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RESEARCH ARTICLE

Groundwater Utilization and Water Quality in Khanaqin District, Diyala Governorate, Northeast of Iraq

Hussein Ilaibi Zamil Al-Sudani

Environmental Research Center, University of Technology-Iraq, Baghdad, Iraq

Correspondence to: Hussein Ilaibi Zamil Al-Sudani, Environmental Research Center, University of Technology-Iraq, Baghdad, Iraq;
Email: dr.hussein_alsudani@yahoo.com

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Abstract: Groundwater is often considered the main source of freshwater in many places worldwide. Due to their importance and susceptibility to depletion and contamination, efficient management of groundwater resources is needed. Groundwater quality depends on many factors, including geology, source water quality, and land use type. The present study dealt with the hydrochemistry of groundwater resources in the Khanaqin district, which is located in Diyala Governorate in the northeast of Iraq. The exposed geological formations in Khanaqin district range in age from Upper Jurassic up to Recent. Quaternary deposits, Bai Hassan and Injana formations were the two main types of groundwater aquifers, unconfined and confined. 68 well samples were used in hydrochemical analysis. The groundwater sampling included both aquifers in the area. The physicochemical parameters showed that the groundwater of aquifers is moderately brackish to saline. A strong linear relationship between the salinity (TDS) and electrical conductivity (EC) was obtained in the studied area. The correlation coefficient (R) was 97.73%. The salinity distribution showed a large area in the northeastern and southwestern parts of the studied area where the salinity decreased below 1000 PPM. The central and eastern parts of the studied area showed a significant increase in salinity concentration. Two polluted locations were located in the area of study with salinity concentration over 2000 PPM. The origin of groundwater was continental with a moderate brackish to saline type. 53% of the two major types of groundwater were determined in the studied area, calcium sulphate and calcium bicarbonate, with 18 samples for each one. The utilization of groundwater in the area indicates that thirty-six samples of groundwater could be used for human purposes, while fifty-eight and sixty-eight samples were utilized to be used for agriculture and animal purposes, respectively.

Keywords: groundwater utilization, water quality, Khanaqin District, Northeast of Iraq

1 Introduction

Globally, more than a third of the water used by humans comes from groundwater. In rural areas, the ratio is higher: more than half of all drinking water worldwide is supplied from groundwater. Groundwater is one of the important components in the development of any area [1]. It is important to study the groundwater quality and quantity to identify its suitability for drinking, irrigation, industrial, and other usages [2]. The availability of good-quality water is essential to preventing diseases and improving the quality of life. The use of water increased due to an increase in human population and activities [3]. The geochemistry of groundwater data provides crucial evidence of rocks' geologic history and indications of groundwater recharge, movement, and storage [4]. Determination of physical and chemical parameters of water is essential for assessing its suitability for various purposes. Generally, the quality of groundwater depends on the composition of recharge water, the interaction between the water and the soil, the soil-gas interaction, the rock with which it comes into contact in the unsaturated zone, the residence time, and reactions that take place within the aquifer [5]. Groundwater is the source of about 40 percent of the water used in the world for all purposes except for hydropower generation and electric power plant cooling. The continued groundwater extraction from the aquifers for all purposes is contributing to groundwater depletion in many parts of the world, thus understanding of groundwater chemistry contributes in determining its usefulness for domestic and agricultural purposes [6, 7]. Salinity, as expressed in total dissolved solids (TDS) is the most important parameter in groundwater hydrochemical studies, where salinity of the groundwater changes by location and time within the hydrogeological basin and water depth in the aquifer. Salinity is the first element in determining the validity of groundwater use for different purposes. The geological and topographical conditions play an important role in changing salinity due to the effects of exposed geological formations, quality of recharged water, and the topography of the basin [8,9].

