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Original Article

Hydrochemical Evaluation of Unconfined Aquifer In Wasit Governorate - East of Iraq

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Abstract - *The main aim of groundwater studies is to assess the physical and chemical characterizations of water-bearing layers as a goal for assessing their suitability for various purposes. Zurbatia area, located within the Wasit governorate to the eastern border of Iraq, was investigated. (40) wells were used to demonstrate the hydrochemical properties. Groundwater aquifer comprises Quaternary deposits and Mukdadiyah formation as an unconfined aquifer. The salinity map showed a regular decrease in salinity concentrations towards the central and southwestern parts of the area due to groundwater recharge from infiltrated surface water. The groundwater of an unconfined aquifer is brackish to saline, with two dominant types of calcium and sodium sulphate. Groundwater utilization indicated that it could only be used for animal purposes due to the high salinity concentration. The central area between Zurbatia and Badra towns can be a qualified location for increasing well drilling due to decreased salinity.*

Keywords - *Hydrochemical Evaluation, Unconfined Aquifer, Wasit Governorate, East of Iraq.*

1. Introduction

Water resources seem abundant, but less than one percent of them are readily available for human use. Worldwide water resources are stressed due to ever-increasing demands associated with exponential world population growth. In arid and semi-arid countries, water shortage problems are more challenging. Water shortage problems are even more challenging in Iraq [1]. The studied area of Zurbatia is located in eastern Iraq within Wasit Governorate, and it is situated between 45° 45' -46° 10' longitude and 33° 00' -33° 15' latitude, as in Figure 1. The study area is about 180 kilometers southeast of Iraq's capital, Baghdad, and spans an area of around 650 km2 [2]. 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. The study area is characterized by a varying topography, showing the region of the low folds represented by Himreen Mountain in the eastern and northeastern parts and a flat plain with a moderate slope towards the southwest [3]. In the area of study, the mainstream is Galal Badra, which flows from inside Iranian territory with two tributaries and discharges water into Shuwaicha Marsh to the south. Most stream water depends on water gained from inside Iranian territory [4]. The climate was characterized as continental semi-arid depending on climate data measured at the Badra meteorological station [2]. This research aims to carry out hydrochemical investigations in the Zurbatia area to evaluate the physical and chemical parameters of groundwater as an essential goal for assessing its suitability for various purposes. The area depends mostly on groundwater for many purposes, especially for agriculture and animal benefits. Several studies have been done to evaluate hydrochemical characteristics and accessibility of the groundwater in the Zurbatia area, as mentioned below:

- In 2011, Al-Shamaa and Al- Azzawi studied the hydrochemical pollution of groundwater in the Badra-Jassan basin in the eastern part of Iraq [5].
- In 2012, Al-Shamaa and Al-Azzawi carried out a study of the hydrological relationship between surface and groundwater in the Badra-JJassan basin [4].
- In (2014), Ali, S.M. and Ali, A.H. study the Hydrochemistry and Geochemical Evolution of an Unconfined Aquifer in Kalal Badrah Basin, Wasit, East of Iraq [6].
- In 2021, Bahet and Malik studied groundwater detection in the Iraq-Wasit Governorate using remote sensing and GIS [7].
- In 2023, Rdhewa et al. studied the changes in groundwater levels and their salinity (Badra Basin, Iraq) [3].

The work plan for the studied area included the following items:

- Office work, including preparing data and information about the area (wells, stratigraphic columns, maps, literature reviews, scientific references, and hydrogeological and hydrochemical data bank).

- Field work, including an inventory of water wells and measuring the water levels and geographical positions of 60 water points. Water sampling of 40 wells in 2023 to measure physical and chemical components and variation of ionic concentrations. The chemical analysis was done in the General Commission of Groundwater Laboratories, Ministry of Water Resources.

