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REVIEW ARTICLE

Groundwater system of Dibdibba sandstone aquifer in south 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. The study area has been chosen to be in south of Iraq within Basrah governorate. Depending on 86 wells, the aquifer has been formed by Dibdibba formation in the west while both Dibdibba and alluvial fan of Wadi AL-Batin in the east and north-eastern part of the area. The aquifer has been investigated during field work where geographical position, elevations, static water levels, depths, thicknesses, maximum yields as well as water sampling were carried out. Depending on hydrogeological and hydrochemical properties of the aquifer, the promising zone of useful exploration of groundwater has been located to be the west of Zubair and Safwan towns. Physicochemical analysis of groundwater aquifer is a brackish to saline water. Groundwater quality of aquifer is not recommended to be used for human and irrigation purposes, even so the farmers have been using this water for irrigation and animal purposes depending on soil nature and plants.

Keywords Groundwater system · Hydrogeology and hydrochemistry · Dibdibba formation · South of Iraq

Introduction

More than a third of all water used worldwide by humans comes from groundwater. In rural areas, the percentage is even higher: more than half of all drinking water worldwide supplied from groundwater (Harter 2015). Scarcity of available surface water resources as well as its quality deterioration were the main reasons towards water exploitation of groundwater basins in order to exploit this resource optimally and maintain the strategic storage of these resources (Al-Sudani 2017). Estimating the physical properties of water-bearing layers is an essential part of groundwater studies, where continuing of groundwater extraction from the aquifers for all purposes is contributing to groundwater depletion in many parts of the world (Al-Sudani 2017; Ramesh and Fritz 2016). One of the most effective ways of determining physical properties is to conduct and analyse changing with time, and water levels (or total heads) of aquifers caused by withdrawals through wells (Delleur 2000). Determination of physical and chemical parameters of water is essential for assessing its suitability for various purposes. Generally, the groundwater quality depends on the composition of recharge water, the interaction between the water and the soil, the soil–gas interaction, the rock with which it comes into contact in the unsaturated zone, the residence time and reactions that take place within the aquifer (Fetter 2000).

The study area is located at the extreme part of south of Iraq within Basrah governorate, bounded by latitudes (29°45′–30°45′) and longitudes (46°35′–48°00′), see Fig. 1. The main goal of this research is the assessment and finding the physical and chemical characterizations of Dibdibba aquifer depending on hydrogeological investigation carried out in south of Iraq, where thousands of groundwater wells extracting water within the aquifer have been used for livestocks and for irrigating salt-tolerant crops.

The area has arid-to-semiarid climate. The climatic data for the years (1950–2000) are as follows: the mean annual temperature is around 24; the mean annual relative humidity ranges from 50 to 55%; the dryness index ranges from 15 to 20; the mean annual amount of evaporation is 2500 mm; and the mean annual rainfall is around 150 mm (Iraqi General Organization for Meteorological Information 2010).

The work plan in the studied area included the office work where preparing data and preliminary information of the area (wells stratigraphic columns, maps, literature

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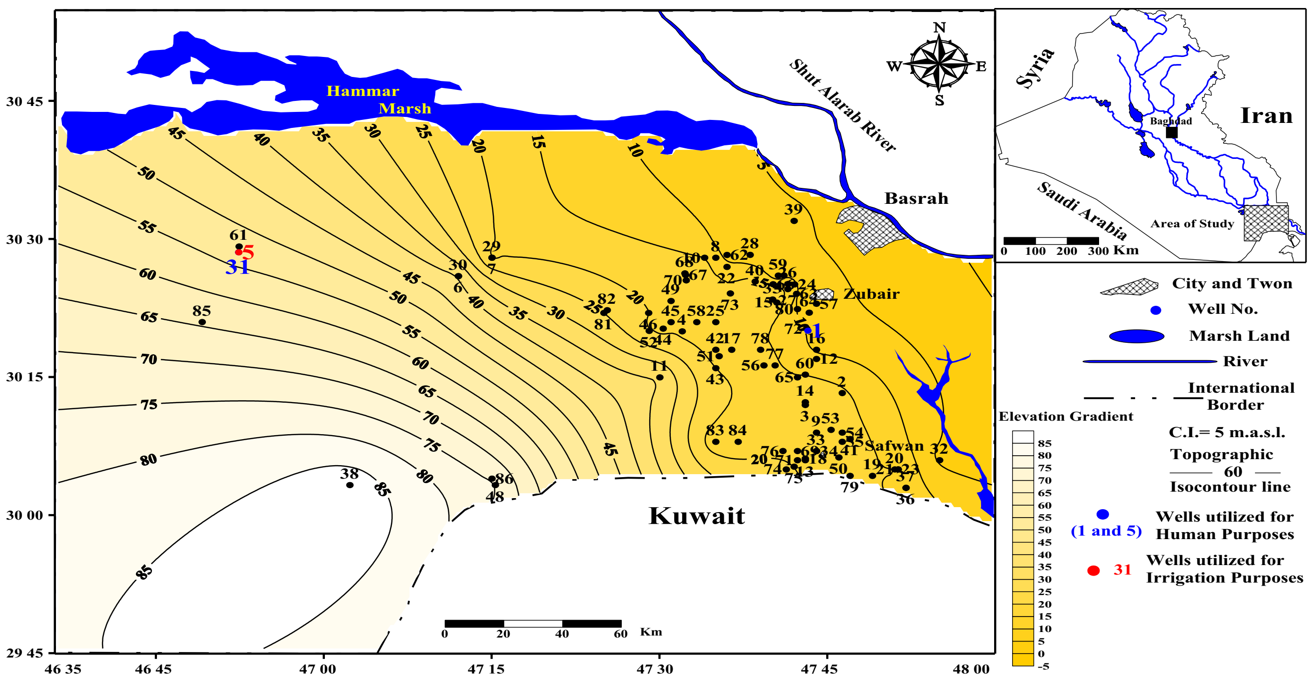

Fig. 1 Topographic and groundwater wells location map in studied area

reviews, scientific references, hydrogeological data bank…) is included. The fieldwork has included three major items, inventory of water wells and measuring water levels in the wells as well as finding geographical positions and levels of 86 water points, sampling of 86 wells during 2015 and finally laboratory analysis of 86 water samples to measure physical and chemical components and variation of ionic concentrations.