The area of study, Khanaqin district, is located in the northeast part of Iraq within Diyala governorate. The area consumes huge quantities of water from groundwater aquifers, either from confined or unconfined aquifers. Both aquifers cover the district as interbedded water-bearing layers. The use of these waters was mainly for human supplies or agricultural uses. Hundreds of drilling wells are distributed in the area of study, penetrating only the unconfined aquifer or the confined aquifer, and sometimes both. In the last decades, the area has suffered from the effects of climate change on precipitation and surface water quantity, which recharge the groundwater aquifers.

This study aims to evaluate the groundwater utilization and determination of groundwater quality in the study area based on available information and exploitation requirements from theoretical and scientific perspectives, in addition to fieldwork. It will focus on evaluating and determining the hydro-geochemistry of the aquifers, which have been exploited largely in the last decade.

2 Description of studied area

The study area is located in Diyala Governorate in the northeast of Iraq, covering 1920 km^2. The geographical location of the studied area lies between longitudes (45º 10'- 45º 45') E and (34º 10 ' - 34º 45') N, as illustrated in Figure 1. The climate of the area is classified as a continental humid to semi-humid climate, as having a mean annual temperature of 22 to 24 °C, a mean annual relative humidity of 45%, and a mean annual amount of rainfall of 200 to 300 mm [10]. There are groups of major towns and villages such as Khanaqin, Jalawla, Balkana, and Quratu. The Diyala River passes the study area from the northeast towards the southwest, while Wind River, as a tributary of Diyala River, springs from the eastern area [11]. The study area is vital, being an agricultural area that depends on groundwater for several purposes. In addition, it is a good poultry and grazing area with high and significant investment from an economic point of view.

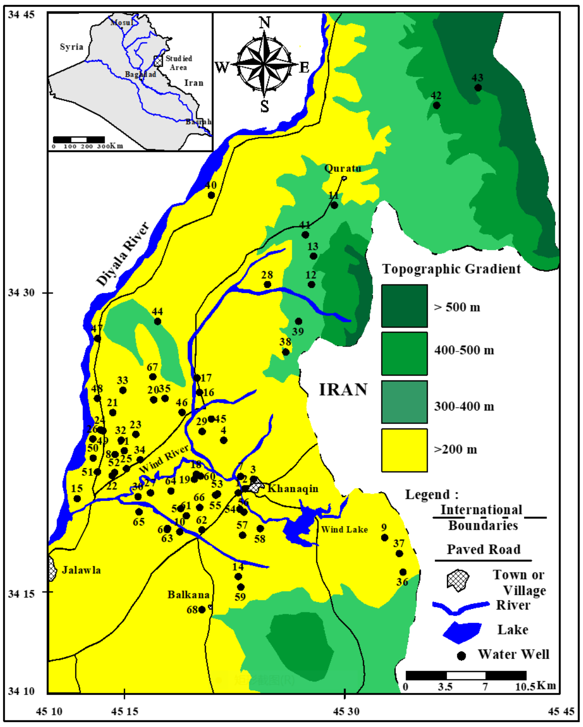

Figure 1 Location, topographic and wells distribution map of studied area

Geologically, the exposed geological formations in Khanaqin district range in age from Upper Jurassic up to Recent. The basin is built up by folded sedimentary sequence. The upper unit of Bai Hassan formation (Pliocene), which covers the older rocks by a clear angular unconformity, is considered as Bammu conglomerate (Pleistocene). Mountains, hills, and flat landscape characterize the examined area, with several ridges serving as its most noticeable morphological features. Additionally, there are a few hillocks that create a complex network of tiny valleys [12]. Structurally, the area is a part of two zones, the High-Folded Zone (north eastern part), and the majority of the area belongs to the foothill zone of the Unstable Shelf at the Nubian-Arabian Platform. Tectonically, the foothill zone here is divided into Hemrin-Makhul and Chemchemal-Butmah subzones. Chia Surakh, Ali Mire, Kiria Pika, Pulkhana, Naodoman are the main structural elements, they are asymmetrical and thrusted anticlines, separated by broad and asymmetrical synclines filled by Tertiary sediments. Tectonically, the area is a part of the unstable shelf of Iraq, as it is within the alluvial plain range, low folded zone, and high folded zone. The majority of the area belongs to the foothill zone of Iraq [13].