2. Geological Setting

The geological map of the study area is built up by about 90% of quaternary deposits. Pre-quaternary rocks belong to the Miocene and Pliocene ages (Fatha, Injana, and Mukdadiyah Formations). Structurally, the map area lies within both the eastern central part of the Mesopotamian zone and the southwestern part of the Foothill zone (Makhul Sub Zone). These two zones represent the outer and central units of the Unstable Shelf of the Nubio-Arabian platform. Areas of study have been effected by the late regional intensive tectonic movements that caused the uplifting of Hemrin structure in the Foothill zone and the development of asymmetrical syncline in the Mesopotamian zone, figure 2 [8].

- Fatha Formation (Middle Miocene): The formation comprises two members. Both members are cyclic in nature. Each cycle starts with claystone, followed by marl, thin limestone, and thick gypsum on top. The formation is forming a continuous, steep escarpment ridge north of Zurbatia only. The upper contact with the overlying Injana Formation is conformable, based on the first appearance of thick sandstone beds. The environment of deposition is closed semi-basins of hypersaline condition, with lacustrine influence, in the upper parts [8].

- Injana Formation (Upper Miocene): The formation is exposed north of Zurbatia town only. It comprises monotoneous alternating at sandstone, claystone, and siltstone beds. The thickness of the formation is about 700 meters. The upper contact with the overlying Mukdadiyah Formation is conformable and gradational, based on the first appearance of pebbly sandstone. The deposition environment is from freshwater to fluvial [8].

- Mukdadiyah Formation (Uppermost Miocene–Pliocene): The formation is exposed in the eastern and northern parts of the studied area. It is composed of alternating medium-coarse-grained sandstone, siltstone, and claystone beds.

- The thickness of the formation is 300–1200 m. The upper contact with the overlying quaternary deposits is unconformable, based on the first appearance of the conglomerate. The environment of deposition is continental and fluvial [8].

2.1. Quaternary Deposits

2.1.1. Alluvial Fan Deposits (Pleistocene–Holocene)

Alluvial fans within the area form a continuous belt along the southwestern limb of the Hemrin structure. The alluvial fans commonly consist of poorly sorted clastic deposits, usually gravels, cabbies, and boulders, with a subordinate amount of sand, silt, and clay. Stratigraphically, the fan deposits lie uncomfortably over the pre-quaternary sediments. Deposits consist predominantly of greenish-gray silty clays. Some fine-sand admixtures often occur too.

2.1.2. Depression fill deposits (Holocene)

The major depression deposits developed in the area is Shuwaicha marsh. They are flat, usually cracked and covered either by small native vegetation or barren. Lithologically, these deposits consist dominantly of greenish-grey silty clays or clays. Some fine sand admixtures often occur too. The depression fill deposits include variable amounts of secondary salts, reaching more than 15% and are in different forms, filling the pores, fissures and crocks

2.1.3. Flood plain deposits (Holocene)

Lithologically, they are composed essentially of well-bedded fine to medium-grain sand with thin silt and clay, then gradually pass to clay and silt in the flood basins.

2.1.4. Valley fill deposits (Holocene)

They are badly sorted mainly due to alternating intense floods and abrupt drops in flow, which caused wide variation in grain size and composition. Lithologically, they are composed of gravel, sand, and silt; their size decreases down streams. The total thickness of the valley fill deposits is unknown, but it does not exceed a few meters [8].

3. Materials and Methods

- Topographic and geological maps at a scale of 1:250000.
- A GPS device to determine the locations and elevations of water wells.
- Stratigraphic sheets and hydrogeological data bank (General Commission of Groundwater, 2023).
- Mathematical programs (Surfer and Excel) were used to analyze the data and information obtained and draw alltypes of contour maps. According to geological information and previous studies conducted in the area, the investigation of 60 inventoried wells revealed the existence of the unconfined aquifer in the Zurbatia area. All geological and hydrogeological information collected during fieldwork was compared with the stratigraphic sheets of drilled wells obtained from the General Commission of Groundwater, Ministry of Water Resources.