Previous studies

Several earlier studies were done within the region as mentioned below; generally, these studies were addressing local area of Safwan–Zubair except one:

1. Hydraulic properties of Dibdibba sandstone using pumping tests data in large diameter wells (Al-Jawad et al. 1989).
2. Hydrogeology of Dibdibba aquifer in Safwan–Zubair area, south of Iraq (Al-Kubaisi 1996).
3. Quaternary–tertiary hydrogeologic boundary condition at Safwan–Zubair area, south of Iraq (Al-Kubaisi 1999).
4. Hydrogeology of Safwan–Zubair area, south of Iraq (Atiaa 2000).
5. Hydrogeology of aquifers in the Western Desert—west and south of Euphrates River (Al-Sudani et al. 2001).
6. Management of groundwater resources of Dibdibba sandy aquifer in Safwan–Zubair area, south of Iraq (Atiaa and Al-Asadiy 2007).
7. Hydrochemical classification of groundwater in Safwan–Al-Zubair area, south of Iraq (Al-Aboodi et al. 2008).
8. Uranium in groundwater of the Al-Batin alluvial fan aquifer, south of Iraq (Al-kinani et al. 2016).
9. Groundwater investigation in Iraqi Marshland area (Al-Sudani 2017).

Geological setting

The map area lies within the Zubair tectonic sub-zone which is the southernmost part of the Mesopotamian Zone of Unstable Shelf. Its southwestern cover lies within the Salman Zone of the Stable Shelf. Most of the structures in the map area have no surface expression; however, Jabal Sanam is the only visible structure which is the unique domed structure penetrated in AL-Batin fan sediments (Yacoub 1992).

- **Rock sequence of Jabal Sanam:** represented by two units, the gypsum unit with 80 m and limestone unit of 18 m thickness.
- **Dibdibba formation (Pliocene–Pleistocene):** the surface exposures of formation do not exceed few metres (3.8 m) and partly exposed on the eastern and southern side of Jabal Sanam. The formation occupies an extensive flat and slightly wavy terrain, on the western part of the area characterized by pebbly, medium to coarse sand and sandstones with calcareous cement. The rock types show that the formation is of fluvial origin.
- **Quaternary Deposits (Pleistocene–Holocene)**

- Alluvial fan of Wadi AL-Batin (Pleistocene): the area includes the major part of the vast Wadi AL-Batin alluvial fan, which extended from Hafer AL-Batin (outside the area) and reaches the southern margin of Hor AL-Hammar, in the north with maximum depth up to 10 m. The Al-Batin alluvial fan composes of gravelly sand and sandy gravels.
- Estuarine Sabkha deposits (Holocene): the estuarine Sabkhas between Shatt Al-Arab and Khor AL-Zubair are supratidal surfaces produced mostly by seaward prorogation of coastline. The deposits consist of silty clay.
- The Tidal flat deposits (Holocene): the tidal flat extended from AL-Fao, in the east and westwards to Um-Qasr and then northwards along both sides of Khor Al-Zubair. The characteristic feature of the tidal flat, at the upper reaches of Khor AL-Zubair, is the dendritic distribution of gullies and channels (creeks).
- Flood plain deposits (Holocene): the Tigris and Euphrates flood plains represent the major depositional element of the Mesopotamian fluvial basin. These flood plains end tell of Lacustrine delta constituting the northern and western margins of the marshes and lakes in southern part of Mesopotamian plain.
- Sheet run-off deposits (Holocene): the sheet run-off deposits form a narrow strip along the eastern margin of Wadi AL-Batin fan. The deposits often include aeolian admixture and sometimes marine sediments (mud), brought by tidal action.
- Marsh and lake deposits (Holocene): the marsh sub-environment differs from other Lacustrine sub-environments by dense concentration of marsh vegetation, which is invariably grading rapidly down into light greenish grey or bluish grey mud, rich in mollusc shells.
- Aeolian deposits (Holocene): it consists, generally, of fine-to-medium grained sand with minor fractions of silt and clay, see Fig. 2 (Yacoub 1992).

Materials

The materials used in this research were:

- Topographic and geological maps of area with different map scales.
- GPS device to determine wells locations and elevations as well as other hydrogeological properties.
- Stratigraphic sheets and hydrogeological data bank (General Commission of Groundwater 2015).
- Grapher and surfer programs demonstrating graphs and contour maps.

Methodology

The geographical position, elevations, static water levels, depths, thicknesses, maximum yields as well as water sampling have been carried out during field work. Comparing the stratigraphic sheets of 84 inventoried drilled wells with water levels measured in these wells taking into consideration the geological setting and cross section of studied area and all information obtained from several earlier studies, the aquifer is classified as unconfined of Dibdibba formation and alluvial fan of Wadi AL-Batin quaternary deposits (Al-Sudani et al. 2001). Hydrochemical properties of water samples such as pH, electric conductivity (EC) and major cations and anions were measured and analysed by standard methods (APHA 2005).

