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RESEARCH ARTICLE

Hydrogeological Conditions and Groundwater Geochemistry of Badra-Zurbatia Area in Wasit Governorate, East of Iraq

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Abstract: Groundwater is vital for domestic and agricultural purposes, particularly in rapidly urbanizing regions worldwide. The area between Badra and Zurbatia, which is located in Wasit Governorate, in the eastern side of Iraq, was investigated during the fieldwork in 2024. The area is important in terms of agriculture and poultry, and livestock husbandry. This research aims to evaluate the groundwater resources in the study area. The research will focus on evaluating and determining the hydrogeological and hyro-geochemical of the confined aquifer, which has been exploited largely in the last decade. (30) Wells were inventoried during the field study and used to demonstrate the hydrogeological conditions and geochemistry of the groundwater aquifer. The results showed that the confined aquifer consists of quaternary deposits and pebbly sandstone layers. The mean thickness, water permeability (transmissivity), and maximum yields of the aquifer were 46 meters, 112 square meters/day, and 655 cubic meters/day of maximum yields, respectively. The distribution map of groundwater salinity demonstrates a regular decrease in concentrations towards the southern part of the area due to groundwater recharge from infiltrated surface water to the unconfined aquifer, according to the hydraulic connection between the confined and the unconfined aquifers. The origin of groundwater is continental, with brackish to saline types. The calcium sulphate is recorded as the main dominant type of groundwater. The utilization of groundwater was mainly for animal purposes.

Keywords: hydrogeological conditions, groundwater geochemistry, Badra-Zurbatia Area, East of Iraq

1 Introduction

Worldwide, more than a third of all human water comes from groundwater. In rural areas, the percentage is even higher: more than half of all drinking water worldwide is supplied from groundwater. Demand is significantly higher in rural areas, where it is even higher [1]. Groundwater is often considered the main source of freshwater in many places throughout the world. Efficient management of groundwater resources is needed, due to their importance and susceptibility to depletion and contamination [2].

The area between Badra and Zurbatia, which extends along the Iraqi-Iranian border, situated in Wasit Governorate in the eastern side of Iraq, was investigated to assess the hydrogeological and hydrochemical characteristics, evaluate the hydraulic parameters, as well as determine the groundwater aquifer quality and utilization in the area. The study area is vital, being an agricultural area that depends primarily and directly on groundwater for long periods of the year. In addition, it is a good poultry and grazing area with high and significant investment from an economic point of view.

The geographical location of the studied area lies between longitudes 45 51' 00" - 46 03' 00" longitude and 33° 00' 00" - 33° 20' 00" latitude, as illustrated in Figure 1, which showed the location, topographic and distribution of water wells in the area of study. The area covers approximately 400 square kilometers [3]. The climate was characterized as continental semi-arid, depending on climate data measured at the Badra meteorological station [4].

Topographically, the basin slopes from the high mountain in the east and northern east to the flat, gentle plain in the west and south, where the plain ends in Shuwaicha marsh, which is located outside the studied area. The area is characterized by a varying topography, showing the region of the low folds represented by Hemrin Mountain in the eastern and northeastern parts and a flat plain with a moderate slope towards the southwest [3].

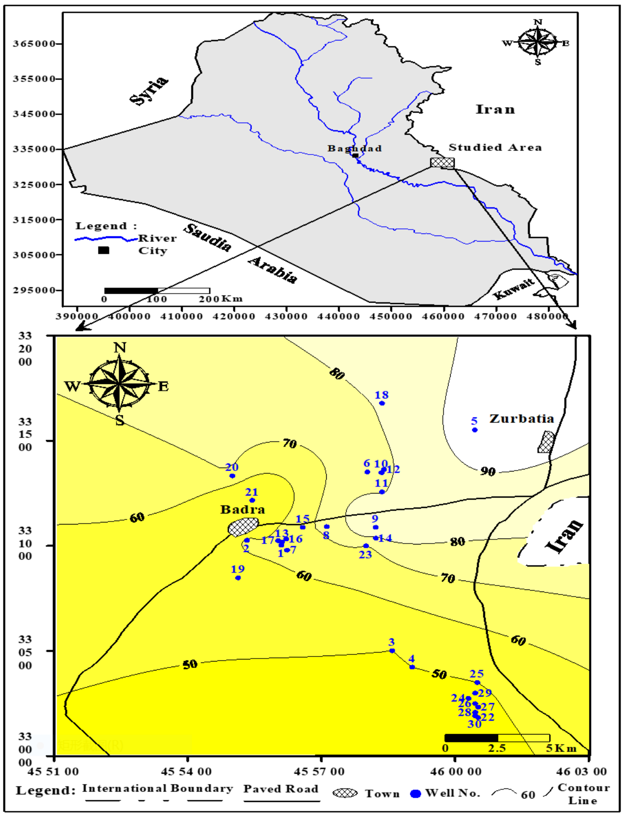

Figure 1 Location and topographic map of studied area modified after [5]

