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Research paper

Groundwater detection and classification using remote sensing and GIS in Najaf, Iraq

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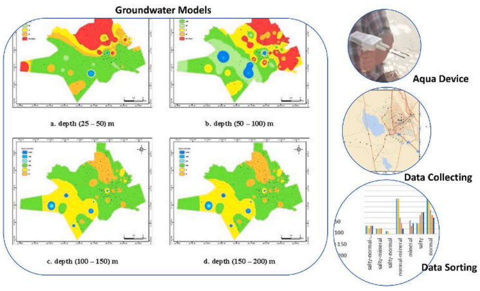
HIGHLIGHTS

- Water demand in Iraq increased for groundwater during the past three decades.
- Detecting the groundwater presence is an expensive process, as it requires drilling wells and conducting chemical and physical tests of the samples to determine their suitability for various uses.
- The usability of Aqua remote sensing device and GIS techniques to explore and assess the location, depth, and type of groundwater have been adopted.
- Five Spatial models are constructed for Groundwater type for five different ranges of depth.

GRAPHICAL ABSTRACT



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ABSTRACT

Due to the shortage of fresh surface water caused by climate change, groundwater has become a vital water supply for household, agricultural, and industrial use. Alternative methods for determining groundwater depth, amount, and quality at a lower cost and less effort are critical. This study aims to determine the depth and kind of groundwater in Najaf City, Iraq, using Aqua detector remote sensing device. Thirty-nine sample locations were chosen in rural and urban regions to cover the city's 441.23 square kilometres. Five geographic models of groundwater depth and type were created using the Inverse Distance Weighting (IDW) interpolation method in ArcGIS software. The results indicate that groundwater is available across the study region, beginning at 100 m and lower depths. Additionally, it has been found that the nature of groundwater fluctuates with the location and depth. The findings of this study aid in selecting wells locations and depths in the study region that generate maximum quality and quantity of groundwater.

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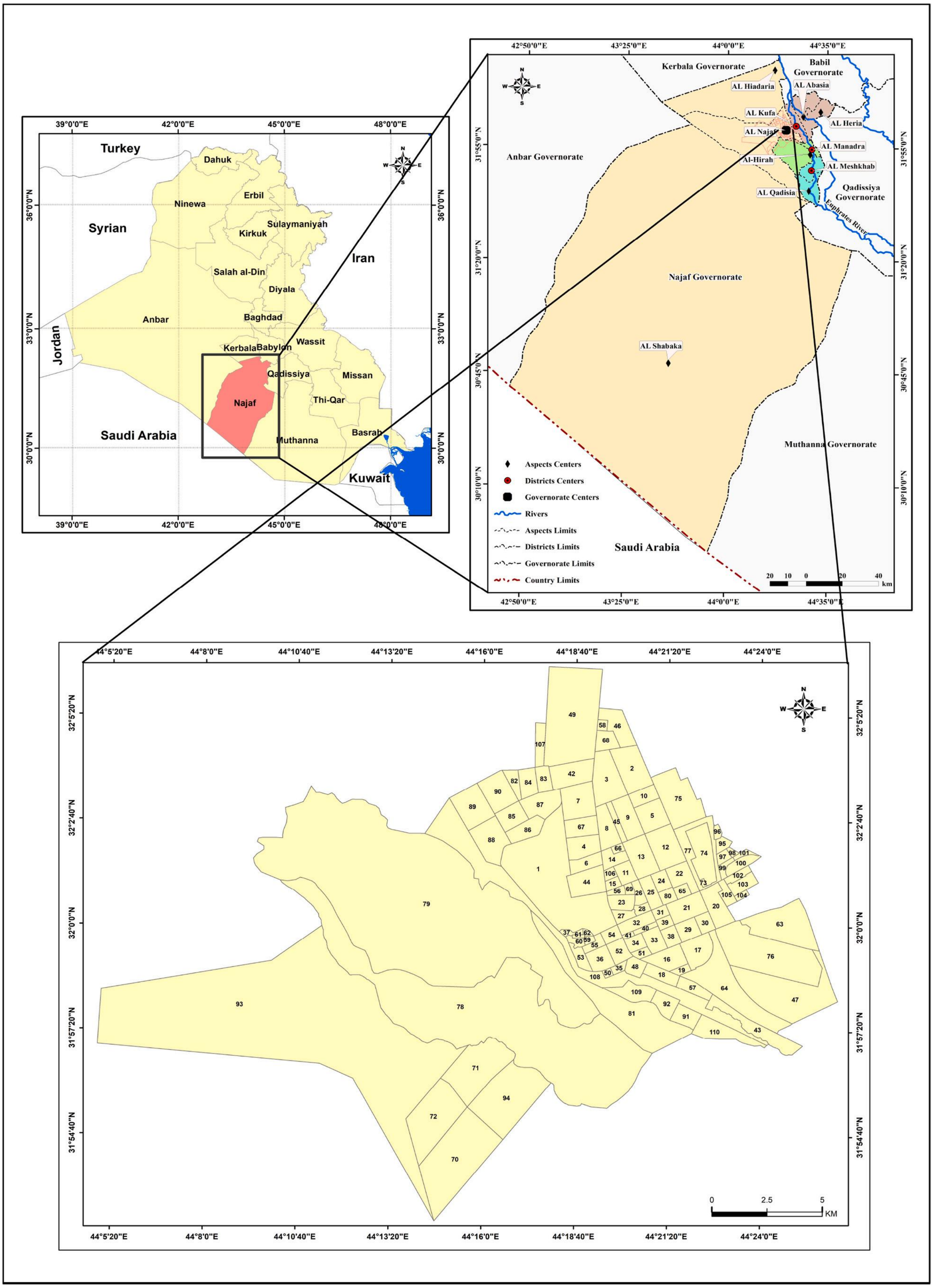


Fig. 1. The study area location map.

