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Original 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 on the eastern side of Iraq, was investigated during the fieldwork in 2024. The area is important in terms of agriculture, poultry, and livestock husbandry. (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. Calcium sulphate is recorded as the 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 on 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 shows 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].

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), scientific references and data from the hydrogeological data bank. The second part included fieldwork 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.

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

- 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].
- 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].

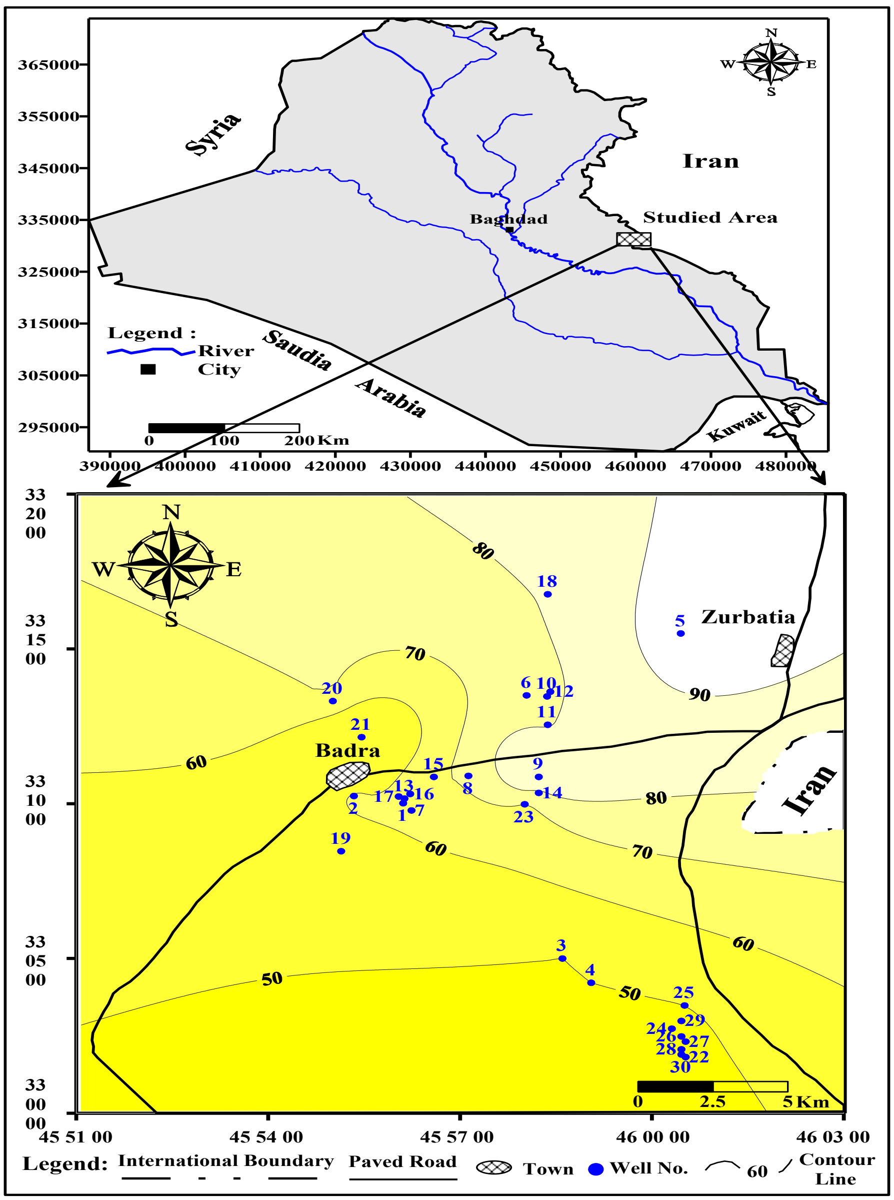

Fig. 1 Location and topographic map of studied area modified after [5].

2. The Geology of 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 southwestern 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 Methods

To achieve the study objective, fieldwork was conducted, which required a set of materials. Topographic and geological maps at different scales and a GIS device were used 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. Results and Discussion

4.1. Hydrogeological Properties of the Confined Aquifer

One of the most important requirements in hydrogeological studies is identifying 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 fieldwork investigation of 30 water wells revealed the existence of a confined aquifer in the area. Although an unconfined aquifer is extended near Earth's surface, as earlier studies mentioned [3,4,5, 7, 8, and 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 formations.