This research aims to evaluate the groundwater resources in the study area based on available information and exploitation requirements from theoretical and scientific perspectives, in addition to field studies. It will focus on evaluating and determining the hydrogeological and hydrochemical of the confined aquifer, which has been exploited largely in the last decade.

The work plan in the study area included two main parts during 2023-2024. 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. The second part included field work to inventory drilled and operating water wells in the study area, to determine their geographical locations, stable water levels, and all other hydrogeological information, in addition to collecting water samples from 30 wells that can be used in hydrochemical analysis to obtain physicochemical characteristics of groundwater.

According to the aim of this research, several previous studies have been found. This research can be divided into two categories:

(1) The first category was the evaluation of hydrogeological properties of the unconfined and confined aquifers, as mentioned by Al-Shamaa and Al-Azzawi (2012) [4], Bahet and Malik (2021) [6], Al-Sudani and Fadhil (2024) [5], and Al-Sudani (2024) [3].

(2) The second category was the assessment of groundwater hydrochemical properties as mentioned by Ali and Ali (2014) [7], Rdhewa et al. (2023) [8], and Al-Sudani and Fadhil (2024) [9].

2 Geology of the Area

The geological map indicates that the Quaternary sediments are widely distributed, reaching 90%, while the older rocks belong to the Miocene and Pliocene periods. The tectonic and structural setting of the study area is divided into two main parts: the eastern central part of the Mesopotamian zone and the south-western part of the Foothill zone (Makhul Sub Zone). These two parts represent the outer and central units of the unstable shelf of the Arabian Nubia region. It has been observed that the region was generally affected by the intense late regional tectonic movements, which caused the uplifting of the Hemrin structure in the Foothill zone while an asymmetric syncline developed in the Mesopotamian region [8].

3 Materials and Methodology

To achieve the study objective, fieldwork was conducted, which required a set of materials. The use of topographic and geological maps at different scales, and the use of a GIS device to determine the locations of water wells that were investigated on-site during the field study in the area. These maps and GIS were used to determine the topographical elevations of these wells. Stratigraphic columns and Hydrogeological Data Bank, which were obtained from the General Commission of Groundwater in the Ministry of Water Resources [10], were also used to compare them with the investigated field data to determine the final information and data that can be used in this study. A set of computer programs, including Excel and Surfer, was used to input all data obtained and process data and information to produce contour maps related to the hydrogeological and hydrochemical characteristics of the unconfined groundwater aquifer.

4 Rustles and Discussion

4.1 Hydrogeological properties of confined aquifer

One of the most important requirements in hydrogeological studies is the identification of aquifer systems. This process relies on a combination of influencing factors, including tectonic, hydrodynamic, and geological aspects, to determine the characteristics and distribution of these aquifers [11].

The field work investigation of 30 water wells revealed the existence of a confined aquifer in the area. Although there is an unconfined aquifer extended near Earth's surface, as earlier studies mentioned [3–5, 7, 8, 12], this research emphasizes the deeper confined aquifer to estimate the hydraulic properties and geochemical behavior. The type of confined aquifer is composed of some Quaternary deposits and pebbly sandstone formation.

The comparison of information collected in the field and stratigraphic columns verified the extension and nature of the unconfined aquifer in the area, as well as well depths recordings and groundwater levels.

Table 1 shows the confined aquifer properties in the area. Thirty wells were used in this study to obtain the hydrogeological characteristics of the aquifer's thickness, transmissivity, and groundwater flow. Figure 2, 3, and 4 demonstrate these maps, respectively. Table 1 also showed that the mean thickness of the aquifer was 57.45 meters while the mean transmissivity was 112.6 m2/day. The average of the total depth of the confined aquifer was estimated to be 63 meters. Using the available data in Table 1, maps of thickness and transmissivity and flow net of the confined aquifer were produced in Figure 2, 3, and 4, respectively.