1. Introduction

Research in recent years has focused on studying groundwater in the Middle East, especially in Iraq (Abdullah et al., 2020; Abdulrazzaq et al., 2020; Abojassim, 2020; Baba, Karem, & Yazdani, 2021; Hassan et al., 2022; Ismail et al., 2020). Until 1970, Iraq depends on surface water resources from its rivers Tigris and Euphrates and their tributaries to supply its water demands. This water has begun to shrink gradually because of hydrological projects in riparian countries (Al-Ansari et al., 2021; Al-Ansari and Adamo, 2018; Al-Ansari et al., 2018).

Climate change has been another reason for the scarcity of surface water in Iraq and the other adjacent states in the Middle East (Abbas et al., 2018; H. Lee, 2007). Due to these reasons, the demand increased for groundwater during the past three decades (Al-Ansari, 2021; H. Al-Bahrani et al., 2021b; Al-Rawabdeh et al., 2013; AlJawad et al., 2018).

Groundwater originates from precipitation (rain and melting ice) that penetrates the soil and is stored in the voids between rocks and soil particles within geological formations. Groundwater consists of nearly 95 percent of fresh water in the earth. The usual geological formations of groundwater supply are sands, gravel, sandstone, and limestone and can be classified as aquifers or confining beds. The aquifer is an unconsolidated rock that will yield water in a useable quantity to a well or spring, while the confining bed is a rock unit having very low hydraulic conductivity that restricts the movement of groundwater either into or out of adjacent aquifers (Chapman, 1996; Heath, 2004; Ojo et al., 2012). The groundwater depth generally relies on the equilibrium between groundwater recharge and groundwater discharge, including infiltration, lateral inflow, surface runoff, evapotranspiration, and other groundwater balance elements (Krogulec et al., 2020; Taylor and Alley, 2002).

Because water is the first general solvent, groundwater usually contains significant concentrations of dissolved solids compared with surface water. Groundwater quality depends on the chemical composition of precipitation, on the biologic and chemical reactions occurring on the land surface and in the soil zone, and on the mineral composition of the aquifers and confining beds through which the water moves horizontally and vertically from an aquifer system to another or even from a geological formation to another in one system (AlJawad et al., 2018; Heath, 2004). The low annual precipitation and the high evaporation also increase groundwater salinity (Mosaffa et al., 2021).

Detecting the groundwater presence is an expensive process, as it requires drilling wells and conducting chemical and physical tests of the samples to determine their suitability for various uses. Therefore, searching for alternative ways to save cost and effort is very important. Remote sensing technology coupled with geographic information system (GIS) is greatly preferred due to the ease of preparing a huge database over large areas required for the study and limited field checks (Khan et al., 2020).

Remote sensing (RS) is defined as detecting goals or studying any phenomena without physical contact between the tools and these targets. This technique depends on the tool's ability to receive and analyze the electromagnetic energy that emits or reflects from the targets (Han, 2012; Lavender and Lavender, 2015; Liang and Wang, 2019; Tempfli et al., 2009).

The usability of RS and GIS techniques to explore and assess the location, depth, and type of groundwater have been adopted by many scholars either to define and identify promising areas for groundwater potential zones (Arefin, 2020; Bourjila et al., 2021; Magesh et al., 2012), (Al-Manmi and Rauf, 2016; Arunbose et al., 2021; Khan et al., 2020; Machiwal et al., 2011; Tahiri et al., 2020), groundwater contamination risk maps (Ducci, 1999; S. M. Lee, Min, Woo, Kim and Ahn, 2003), or to determine groundwater quality (Babiker et al., 2007).

The gap in studying and classifying the groundwater in Iraq still exists; even so, the development and utilization of groundwater began in 1935 when the first groundwater well was mechanically drilled (Al-Ansari et al., 2014). The traditional methods of selecting drilling locations and well depths make the results unexpected for groundwater quantity and quality; unfortunately, these methods are not always guaranteed.

This study employs the Aqua remote sensing device and the GIS software to detect the type and depth of groundwater at several locations in Najaf City. Finally, spatial models are constructed for the results. The dependence of these results develops groundwater sustainability in the study region since it reduces the mix of normal groundwater with salty and polluted ones located above it during the drilling process. As a result, it preserves the groundwater from deterioration and pollution. It also lessens the wells' drilling that produces low productivity or inferior groundwater. This manuscript aims and objectives are to build digital classification maps that illustrate and clarify the depth and type of groundwater at Najaf City using the Aqua remote sensing device and GIS.

2. Materials and methods

2.1. The study area

2.1.1. A- location

The current investigation involves determining the groundwater type and depth of 39 sites along the urban and rural regions of Najaf City via the remote sensing device 'Aqua' to build GIS models to illustrate the type and depth classifications of groundwater on Najaf map, where the selected sites cover the boundary of the city and the important places. Najaf City is the capital of Najaf Governorate, which locates in the southern-west of Iraq (Fig. 1), with a 28,824 km^2 area. The average high temperature of 14 °C in January to 42 °C in July, and the average low temperature of 6 °C in January to 29 °C in July. The city population 1,220,145, and a population-distribution Rural-Urban: 28.9%–71.1%. Moreover, it has a typical desert climate with only 99 mm of the yearly rainfall, so desert plains dominate its landscape (Jasim et al., 2021; Jasim et al., 2022). The city also contains the largest Islamic cemetery in the world, Wadi Al-Salam Cemetery, which covers 6.01 km^2 (Fattah and Caso, 2009).

According to the hydro-geological system of Iraq, most lands of Najaf City locates in the southern desert zone. This system is classified into seven hydrological zones by Al-Jibori and Al-Basrawi (HK and Al Basrawi, 2013). Beneath Najaf City, there is a vast groundwater aquifer called Dammam aquifer, the quality of this aquifer is highly variable, with a total dissolved solid ranging between 390 mg/L to about 5000 mg/L. Most previously excavated wells contain salty chloride type. However, some wells have sulfate types with a smell of H_2S (AlJawad et al., 2018).