The hydrogeological situation of the studied area, characterized by Quaternary deposits, Bai Hassan and Mukdadiyah formations reflect the unconfined aquifer while confined aquifer consists of Mukdadiyah and Injana formations, as mentioned by Al-Sudani et al. [3, 11, 14, 15].

There are several studies have been done to evaluate morphometric properties and the hydrogeological evaluations of groundwater quality accessibility in Diyala Governorate for domestic and agricultural uses. Some of this research is dated as follows, which can be used in comparison depending on their results and the aim of this study:

(1) Hassan et al. (2014) studied the Morphometric Properties of Bulkana (Naft Khanah) North-East Iraq from Topographic Maps [16].

(2) Salman (2014) studied Hydrogeographic analysis of the reality of groundwater in the Khanaqin city and its investment possibilities [17].

(3) Al-Sudani (2017) studied the hydraulic parameters of groundwater aquifers in Khanaqin basin [14].

(4) Al-Sudani (2018) studied the hydrochemical evaluation and utilization of groundwater in Khanaqin area, Diyala governorate, east of Iraq [3].

(5) Al-Sudani (2018) studied the morphometric properties and water balance using thornthwaite method in Khanaqin Basin [10].

(6) Al-Sudani et al. (2018) studied the groundwater system of Khanaqin Basin in Diyala Governorate – East of Iraq [15].

(7) Alkilab et al. (2021) studied the water quality evaluation of selected springs in Qazania area, Diala governorate [18].

(8) Al-Hathal and Iman (2022) studied the effect of climate on the difference in groundwater levels in the Khanaqin district [19].

(9) Mahmood et al. (2025) studied Hydraulic Characteristics of Groundwater of Khanaqin Sub-Basin, Diyala Governorate, Northeast of Iraq [11].

3 Methodology and Materials

The optimal utilization of land and water resources is essential for sustainable development, Hence, these resources are generally depleting due to rapid increases in population, urbanization, and industrialization. The work plan in the study area included two main parts in 2024. The first part was the office work, which included collecting all available information and data about the area (maps, water wells, stratigraphic columns), in addition to scientific references and data from the hydrogeological data bank [20]. The second part included fieldwork to inventory drilled and operating water wells in the study area, to determine their geographical locations and to collect water samples from 68 wells that can be used in hydrochemical analysis to obtain physicochemical characteristics of groundwater to evaluate and assessment of groundwater aquifers. The analyzed hydrochemical parameters, such as pH, electrical conductivity, total dissolved solids, as well as Cations and Anions, are used to describe groundwater quality and its suitability for different purposes.

The topographic and geological maps were used in the fieldwork, and the use of a GIS device was used to determine the locations of water wells. A set of computer programs, including Excel, Surfer, and Grapher, was used to input all data obtained and process data and information to produce contour maps related to the hydrochemical characteristics of the groundwater aquifers.

4 Results and Discussion

4.1 Hydrochemistry properties of aquifers

The geological history of rocks, indications of groundwater recharge and movement in aquifers, as well as the storage coefficient, depend mainly and largely on hydro-chemical analyses of groundwater samples as crucial evidence [21]. Groundwater quality depends on many factors, including geology, source water quality, and land use type, and it is based on the physical and chemical soluble parameters due to weathering from source rocks and anthropogenic activities [22, 23].

Hydrochemical analytical data of groundwater properties are shown in Table 1. Sixty-eight samples were analyzed to obtain the physicochemical parameters. The results of pH, electrical conductivity (EC), and total dissolved solids (TDS) showed a variation as represented by minimum and maximum values. The range of pH was (7.1) to (8), the EC of (383) to (4130) μmhos/cm, and TDS was (267) to (3686) mg/l. Accordance to references, the groundwater of aquifers is moderately brackish to saline where (TDS $>$ 1000 mg/l) [21].