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 depth 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. Figures 2, 3, and 4 demonstrate these maps, respectively. The table 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 the confined aquifer's thickness, transmissivity, and flow net were produced in Figures 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 northeastern 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 area's eastern side, while this thickness decreased on the western side. The aquifer on the area's eastern side consists of an interbedded layer of pebbly sandstone formation and Quaternary deposits.

In contrast, 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.

In contrast, this thickness decreases in the rest of the areas because the static water surface is closer to the ground surface, reducing 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].

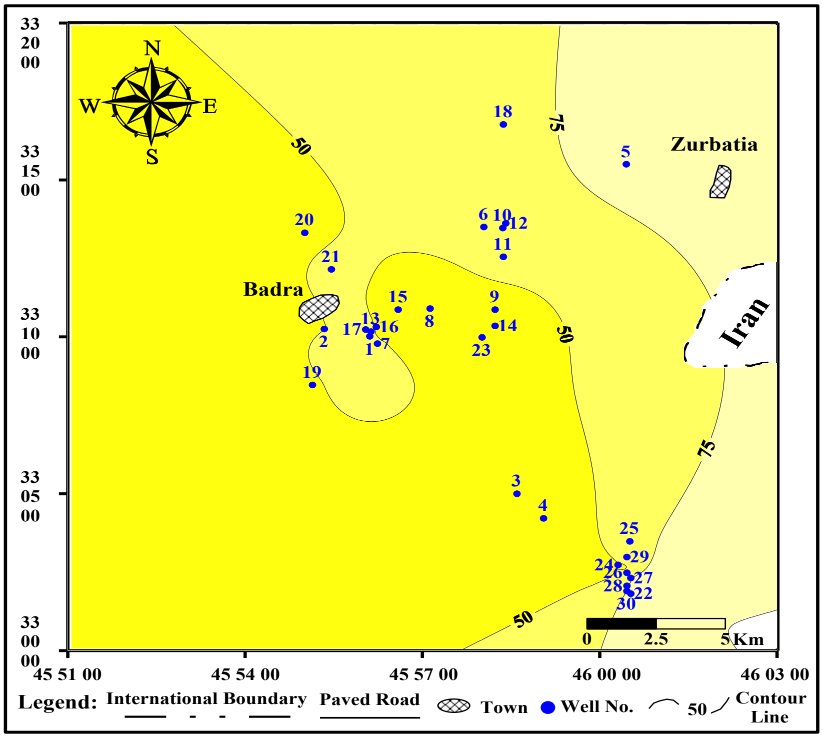

Fig. 2 Thickness map of the confined aquifer

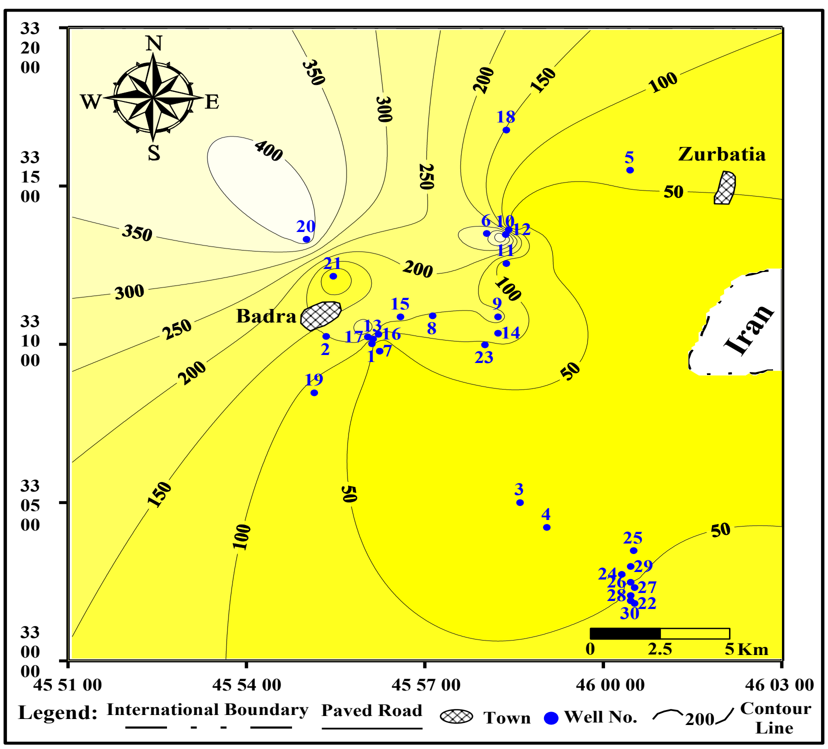

Fig. 3 Transmissivity map of a confined aquifer

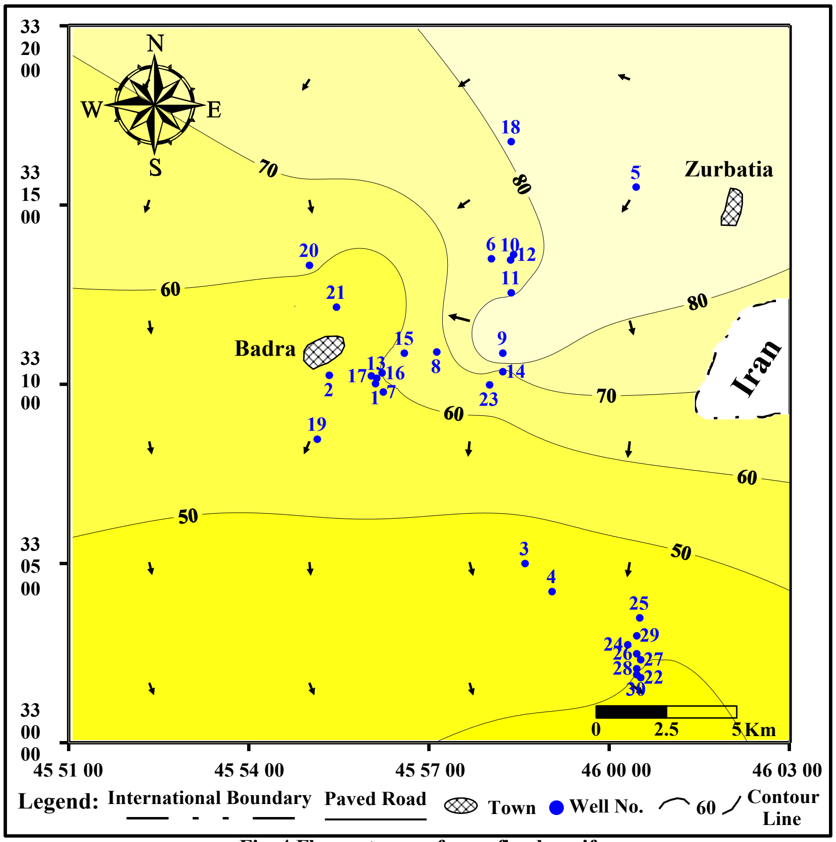

Fig. 4 Flow net map of a confined aquifer

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 massive sandstone layers, is characterized by its symmetrical and regular layer extension on the northeast side of the area, reflecting 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 is 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, which is related to the continuous groundwater movement path in this area [14,15].

Groundwater movement depends on the topographic slope in the unconfined aquifers. Figure 4 shows the groundwater movement map in the study area, where groundwater generally 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 groundwater through formation extension beneath the Quaternary deposits. The geological conditions, particularly the structural situation and 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].

4.2. Geochemical properties of a confined aquifer

The geological history of rocks, indications of groundwater recharge and movement in aquifers, and the storage coefficient depend mainly and largely on hydrochemical 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 [19,20,21].

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. According to references, the groundwater of unconfined aquifers is brackish to saline where (TDS > 1000 mg/l) [18].

