SSRG International Journal of Recent Engineering Science
ISSN: 2349–7157 / https://doi.org/10.14445/23497157/IJRES-V11I5P120

Volume 11 Issue 5, 206-212, Sep-Oct 2024

Original Article

Hydrogeological Investigation of Groundwater Aquifer - East of Iraq

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Received: 27 August 2024 Revised: 30 September 2024 Accepted: 17 October 2024 Published: 30 October 2024

Abstract *- Water resources seem abundant, but less than one percent of them are readily available for human use. The area between Badra and Zurbatia, located on the eastern border of Iraq within the Wasit governorate, was investigated. (60) wells were inventoried during the field study, and only (40) wells were used to demonstrate their hydrogeological properties. The unconfined 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 central area between Zurbatia and Badra towns can be a qualified location for increasing well drilling.*

Keywords *- Hydrogeological Investigations, Groundwater aquifer, Badra-Zurbatia area, East of Iraq.*

1. Introduction

Life could not exist on earth without water, where surface water is the main source utilized for various purposes, and when it is depleted or scarce, groundwater will assume the first job in local water assets [1]. The studied area between Badra and 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 shown 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 [1]. 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 [3]. 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 hydrogeological investigations between the Badra and Zurbatia areas to evaluate the most important product groundwater aquifer and achieve optimum use of groundwater in terms of sustainable water management. The area depends mostly on groundwater for many purposes, especially for agriculture and animal benefits.

Several studies have been done to evaluate the hydrogeological situation and accessibility of the groundwater in the between 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 [4].
2- In 2012, Al-Shamaa and Al-Azzawi carried out a study of the hydrological relationship between surface and groundwater in the Badra-JJassan basin [3].
3- In 2012, Al-Shamaa and Al-Azzawi studied the estimation of groundwater recharge in the Badra-JJassan basin using the annual water surplus method [2].
4- In 2021, Bahet and Malik studied groundwater detection in the Iraq-Wasit Governorate using remote sensing and GIS [5].

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 the inventory of 60 water wells,

where investigations included measures of geographical position, elevations, static water levels, depths, thicknesses, and maximum yields. 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 Resources.

