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Research Article

Hydrogeological and Hydrochemical Study of Groundwater 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 Wasit Governorate, which is located in eastern Iraq, is an important area in terms of agriculture and poultry and livestock husbandry. The area mainly depends on groundwater, especially on the Iraqi-Iranian border. The area was investigated (40) wells inventoried during the field study and used to demonstrate the hydrogeological and hydrochemical properties. The groundwater aquifer is composed of Quaternary deposits and Mukdadiyah formation. The mean thickness, transmissivity, and maximum yields were 53 meters, 114 m^2/day, and 600 m^3/day, respectively. The groundwater moved partially to the western parts and mainly towards the southern parts of the area towards Shuwaicha Marsh, which is located outside the study area. 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 is brackish to saline, with two dominant calcium and sodium sulphate types. The central area between Zurbatia and Badra towns can be a qualified location to increase well drilling due to salinity decreasing as the transmissivity and maximum yields increase.

Keywords

Hydrogeological and Hydrochemical Study, Groundwater 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 that are 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, which is located in the northeastern part of Wasit governorate to the east of Iraq, 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 km^2 [2]. This research aims to carry out hydrogeological and hydrochemical investigations in the Zurbatia area to evaluate the most important product groundwater aquifers and achieve optimum use of groundwater in terms of sustainable water management as well as determine physical and chemical parameters of groundwater as an essential goal for as-

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sessing its suitability for various purposes. The area depends mostly on groundwater for many purposes, especially for agriculture and animal benefits. 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 north-eastern 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].

Several studies have been done to evaluate the hydrogeological and hydrochemical accessibility of the groundwater in the Zurbatia area, as mentioned below:

1. In 2002, Al- Azzawi presented research for the Badra basin, including studying the groundwater hydraulic characteristics of the aquifers in the basin. In addition, the levels of aquifer recharge and their locations were determined [5].
2. In 2011, Al-Shamaa and Al- Azzawi studied the hydrochemical pollution of groundwater in the Badra - Jassan basin in the eastern part of Iraq [6].
3. In (2012), Al-Shamaa, and Al- Azzawi study the estimation of groundwater recharge in the Badra-Jassan basin using the annual water surplus method [2].
4. In 2012, Al-Shamaa and Al- Azzawi carried out a study of the hydrological relationship between surface and groundwater in the Badra-Jassan basin [4].