Table 1 Hydrochemical characteristics of aquifers in the studied area

Parameter	No. of values	Minimum	Maximum	Mean
Ph	42	7.1	8	7.4
Ec (mcomh/cm)	68	383	4130	1541
TDS (mg/l)	68	267	3686	1185
Na (mg/l)	68	9	485	111
Ca (mg/l)	68	24	544	150
Mg (mg/l)	68	8	168	58.2
SO_4 (mg/l)	68	10	1843	501
Cl (mg/l)	68	9	665	136
HCO_3 (mg/l)	68	14	489	171
NO_3 (mg/l)	68	1	80	8.6
SAR	68	0.31	9.67	2.67

4.2 Electrical Conductivity and Salinity Relationship

Electrical conductivity (EC) measures the ability of a solution to conduct electricity, while Total Dissolved Solids (TDS) measures the amount of dissolved solids in a liquid. TDS includes all dissolved substances, both those that conduct electricity (like ions) and those that don't (like some organic matter). EC is primarily influenced by the concentration of ions in the solution, as ions are what carry the electrical current. TDS is usually measured in parts per million (ppm), while EC is measured in micro Siemens per centimeter (μS/cm). Electrical Conductivity (EC) can be defined as the ability of a solution to conduct electricity [24].

These two parameters are correlated and usually expressed by a simple equation. The values of EC and TDS are correlated [25, 26]:

$$TDS = k\ EC\ (in\ 25^{\circ}C) \tag{1}$$

where k is a constant.

Conductivity or electrical conductivity (EC) and total dissolved solids (TDS) are frequently used as water quality parameters, especially in the coastal area. These two parameters are indicators of salinity level which make them very useful as one way in studying seawater intrusion [27, 28]. In the study area, the hydrochemical relationship between EC and TDS was demonstrated in Figure 2.

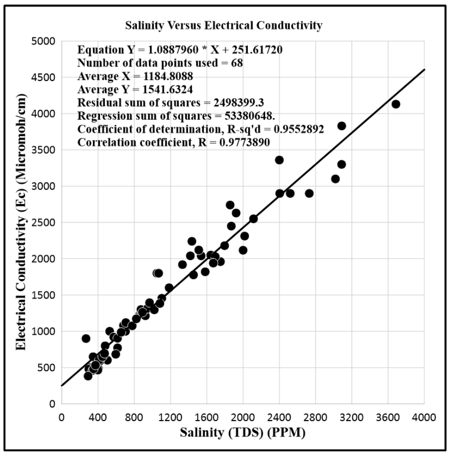

Figure 2 Salinity versus Electrical Conductivity relationship

It is obvious from the figure that there is a strong linear relationship between the Salinity expressed by Total Dissolved Solids (TDS) and Electrical Conductivity (EC). The correlation coefficient (R) was 97.73%. This hydrochemical model can be used to determine the salinity of groundwater in any location directly by measuring TDS or EC to predict the qualified area for drilling water wells.

4.3 Salinity Distribution in the studied area

Salinity is the first element in determining the validity of groundwater use for different purposes. The geological and topographical conditions play an important role in changing salinity due to the effects of exposed geological formations, the quality of recharged water, and the basin's topography [8]. The main factors that affect the variation of groundwater salinity are the recharge and drainage areas, rock type, depth of aquifer, and the path of groundwater movement, as long as groundwater recharge, infiltrated waters reduce the groundwater salinity concentration due to dilution and ionic exchange, and mixing processes between groundwater and the recharged water [22]. Figure 3 demonstrates the groundwater salinity distribution map in the studied area.