Thirty-nine sites were selected to study and excavate groundwater type and depth using a new method that depends on the remote sensing device 'Aqua'. The coordinates of these locations were determined with a GPS device. This new method of detecting groundwater that adopts a remote sensing device differs from the previous traditional methods, which depend on the drilling of the wells and studying the morphology and geology of the region because these methods are more costly, less efficient, slow, and random.

2.1.2. B- soil description

In general, sand makes from 50 to 85% of the soil, with a few layers of clay and silty clayey soil at various depths. The most common soil conditions are thick to extremely dense sand and cemented sand. In most regions, the angle of internal friction (Ø) exceeds (35°). In most of the analyzed regions, the carrying capacity from SPT values exceeds 10 Ton/m^2, and the amount of sulfate in the water approaches 10%. Gypsum concentration is high, reaching up to 25% in some areas (Al-Maliki et al., 2018; Sohaib K Al-Mamoori et al., 2018; AlMAMOORI, 2017).

Table 1
Formation description in the study area according to (Jassim and Goff 2006).

Formation	Age		Environment	Lithology description
Dibdibba	TERTIARY	Upper Miocene Pliocene (AP11)	Freshwater environment (Delta)	Sand, pebbles, claystone, sandstone, and silt
Injana		Upper Miocene (AP11)	Lagoon environment	Sandstone, siltstone, and claystone with thin limestone
Fatha		Middle Miocene (AP11)	deposited in broad basin following a marine transgression	Mudstone, gypsum, and silt, interbedded with limestone and marl.
Euphrates		Late lower Miocene (AP11)	Deposited reef and behind the reef	Basal breccia, limestone, and marl
Dammam		Middle-Late Eocene (AP10)	Deposited on a shallow marine shelf with high energy nummulitic shoals and deposited in a lagoonal environment in a subtropical sea.	Consists mainly of neritic shoal limestones often recrystallized and/or dolomitized, nummulitic

2.1.3. C- Geomorphology

Different deposits cover the studied region geologically. The Dibdiba formation (Pliocene–Pleistocene) is the oldest, and it may be found in a tiny region west of the study area in the Tar An-Najaf. Sandstone is the lithological component of the Dibdiba (Sohaib Kareem Al-Mamoori et al., 2020). Ill-sorted, fine-coarse-grained tiny pebbles with a thickness of around 10 m are frequently recorded (Barwary and Slewa, 1994). The Dibdiba Formation has a lower contact with the Injana Formation (Upper Miocene). The Injana has a thickness of 20–35 m and is mainly made up of red, partially greenish silty, sandy calcareous claystone and lenticels of grey, brownish, greenish, and yellowish sandstone, with thin layers (0.30 m) of marly and chalky limestone thrown in for good measure (Barwary and Slewa, 1994; Buday and Jassim, 1987). Gypcrete (Pleistocene–Holocene) is found in most of the research region to a thickness of (0.5–2) m of secondary gypsum in a powdery form or fibrous prismatic, hard well-crystallized form, and as brownish spongy form. Flood plain and Anthropogenic deposits are the Holocene deposits located in a limited region east and south of the study area. The Flood Plain deposits are made up of a loam made up of clayey silt deposits from the Euphrates river that may be up to 15 m thick (Jassim and Goff, 2006). The bodies of old irrigation canals and hillocks of ancient towns make up the majority of anthropogenic deposits (Al-Kubaisi et al., 2018). Table 1 describes the geological formation in the study area, while the Geological map is presented in Fig. 2.

2.2. Aqua Remote Sensing Device

Aqua is a device that uses the remote sensing (RS) technique to detect location, depth, and type of groundwater, Figs. 4 and 5. This device records the long electromagnetics reflected from different types of water to cover a 200 m searching radius and up to 200 m depths, besides its ability to recognize between normal, salty and mineral waters (Al-Bahrani, 2018a). Al-Bahrani (2018b) discovered the aptitude of this device to detect and monitor the magnetic effect in salty water, which can improve the magnetic treatment system of salty groundwater (H. S. Al-Bahrani, 2018a). Al-Bahrani and others also discovered another usage of the Aqua device, and they found its ability to detect hydrocarbons contamination of surface and underground water in different vertical and horizontal spaces (H. S. Al-Bahrani et al., 2021a).

The following steps were conducted carefully to carry out this study: firstly, the site was selected and recorded its coordinates, then the Aqua device was operated to detect the type and depth of groundwater at that site and typed its information. Next, the same previous actions were done precisely at the other sites inside and around the city. After that, the data was entered into Excel and ArcGIS software to analyze it statistically and build digital maps showing groundwater type and depth classifications in Najaf City..

Aqua can detect water at disconnected depths (0, 25, 50, 100, 150, and 200 m). It can also scan horizontal circles with radiuses of 0, 25, 50, 100, 150, and 200 m. The device can recognize different types of water, i.e. normal, salty, and mineral. It can also recognize carbonic and hydrocarbon polluted water (H. Al-Bahrani et al., 2021b). The work with this device is entirely sensible to wind speed; from the author's experience, it is better to use it when the wind is silent (less than 10 km/h) to get more accurate results. Plastic pollution also confuses its outcomes. As a result, it should consider these obstructions when a person uses this device to detect groundwater.