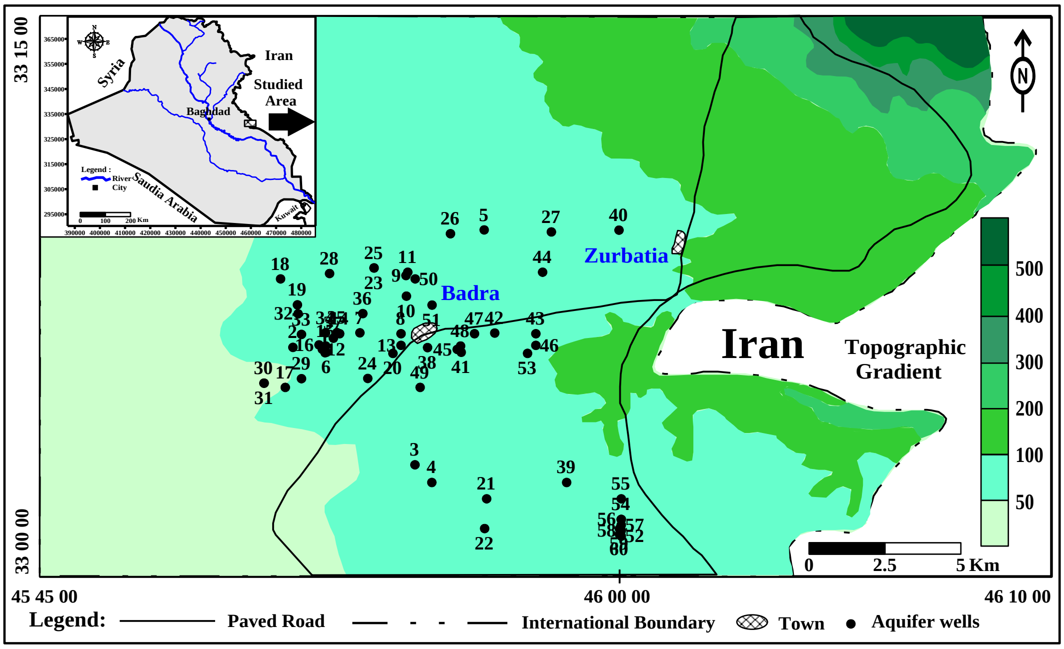

Figure 1. *Location and topographic map of studied area.*

5. In (2014), Ali, S. M. and Ali, A. H. study the Hydrochemistry and Geochemical Evolution of Unconfined Aquifer in Kalal Badrah Basin, Wasit, East of Iraq [7].
6. In (2019), Rahi et al. Study the assessment of surface water resources in eastern Iraq, including Wasit governorate [1].
7. In 2021, Manhi and Al-Kubaisi study the estimation of the annual runoff of the Galal Badra transboundary watershed using the arc swat model in Wasit, Eastern Iraq [8].
8. In 2021, Bahet and Malik study the detection of groundwater in the Iraq-Wasit Governorate using remote sensing and GIS [9].
9. 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:

1. Office work, including preparing data and information about the area (wells, stratigraphic columns, maps, literature reviews, scientific references, and hydrogeological data bank).
2. Field work, including inventory of water wells and measure the water levels and geographical positions of 60 water points. water sampling of 40 wells in 2023 in order 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 Re-

sources.

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 [10].

1. Fatha Formation (Middle Miocene):

The formation consists of 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 [10].

2. Injana Formation (Upper Miocene):

The formation is exposed north of Zurbatia town only. It is composed of 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 environment of deposition is from fresh water to fluvial [10].

3. Mukdadiyah Formation (Uppermost Miocene–Pliocene):

The formation is exposed in the eastern and northern parts of the studied area. It is composed of an alternation of 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 [10].

4. Quaternary Deposits:

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) 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 amount of secondary salts, reach more than 15% and in different forms, filling the pores, fissures and crocks.

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.

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 gravels, sands, and silt; their size is decreasing down streams. The total thickness of the valley fill deposits is unknown, but it does not exceed a few meters [10].

3. Materials

1. Topographic and geological maps at a scale of 1:250000.
2. A GPS device to determine the locations and elevations of water wells.
3. Stratigraphic sheets and hydrogeological data bank [11].
4. Mathematical programs (Surfer and Excel) were used to analyze the data and information obtained and draw all types of contour maps.

4. Methodology

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 area. All geological and hydrogeological information collected during field work 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.