Rustles and discussion

Hydrogeological properties of aquifer

The 86 drilled wells shown in Fig. 1 indicate that Dibdibba formation and alluvial fan form the water-bearing layer to the east and northeastern part of studied area, while only Dibdibba formation forms aquifer in the west and southwestern part (Al-Sudani et al. 2001; Al-Sudani 2017). Table 1 shows hydrogeological properties of the aquifer.

Based on earlier studies, the aquifer is classified as unconfined to semi-confined where a hard clay stone layer called Jojab separates aquifer layers with different hydraulic conductivity values as in Fig. 3. The upper part of Dibdibba formation is the most productive units consisting of sands and gravels. The transmissivity of the aquifer was generally greater than 300 m^2/d, and the saturated thickness of this layer extended from 15 to 20 m with an average of 17.5 m, while the thickness of the unsaturated zone was 4–130 m (Al-Jawad et al. 1989; Al-Kubaisi 1996, 1999; Atiaa 2000). The results obtained from this research were almost the same with transmissivity ranged between 15 and 685 m2/day and mean saturated thickness of 16.44 m. The aquifer investigated in this research depending on wells depth was not exceeding 110 m which means the wells did not penetrate Jojab claystone.

Thickness of the aquifer is shown in Fig. 4 where increasing values reaching 55 m in the west of area due to increasing thickness of Dibdibba formation. The thickness of saturated aquifer in the eastern and northeastern part of the area ranged between 15 and 20 m, where aquifer consists of both Dibdibba and Quaternary deposits of alluvial fan. Depths of

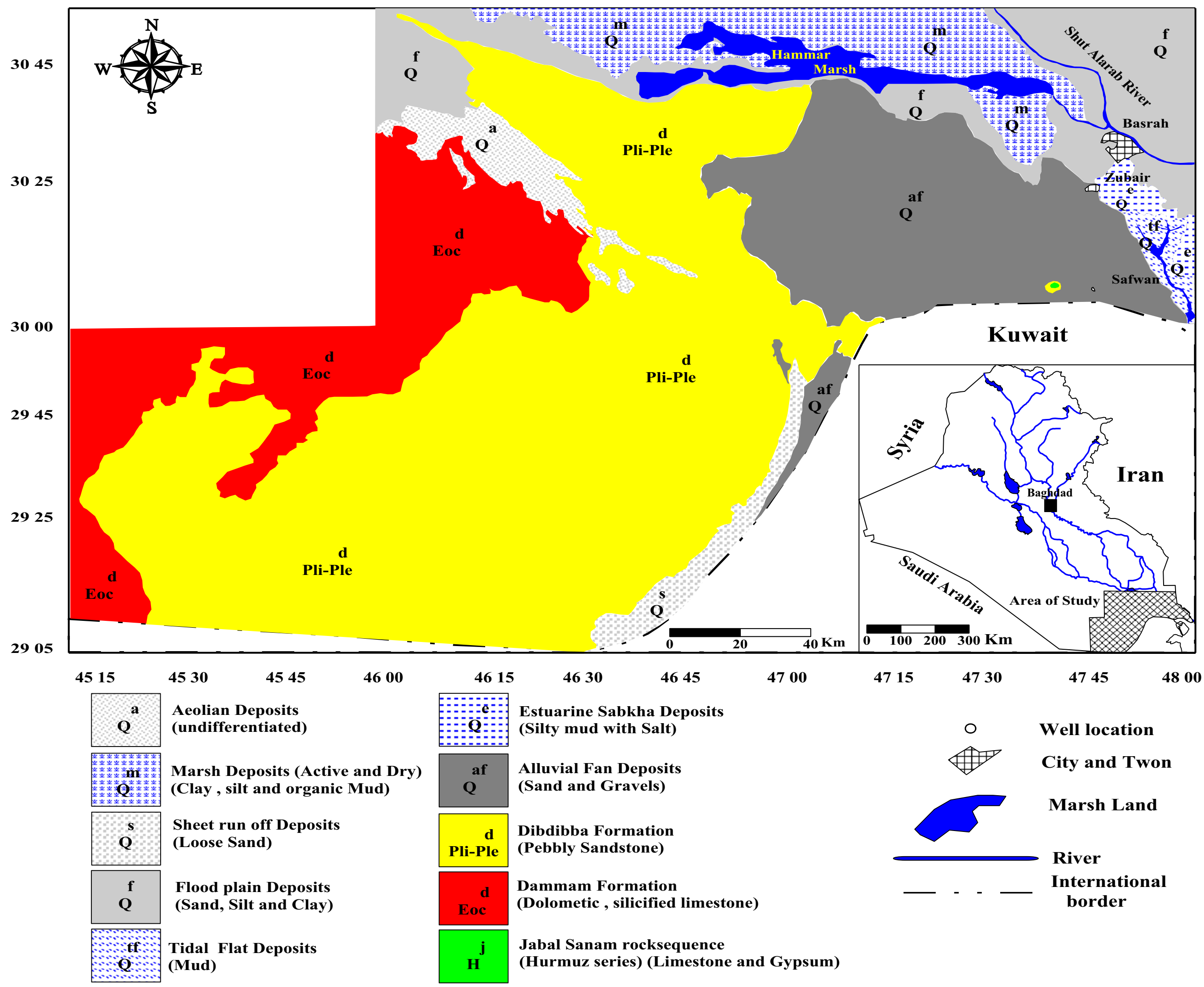

Fig. 2 Geological map of the area (Yacoub 1992) modified by author

Table 1 Statistical data show hydrogeological properties of aquifer

Statistics	Elevation (m)	Static w. level (m)	Water table (m.a.s.l.)	Dynamic water level (m)	Total depth (m)	Thickness (m)	Maximum yield (m^{*3}/day)	Spec. capacity (m^{*2}/day)	Transmissivity (m^{*2}/day)
Number of values	86	84	84	82	85	83	85	81	81
Minimum	4	2	− 6	4	16	7.5	138	14	15
Maximum	88	71	80.2	80	110	63	1683	990	658
Mean	20.33	13.78	6.08	17.65	30.17	16.44	530.42	213.8	224.1
Standard deviation	15.22	10.77	11.84	12.82	14.62	6.39	206.08	147.7	134.6

drilled wells in this area ranged between 16 and 50 m which affects on aquifer saturated thickness.

