their strong impact on humans.

The overall calculation of WAWQI using (Eq. 3) given below:

$$\text{WAWQI} = \frac{\sum_{i=1}^n Q_i W_i}{\sum_{i=1}^n W_i} \quad (3)$$

The Criteria of classification which Based on the calculated WAWQI value, the groundwater quality can be classified as follows in Table 2.

Table 2. Classification criteria of groundwater quality (Brown et al., 1970)

WAWQI Value	Water Quality Status
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very Poor
>100	Unsuitable for drinking

Qi, Wi, and WAWQI were calculated using Microsoft Excel for all 33 well models, in addition to calculate the final classification for water quality suitability.

3.4. GIS-Based Geospatial Analysis and Interpolation

ArcGIS 10 software was used to conduct the Geospatial analysis within a GIS environment for the purpose of understanding and interpreting the geographic spatial distribution of groundwater well data quality over the study area. The calculated results of WAWQI for well models were linked to the well coordinates, then the Inexact Inverse Distance Weighting (IDW) type spatial interpolation method was used to represent the spatial variation of groundwater quality in the form of a continuous raster surface for the study area according to (Chowdhury et al., 2012; Adimalla, 2019). IDW is chosen because it is a local interpolation technique that, when applied to unevenly dispersed groundwater wells, effectively captures short-range spatial variability by giving neighboring sampling locations more influence (Li and Heap, 2014).

3.5. The Hydrogeological Statue for Geospatial Interpolation

The interpolation technique was used to create a quality raster if the groundwater is located in a single aquifer. When groundwater wells are examined within a single aquifer, the application of geospatial interpolation techniques is scientifically justified because the aquifer constitutes a hydraulically and geochemically continuous system in which groundwater quality parameters are expected to gradually change under similar lithological, hydraulic, and recharge conditions, allowing for the reliably transposition of measurements from separate wells to a continuous raster surfaces (Freeze and Cherry, 1979; Domenico and Schwartz, 1998; Fetter, 2001). Conversely, preform interpolation for wells falls within more than single aquifer, then misleading data is results because it combines data from distinct hydrogeological units with different flow systems and geochemical characteristics; therefore, groundwater quality mapping should be carried out separately for each aquifer or classified by aquifer type to ensure hydrogeological consistency (Burrough et al., 1998; Li and Heap, 2014).

4. Results and Discussion

4.1. The Hydrochemical Characteristics for Groundwater

The final results of the hydro-chemical and geospatial analyses revealed significant variations in the groundwater quality within the study area.

The hydro-chemical characteristics of the 33 well samples (Table 3) which were monitored before, reveal a high degree of spatial variability in the groundwater quality over the study area. The analytical results indicate that many key parameters most notably total dissolved solids (TDS), sulfate (SO_4^{2-}), nitrate (NO_3^-), and sodium (Na^+), exceed the maximum permissible limits that set by the World Health Organization (WHO, 2022) in a large percentage of the sites sampled. These peaks in sulfate and salinity levels are generally considered an indicator of long periods of groundwater retention and circulation through the secondary gypsum occurring within these layers of the Injana in addition to overlying Quaternary deposits (Freeze and Cherry, 1979; Domenico and Schwartz, 1998; Al-Kubaisi et al., 2022). This variation in the chemistry of major ions underscores the dominance of water and rock interaction as the primary driver of regional hydro-chemical evolution. Processes such as the heterogeneous dissolution of minerals and cation exchange appear to be intensified by the prevailing arid and semi-arid climatic regime, which promotes evaporative enrichment (Fetter, 2001). These results are consistent with previous studies in the Tikrit vicinity, reinforcing a broader regional narrative of gradual groundwater salinization resulting from both rock composition and climatic stressors (Ismail et al., 2023).