The hydrogeological data measured in the field were geographical position, elevations, static water levels, depths, thicknesses, and maximum yields, while the hydrochemical parameters included the major cations and anions, TDS, EC, pH, and Sodium Absorption Ratio (SAR). The mathematical programs (surfer and grapher) were used to demonstrate the results as contouring maps of hydrogeological and hydrochemical properties.

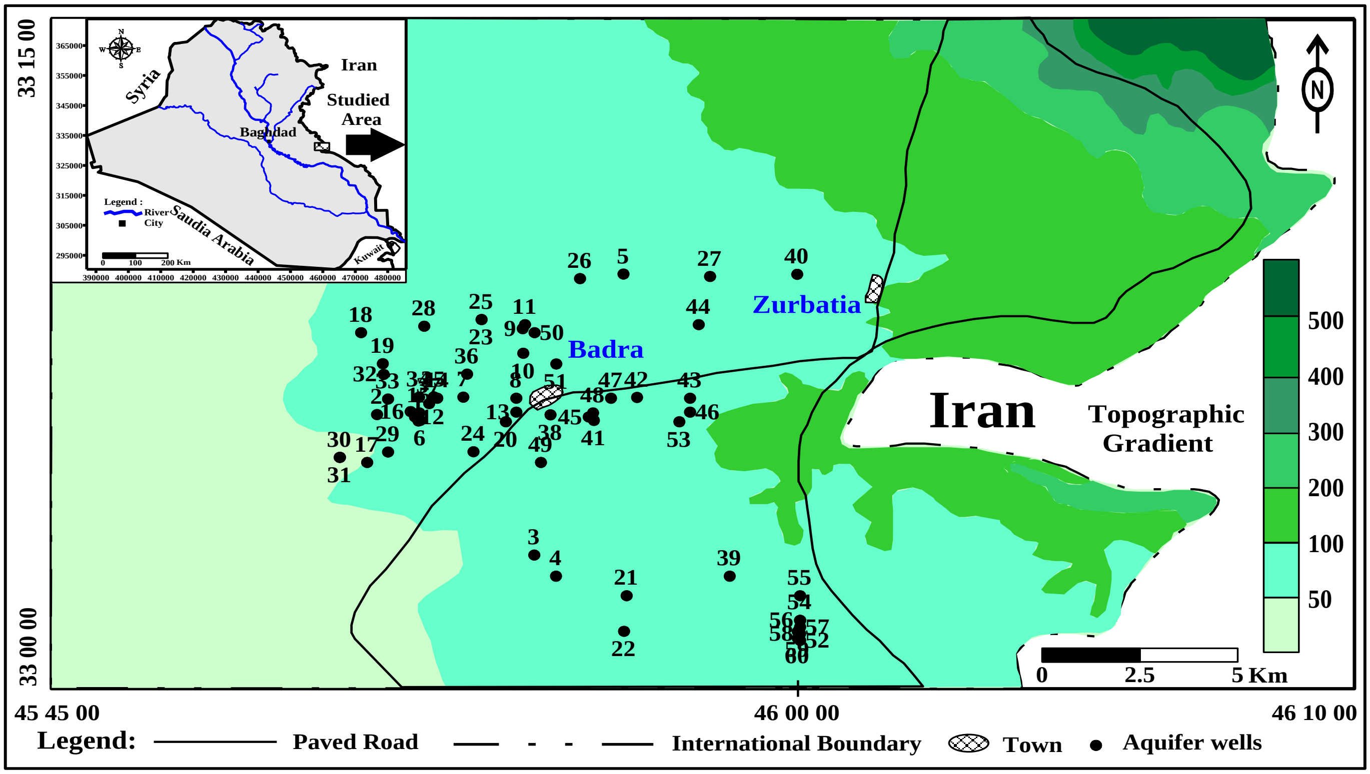

Fig. 1 Location and topographic map of the studied area

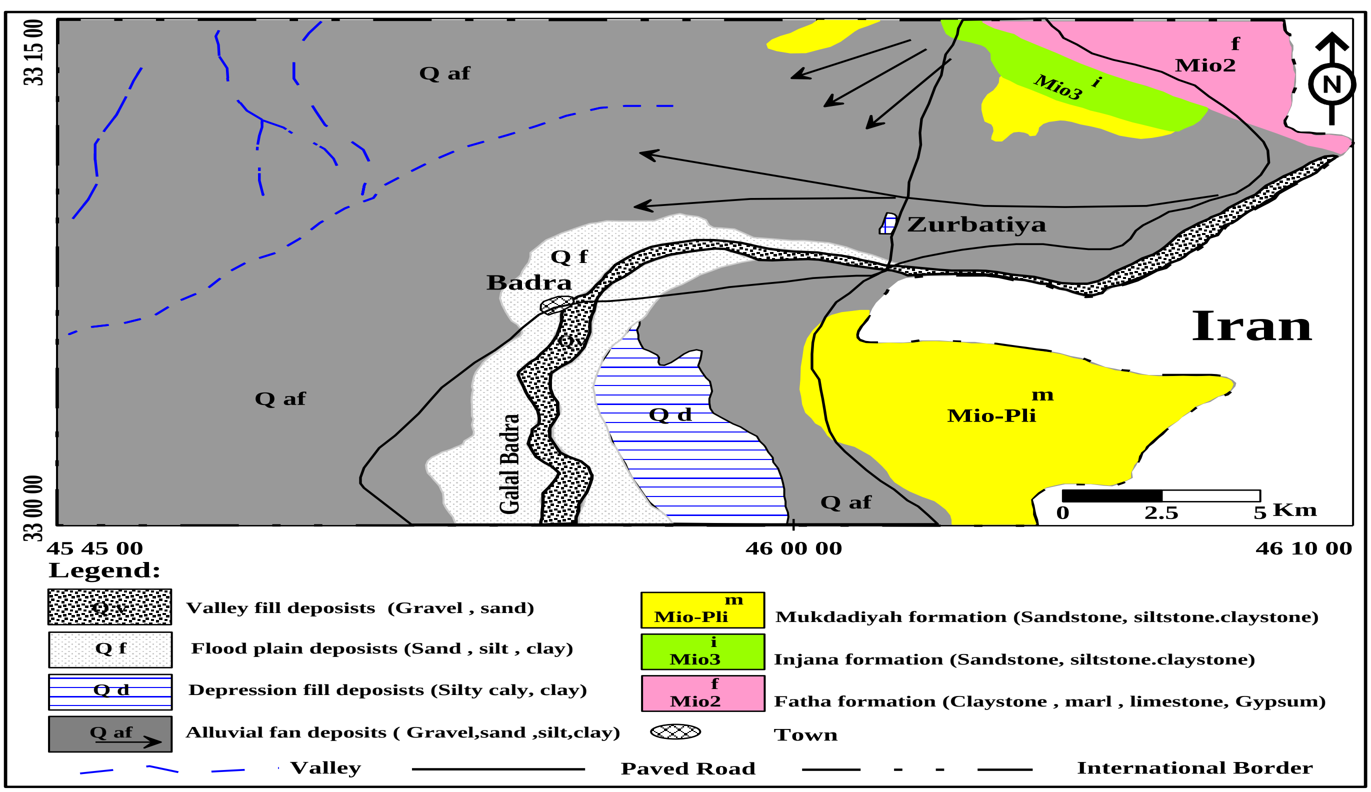

Fig. 2 Geological map of the area [modified after 8]

4. Results and Discussion

4.1. Hydrogeological Characteristics of Unconfined Aquifer

The geological formations extended and exposed in the Zurbatia area, as shown in Figure 2, determine the type of groundwater aquifer, composed of both Quaternary deposits and the Mukdadiyah formation as an unconfined aquifer. Depending on the geological formation, the aquifer is composed mainly of the Mukdadiyah formation with a few meters of Quaternary deposits in the eastern and northeast parts of the studied area. While in the central and southern parts of the studied area, the Quaternary deposits make this aquifer with a few meters of Mukdadiyah formation according to well depths and penetrations. In the western parts, the aquifer is mainly composed of Quaternary deposits. Drawing on geological and hydrogeological data and information, several earlier studies identified the types of aquifers in the region, denoted by confined and unconfined aquifers [4,6,7,9].