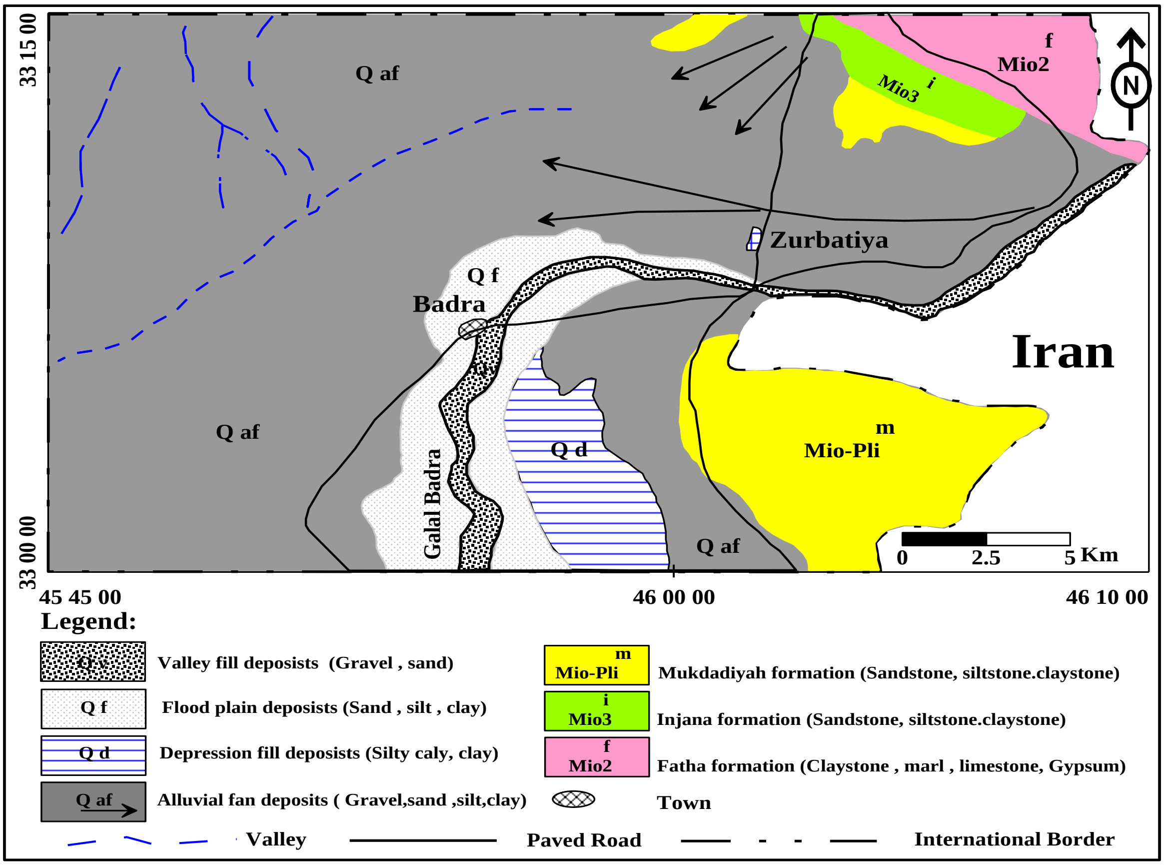

Figure 2. *Geological map of the area modified after [10].*

5. Rustles and Discussion

5.1. Hydrogeological Properties of Aquifer

The geological formations extended and exposed in the 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 makes 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, 5, 7, 9]. As previously mentioned, the field study in this research determined that only unconfined aquifer was identified based on the depth of the wells that penetrated Quaternary deposits and Muqdadiyah formation all over the study area. This was determined based on the determination of water well locations drilled in the area, in addition to studying the cross-sections of the stratigraphic wells, the geological situation, and the geological formation exposed. Table 1 shows the hydrogeological properties of unconfined aquifer in the area, where (40) well were used in this study to demonstrate thickness, transmissivity, maximum yield and groundwater flow net maps as showed in figures 3, 4, 5. and 6 respectively.

Table 1. *Hydrogeological properties of unconfined aquifer in the area.*

Parameter	Number of values	Minimum	Maximum	Mean
Elevation (m)	40	35	103	64
Total depth (m)	40	30	127	60

Parameter	Number of values	Minimum	Maximum	Mean
Static water level (m)	40	0	10.5	4.90
Dynamic water level (m)	40	3.1	35.5	16
Water Table (m.a.s.l.)	40	31	98	59
Depth to water (m)	40	2	47	8.4
Thickness (m)	39	25	92	53
Maximum yield (m^3/day)	38	155	825	600
Transmissivity (m^2/day)	34	10	445	114

Structural, topographical, and geological factors generally affect the hydrological basin [12]. As the study area is represented by topographic highs represented by Hamrin mountains located in the eastern and northeast parts of the basin, as previously mentioned, these highs gradually decrease from the northeast towards the southwest and south, as shown in figure 1. This caused an increase in aquifer thickness in the northeastern and eastern parts of the area, while this thickness decreased towards the southwest. The aquifer in this area is formed by both Muqdadiyah formation and Quaternary sediments, which are characterized by a greater thickness than other parts of the studied area in which the aquifer is formed mainly by Quaternary sediments, especially in the central and southwestern parts. The economic aspect affects the well drilling operations, as the beneficiaries of the wells drilled in the area depend on the lowest depths to reach the groundwater and use it for various purposes. Thus, it is recorded that the thickness of the penetrated aquifer decreases, particularly in the central and southwestern area, as the lowest financial cost of drilling is sufficient to invest in groundwater properly. Figure 3 shows a map showing the distribution of the thickness of the unconfined aquifer in the study area.