Table 3.The hydro-chemical characteristics of the 33 wells samples in the study area

We ll	X	Y	TDS	K	Na	Mg	Ca	Cl-	SO ₄ ²⁻	HCO ₃	NO ₃	pH
1	43.41	34.74	2300.0	11.7	322.0	73.0	221.0	465.0	691.00	238.0	2.11	6.6
2	43.50	34.83	1950.0	4.30	311.0	60.8	128.2	360.0	500.00	269.0	45.0	7.9
3	43.42	34.80	2820.0	6.60	360.0	97.0	241.0	466.0	800.00	370.0	8.50	7.6
4	43.42	34.80	2020.0	2.55	300.0	43.0	140.2	270.0	620.00	177.0	20.0	7.7
5	43.47	34.84	1650.0	5.50	150.0	80.0	181.0	178.0	629.00	245.0	11.6	8.1
6	43.46	34.83	1980.0	5.47	344.0	52.0	120.2	266.0	600.00	311.0	15.0	8.1
7	43.46	34.83	2300.0	4.60	299.0	85.1	229.0	355.0	769.00	302.0	24.0	7.9
8	43.57	34.69	1730.0	4.30	230.0	37.0	120.2	142.0	580.00	191.0	11.0	8.1
9	43.47	34.88	1920.0	4.30	230.0	73.0	126.2	295.0	634.00	155.0	22.0	7.9
10	43.43	34.84	1820.0	4.30	288.0	45.0	80.10	178.0	535.00	190.0	32.0	8.1
11	43.55	34.68	2910.0	10.1	368.0	100.0	323.1	490.0	1100.0	219.0	1.28	7.6
12	43.42	34.79	2683.0	12.6	405.0	100.0	230.0	258.0	1072.0	312.0	1.80	7.8
13	43.55	34.72	3500.0	5.40	345.0	180.0	366.0	5.40	1407.2	255.0	20.0	7.9
14	43.40	34.82	2390.0	4.00	339.0	108.0	210.0	518.0	560.00	445.0	3.00	7.6
15	43.38	34.78	1950.0	3.00	212.0	108.0	196.0	461.0	413.00	395.0	4.00	7.1
16	43.35	34.71	3412.0	6.20	511.0	130.0	312.0	670.0	1069.0	360.0	11.0	7.1
17	43.45	34.87	20911.	4.50	255.0	85.0	181.0	439.0	520.00	149.0	7.50	7.7
18	43.50	34.79	2930.0	2.50	466.0	93.0	202.0	520.0	570.00	443.0	4.50	7.9
19	43.47	34.78	3158.0	5.10	470.0	94.0	210.0	540.0	570.00	450.0	1.10	8.5
20	43.47	34.80	2572.0	11.0	302.0	130.0	220.0	700.0	325.00	419.0	2.00	8.2
21	43.45	34.83	2912.0	3.50	520.0	100.0	214.0	560.0	380.00	499.0	2.90	8.8
22	43.42	34.78	2769.0	3.50	467.0	99.0	210.0	530.0	460.00	440.0	5.40	7.8
23	43.50	34.82	2027.0	5.00	220.0	115.0	190.0	479.0	417.60	390.0	5.00	7.7
24	43.61	34.74	1580.0	2.33	198.0	76.00	140.2	290.0	481.00	220.0	5.50	7.7
25	43.59	34.73	2310.0	5.00	300.0	85.10	200.4	260.0	922.00	211.0	2.32	7.6
26	43.58	34.72	1980.0	5.80	221.0	110.0	181.0	150.0	1028.0	110.0	10.0	7.9
27	43.58	34.72	2100.0	5.40	276.0	67.00	221.0	198.0	937.00	171.0	10.0	7.7
28	43.59	34.66	1922.0	9.10	213.0	65.00	107.0	202.0	589.00	140.0	6.10	7.2
29	43.59	34.71	1656.0	5.20	265.0	35.00	108.0	242.0	502.00	135.0	9.10	7.9
30	43.58	34.71	1965.0	2.80	140.0	111.0	225.0	239.0	799.00	121.0	11.0	7.2
31	43.59	34.65	1822.0	4.00	131.0	101.0	222.0	241.0	800.00	132.0	3.10	7.9
32	43.61	34.68	2100.0	3.50	138.0	104.0	229.0	248.2	802.10	140.0	3.32	7.7
33	43.60	34.73	1987.0	5.40	274.0	66.00	219.0	195.0	935.00	164.0	10.0	7.8

4.2. Weighted Arithmetic Water Quality Index Analysis and Classification

The Water Quality Index (WAWQI) was calculated for each 33 groundwater wells in the study area using physicochemical analysis of TDS, pH, Na⁺, Mg²⁺, Ca²⁺, SO₄²⁻, HCO₃⁻, CO₃²⁻ and NO₃⁻ concentrations which were compared to the WHO (2022) drinking water standards which then classified based on quality (Tables 2 and 4) exhibit the WAWQI classification.