4.2. Hydrochemical Evaluation of Unconfined Aquifer

Table 1 shows the statistical data of hydrochemical groundwater properties of the unconfined aquifer in the area, where (40) wells were used in this study to analyze the physicochemical parameters. The ranges of pH, electrical conductivity (EC) and total dissolved solids (TDS) represented as minimum and maximum were (7.11) to (8) and (3100) to (5820) µmhos/cm, (2249) to (4112) mg/l respectively. These values indicate that groundwater of unconfined aquifers is brackish to saline types where (TDS > 1000 mg/l) [10]. The groundwater salinity is affected by the variation of groundwater recharge sources, ion exchange activities, and the ability to substitute between the main ions. A group of factors, including recharge and drainage areas and groundwater movement trends, in addition to the depth and rockiness of the aquifer, play an effective role in this variation. Groundwater recharge reduces the water salinity concentration through dilution and mixing processes between groundwater and the water feeding it [3]. Figure 3 demonstrates the area's groundwater salinity distribution map of the aquifer. The map shows high values of salinity concentration in the recharge area to the northern and eastern border of the area. The geological map in Figure 2 shows the Fatha Formation's exposure in the northeastern part of the area, where this formation consists of gypsum and limestone. The ionic desolation of these layers by surface water and infiltration of these water into the aquifer will increase salinity concentrations in the recharge area. The continuous movement of this groundwater away from the Fatha formation in the recharge area towards the discharge area in the southwestern parts of the area will lead to a decreased concentration of salinity due to the continuous recharge of surface water to unconfined aquifer formed by the Muqdadiyah formation and the Quaternary sediments.

Therefore, the number of wells drilled in these areas is very small and sometimes absent due to the high salinity concentrations. The surface water coming from Iran's territory within the Galal Badra helps reduce the salinity concentration of the groundwater locally when it infiltrates the aquifer. On the other hand, the unconfined aquifer may be recharged from the confined aquifer in some areas by hydraulic connections [1], which is likely to have a high groundwater salinity concentration, especially in the recharge areas, as shown in Figure 3. All previous studies stated that groundwater salinity of unconfined or confined aquifers in this area indicated high concentrations over decades as mentioned in [1,2,3,4,7 and 11], meaning that groundwater is originally contaminated with highly ionic concentrations for several reasons. As the area's climate was characterized by continental semi-arid, thus low precipitation rates were recorded in the area with low surface runoff in the Galal Badra stream. Reusing irrigation water and other utilizations of groundwater in the area may also increase the groundwater salinity.

4.3. Groundwater Origin and Types

Some hydrochemical formulas are used to determine the origin of continental and marine groundwater based on chloride, sodium, and sulphate ion concentrations measured in the epm [12,13]. The Kurlov formula determines groundwater quality based on the concentrations of positive and negative ions in epm% [14]. Table 2 indicates the groundwater types of unconfined aquifers in the area. As mentioned before, the groundwater is brackish to saline, where (TDS>1000 mg/l), while the origin of this water is continental, as aquifer layers and sediments were originally deposited in a continental deposition environment. Calcium and sodium sulphate were the two dominant types of groundwater in the area, which is naturally according to the aquifer rock type. The limestone and gypsum of the Fatha formation provide groundwater with diluted calcium ions, while other formations (Injana, Muqdadiyah and Quaternary deposits) provide groundwater with diluted sodium ions in ionic exchange activities.