The variation of groundwater source recharge and ionic exchange activities directly affect 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 recharges, infiltrated waters reduce the groundwater salinity concentration due to dilution, ionic exchange, and mixing processes between groundwater and the recharged water [8,21]. Figure 5 demonstrates the area's groundwater salinity distribution map of the confined aquifer. The salinity and ionic concentrations show high values in the recharge area near the international border. 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 [3,4,5,9]. The continuous movement of groundwater away from the recharge area towards the discharge area in the southern part of the area will increase the salinity concentration 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 composed of gypsiferous material, causing the groundwater salinity and ionic concentrations to be highly valued [5].

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

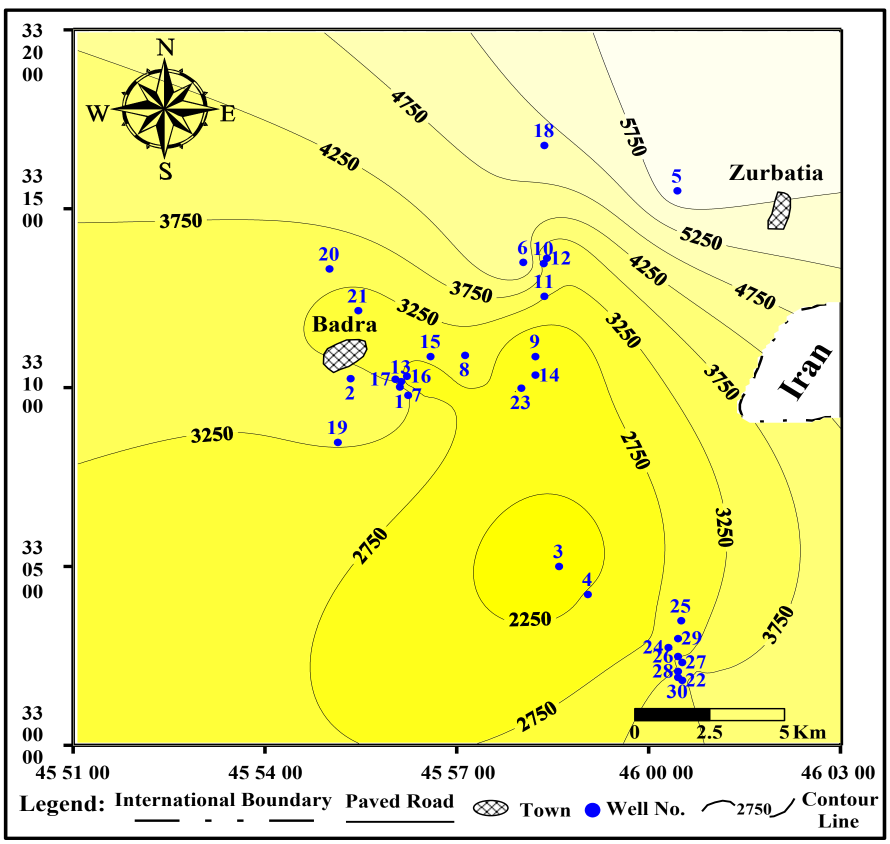

Fig. 5 Groundwater salinity distribution map of a confined aquifer

4.3. Groundwater Origin and Types

A set of hydrochemical formulas has been relied upon to determine the origin of water, especially groundwater, which is 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 the groundwater aquifer continuously during water surplus within the groundwater recharge areas in the eastern and northeastern areas of the area, indicating 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 another formation provides the groundwater with diluted sodium and magnesium ions in ionic exchange activities.

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	Ca- Sulphate	10
Maximum	23	30.2	13.75	39.7	21.88	7.74		
Mean	19	25.46	6.32	29.94	17.53	4.22		
Minimum	20	17	4.08	2.8	22.11	2.75	Na- Chloride	4
Maximum	81.4	40	10.08	42	81.01	5.64		
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	Na- Sulphate	3
Maximum	30	18.8	4.83	27.5	23.01	3.93		
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 a wide range due to quaternary deposits, which consisted of medium-grained sand, silt and clay with a high percentage of sand that holds only (20%) of the irrigation water and it is irrigated daily to maintain the nutrients needed by the cultivated plants, which bears the high 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	EC (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	Number 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. Conclusion

- 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 of 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 an unconfined aquifer, which connected hydraulically with the confined aquifer.
- The hydrogeochemical 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 international standards showed that almost all groundwater samples 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.

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