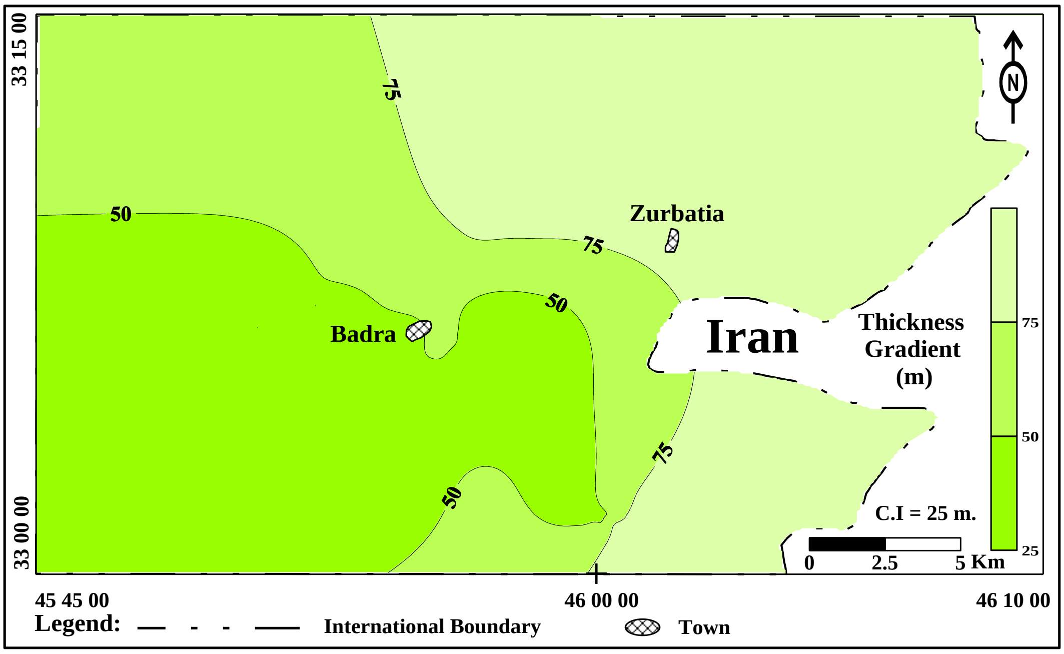

Figure 3. *Thickness map of the unconfined aquifer.*

Texture, types of sediments and the degree of sorting of these sediments that formed aquifer affect on the transmissivity and storage coefficient of groundwater [13]. In the eastern and northeastern parts of the area, the aquifer consists of symmetrical and regular layers of sandstone of Muqdadiyah Formation, which is characterized by good hydraulic properties of groundwater storage capacity, as shown in Figure 2. Meanwhile, the Quaternary sediments are affected by the fact that most of their sediments are not well sorted, starting from the northeastern parts. These sediments begin to gradually transform into good sorting as we move towards the western and southwestern parts, so that the transmissivity values increased. In addition, the northeastern and eastern parts of the area represent the areas of surface runoff and groundwater recharge for the aquifer. These areas often have low transmissivity values, as they are represent a continuous groundwater movement [14]. Figure 4 shows transmissivity map of unconfined aquifer in the area.

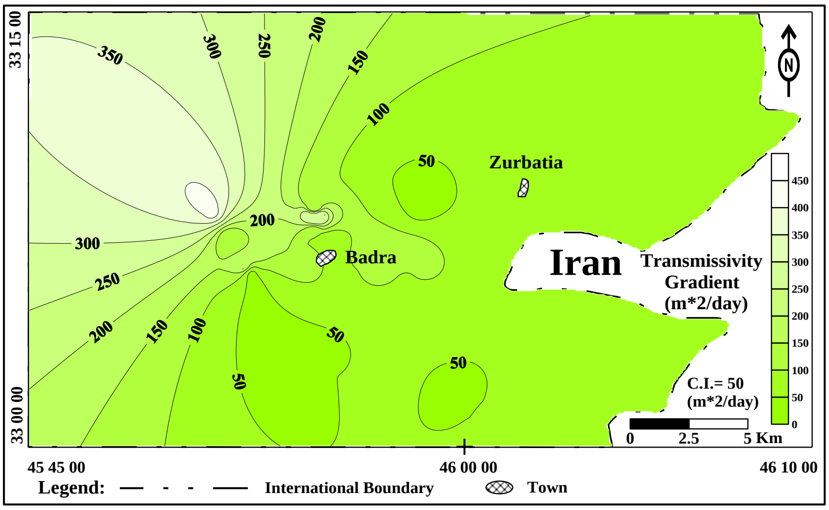

Figure 4. Transmissivity map of the unconfined aquifer.