Table 1. Hydrochemical properties of unconfined aquifer in the area

Parameter	Number of values	Min.	Max.	Mean
Ph	40	7.11	8	7.54
Ec (mcomh/cm)	40	3100	5820	4061.2
TDS (mg/l)	40	2249	4112	3065.9
Na (mg/l)	40	235	731	463.4
Ca (mg/l)	40	69	604	377.7
Mg (mg/l)	40	37	185	85.83
SO_4 (mg/l)	40	134	1906	1133.3

Cl (mg/l)	40	359	994	645.8
HCO_3 (mg/l)	40	61	541	226.2
NO_3 (mg/l)	25	0.1	18	6.88
SAR	40	4.23	14.04	6.66

Table 2. Groundwater types of unconfined aquifer in the 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	16.21	19.2	3.33	20	14.50	2.45	Ca- Sulphate	17
Maximum	23	30.2	13.75	39.70	21.88	7.74		
Mean	18.92	25.55	5.8	29.47	17.80	4.20		
Minimum	16.34	3.45	3.08	10.64	10.11	1.96	Na- Sulphate	16
Maximum	30	18.8	15.41	33.33	23.01	17.42		
Mean	20.60	12.969	8.64	21.11	16.62	10.80		
Minimum	14.74	10.45	4.08	2.79	14.64	2.75	Na- Chloride	6
Maximum	31.78	20	8.83	21.60	28	14.48		
Mean	24.058	16.875	6.625	16.32	23.81	5.03		
	10.21	12.3	9.58	7.73	15.77	17.45	Ca- Bicarbonate	1