Table 4. The Water Quality Index values for each 33 groundwater wells in the study area

Well ID.	WAWQI	Class	Well ID.	WAWQI	Class
1.00	86.38	Very Poor	31.00	118.68	Unsuitable
2.00	108.88	Unsuitable	32.00	82.57	Very Poor
3.00	118.16	Unsuitable	33.00	95.15	Very Poor
4.00	78.30	Very Poor	34.00	128.71	Unsuitable
5.00	71.52	Poor	35.00	89.38	Very Poor
6.00	107.97	Unsuitable	36.00	88.72	Very Poor
7.00	60.46	Poor	37.00	91.66	Very Poor
8.00	82.73	Very Poor	38.00	95.42	Very Poor
9.00	72.99	Poor	39.00	74.96	Poor
10.00	87.50	Very Poor	40.00	61.21	Poor
11.00	95.15	Very Poor	41.00	76.92	Very Poor
12.00	59.10	Poor	42.00	168.31	Unsuitable
13.00	74.31	Poor	43.00	83.54	Very Poor
14.00	62.94	Poor	44.00	88.35	Very Poor
15.00	135.55	Unsuitable	45.00	96.45	Very Poor
16.00	133.92	Unsuitable	46.00	88.71	Very Poor
17.00	143.00	Unsuitable	47.00	84.72	Very Poor
18.00	159.35	Unsuitable	48.00	55.71	Poor
19.00	80.67	Very Poor	49.00	85.89	Very Poor
20.00	85.14	Very Poor	50.00	61.36	Poor
21.00	187.30	Unsuitable	51.00	85.68	Very Poor
22.00	91.31	Poor	52.00	85.92	Poor
23.00	80.76	Poor	53.00	85.72	Poor
24.00	81.22	Poor	54.00	86.87	Poor
25.00	160.39	Unsuitable	55.00	66.94	Poor
26.00	109.06	Unsuitable	56.00	88.04	Poor
27.00	131.22	Unsuitable	57.00	89.01	Poor
28.00	91.97	Poor	58.00	131.96	Unsuitable
29.00	94.10	Poor	59.00	128.24	Unsuitable
30.00	78.85	Poor			

The WAWQI results indicated that the groundwater quality of most wells in the study area was classified as poor and unsuitable, primarily due to high concentrations of sulfites, salts and nitrates, which exceeded the limits permitted by the WHO (2022), as shown in Fig. 2.