Figure 5 shows the maximum yields map of the unconfined aquifer in the area, where a moderate decrease in maximum yields is observed in the area of study. As mentioned before, it is observed from the geological map in figure 2 that all types of quaternary sediments basically formed the aquifer in the southern and southwestern parts. The mixing of these sediments with different sorts of particles affects the hydraulic properties of the aquifer. The variation of quaternary sediment lithologies and their accumulation in different sizes in the aquifer affect on groundwater maximum yields negatively [15]. The same effect was recorded on transmissivity, as mentioned earlier. The maximum yields of groundwater is also affected, on the other hand, by the depth and efficiency of the drilled wells, as the thickness of the aquifer, as we explained previously, also decreases in these areas as a result of the low depths drilled to reach the groundwater.

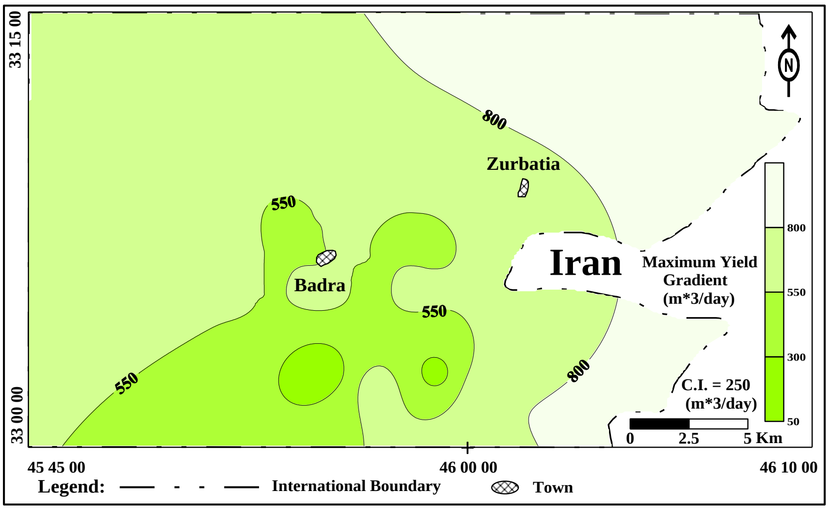

Figure 5. Maximum yields map of the unconfined aquifer.

Figure 6 shows the groundwater flow net map in the unconfined aquifer in the study area, where the topographical and structural geology conditions play a fundamental role in the movement of groundwater from the recharge area towards the discharge area, which are often water bodies [16]. The map demonstrates the groundwater movement paths starting from the northern and eastern parts near the Hamrin Mountains heights, which also represent the Iraqi-Iranian international borders. These regions of the study area represent the groundwater recharge areas as a result of the infiltration of surface water into the Muqdadiyah formations, primarily, and finally moving to the quaternary sediments. The topographic slope plays a major role in the movement of this groundwater in different directions. Partially to the western parts of the study area, and primarily towards the southern parts of the area towards the Shuwaicha marsh area which is located outside the area of study. Some previous studies mentioned the same result regarding groundwater movement indicated in this study [4, 5, 9].