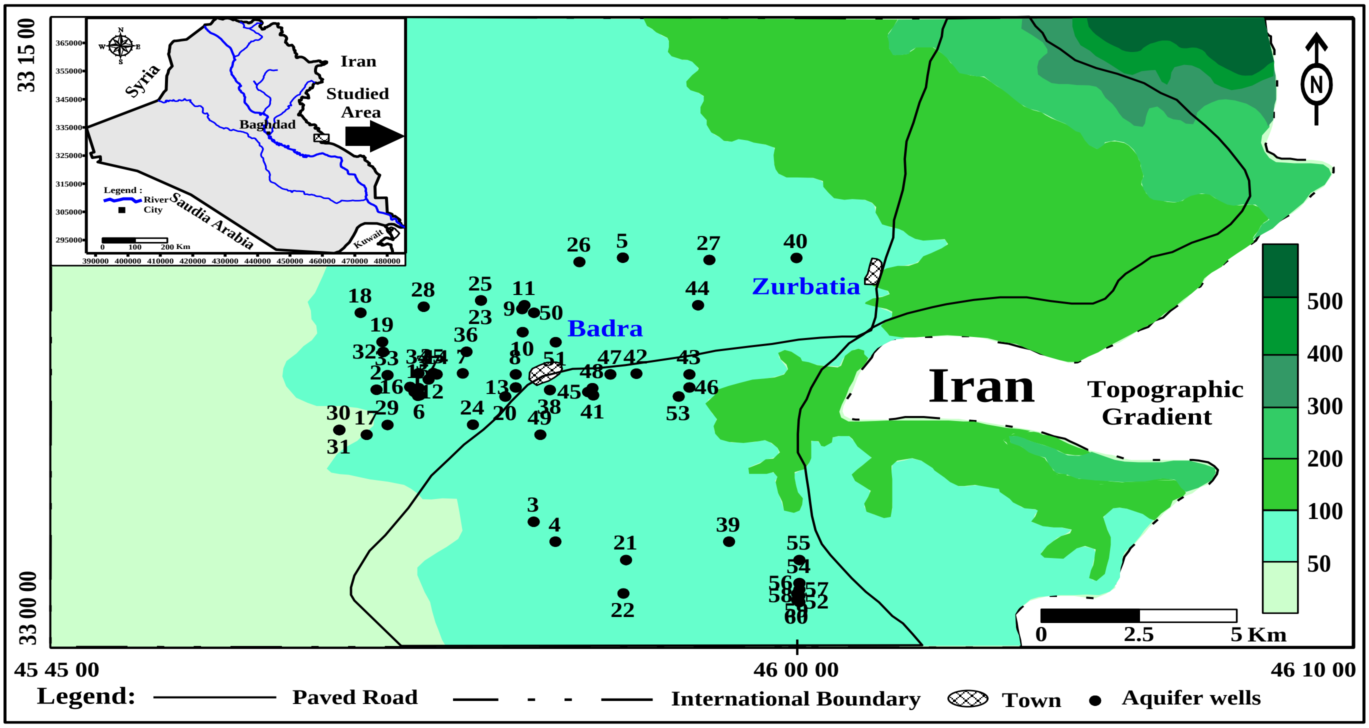

Fig. 1. Location and topographic map of the studied area

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.

2.1. 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.

2.2. Injana Formation (Upper Miocene)

The formation is exposed north of Zurbatia town only. It is composed of monotoneous alternating 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 freshwater to fluvial.

2.3. 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.

2.4. Quaternary Deposits

2.4.1. 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.

2.4.2. 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, reach more than 15% and in different forms, filling the pores, fissures and crocks.

2.4.3. 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.

2.4.4. 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.