Figure 5 shows transmissivity contour map of the aquifer where this value increased gradually from west side of the area towards east and northeast. The main reason that transmissivity coefficient decreases while saturated thickness increases in the western part of the area is due to rising Dibdibba formation thickness, that is, calcareous

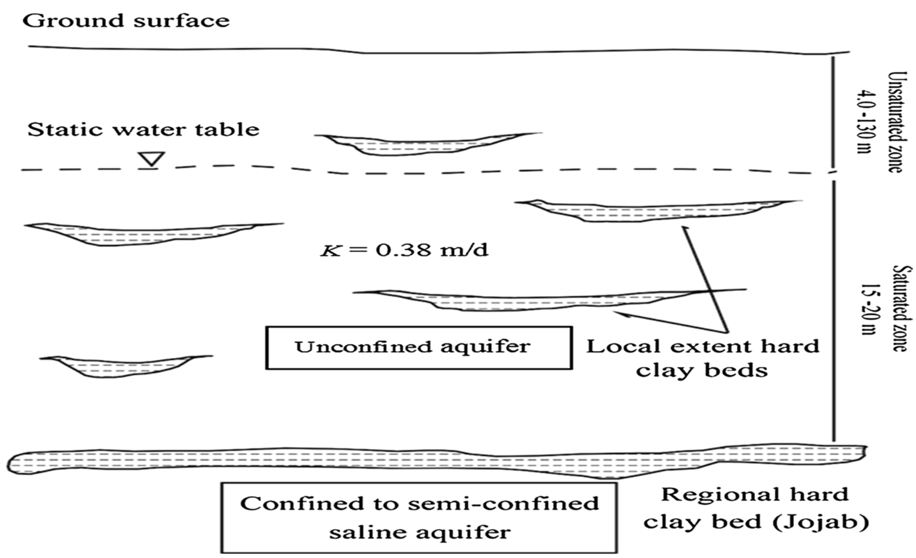

Fig. 3 Prototype of aquifer system in the study area modified after (Al-Jawad et al. 1989; Al-Kubaisi 1999)

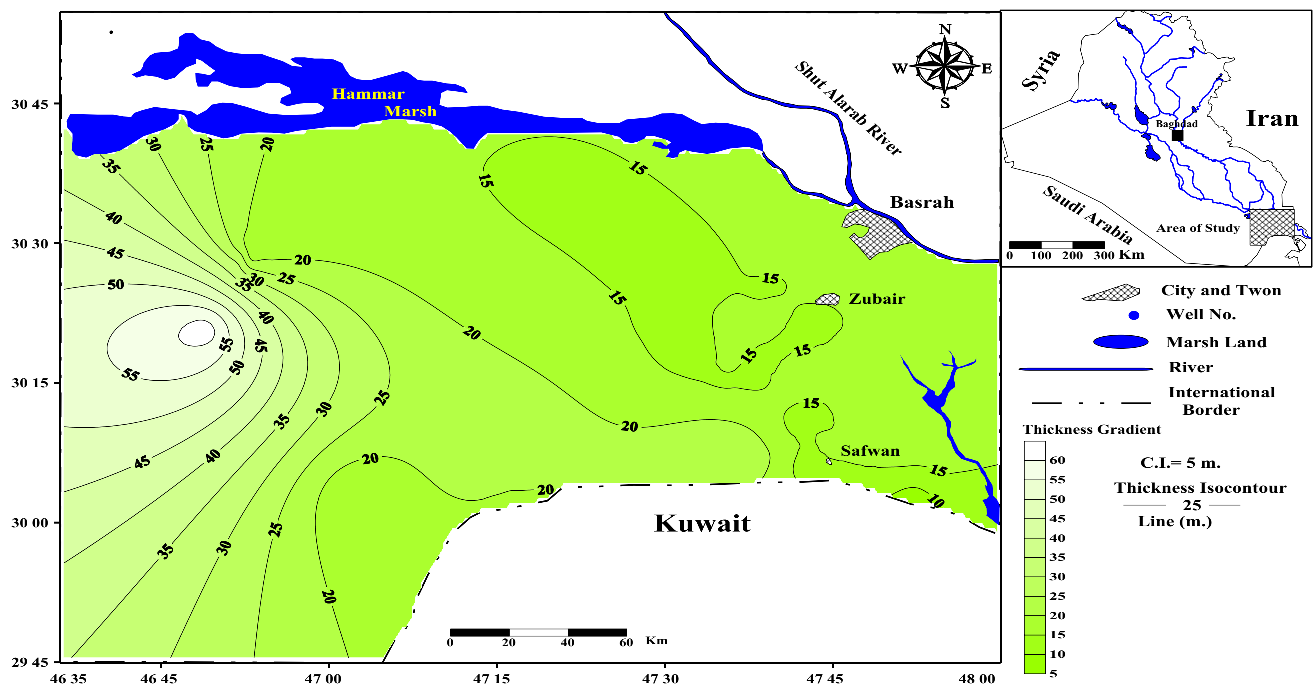

Fig. 4 Saturated thickness contour map of aquifer

cement composing the lithology of Dibdibba formation with sand and sandstones. This cement adversely affects on permeability which is the most significant rock properties of groundwater movement velocity. On the other hand, the transmissivity increases towards east and northeastern part of the area while saturated thickness is at it least values. The gravelly sand and sandy gravels composing alluvial fan of Wadi AL-Batin deposits with limited wells depth penetrating Dibdibba formation in this area are the main reason behind increasing this value.