The procedure of the Aqua work to detect the type and depth of

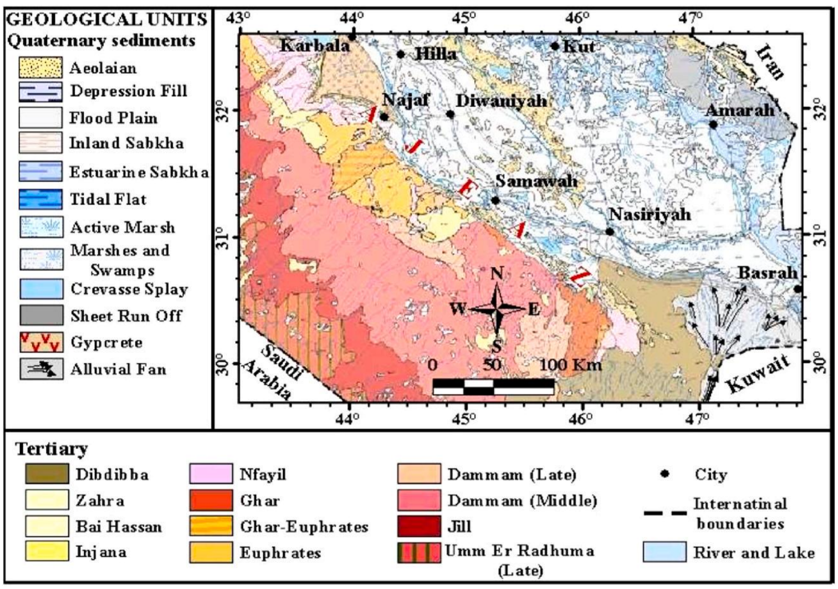
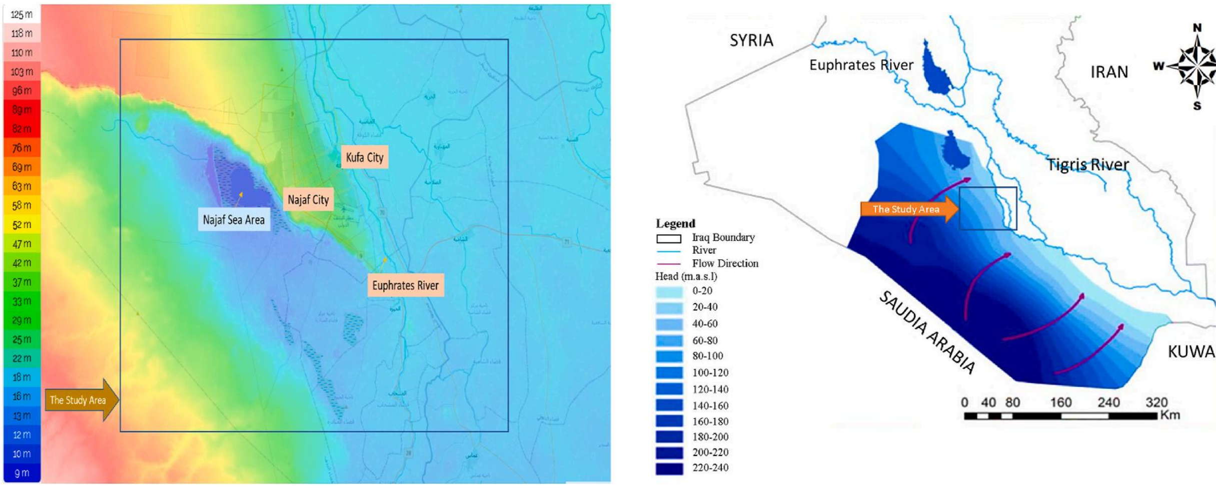


Fig. 2. Geological Map of the Study Area (After Sissakian et al., 2017), Najaf Governorate is a flat region extending from the Euphrates River northeast to the Saudi Arabian border in the southwest. The western part of the study area constitutes a low natural area called Al-Najaf See Area and extends next to the Euphrates River, separated by only 15 km. The lands of this depression appear as a flat plain area estimated at 44 square km. Fig. 3 shows groundwater's topography and growndwater movement in the study area.



a b

Fig. 3. a- Topographic map of the study area [https://en-ca.topographic-map.com/maps/9dba/Najaf], b- Groundwater Movement of the Study Area. (Khalaf and Hassan, 2016; Sissakian et al., 2017).

Fig. 4. Aqua remote sensing device.

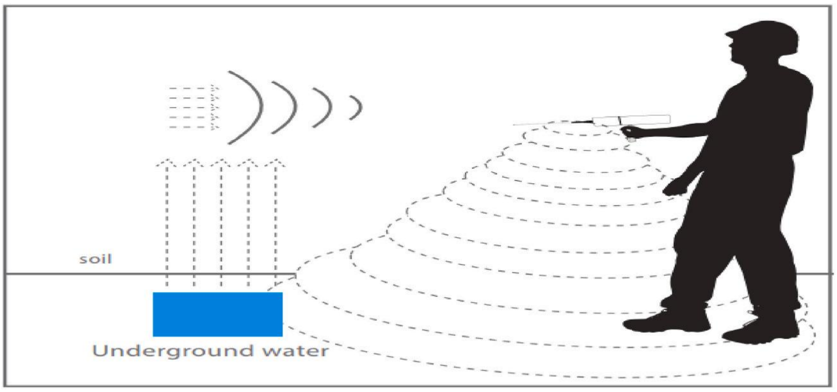


Fig. 5. Detection procedure of Aqua device.

groundwater relied on the following steps: in the beginning, the device was powered, then the option of horizontal distance was put on 25 m to cover a circular area 25 m radius. Next, a normal water option and a depth of 25 m were selected, and then the scan icon was activated to operate the detecting system. When the device begins to rotate horizontally around itself, it detects normal groundwater at a depth range of 0–25 m. The previous steps were repeated accurately and carefully for the other water types (salty and mineral) and the other depths (50, 100, 150, and 200 m). Finally, the information was recorded about groundwater type and depth range and transferred to the other locations to do the same procedure..

2.3. Data collection

Thirty-nine points were selected to examine the type and depth of groundwater in the study area. Fig. 6 shows these points' locations. According to their importance, the selected points cover most rural and urban regions of Najaf City..

The results of the remote sensing investigation illustrate the dissimilarity of groundwater quality with depth change, which was introduced in Table 2. As it is seen, the groundwater can be found below 100 m depth, and the possibility of finding normal water will also increase when drilling wells beyond 100 m. Below this depth, there is no

Table 2
Frequency of the quality-depth groundwater detected points.