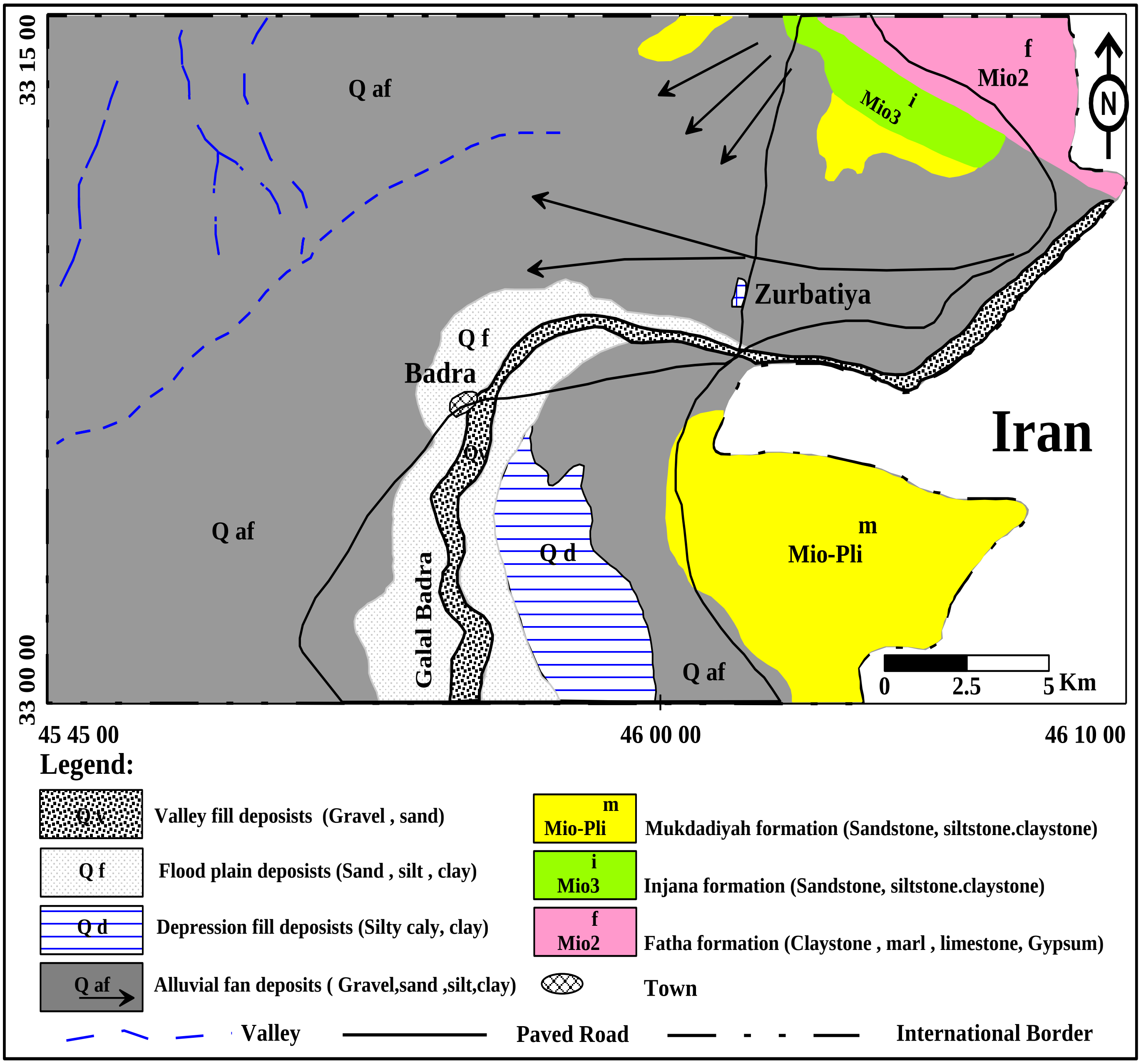

Fig. 2 Geological map of the area modified after

3. Materials and Methods

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 (General Commission of Groundwater, 2023).
4. Mathematical programs (Surfer and Excel) were used to analyze the data and information obtained and draw all types 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 between the Badra and Zurbatia areas. 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. The mathematical programs (surfer and grapher) were used to demonstrate the results as contouring maps of hydrogeological properties of the unconfined aquifer between the Badra and Zurbatia areas.

4. Results and Discussion

4.1. Hydrogeological Investigation of Groundwater 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 [3-6]. As previously mentioned, the field study in this research determined that only an 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 the unconfined aquifer in the area where (40) wells were used in this study to demonstrate thickness, transmissivity, maximum yield and groundwater flow net maps, as shown in figures 3, 4, 5 and 6, respectively.

Table 1. Hydrogeological properties of unconfined aquifer in the area

Parameter	Number of values	Min.	Max.	Mean
Elevation (m)	40	35	103	64
Total depth (m)	40	30	127	60
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 (m3/day)	38	155	825	600
Transmissivity (m2/day)	34	10	445	114

Structural, topographical, and geological factors generally affect the hydrological basin [7]. 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 areas, 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. Texture, types of sediments and the degree of sorting of these sediments that formed aquifer affect the transmissivity and storage coefficient of groundwater [8]. In the eastern and northeastern parts of the area, the aquifer consists of symmetrical and regular layers of sandstone of the 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 increase. 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, representing a continuous groundwater movement [9]. Figure 4 shows a transmissivity map of the unconfined aquifer in the area.