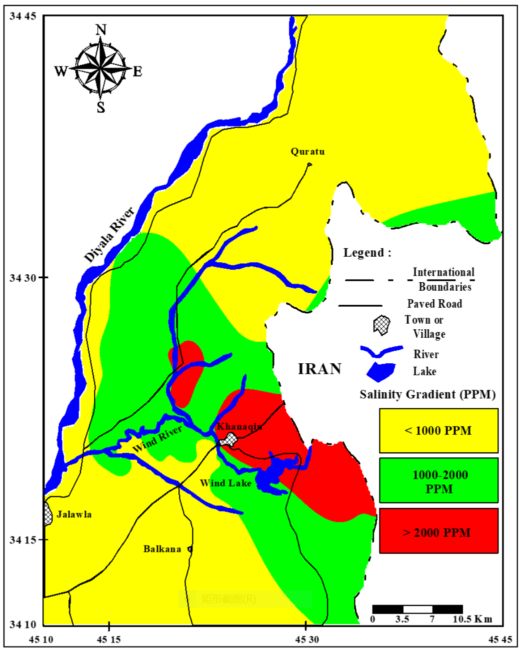

Figure 3 Salinity Map of the studied area

The salinity distribution showed a large area in the north-eastern and south-western parts of the studied area where the salinity decreased below 1000 PPM. The central and eastern parts of the studied area showed a significant increase in salinity concentration due to the existence of several geological formations exposed on the eastern side of the area, composed of Gypsum and evaporates layers, forming the groundwater aquifers. These geological formations have trapped groundwater with high ionic concentrations, which reflects the high value of salinity [14]. The same results were found by Al-Sudnai (2018) [3], but the salinity was much lower than the result of this study, which means that time and climate change affect groundwater quality.

The salinity distribution map also showed two locations of groundwater pollution. The polluted areas have salinity concentration over 2000 PPM. The first location was narrow and located in the central area of the study. The second location was much larger and located near the Iranian international border, as shown in Figure 3.

4.4 Groundwater origin and types

According to the Kurlov formula [29], which depends on the positive and negative ionic concentrations measured in epm%, the groundwater quality can be determined in this study. The groundwater in the study area was characterized to be moderately brackish to saline (TDS > 1000 mg/l), as mentioned previously, while the origin of groundwater was continental as a result of its presence in the continental layers, which were deposited in a continental deposition environment. Table 2 shows the origin of groundwater in the studied area.

Table 2 Groundwater types of groundwater aquifers in the studied area

Statistics	r(Na) epm	r(Ca) epm	r(Mg) epm	r(SO_4) epm	r(Cl) epm	r(HCO_3) epm	Kurlov Formula	Sum of wells
Minimum	2.00	7.15	1.58	8.89	1.15	0.48		
Maximum	16.30	27.20	14.00	38.39	5.69	10.22	Ca-Sulphate	18
Mean	6.44	15.60	7.73	23.20	3.54	6.05		
Minimum	0.4	1.25	0.75	0.41	0.25	2.19		
Maximum	3.70	8.20	6.83	8.87	3.94	12.90	Ca-Bicarbonate	18
Mean	1.60	4.22	2.82	3.29	1.46	7.77		
Minimum	2.08	1.40	0.66	1.46	2.47	0.45		
Maximum	10.40	8.60	9.25	10.14	15.26	5.29	Na-Chloride	12
Mean	4.38	3.10	2.73	3.68	5.38	1.67		
Minimum	3.70	1.95	1.66	6.37	1.69	1.58		
Maximum	10.65	9.40	10.75	19.37	6.78	7.00	Mg- Sulphate	9
Mean	5.40	6.183	6.66	11.61	4.42	4.08		
Minimum	9.78	1.85	1.66	6.41	4.5	5.35		
Maximum	21.08	15.75	12.50	25.16	18.73	15.77	Na- Sulphate	5
Mean	13.57	8.49	6.11	13.85	10.01	9.04		
Minimum	2.00	1.90	2.00	0.21	2.60	3.06		
Maximum	2.21	2.10	2.08	1.813	2.78	4.03	Na-Bicarbonate	3
Mean	2.10	2.017	2.05	1.25	2.66	3.42		
Minimum	0.95	1.20	1.00	0.52	1.41	0.93		
Maximum	3.26	4.00	1.75	3.70	4.78	1.29	Ca-Chloride	2
Mean	2.11	2.60	1.375	2.11	3.10	1.11		
	3	5.40	7.75	7.60	1.60	11.90	Mg-Bicarbonate	1