Groundwater depth (m)	Groundwater status								Total
	No water	Normal N	Salty S	Mineral M	NM	SN	SM	SNM	
0-25	16	6	8	4	2	0	0	3	**39**
25-50	12	7	8	3	4	0	2	3	**39**
50-100	8	9	7	5	6	0	2	2	**39**
100-150	0	16	4	0	13	1	2	3	**39**
150-200	0	16	4	0	13	1	2	3	**39**

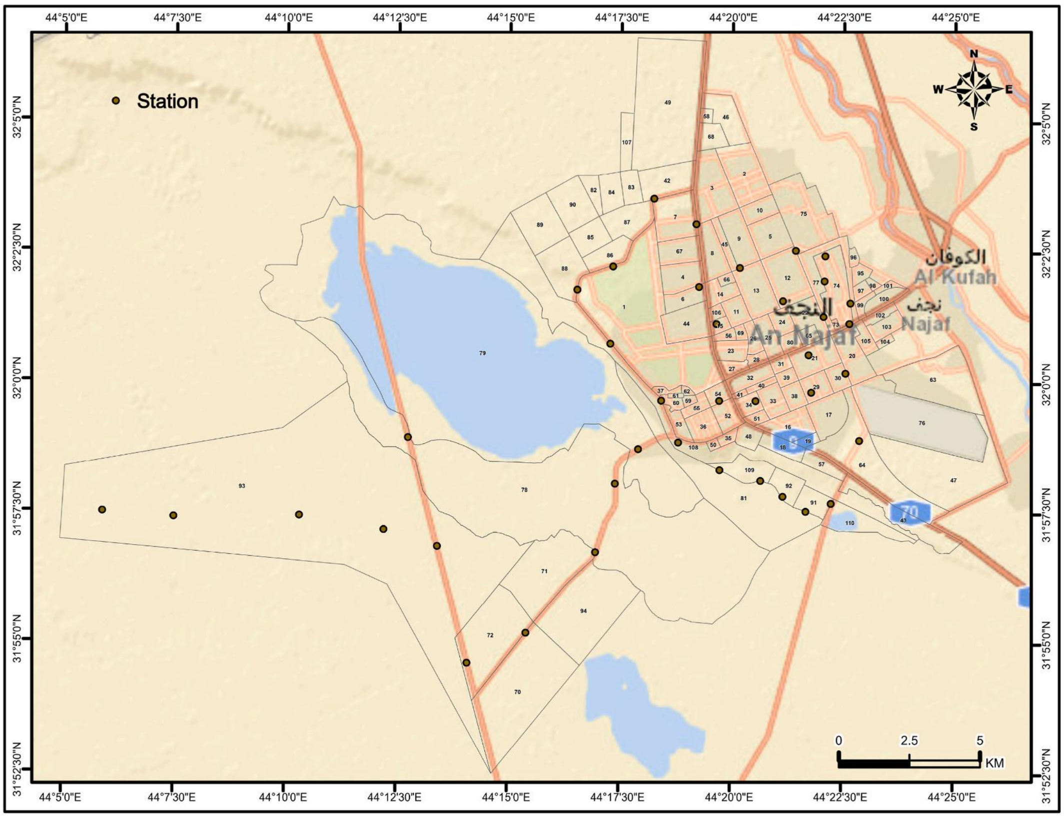


Fig. 6. The selected point's location.

pure mineral water; however, there is a mixture of mineral water with normal or salty waters..

The normal water can be found at deeper depths, and its percentage up the 25 m is few, as shown in Fig. 7.

2.4. GIS interpolation methods

A geographical information system (GIS) is an integrated system that combines spatial data with hardware and software to manage, analyze, and display all forms of geographical information (Sohaib Kareem Al-Mamoori and Al-Maliki, 2016; Bolstad, 2016; Li et al., 2011). This system can be used as an archive, an analytical, and a decision support system. A GIS can do many types of analysis such as data query, derivative mapping, and process modelling to produce and build different types of tables, maps, and databases. Its work depends on storing two types of data that are found on a map. These are the geographic features and the attributes or qualities of these features. However, most systems use one of two fundamental map representation techniques; vector and raster (Eastman et al., 1993).

In this study, the GIS technique to build classification maps for the type and depth of groundwater depended on the following: Each point recorded in the study has its coordinates, represented by the latitude and longitude values using GPS. In addition, the water type was recorded for each point for depths of 25, 50, 100, 150, and 200 m by the Aqua device. These points were firstly drawn according to the coordinates using a polygon as a point via the ArcGIS software. By introducing the water quality to the five depths classifications 0–25, 25–50, 50–100, 100–150, and 150–200 m, the water quality became known at each point. Interpolation was used and represented by the Inverse Distance Weighting (IDW) method to draw the contour line for water quality. This method is commonly used as a deterministic interpolation available in ArcGIS. This method is summed up by estimating the point values unknown on the map based on data and distances of points known values. The IDW method is applied to each of the five depths mentioned above. Thus, we

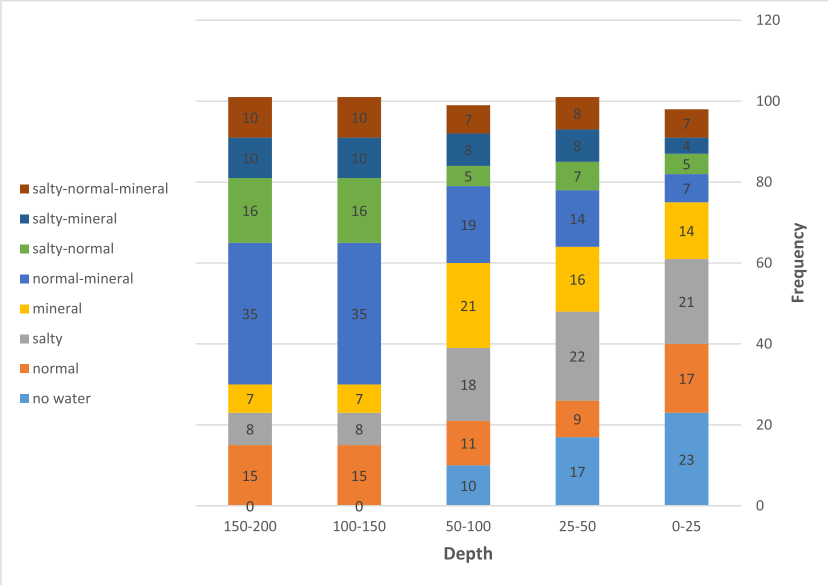


Fig. 7. Frequency of the quality-depth groundwater detected points.