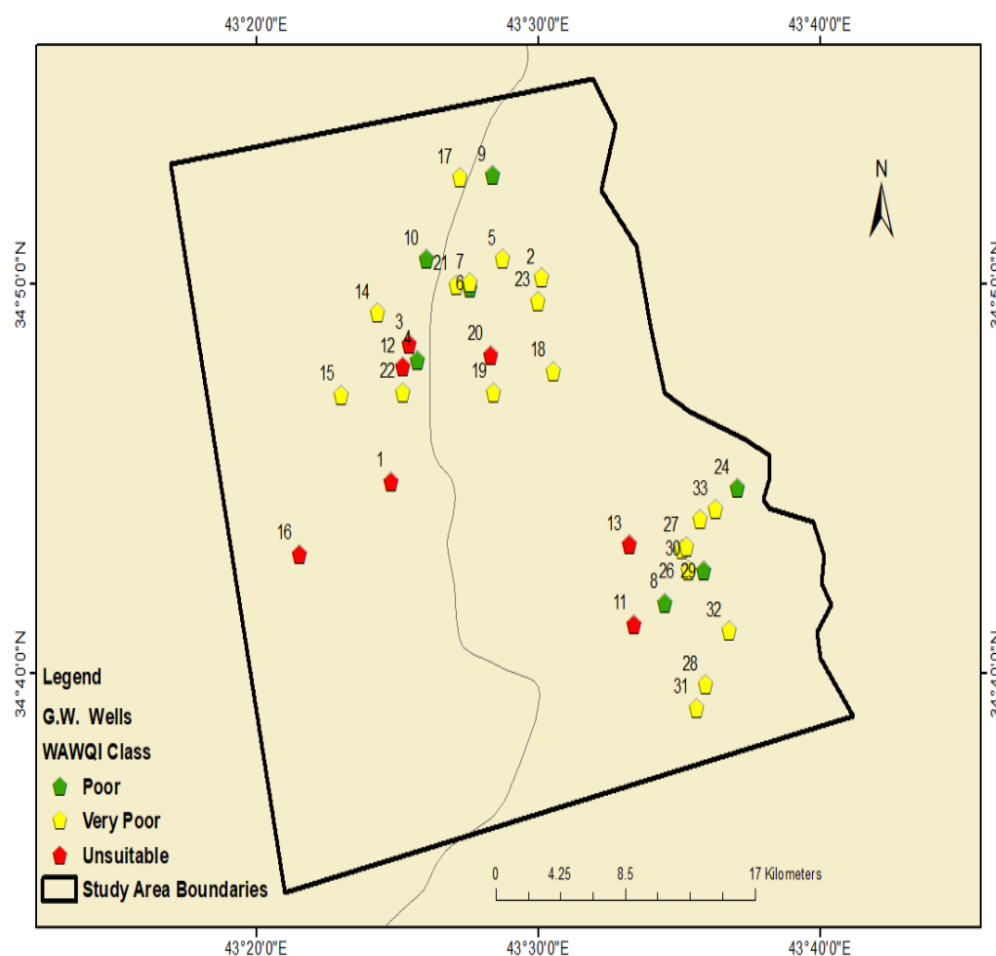


Fig. 2. The WAWQI classes for groundwater well sample locations in the study area

4.3. The Geospatial Distribution of Weighted Arithmetic Groundwater Quality

The variation of the groundwater quality patterns in the study area was clearly represented by spatial distribution maps produced by interpolation IDW technique using ArcGIS software. The WAWQI index was represented as a continuous raster surface (Fig. 3), indicating that well areas with better water quality (poor to very poor) are concentrated in the central parts and southeastern (and also in north part) of the study area, while the well of areas with higher WAWQI values reflected lower water quality (unsuitable) which are concentrated in the central western and southwestern parts of the study area.

The variation in the groundwater quality of the study area is attributed to the fact that the Injana Aquifer is a multi-water-bearing horizon, resulting from the interbedding of permeable and impermeable rock units according to Al-Joboory (2011). In the central western and southwestern part of the study area, the groundwater is unsuitable for drinking purposes, while in most other parts are considered very poor in quality, also there are a few sites with poor groundwater quality. This variation in the groundwater quality of the study area is coming because of the key role played by the presence of partial hydraulic connection in some parts of the aquifer, due to the clay layers separating its units being fractured, in addition to the presence of local or regional deep faults according to Jassim and Goff (2006). In general, the heterogeneity in the lithology of the aquifer, topographic gradient, bedding inclination, and mixing between aquifers have all contributed to this variation.