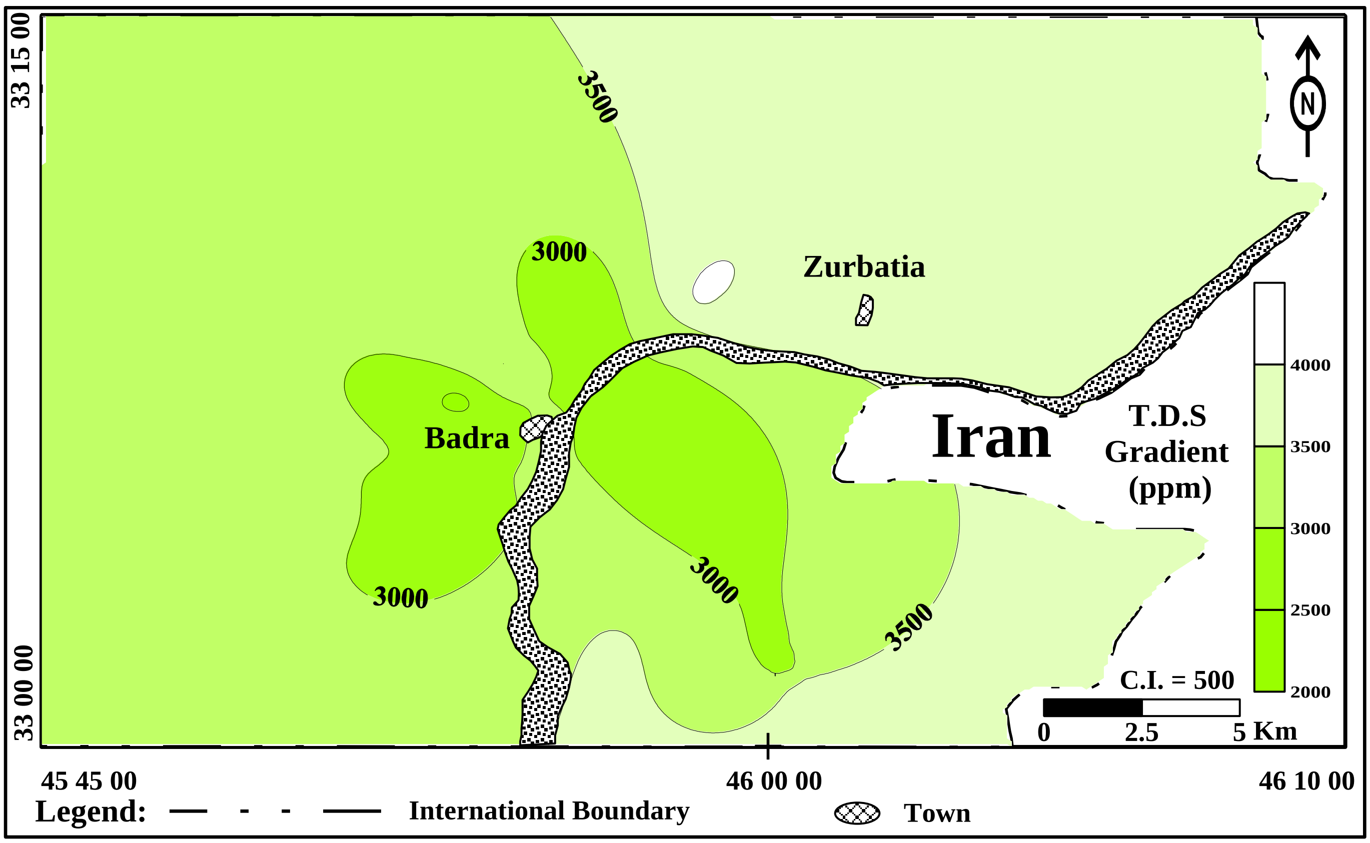

Fig. 3 Groundwater salinity distribution map of unconfined aquifer

4.4. Groundwater Utilization

According to Table 1, where (40) groundwater samples were analyzed, the groundwater utilization indicated that it could be used for animal purposes only. The high concentration of salinity, cations, and anions caused the groundwater to be contaminated. Table 3 shows the groundwater utilization of unconfined aquifers in the area. 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.

Table 3. Groundwater utilization of unconfined aquifer in the 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	Number of suitability wells	Utilization
Number of samples	40	40	40	40	40	40	40	40	40	25	40		
Minimum	7.11	3100	2249	69	37	235	359	61	134	0.1	4.23		
Maximum	8	5820	4112	604	185	731	994	541	1906	18	14.04		
(WHO. 2011) [15]	6.5-8.5	-	1000	75	125	200	250	200	250	50	-	0	Human Purposes
(IQS. 2001) [16]	6.5-8.5	-	1000	50	50	200	250	200	250	50	-		
Standard FAO/1989(Ayers and Westcot. 1994)	-	-	2000	40	5	20	30	10	20	-	15	0	Irrigation purposes
Standard FAO/1989 Poultry + Livestock (Ayers and Westcot. 1994)	-	5000	-	-	250	-	-	-	-	100	-	40	Animal purposes

5. Conclusion

1. The type of groundwater aquifer in the Zurbatia area is composed of quaternary deposits, and the Mukdadiyah formation is an unconfined aquifer.
2. The groundwater salinity distribution map showed that salinity decreased towards the central and southwestern parts of the area, reflecting a regular decrease in salinity due to groundwater recharge from infiltrated surface water.
3. Values of physicochemical parameters of groundwater indicate brackish to saline water, with calcium and sodium sulphate as the two dominant types of groundwater. Diluted calcium ions of limestone and gypsum layers of Fatha formation provide groundwater with this ion, while diluted sodium ions come from other formations (Injana, Muqdadiyah, and Quaternary deposits) and provide this ion through ionic exchange activities.
4. Groundwater utilization indicated that it could be used for animal purposes only due to the high concentration of salinity, cations, and anions. However, the groundwater is widely used in irrigation and gravel quarries in the area.
5. According to the hydrochemical characteristics of the unconfined aquifer, the central area between Zurbatia and Badra towns can be a qualified location to increase well drilling. The salinity decreased as the transmissivity and maximum yields increased.

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