Table 1 Confined Aquifer Hydrogeological Properties

	Elevation (m)	Total depth (m)	Static water level (m)	Dynamic water level (m)	Piezometric Level (m.a.s.l.)	Thickness (m)	Transmissivity (m^2/day)
Number of values	30	30	29	29	29	29	23
Minimum	35	30	0	0	31	24.5	10
Maximum	103	127	10.5	35.4	97.5	125	445
Mean	63.27	63	4.517	14.95	58.14	57.45	112.6

The combined factors of tectonic settlement, topographic elevations, and geological situation directly influence the hydrological basin situation [13]. The studied area is characterized by mountainous highlands in the north-eastern parts, where the topographic elevations gradually decline towards the south, southwest, and west of the area, as shown in Figure 1. This directly impacted the thickness of the confined aquifer, as shown in Figure 2, which represents a map of aquifer thickness in the area. The thickness increased on the eastern side of the area, while this thickness decreased on the western side of the area. The aquifer on the eastern side of the area consists of an interbedded layer of pebbly sandstone formation and Quaternary deposits, while only Quaternary deposits form the aquifer in the remaining parts of the area of study. This reflects a noticeable increase in the thickness of the aquifer in the groundwater recharge areas to reach the groundwater level, while this thickness decreases in the rest of the areas because the static water surface is closer to the ground surface and reduces the cost of drilling wells. The nature of the groundwater in the recharge area always becomes deeper than the transfer or drainage areas, which makes the water wells penetrate deeper in the recharge area and less in the rest of the groundwater basin [5, 13].

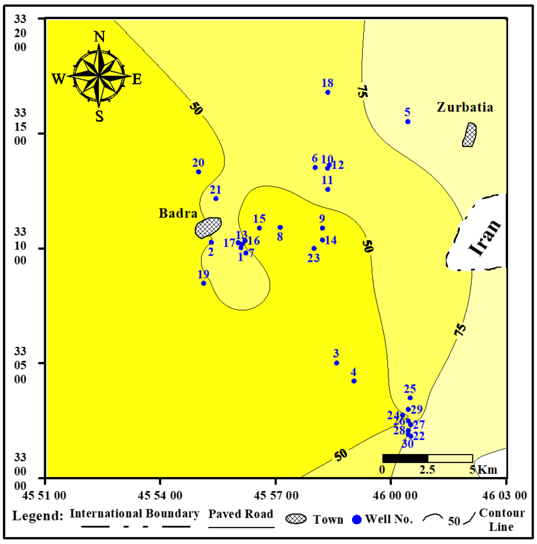

Figure 2 Thickness map of the confined aquifer

The hydraulic properties of the aquifers, represented by the transmissivity and storage coefficient, are greatly affected by the lithological nature of the rocks and sediments of the water-bearing layers, which directly depends on the type and texture of these deposits, as well as the degree of their sorting [14]. The nature of the pebbly sandstone Formation, which is formed from layers of massive sandstone, is characterized by its symmetrical and regular layer extension on the northeast side of the area, which reflects good hydraulic properties for storage coefficient and transmissivity. This is observed in the eastern and northeastern regions, as shown in Figure 3. In the western and southwestern sides of the area, high transmissivity values were observed. The confined aquifer in these areas formed from Quaternary deposits, which are characterized by poorly sorted deposits, especially in the northeastern parts. They begin to gradually transform into good sorting as we move towards the western part of the region, such that the permeability values increase. The eastern and northeastern parts of the basin represent groundwater recharge and surface runoff of rainwater, thus, transmissivity is directly affected and significantly decreased related to the continuous groundwater movement path in this area [14, 15].

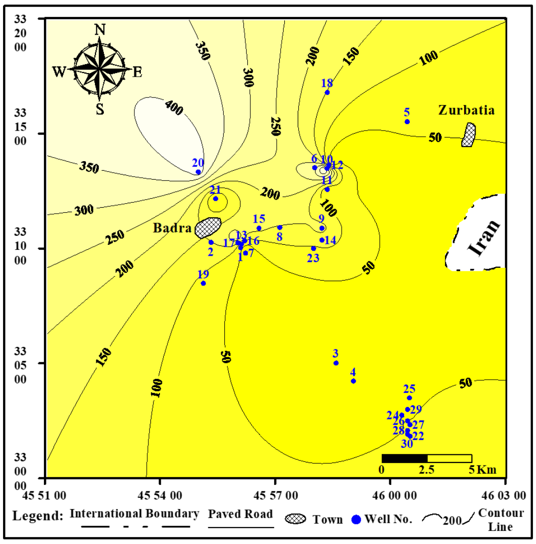

Figure 3 Transmissivity map of confined aquifer

Groundwater movement depends on the topographic slope in the unconfined aquifers. Figure 4 shows the groundwater movement map in the study area, where generally, groundwater flows from the eastern and northeastern regions, which are groundwater recharge areas near the foothills of the Hamrin Mountains, towards the south. The exposure of the pebbly sandstone Formation, which forms the aquifer, along with some Quaternary deposits in the eastern and northeastern regions, directly affects the groundwater movement through formation extension beneath the Quaternary deposits. The geological conditions, particularly the structural situation, in addition to the topographical gradient, play a fundamental role in the movement of groundwater from the recharge area towards the drainage area, which is often a water body [16, 17].