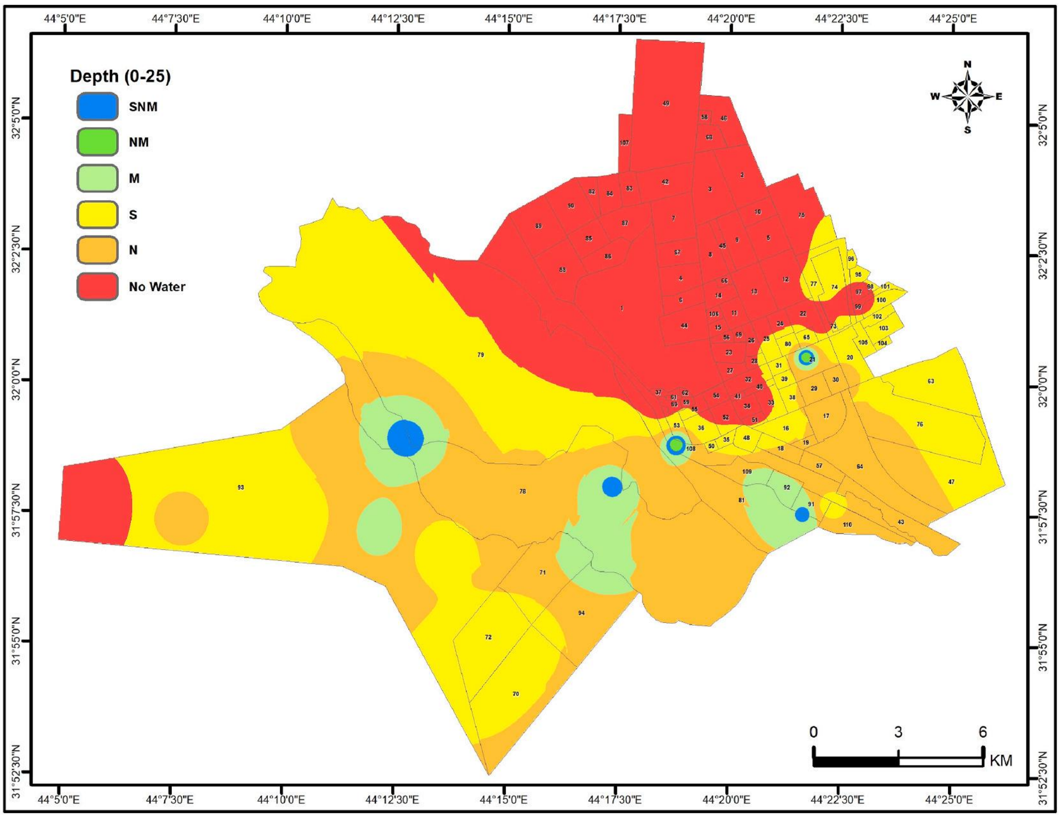


Fig. 8. GIS groundwater model at depth 0–25 m.

get five maps depending on the water quality input with different classifications. The resulting maps are converted into a raster with 30 × 30 m for each depth. Each water classification area is calculated by multiplying the number of cells by the area of one cell (30 × 30), so the total area is calculated for each type and different water depths.

3. Results and discussion

The outcomes of the Aqua device of each point with its coordinates were entered into the ArcGIS Software to build five spatial depth-quality models. In these models, the depth classifications of this study are (0–25), (25–50), (50–100), (100–150), and (150–200) m. These five models are classified into eight water quality categories: no water, normal, salty, mineral, normal-mineral, salty-normal, salty-mineral, and salty-normal-mineral water.

Figs. 8 and 9 show the groundwater spatial depth–quality models in Najaf City. Red spots represent no water, while orange shows the areas with normal groundwater suitable for domestic, industrial, and