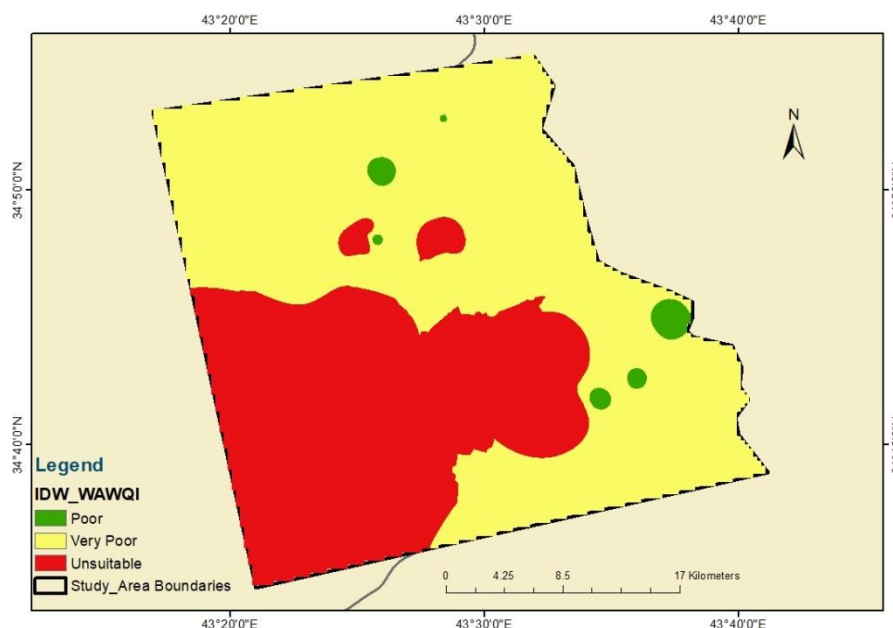


Fig. 3. IDW Interpolation raster surface for WAWQI index for the study area

The WAWQI raster map shows that areas of low groundwater quality, the highest WAWQI values were found that is because of high ion concentrations (especially sodium). The concentrations of sodium (Na), sulfates (SO_4), and total dissolved solids (TDS) are a result of fault and fold control over groundwater flow, as well as filtration processes within the sandstone and shale units. Conversely, wells within the Injana Formation showed lower WAWQI values due to high permeability and low mineral solubility within the formation's rock units.

5. Conclusions

The given results suggest spatial heterogeneity and general deterioration of groundwater quality throughout the examine location. Hydro-chemical analyses of 33 wells show that key parameters, especially general dissolved solids (TDS), sodium (Na^+), sulfate (SO_4^{2-}), and nitrate (NO_3^-), frequently exceed (WHO, 2022) permissible limits, rendering maximum groundwater incorrect, unsuitable or very poor for drinking purposes. This degradation is mainly attributed to prolonged groundwater residence times and intensive water rock interaction within secondary gypsum and silt layers of the Injana Formation and the overlying Quaternary deposits. The dominance of salinity-associated ions highlights interaction between water, rock and evaporative enrichment as the primary processes controlling regional hydrochemical evolution.

The geospatial assessment using of the WAWQI and IDW interpolation technique reveals clear spatial styles in groundwater quality. The higher WAWQI values, indicating unsuitable water best, are concentrated in the western and southwestern parts of the study area, while groundwater quality decline significantly (from poor to very poor) in the southeastern, and northern regions. This variation demonstrates the complex hydrogeological nature of the Injana Aquifer as a multi-layered water-bearing stratum, characterized by overlapping permeable and impermeable units, variable well depths, and greater partial hydraulic interconnection through fractured clay layers and structural features that includes folds and faults. Overall, lithological heterogeneity, structural controls, topography and aquifer mixing together govern groundwater pleasant distribution, resulting in limited zones of poor but great unsuitability for potable use.

Declaration of Competing Interest

The authors declare that they have no competing financial interests or personal relationships that could influence the work reported in this study.

Acknowledgments

We would like to thank Al-Karkh University of Science for facilitating the sample analysis procedures and thus completing the research.

Statements and Declarations

The author has read and agreed to the pdf version of the manuscript. The author did not receive support from any organization for the submitted work. No funding was received to assist with the preparation of this manuscript. No funding was received for conducting this study. No funds, grants, or other support were received. The author has no relevant financial or non-financial interests to disclose. The author has no competing interests to declare that are relevant to the content of this article. The author has no financial or proprietary interests in any material discussed in this article.

Funding

Not

Availability of data and materials.

The datasets used and/or analysed during the current study available from the author.