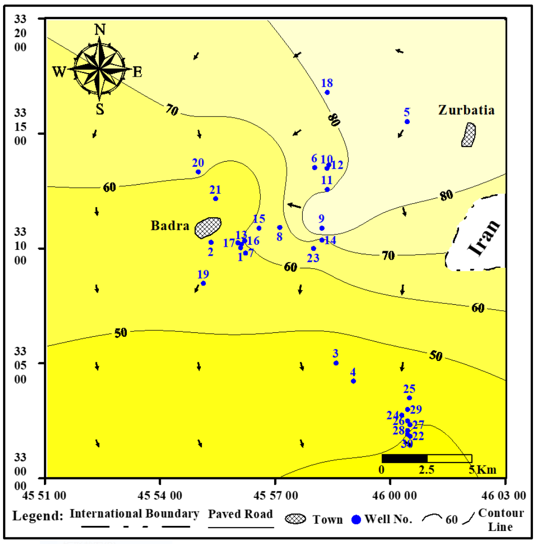

Figure 4 Flow net map of confined aquifer

4.2 Geochemical properties of confined aquifer

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 [18]. 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 [19–21]. Hydrochemical analytical data of groundwater properties are shown in Table 2. Twenty-four 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 (7.2) to (9.5), the EC of (2250) to (6450) μmhos/cm, and TDS was (1800) to (6075) mg/l. Accordance to references, the groundwater of unconfined aquifers is brackish to saline where (TDS $>$ 1000 mg/l) [18].

Table 2 Confined Aquifer Geochemical Characteristics

	Ph	Ec (mcomh/cm)	TDS (mg/l)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	SO_4 (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	NO_3 (mg/l)	SAR
Number of values	16	27	24	23	24	24	23	18	24	7	23
Minimum	7.2	2250	1800	280	240	34	134	515	61	2	3.76
Maximum	9.5	6450	6075	1886	1160	1879	2016	2876	240	18	16.27
Mean	7.81	3898.6	3236.1	611.13	493.5	148.21	1305.2	942.67	126.4	10.9	6.37

The variation of groundwater sources recharge and ionic exchange activities directly affects groundwater salinity. Several factors play an effective role in this variation. The main factors 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 [8, 21]. Figure 5 demonstrates the groundwater salinity distribution map of the confined aquifer in the area. The salinity and ionic concentrations show high values in the area of recharge near the international border, where Fatha Formation is exposed in the northeastern part of the area, where this formation consists of gypsum and limestone. The ionic dissolution of these layers by surface water and infiltration of this water into the aquifer will increase salinity concentrations in the recharge area, as mentioned in previous studies [3–5, 9].

The continuous movement of groundwater away from the recharge area towards the discharge area in the southern part of the area will lead to an increase in the concentration of salinity due to the continuous ion exchange activities [19]. In the eastern part of the area near the international border, the Quaternary deposits consist of slope deposits which are composed of gypsiferous material, causing the groundwater salinity and ionic concentrations to be highly valued [5].

4.3 Groundwater origin and types

To determine the origin of water, especially groundwater, a set of hydrochemical formulas has been relied upon, which are directly based on the concentrations of chemical elements present in groundwater samples. The most important of these elements are chloride, sodium, and sulfate ions, measured in epm% [22]. According to the Kurlov formula [23], which depends on the positive and negative ionic concentrations measured in epm%, the groundwater quality can be determined in this research. The groundwater in the confined aquifer in the study area was characterized to be 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 confined aquifer, which is composed of continental layers that were deposited in a continental deposition environment. Surface water infiltrates into the groundwater aquifer continuously during water surplus within the groundwater recharge areas in the eastern and north-eastern areas of the area, which indicates the origin of this groundwater. Table 3 shows the origin and the three major groundwater types as recorded as calcium sulphate, sodium chloride, and sodium sulphate, with one sample of magnesium chloride found, which is naturally occurring according to the aquifer rock type. The limestone and gypsum of Fatha formation provide groundwater with diluted calcium ions, while other formation provides the groundwater with diluted sodium and magnesium ions in ionic exchange activities.