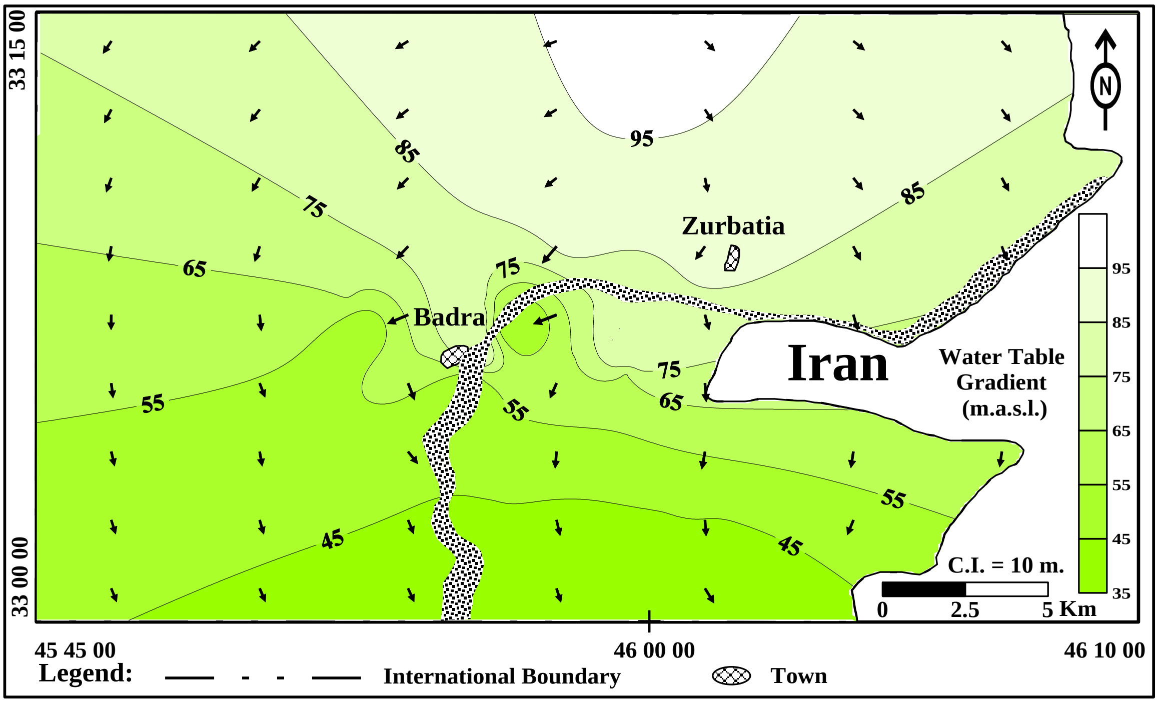

Figure 6. Flow net map of groundwater in the unconfined aquifer.

5.2. Hydrochemical Properties of Aquifer

Table 2 shows the statistical data of hydrochemical groundwater properties of unconfined aquifer in the area, where (40) well 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 aquifer is brackish to saline types where (TDS > 1000 mg/l) [17].

Table 2. Hydrochemical properties of unconfined aquifer in the area.

Parameter	Number of values	Minimum	Maximum	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

Parameter	Number of values	Minimum	Maximum	Mean
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

The salinity of groundwater is affected by the variation of groundwater recharge sources, ion exchange activities, and the ability of substitution between the main ions. A group of factors, including recharge and drainage areas, groundwater movement trends, in addition to the depth and rockiness of the aquifer, play an effective role in this variation. Groundwater recharge reduces the concentration of water salinity through dilution and mixing processes between groundwater and the water feeding it [1]. Figure 7 demonstrate the groundwater salinity distribution map of aquifer in the area. The map shows highly values of salinity concentration in the area of recharge to the northern and eastern border of the area. The geological map in Figure 2 shows the exposed of the Fatha Formation 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 aquifer formed by Muqdadiyah Formation and the Quaternary sediments. Therefore, we find that the number of wells drilled in these areas is very few and sometimes absent due to the high salinity concentrations. The surface water coming from Iran's territory within the Galal Badra helps, when it infiltrates the aquifer, locally in reducing the salinity concentration of the groundwater. On the other hand, the unconfined aquifer may be recharged from the confined aquifer in some areas by hydraulic connections [2], which is likely to have high groundwater salinity concentration, especially in the recharge areas, as shown in figure 7. All previous studies stated that groundwater salinity of unconfined or confined aquifers in this area indicted highly concentrations over decades as mentioned in [1-4, 8, 9], which mean that groundwater is originally contaminated with highly ionic concentrations due to several reasons. As the climate of area was characterized by continental semi-arid, thus low precipitation rates was recorded in the area with low surface runoff in Galal Badra stream. Reuse of irrigation water and other utilizations of groundwater in the area may also increasing the groundwater salinity.