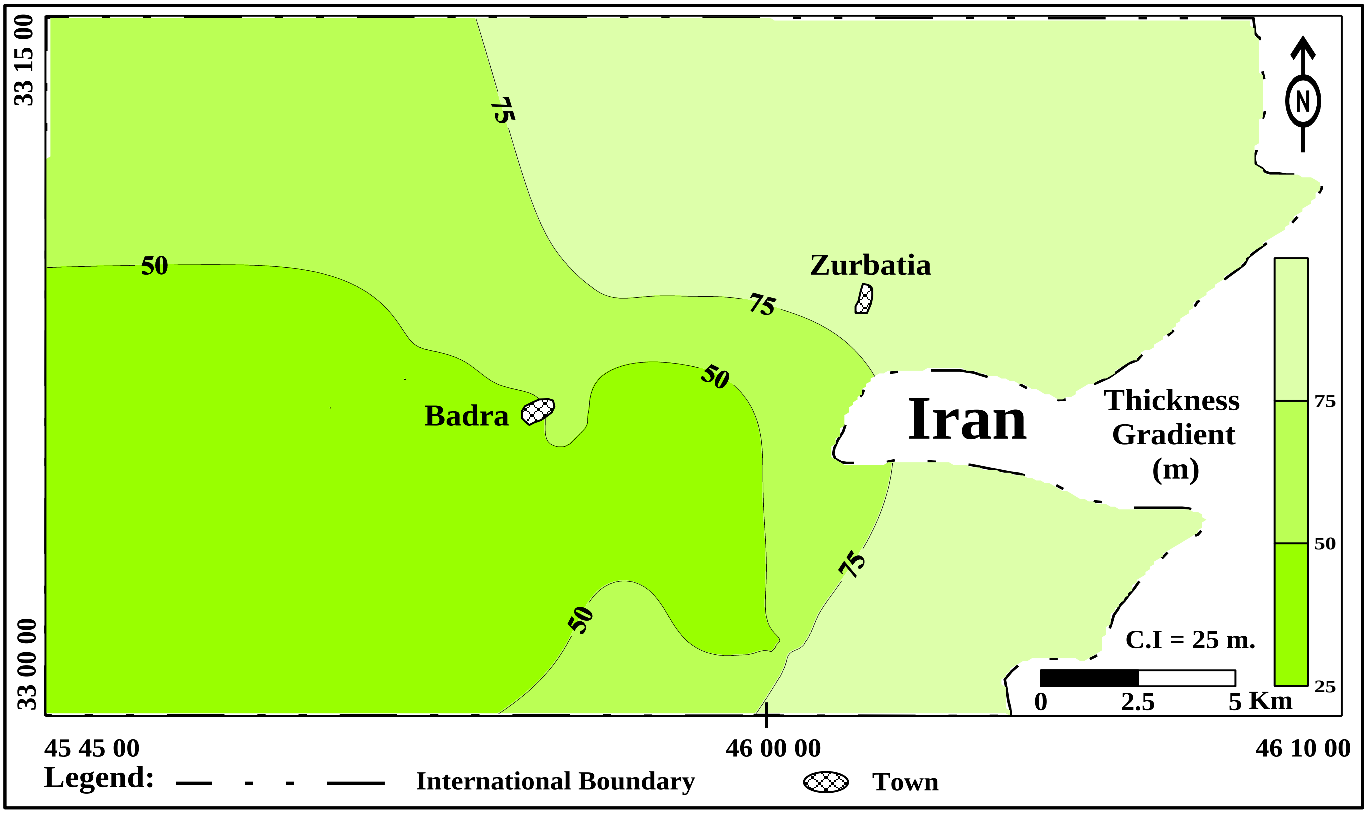

Fig. 3 Thickness map of the unconfined aquifer

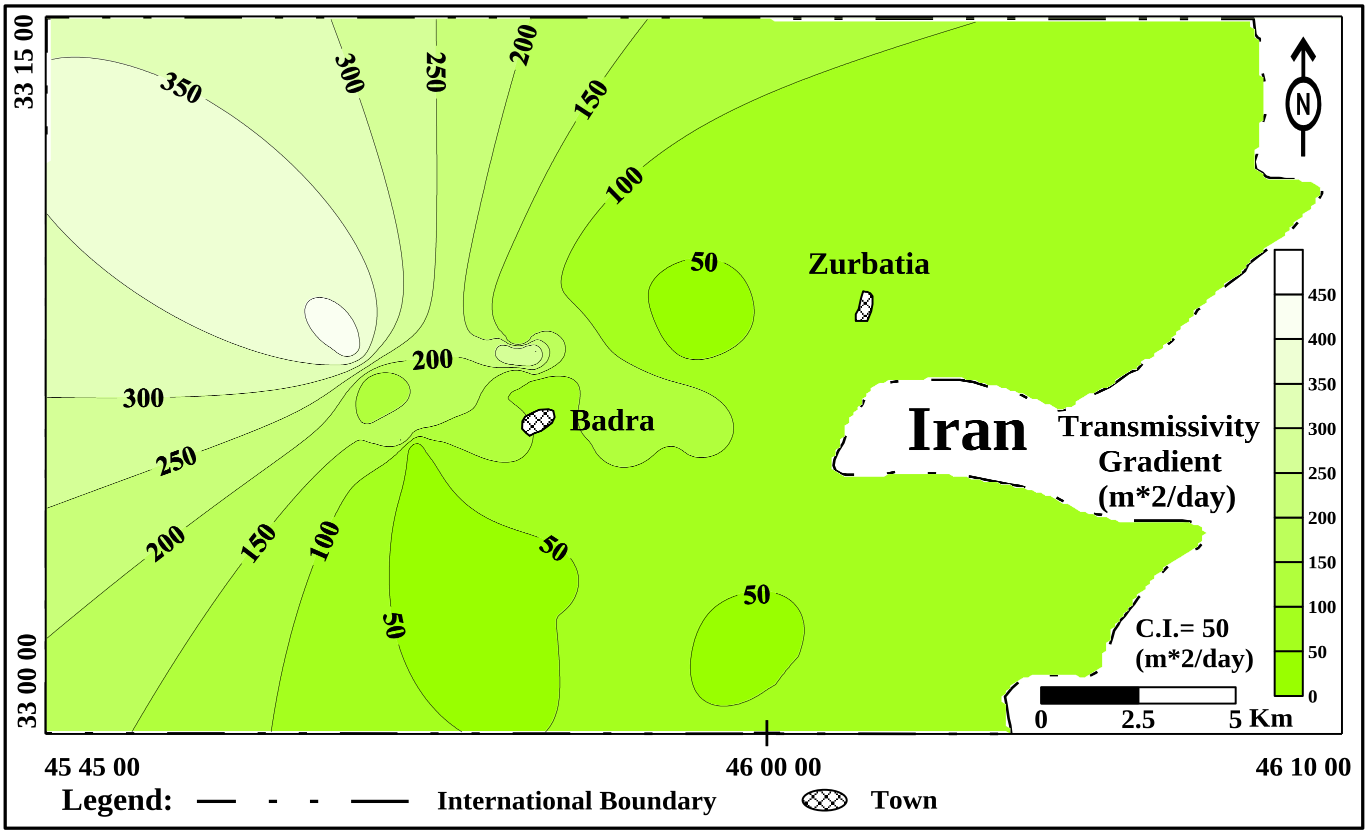

Fig. 4 Transmissivity map of the unconfined aquifer

Figure 5 shows the maximum yield map of the unconfined aquifer in the area, where a moderate decrease in maximum yields is observed in the study area. 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 groundwater maximum yields negatively [10].

The same effect was recorded on transmissivity, as mentioned earlier. The maximum yields of groundwater are 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.