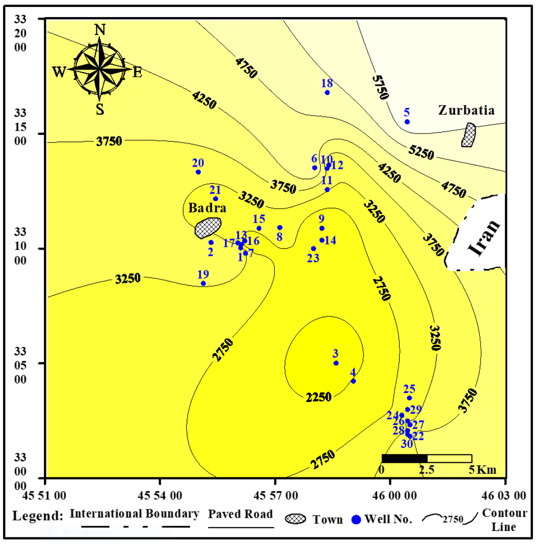

Figure 5 Groundwater salinity distribution map of confined aquifer

Table 3 Confined Aquifer Groundwater Types

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	16.2	19.2	3.33	20	14.5	2.55		
Maximum	23	30.2	13.75	39.7	21.88	7.74	Ca- Sulphate	10
Mean	19	25.46	6.32	29.94	17.53	4.22		
Minimum	20	17	4.08	2.8	22.11	2.75		
Maximum	81.4	40	10.08	42	81.01	5.64	Na- Chloride	4
Mean	40.5	23.85	6.9	21.6	39.78	3.71		
Minimum	20.48	17.2	4.5	22.64	20	1.96		
Maximum	30	18.8	4.83	27.5	23.01	3.93	Na- Sulphate	3
Mean	24.5	18.27	4.61	24.96	21.09	3.02		
	82	58	156.6	22.7	80.3	3.22	Mg- Chloride	1

4.4 Groundwater Utilization

The 24 analyzed groundwater samples, as shown in Table 4, indicated that groundwater utilization could be used for animal purposes only, and only one well could be used for irrigation purposes. The high concentration of salinity, cations, and anions caused the groundwater to be contaminated. However, the nature of the soil in the area and the depth of the groundwater qualified water for agricultural uses in wide range due to quaternary deposits which consisted of medium grained, sand, silt and clay with high percentage of sand which holds only (20%) of the irrigation water and it is irrigated daily to maintain the nutrients needed by the cultivated plants, which bears the highly concentrations of highly concentrated groundwater, while decreasing topographic elevations of the area helps in accelerating the drainage process [24].

Table 4 Groundwater utilization of Confined Aquifer

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	Utilization
Number of samples	16	27	24	23	24	24	23	18	24	7	23		
Minimum	7.2	2250	1800	280	240	34	134	515	61	2	3.76		
Maximum	9.5	6450	6075	1886	1160	1879	2016	2876	240	18	16.27		
WHO (2011) [25]	6.5-8.5	-	1000	75	125	200	250	200	250	50	-	0	Human Purposes
IQS (2011) [26]	6.5-8.5	-	1000	50	50	200	250	200	250	50	-		
Standard FAO/1989 [27]	-	-	2000	40	5	20	30	10	20	-	15	1	Irrigation purposes
Standard FAO/1989 Poultry + Livestock [27].	-	5000	-	-	250	-	-	-	-	100	-	23	Animal purposes

5 Conclusions

The interbedded pebbly sandstone formation and Quaternary deposits produced the confined aquifer in the area. The mean thickness of this aquifer was 46 meters, while the transmissivity mean was 112 m^2/day. According to the topographic situation of the area, the direction of groundwater movement begins from the northern parts toward the southern parts in the studied area.

The groundwater salinity distribution map showed that salinity decreased towards the southern part of the area, reflecting a regular decrease in salinity due to groundwater recharge from infiltrated surface water to unconfined aquifer which connected hydraulically with confined aquifer. The hydro-geochemical properties of groundwater in the confined aquifer, which are determined by the values of physicochemical parameters, indicate the continental origin of brackish to saline groundwater. The dominant type of groundwater was calcium sulphate, sodium chloride, and sodium sulphate

The utilization of groundwater according to the international standards showed that almost all samples of groundwater can be used for animal purposes due to the high concentration of salinity, cations, and anions. However, the groundwater is widely used in irrigation and gravel quarries in the area.

Conflicts of Interest

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

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