Maximum yields depend on transmissibility of lithology of water-bearing and groundwater flow direction (Fetter 2000). The maximum yield (well discharge) of 85 wells ranged between 138 and 1683 m^3/day, and mean well discharge was 530 m^3/day. Maximum yields contour map is demonstrated in Fig. 6 where it increases gradually from west side of the area towards east and northeastern direction. It seems that maximum yield distribution has the same distribution as transmissivity. The hydrogeological properties of this aquifer indicate that saturated thickness was the

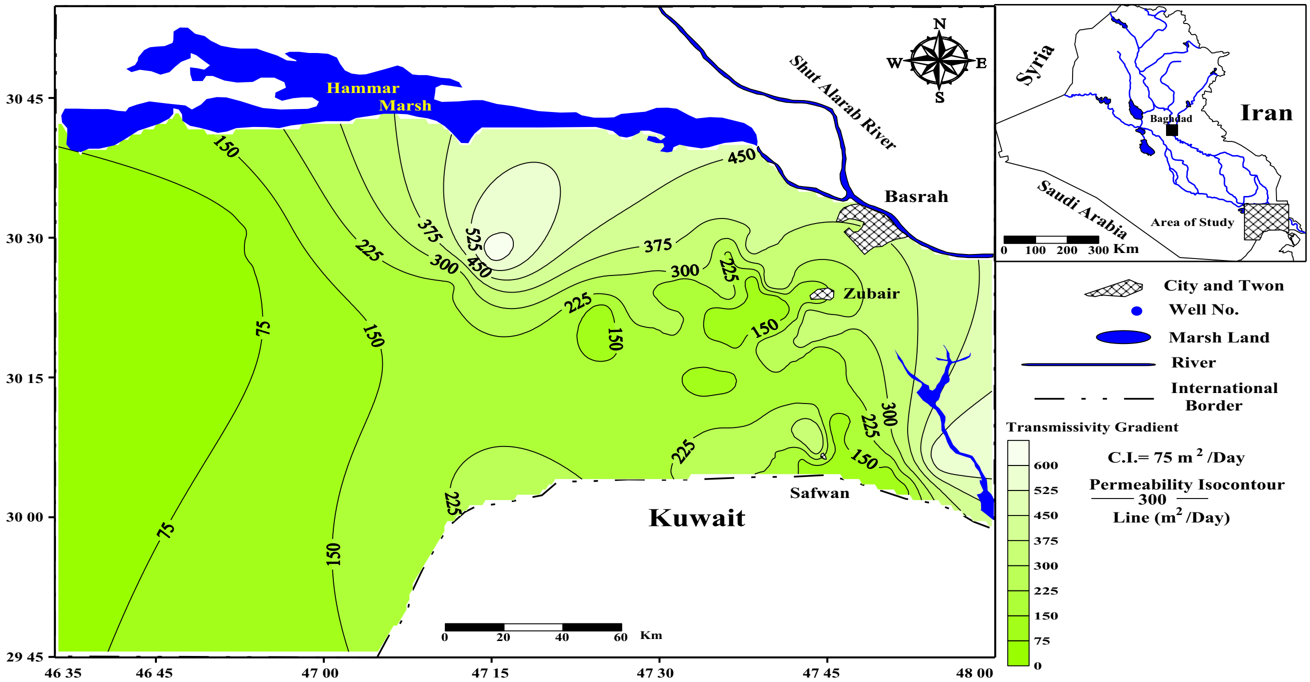

Fig. 5 Transmissivity contour map of aquifer

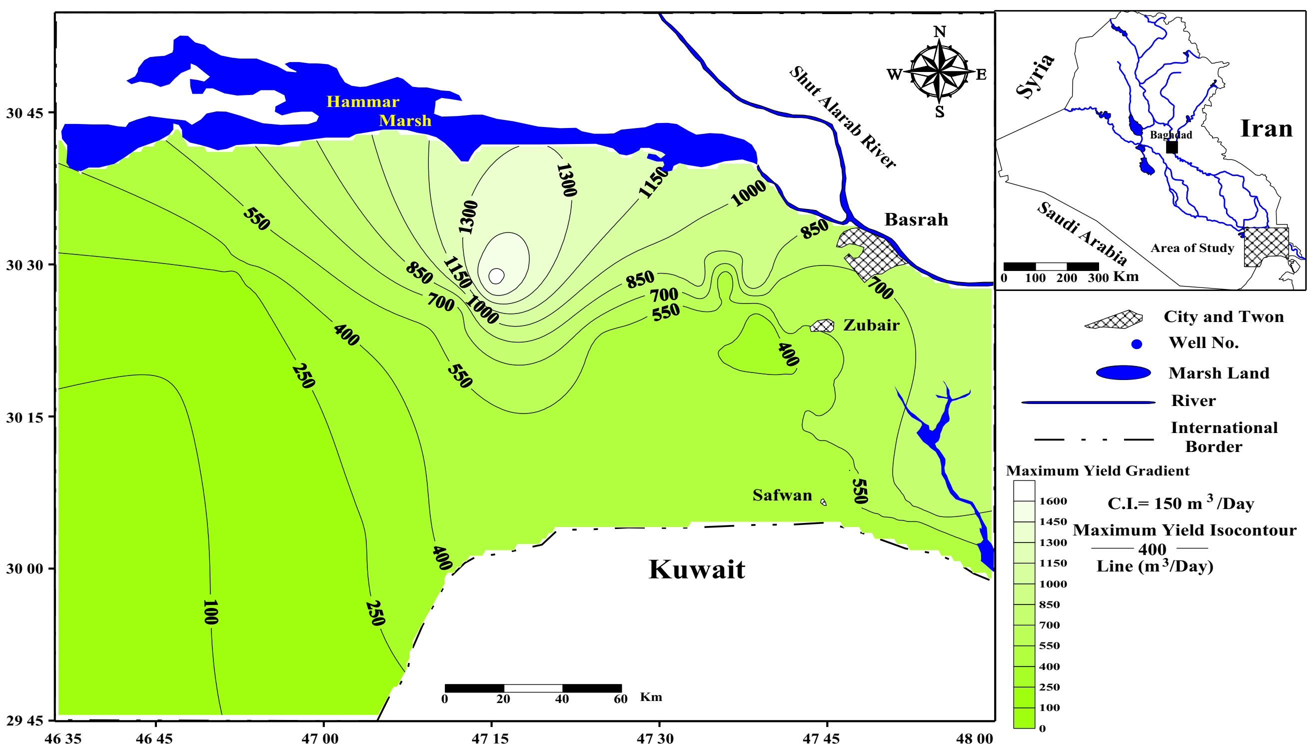

Fig. 6 Maximum yield contour map of the aquifer

lowest values in east and northeastern part of area while transmissibility and maximum yields were the highest values with the assembly of groundwater flow. As mentioned before, the aquifer was mainly formed by quaternary deposits and Dibdibba formation where its lithology differences were the main causes of maximum yields increasing.

The groundwater movement depends on hydraulic heads in aquifer as well as dipping and inclination of water-bearing strata (Al-Sudani 2018). The influence of topography in the eastern part of the area and aquifer layers dipping with hydraulic pressure in the western part were the major causes of groundwater movement in this aquifer as shown in Fig. 7. The water table (groundwater flow direction) map has a radial flow from southern area towards west, north, east and northeastern directions.

Hydrochemical properties of aquifer

Groundwater Chemistry

The statistical data of hydrochemical groundwater samples are shown in Table 2. The ranges of pH, electrical conductivity (EC) and total dissolved solids (TDS) represented as least and greatest were 6.9 to 8.9 and 1550 to 25,799 µmhos/cm, 500 to 21,688 mg/l omit. These values indicate that groundwater is brackish to saline types where TDS > 1000 mg/l (Sinivas and Nageswarara 2013).

Although the lithology of aquifer is continental depositional environments, the high values of total dissolved solids (TDS) as a result of high concentration of anions and cations in groundwater are caused by using irrigation water with high salinity continuously and widely to irrigate crops in the area. This recurrence process led to concentrating ions within porous media where irrigated water percolates and infiltrates deep to saturated zone with fertilizers used for agriculture. The arid-to-semiarid climate condition of the area is another reason of increasing salinity in groundwater as mean annual rainfall around 150 mm was not sufficient to enhance groundwater quality by groundwater recharge and dilution (Al-Sudani 2017; Al-Sudani 2018).

Distribution of groundwater salinity within area

Salinity as expressed in total dissolved salts (TDS) is the most important factor in groundwater hydrochemical studies, where salinity of the groundwater changes by site and time within the hydrogeological basin and water depth in aquifer. The salinity is the first element in determining the validity of groundwater use for different purposes. The geological and topographical conditions play an important role in changing salinity values because of effects of geological formations exposures and quality of water recharging the aquifer affected by topography of the basin (Robinson and Ward 2017). Depending on data in Table 2, the groundwater salinity distribution within the area has been illustrated in Fig. 8 where salinity increased towards east and northeastern part of the area to reflect a regular increase in salinity concentrations due to groundwater

