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Potential Groundwater Spatial Planning in Thi-Qar Using Geographic Information Systems (GIS) and Remote Sensing

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Abstract Groundwater is one of the most important sources of freshwater, especially in areas suffering from scarcity of surface water or limited water resources. This research aims to identify potential areas for groundwater in Thi-Qar Governorate using Geographic Information Systems (GIS) and Remote Sensing (RS) techniques. Multiple data sources, including satellite images, digital elevation model (DEM), soil and geology maps, and land use land cover (Lu/Lc) data, were collected and analyzed to determine the factors affecting groundwater distribution. The research was based on creating a model through which multiple variables were analyzed using Analytical Hierarchy Process (AHP). These factors were combined using equations within a GIS environment to produce a final map showing areas with high groundwater potential. The results showed that areas with very high groundwater potential are mainly concentrated in the marshland's areas (Al-Hammar, Al-Chibayish) in the southern and southeast parts of the Thi-Qar Governorate. While the eastern and northeastern regions have a low to very low potential for groundwater, the reason is that the soil in the northern regions of Thi-Qar (such as Shatra and Al-Rifai) is often heavy clay soil with low permeability, which hinders water infiltration into the groundwater layers, in addition to the absence of sand layers that enhance groundwater movement. Additional field studies are recommended to validate the results and enhance accuracy.

Keywords Groundwater · Thi-Qar Governorate · GIS · Remote Sensing · Analytical Hierarchy Process

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Introduction

Groundwater, stored in subsurface geological formations known as aquifers, constitutes a vital water resource, occupying the interstitial spaces between soil particles and rock formations (Tziritis et al., 2020; Sharghi et al., 2025). However, excessive groundwater abstraction has led to significant environmental and geotechnical consequences, especially in urban areas where land subsidence occurs due to soil void compaction. This phenomenon contributes to surface deformations, including soil cracking, infrastructure damage, and, in severe cases, landslides (Al-Dabbas et al., 2020; Ali et al., 2022). Conversely, in certain regions such as the Thi-Qar Governorate of Iraq, rising groundwater levels pose a critical threat to infrastructure stability. Groundwater infiltration into building foundations, road networks, and drainage systems accelerates structural deterioration, leading to collapses and increased susceptibility to urban flooding (Al-Dabbas et al., 2020). These hydrological imbalances necessitate the implementation of sustainable groundwater management strategies to mitigate negative environmental impacts and maintain long-term water security.

The increasing global demand for freshwater, exacerbated by climate change and rapid population growth, has intensified the reliance on groundwater as an alternative resource (Ülker et al., 2018; Çelik et al., 2024; Orhan et al., 2021; Sharghi et al., 2025). Iraq, particularly its southern regions, including Thi-Qar, faces acute surface water shortages due to declining river inflows and prolonged drought conditions (Ethaib et al., 2022; Al-Ansari, 2021). In the past decades, this scarcity has triggered socioeconomic instability, exacerbated resource allocation conflicts, and disrupted local livelihoods (Monshipouri et al., 2024). In response, both government authorities and private households have increasingly turned to groundwater extraction for drinking water supply and agricultural irrigation (Gregory et al., 2024). However, unregulated exploitation of groundwater without proper hydrogeological assessment can lead to further depletion, pollution, and long-term ecological degradation (Gambo et al., 2024; Ebrahim et al., 2023). Therefore, effective groundwater resource management requires an integrated scientific approach to ensure its sustainable use

Advances in Geographic Information Systems (GIS) and Remote Sensing (RS) have significantly improved groundwater investigations and provided robust spatial analysis techniques for hydrogeological assessments (Hassan et al., 2023; Singh et al., 2020). These geographic information technologies facilitate the identification of groundwater potential zones by incorporating geological, topographic, climatic and hydrological parameters into predictive spatial models (Al-Bahrani et al., 2022; Foshtami et al., 2023). Previous studies have demonstrated the effectiveness of GIS and UA in groundwater quality assessment, land use/land cover change detection and aquifer vulnerability mapping in various regions including Iraq (Hassan et al., 2023; Singh et al., 2020). This study aims to integrate GIS and UA methodologies to identify groundwater potential zones in Thi-Qar Governorate by providing a comprehensive hydrogeological framework for sustainable resource management. The resulting spatial model will support policy makers in optimizing groundwater extraction strategies while minimizing ecological and infrastructural risks by ensuring a scientifically informed approach to the management of water resources in the region.