Two major types were recorded, where about 53% of the groundwater types were recorded as calcium sulphate and calcium bicarbonate, with 18 samples for each one. The bicarbonate reflects a good recharging rate in the area, which makes groundwater fresh and suitable for many purposes, as will be mentioned. The second two types of groundwater, with 21 samples, were sodium chloride and magnesium sulphate, with approximately 30%. The other types of groundwater were indicated as sodium sulphate, sodium bicarbonate, and calcium chloride (15%), with 10 samples. Only one sample was recorded as magnesium bicarbonate. The types of groundwater as aquifers of continental deposition environment indicate the ionic exchange and groundwater aquifer recharging in the area, as bicarbonate was highly reacted with the original groundwater in the aquifers. The main cations and anions of calcium, sodium, magnesium, and sulphate are the main aquifers forming rocks. The results obtained in this study differed significantly from the other results obtained in previous studies as related to groundwater types.

4.5 Groundwater Utilization

The 68 analyzed groundwater samples, as shown in Table 3, indicated that only thirty-six samples of groundwater could be used for human purposes, fifty-eight samples are qualified to be used in agriculture, while all sixty-eight samples indicate that to can be used for animal purposes. Salinity as reflected by cations and anions caused by groundwater contamination in some areas of the Khanaqin district due to concentrations increasing.

Table 3 The utilization of groundwater in the studied area

Parameter	PH	E.C. (μmoh/cm)	TDS (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	NO_3 (mg/l)	SAR	No. of suitability wells
Number of samples	42	68	68	68	68	68	68	68	68	48	68	
Minimum	7.1	383	267	24	8	9	9	14	10	1	0.31	
Maximum	8	4130	3686	544	168	485	665	489	1843	80	9.67	
(WHO. 2011) [30]	6.5-8.5	-	1000	75	125	200	250	200	250	50	-	36^a
(IQS. 2001) [31]	6.5-8.5	-	1000	50	50	200	250	200	250	50	-	
Standard FAO/1989 [32]	-	-	2000	40	5	20	30	10	20	-	15	58^b
Standard FAO/1989 Poultry + Livestock [32]	-	5000	-	-	250	-	-	-	-	100	-	68^c

Notes: ^{a} Human Purposes; ^{b} Irrigation purposes; ^{c} Animal purposes.

According to some previous studies and reports conducted in surrounding areas, it seems that the nature of the soil in the area and the depth of the groundwater qualify the groundwater widely in agricultural utilization. The soil formed from medium-grained sand, silt, and clay of Quaternary deposits that retains only 20% of the irrigation water, as agricultural lands are irrigated with limited quantities daily to preserve the nutrients needed by cultivated plants. Also, the nature of cultivated plants often tolerates irrigation water with high salt concentrations, while the topographical slope acts as a factor that helps accelerate in accelerating the drainage process [33].

5 Conclusion

The hydrogeological situation of the studied area is characterized by extending both unconfined and confined aquifers composed by Quaternary deposits and older geological formations belonging to the Pliocene age. Sixty-eight well samples were used in hydrochemical analysis to obtain physicochemical characteristics of groundwater to evaluate and assess the quality of groundwater aquifers and their utilization.

The range of physicochemical parameters of pH was (7.1) to (8), EC of (383) to (4130) μmhos/cm, and TDS was (267) to (3686) mg/l. A strong linear relationship between the salinity expressed by Total Dissolved Solids (TDS) and Electrical Conductivity (EC), as a hydrochemical model, was obtained in the studied area. The correlation coefficient (R) was 97.73%.

The salinity distribution map in the area showed two locations of groundwater pollution. The polluted areas have salinity concentration over 2000 PPM. The first location was narrow and located in the central area of the study. The second location was much larger and located near the Iranian international border. The origin of groundwater was continental with a moderate brackish to saline type. 53% of the two major types of groundwater were determined in the area, calcium sulphate and calcium bicarbonate, with 18 samples for each one. Thirty-six samples of groundwater could be used for human purposes, while fifty-eight and sixty-eight samples were utilized to be used for agriculture and animal purposes, respectively.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

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