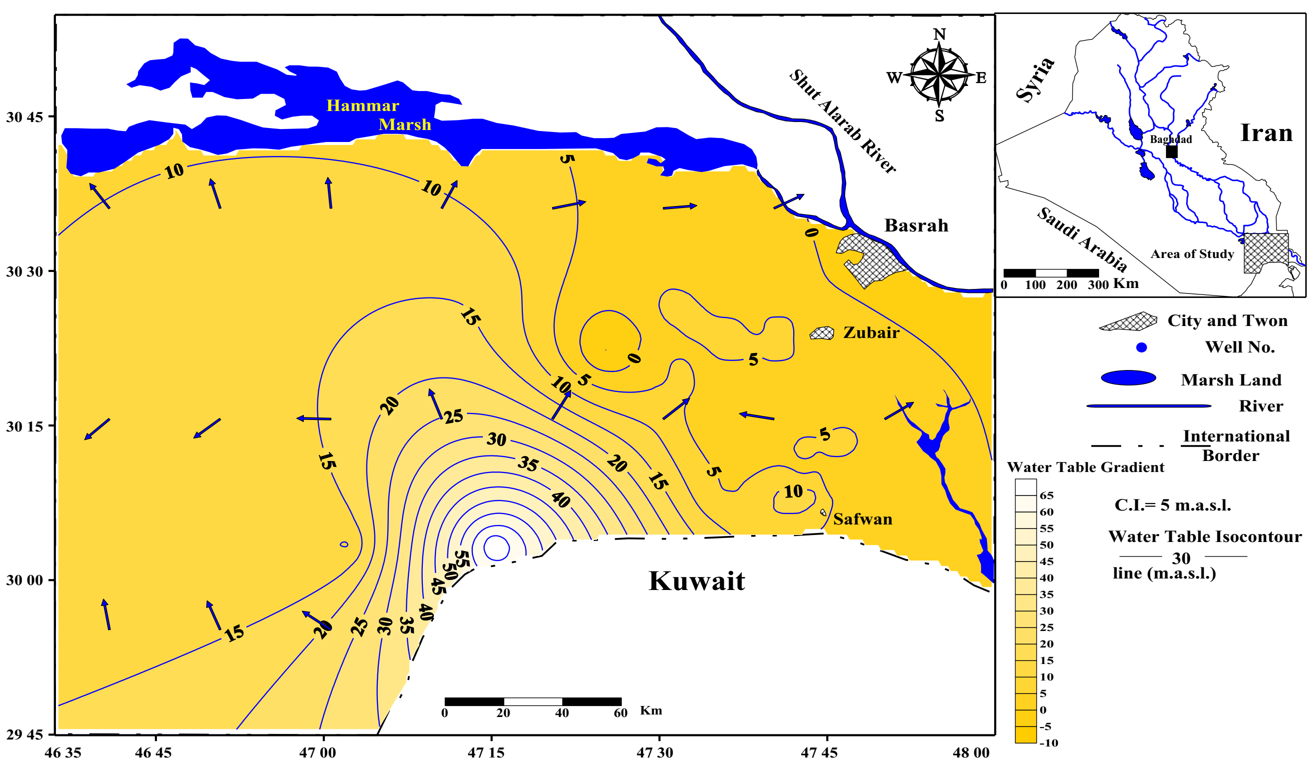

Fig. 7 Groundwater flow map of the aquifer

Table 2 Statistical data show hydrochemical properties of aquifer (Robinson and Ward 2017)

Statistics	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 values	41	81	86	83	82	79	73	81	79	66	74
Minimum	6.9	1550	500	75	32	120	104	43	170	4	1.9
Maximum	8.9	25,799	21,688	1333	2000	6210	9052	599	6885	118	63
Mean	7.65	8467	6534	504	247.5	1403	1761	129.4	2381	50.9	13.6
Standard deviation	0.376	4648	3604	214	356	1053	1686	70.2	1199	22.9	8.86

flow direction under pressure. Rock sequence of Jabal Sanam located near Safwan–Al-Zubair area which consists of gypsum unit with 80 m and limestone unit of 18 m thickness leads to increase in reaction between water-bearing layers and groundwater within the direction of flow. Long distance of groundwater movement from southern part of the area towards northern east reflects another factor in increasing salinity concentrations. Groundwater recharge area within specific area in western part, where Dibdibba formation exposed on surface, locally reduces salinity concentrations as groundwater moves towards northern west as seen in Fig. 8.

Groundwater origin and quality

Sulin classification used to find water origin and quality of groundwater in the area. Figure 9 shows the water origins and types of groundwater samples according to Sulin classification (Bonton et al. 2010), where continental origin and Na_2SO_4 water type were recorded for all samples while only 8 were marine origin and $MgCl_2$ water types. The aquifer in the area as mentioned before represented by Dibdibba and alluvial fan of Wadi AL-Batin deposits with continental depositional environments as a typical condition of groundwater origin and type in this aquifer. The only 8 samples represent marine origin caused by reaction and dissolution of chemical components of rock sequence of Jabal Sanam which consists of gypsum and limestone with groundwater as it is moving from recharge area towards discharge area as shown in Fig. 7.

Groundwater utilization

Table 3 shows groundwater utilization where only 2 wells can be used for drinking purposes, while only one well is useful for agriculture purposes (Fig. 1). Thirty wells are useful for animal purposes, and 53 wells are non-useful for any purposes due to high salinity concentration. However, the nature of the soil in the area and the depth of the groundwater qualified water for agriculture used in significant and wide range due to quaternary deposits consist of gravelly sand and sandy gravels which hold only 20% of the irrigation water and it is irrigated daily to maintain the nutrients needed by the cultivated plants which bear the high concentrations of saline water while decrease in elevations helps in accelerating the drainage process (Al-Sudani et al. 2001; Al-Sudani 2017).

Conclusions

1. The aquifer investigated in this research depends on depth of 86 wells indicating that Dibdibba formation and alluvial fan of Wadi AL-Batin deposits forming the