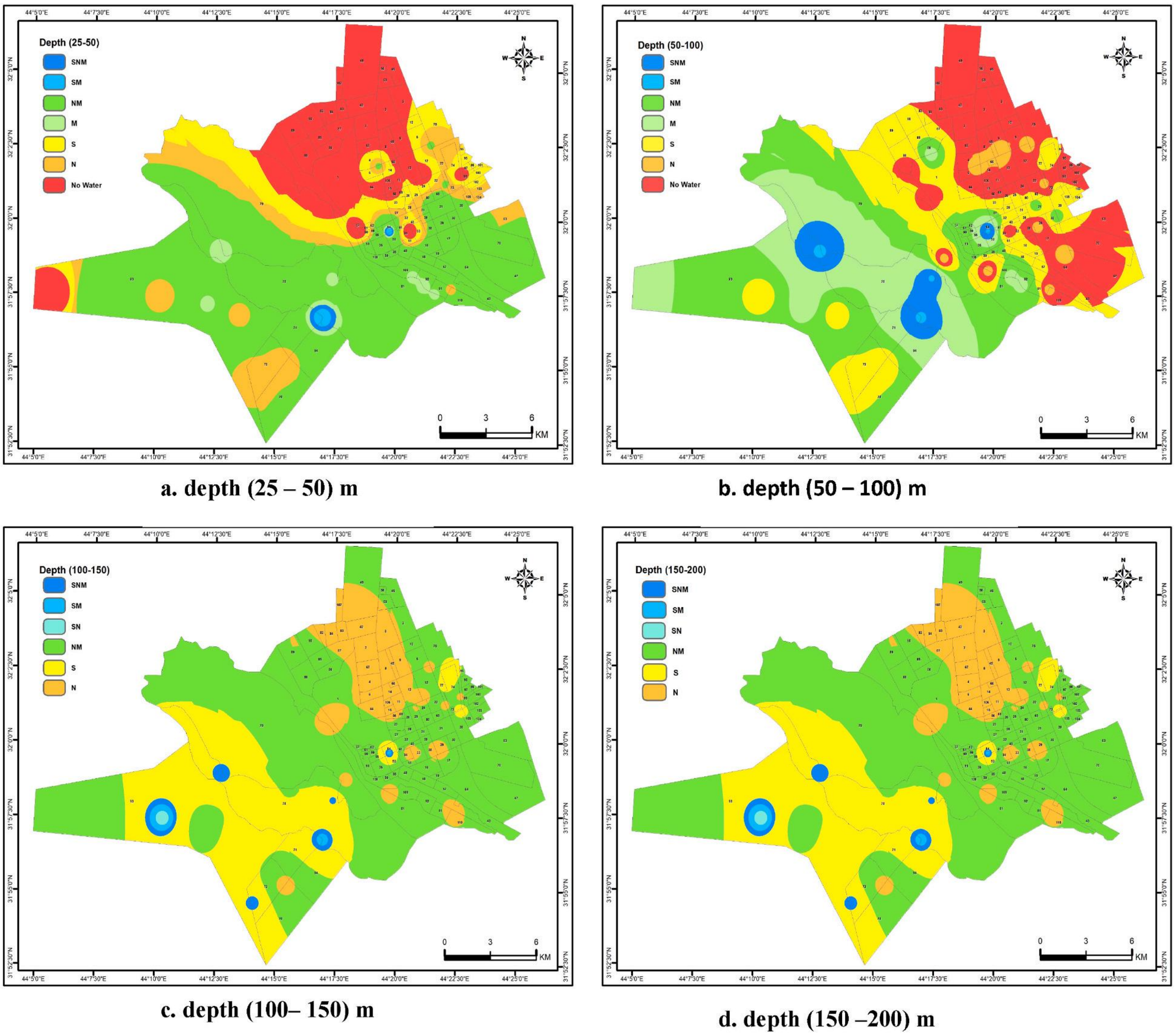


Fig. 9. Groundwater models.

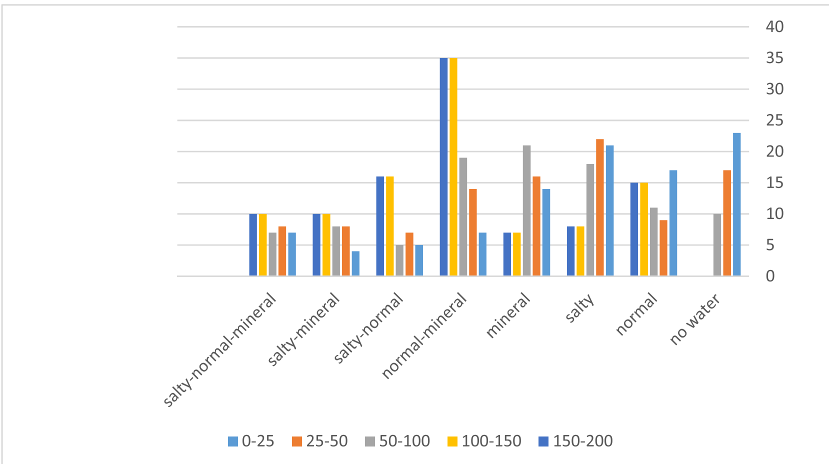


Fig. 10. Area Percentage (%) of groundwater. Verification of these results depends on many ways.

agricultural purposes. The yellow colour represents salty groundwater unsuitable for most uses. In contrast, the light green colour shows the mineral groundwater with high concentrations of carbonates and bicarbonates compounds or significant amounts of organic carbon. The other colours denote the mixed states of the three-groundwater types (normal, salty, and mineral).

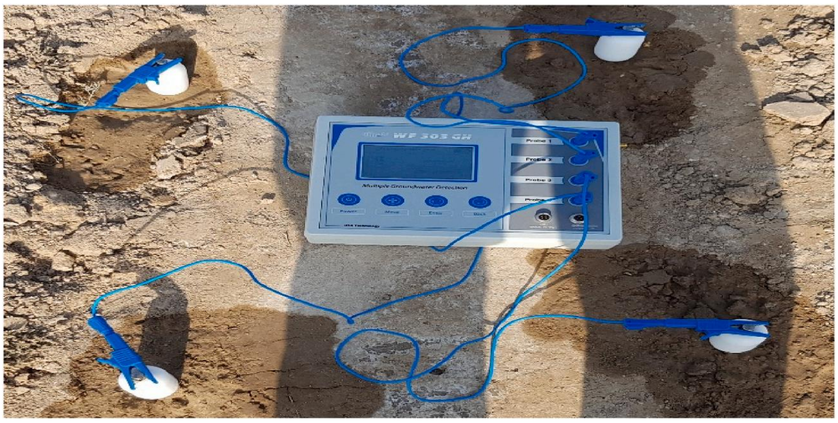


Fig. 11. The Geophysical Detector of WF-303 GH, used to verify the results.

a: The LRL unit of WF-303 GH, *b: The geophysical unit of WF-303 GH,*

Fig. 12. a: The LRL unit of WF-303 GH, b: The geophysical unit of WF-303 GH.

Table 3
Area Percentage (%) of groundwater.

Groundwater Status	Groundwater Depth (m)				
	0–25	25–50	50–100	100–150	150–200
No Water	23	17	10	0	0
Normal	17	9	11	15	15
Salty	21	22	18	8	8
Mineral	14	16	21	7	7
Normal-Mineral	7	14	19	35	35
Salty-Normal	5	7	5	16	16
Salty-Mineral	4	8	8	10	10
Salty-Normal-Mineral	7	8	7	10	10
Total	100	100	100	100	100

It is clear from these five visible models that the red colour (No Water) disappears below 100 m. Figs. 8, 9a and 9b show that the red colour concentrated in the eastern part for depths of 0–100, and this is normal because the area is topographically high, while the western part contains salty water and few parts have normal water, and this is due to the depression of the western region. Therefore, it can be generalized that Najaf groundwater is available at depths greater than 100 m..