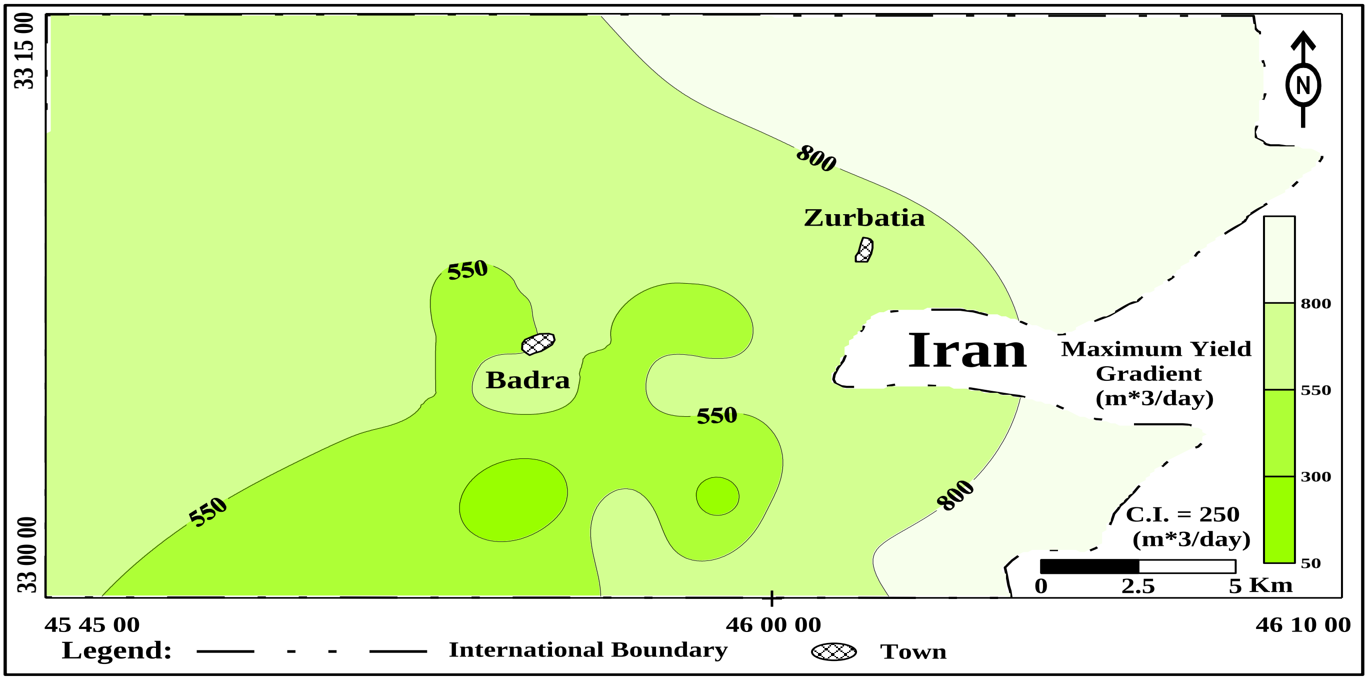

Fig. 5 Maximum yields map of the unconfined aquifer

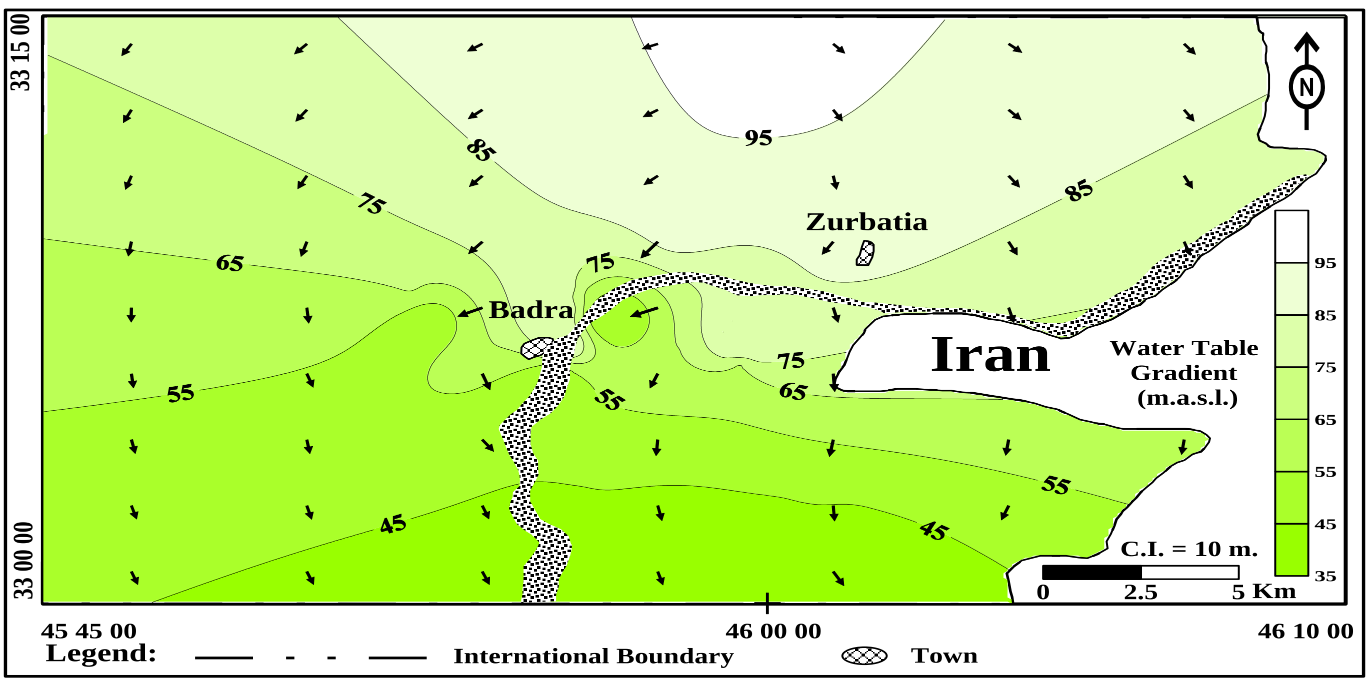

Fig. 6 Flow net map of groundwater in the unconfined aquifer

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 [11]. The map demonstrates the groundwater movement paths starting from the northern and eastern parts near the heights of the Hamrin Mountains, representing 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, it is towards the Shuwaicha marsh area, which is located outside the study area. Some previous studies mentioned the same result regarding groundwater movement indicated in this study [3, 4, 5].

5. Conclusion

1. The type of groundwater aquifer area between Badra and Zurbatia area is composed of quaternary deposits and Mukdadiyah formation as an unconfined aquifer. The mean thickness of this aquifer was (53) m, while the transmissivity mean was (114) m2/day with (600) m3/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 study area's western, southwestern, and southern parts due to topographic slope. The groundwater moved partially to the western parts and primarily towards the southern parts of the area.
3. According to the hydrogeological properties of the aquifer, the central area between Zurbatia and Badra towns can be a qualified location to increase well drilling.

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