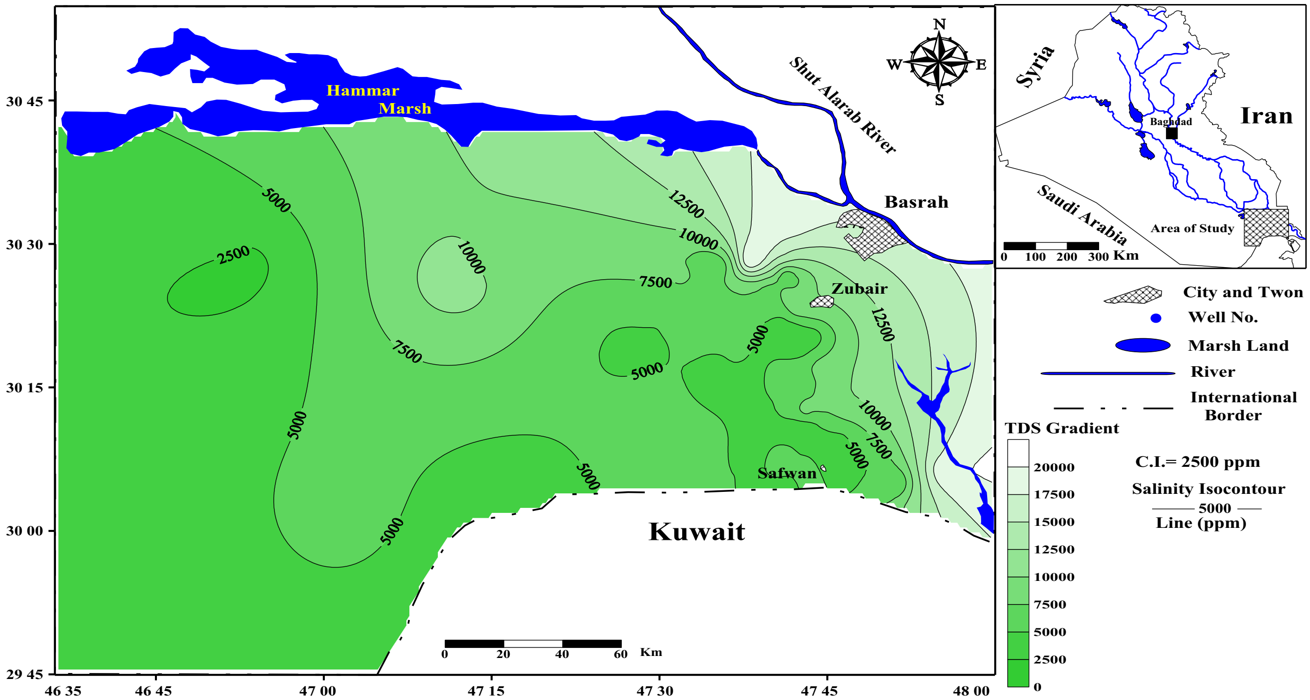

Fig. 8 Groundwater salinity distribution map of the aquifer

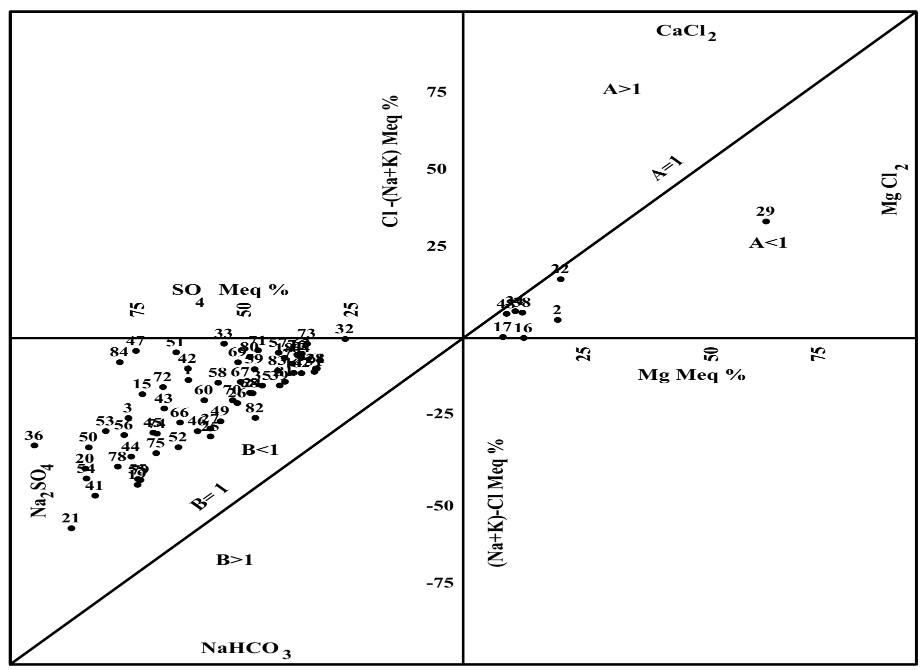

Fig. 9 Origins and types of groundwater samples in study area

water-bearing layer to the east and northeastern part of studied area, while only Dibdibba formation forms aquifer in the west and southwestern part. The depth of aquifer was not exceeding 110 m which means wells did not penetrate Jojab claystone.

2. Depending on hydrogeological and hydrochemical properties of the aquifer, the promising zone of useful exploration of groundwater is located to the west of Zubair and Safwan towns. Depth, thickness, maximum yield and transmissivity as well as groundwater flow direc-

Table 3 Groundwater utilization standards

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 and names	Utilization
Number of samples	41	81	86	83	82	79	73	81	79	66	74		
Minimum	6.9	1550	500	75	32	120	104	43	170	4	1.9		
Maximum	8.9	25,799	21,688	1333	2000	6210	9052	599	6885	118	63		
WHO (2011)	6.5–8.5	–	1000	75	125	200	250	200	250	50	–	2 (1,5)	Human purposes
IQS (2001)	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	1 (31)	Irrigation purposes
Standard FAO/1989 Poultry + Livestock (Ayers and Westcot 1994)	–	5000	–	–	250	–	–	–	–	100	–	30	Animal purposes

tion have qualified this area to being promising zone although groundwater quality is highly concentrated.

3. Physicochemical analysis of groundwater aquifer is brackish to saline water.
4. The typical condition of continental origin and (Na2SO4) water type were recorded for groundwater in the area.
5. Groundwater quality is not recommended to be used for human and irrigation purposes, even so the farmers have been using this water for irrigation and animal purposes depending on soil nature and plants.

Compliance with ethical standards

Conflict of interest The author declares that they have no conflicts of interest.

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