The orange spots (normal water) are larger in shallow depths (0–25) m than their areas in depths (25–100) m, particularly in the rural regions at the west of Najaf. However, the orange spots of normal groundwater enlarge in urban regions with increasing depth. The yellow colour reduction (salty groundwater) with depth increasing is also observed. Furthermore, the type mixture of groundwater accumulates at (100–200) m depths. It is also noticed that the water quality model at depth (100–150) m is as similar to the model at depth (150–200) m. They are supposed to be in the same hydrological layer, and there is

Table 4
Field verification of TDS with water type classification.

Well no.	Depth (m)	Longitude (East)	Latitude (North)	TDS (mg/L)	Degree of restriction	water type classification
1	38	44 22 34	32 01 6.76	2735	Severe	Salty (S)
2	55	44 22 6.3	32 02 26.4	2850	Severe	Salty (S)
3	35	44 22 34	32 00 11	1420	Slight to moderate	Normal (N)
4	150	44 16 17.7	31 55 15.5	2150	Severe	Normal mineral (NM)

hardly any human intervention at these depths..

The groundwater area covered with these spatial models is 441.23 km. Table 3 and Fig. 10 classify the area percentage of groundwater according to its status and depth in the study region, which is found via the Aqua device and GIS software results. It is found that only 23% of the study area does not have groundwater at a depth range of 0–25 m. Simultaneously, 17% of normal water is at this depth suitable for agriculture and other uses, while 21% is unsuitable salty water..

1. The previous positive experiments of using the Aqua device to detect the location, type, and depth of groundwater must be presented with a certain verification of the results of this study.
2. In addition, the investigation of the depth and type of wells that were located in the study area by many previous researchers (Al-Kubaisi et al., 2018; Alikhan et al., 2020; Khassaf and Hassan, 2017) proved the accuracy of results of these GIS classification models.
3. Another check was done by comparing the results of the Aqua detector with a new detecting device, WF-303 GH (Fig. 11). It was found that the detecting results of these two different devices were similar. WF-303 GH is one of the newest instruments used to detect groundwater, made by the MWF American-Turkish Company. Its accuracy is enhanced in comparison with other instruments because it detects groundwater depending on two different systems; the first one is the long-range locator system (LRL), its search principle is receiving electrostatic fields of water by digital frequency signal processing to search for water to a 1000 m maximum depth and to a 2000 m maximum horizontal radius, it also recognizes between normal, salty, mineral and all water types, the new excellence in this unit is the wireless connection between it and the ground reinforcement unit in the same instrument, this virtue reduces the confusion in the ground to increase the search accuracy (Fig. 12a). The second system is the geophysical search system, which measures and analyzes the ground's electrical resistance levels and polar grouping according to automatic processing. This unit can automatically detect water depth (up to 800 m), water type (fresh, salty, and mineral), water density (quantity of water in percentages), the highest value of groundwater flow between research electrodes, and cavities (Fig. 12 b). The basic principles of electrical resistance work and other geotechnical methods are found in (Rolia and Sutjiningsih, 2018).
4. Table (3) represents field verification by measuring the coordinates and the total dissolved solids (TDS) of some wells in the study area, comparing the results with the water type classifications of the digital maps in Fig. 9. The total dissolved solids (TDS) of water is classified into three categories by Food and Agriculture Organization (FAO) according to the degree of restriction (Ayers and Westcot, 1985). There is no restriction when TDS is below 450 mg/L, slight to moderate restriction when its range equals (450–2000) mg/L and severe restrictions when it is greater than 2000 mg/L. The expression 'no restriction' means no soil or cropping problems are recognized or experienced at TDS less than 450 mg/L, the expression meaning of 'slight to moderate restriction' is gradually increasing care in the selection of crops and requirements of management alternatives when full yield potential is to be carried out. If the water quality is classified as 'severe restrictions', the water user should face soil and cropping problems or reduced yields. In some
5. Cases, it has been seen that farmers have used water with TDS greater than 2000 mg/L (severe restrictions) to cultivate plants such as tomatoes, cucumbers, onions, barely, and other salt-restricted plants. This happens when the dissolved solids in water are not severely harmful to these plants. Therefore, it is recommended when using poor water quality for irrigation to conduct a series of pilot farming studies to decide the best farming and cropping techniques that need to be applied. The parallel of the data in the last two columns of Table (4) gives acceptable verification for the digital maps.

4. Conclusions

We have studied in this research the groundwater type and depth in Najaf City using the Aqua remote sensing device and modelling the results with GIS to build digital classification maps of groundwater type and depth. It is concluded from this study the possibility of detecting and excavating the location and depth of good quality groundwater by using the appropriate groundwater finder such as Aqua or WF303GH. The study area has different types of groundwater, such as normal, salty, and mineral. Additionally, it contains a mixture of all three types, as the composition of groundwater varies according to its location and depth. The results prove that about 77% of the underground water in the study region exists at depth (0–25) m. However, groundwater can undoubtedly be found in Najaf City if one drills his well at a depth greater than 100 m The digital maps determine the normal type of groundwater in the study area, which can be found at shallow depths in the city's west (rural). It is also available at depths greater than 100 m in the northern-east Najaf (urban). Building groundwater depth–quality models is a helpful suggestion for decision-makers and investors. It helps them select the best places for agricultural and industrial projects depending on availability, depth, and type of groundwater. This recommendation should be replicated, and further work is needed in the near future.

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Informed consent statement

Not applicable.

Authors consent to publish

As Corresponding Author, I confirm that the manuscript has been read and approved for submission by all the named authors.

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