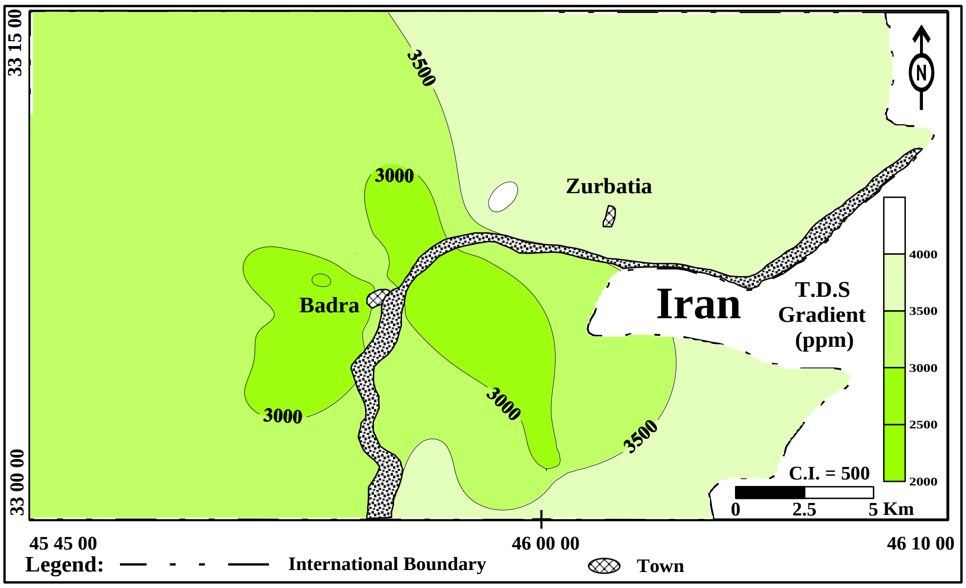

Figure 7. Groundwater salinity distribution map of unconfined aquifer.

5.3. 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 [18, 19]. The Kurlov formula determines groundwater quality based on the concentrations of positive and negative ions in epm% [20]. Table 3 indicates the groundwater types of unconfined aquifer 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 Fatha formation provides groundwater with diluted calcium ion, while other formation (Injana, Muqdadiyah and Quaternary deposits) provides the groundwater with diluted sodium ion in ionic exchange activities.

Table 3. 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		
Maximum	23	30.2	13.75	39.70	21.88	7.74	Ca- Sulphate	17
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		
Maximum	30	18.8	15.41	33.33	23.01	17.42	Na- Sulphate	16
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		
Maximum	31.78	20	8.83	21.60	28	14.48	Na- Chloride	6
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

5.4. Groundwater Utilization

According to table 2 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 4 shows the groundwater utilization of unconfined aquifer in the area. 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 [21].

Table 4. 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		

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
Maximum	8	5820	4112	604	185	731	994	541	1906	18	14.04		
[22]	6.5-8.5	-	1000	75	125	200	250	200	250	50	-	0	Human Purposes
[23]	6.5-8.5	-	1000	50	50	200	250	200	250	50	-		
Standard FAO/1989 [24]	-	-	2000	40	5	20	30	10	20	-	15	0	Irrigation purposes
Standard FAO/1989 Poultry + Livestock [24].	-	5000	-	-	250	-	-	-	-	100	-	40	Animal purposes

6. Conclusions

1. The type of groundwater aquifer in the area is composed of quaternary deposits and Mukdadiyah formation is an unconfined aquifer. The mean thickness of this aquifer was (53) m, while transmissivity mean was (114) m^2/day with (600) m^3/day of maximum yields which indicates a suitable aquifer to use groundwater for several purposes.
2. Groundwater movement paths start from the northern and eastern parts toward the western, southwestern, and southern parts of the study area due to topographic slope. The groundwater moved partially to the western parts and primarily towards the southern parts of the area.
3. 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.
4. 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.
5. 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.
6. According to the hydrogeological and hydrochemical properties of the aquifer, the central area between Zurbatia and Badra towns can be a qualified locations to increase well drilling. The salinity decreased as the transmissivity and maximum yields increased.

Abbreviations

PH	Potential of Hydrogen
E.C.	Elecrtical Conductivity
TDS	Total Dissolved Solids
SAR	Sodium Adsorption Ratio.

Author Contributions

Hussein Ilaibi Zamil Al-Sudani is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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