References

- Adimalla, N., 2019. Groundwater quality for drinking and irrigation purposes and potential health risks assessment: A case study from semi-arid region of South India. *Exposure and Health*, 11(2), 109–123. <https://doi.org/10.1007/s12403-018-0288-8>
- Ahmed, S.H., Ibrahim, A.K.M., Abed, M.F., 2023. Assessing the quality of the groundwater and the nitrate exposure, North Salah Al-Din Governorate, Iraq. *Tikrit Journal of Engineering Science*, 30(1), 25–36. <https://doi.org/10.25130/tjes.30.1.3>
- Al-Waeli, J.M.A., Ali, S.K., Mohammed, A.H., 2021. Using Geographic Information Systems (GIS) Program and Water Quality Index (WQI) to Assess and Manage Groundwater Quality in the City of Baghdad. *The Journal of Engineering*, 27(3), 93–112. <https://doi.org/10.31026/J.ENG.2021.03.07>
- Al-Joboory, N.H.T., 2011. Hydrogeological Condition of Baiji - Tikrit Sub basin. MSc. Thesis, College of Science, University of Tikrit. (in Arabic).
- Al-Kubaisi, KA., Hassanein, M.M., Abduelkarem, A.R., 2022. Prevalence and associated risk factors of self-medication with over-the-counter medicines among university students in the United Arab Emirates. *Pharmacy Practice*, 20(3), 2679. <https://doi.org/10.18549/PharmPract.2022.3.2679>
- APHA (American Public Health Association), 2017. Standard Methods for the Examination of Water and Wastewater. 23rd ed. Washington, DC: APHA. <https://dokumen.pub/standard-methods-for-the-examination-of-water-and-wastewater-23th-23thnbsped-9780875532875.html>
- Brown, R.M., McClelland, N.I., Deininger, R.A., Tozer, R.G., 1970. A water quality index—do we dare? *Water and Sewage Works*, 117(10), 339–343.
- Burrough, P.A., McDonnell, R.A., Lloyd, C.D., 2015. Principles of Geographical Information Systems (3rd ed.). Oxford University Press, Oxford.
- Chatterjee, C., Raziuddin, M., 2002. Determination of water quality index of a degraded river in Asanol Industrial area, Raniganj, Burdwan, West Bengal. *Nature, Environment and Pollution Technology*, 1(2), 181–189.

- Chowdhury, R.M., Muntasir, S.Y., Hossain, M.M., 2012. Water quality index of water bodies along Faridpur–Barisal Road in Bangladesh. *Global Engineering and Technology Review*, 2(3), 1–8.
- Domenico, P.A., Schwartz, F.W., 1998. *Physical and Chemical Hydrogeology* (2nd ed.). Wiley, New York.
- Fetter, C.W., 2001. *Applied Hydrogeology* (4th ed.). Prentice-Hall, Upper Saddle River, New Jersey.
- Freeze, R.A., Cherry, J.A., 1979. *Groundwater*. Prentice-Hall, Englewood Cliffs, New Jersey.
- Ismail, A.H., Shareef, M. A., Hassan, G., Alatar, F.M., 2023. Hydrochemistry and water quality of shallow groundwater in the Tikrit area of Salah Al Din Province, Iraq. *Applied Water Science*, 13, 197. <https://doi.org/10.1007/s13201-023-02008-y>
- Jassim, S.Z., Goff, J.C., 2006. Tectonic framework. In: Jassim, S.Z., Goff, J.C. (Eds.), *Geology of Iraq*. Dolin, Prague and Moravian Museum, Brno, 45–56.
- Li, J. and Heap, A.D., 2014. Spatial interpolation methods applied in the environmental sciences: A review. *Environmental Modelling and Software*, 53, 173–189. <https://doi.org/10.1016/j.envsoft.2013.12.008>
- Mohamed, A.A., Kannapiran, A., Suliman Badawi, Supriya S. 2026. Geospatial analysis of surface water and groundwater quality using GIS in Ishaka subcounty, Bushenyi District, Uganda. *Scientific Reports* 16, 11549. <https://doi.org/10.1038/s41598-026-43003-y>
- Tyagi, S., Sharma, B., Singh, P. and Dobhal, R., 2013. Water quality assessment in terms of water quality index. *American Journal of Water Resources*, 1, 34-38. <https://doi.org/10.12691/ajwr-1-3-3>
- World Health Organization (WHO), 2022. *Guidelines for Drinking-water Quality* (4th ed.). World Health Organization, Geneva. <https://www.who.int/publications/i/item/9789240045064>