Methodology

Study area

Thi-Qar Governorate is in the southern part of Iraq, as shown in Figure (1). The governorate is located between latitudes 30° and 32° north and longitudes 45° and 47° east. It is bordered by Wasit Governorate to the north, Maysan Governorate to the east, Muthanna Governorate to the west and Basra Governorate to the south (Al-Abas et al. 2022). Its area is about 12,900 km2 and its population is more than two million. The governorate is located in the alluvial plain formed by clay and silt deposits as a result of the continuous river activity of the Tigris and Euphrates rivers. The area is characterized by its low and flat surface, with a slight slope towards the southeast. The average temperature in summer exceeds 40°C, while in winter it drops to about 10°C. Rainfall is low and irregular, with an annual rainfall rate of about 100 mm (Muhaimeed et al. 2014).

Data processing

The data processing of this study includes element maps. These maps were created and precisely described in order

to determine the probability of groundwater in the Thi-Qar region. Elevation, Slope, and drainage density were the three types of data that were first retrieved using a digital elevation model (DEM) of 30 m that was sourced from the USGS website and based on GIS technology.

Additionally, the Geological Survey Department provided a geological map of the research region, which was adopted. The Land Use and Land Covers (Lu/Lc) were generated using an exploration journey of the sub-basin using data from the Esri website (10 m) to determine land uses and land covers (Lu/Lc). The soil map was produced based on soil investigation reports carried out in Thi-Qar Governorate, based on the scientist's proposed Analytical Hierarchy Process (AHP) (Wijayaningtyas et al. 2024, Arunbose et al. 2021, Dar et al. 2022). Each

Table 1. Groundwater Potential Zone Factors by Weight for Thi-Qar governorate.

Factors	Geology	Soil	Land use and Landcover	Drainage Density	Slope	Elevation	Weight
Geology	1	3	5	5	7	9	0.458
Soil	0.333	1	2	2	3	5	0.200
Land use and Landcover	0.333	0.500	1	2	2	4	0.143
Drainage Density	0.200	0.500	0.500	1	2	2	0.093
Slope	0.143	0.333	0.500	0.500	1	2	0.065
Elevation	0.111	0.200	0.250	0.500	0.50	1	0.041

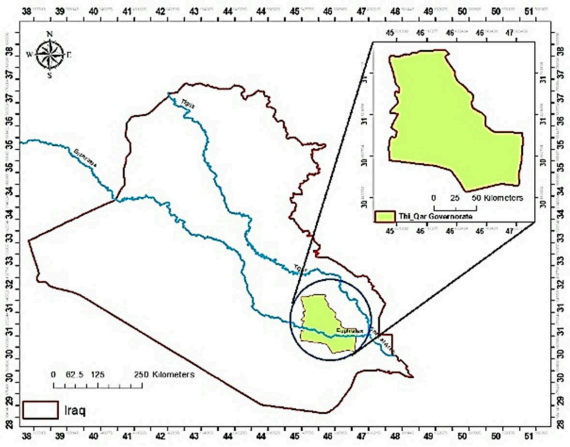

Figure 1. Study area

component must be assigned a weight based on how strongly it affects the area (Table 1). A rating ranging from 1 to 5 (very low to very high) was given to each individual topic on the map based on how it affected the groundwater potential zone table. The following formula was used to construct a groundwater potential map using the GIS software's overlay index for spatial analysis.

$$\text{Ground water potential map} = (G_w \times G_R) + (S_w \times S_R) + (Lu/Lc_w \times Lu/Lc_R) + (D_w \times D_R) + (SO_w \times SO_R) + (E_w \times E_R) \quad (1)$$

Where:

(G_w) Weight Geological and (G_R) Rating Geological. (S_w) Weight Slope and (S_R) Rating Slope. (Lu/Lc_w) Weight land use land cover and (Lu/Lc_R) Rating land use land cover. (D_w)Weight Drainage density and (D_R) Rating Drainage density. (SO_w) Weight Soil and (SO_R) Rating Soil. (E_w) Weight Elevation and (E_R) Rating Elevation.

The groundwater potential map creation process is illustrated in the flowchart in Figure 2.

Results and Discussion

Geology

Thi-Qar Governorate is located within the Iraqi alluvial plain, which is one of the most important geological units in Iraq. The alluvial plain is characterized by its relatively recent sedimentary formations dating back to the Pleistocene and Holocene eras as shown in Figure 3, resulting from the continuous river sediments of the Tigris and Euphrates rivers, in addition to sediments resulting from the environmental activity of the marshes (Abdullah et al. 2023). The main geological formations in Thi-Qar are the marsh deposits (Marsh Deposits) spread in the southeastern regions, especially around the Chibayish and Hammar marshes, with a percentage of about 30%. Modern river deposits (Fluvial Deposits) cover the areas adjacent to the Tigris and Euphrates rivers and their tributaries, with a percentage of about 40%. Sand deposits (Aeolian Sand Deposits) are found in the northwestern and eastern regions of the governorate, with a percentage of about 15%. Older Clay Deposits appear in scattered areas of the governorate and represent older sedimentary stages, with a percentage of about 10%. Gypseous deposits are found in small quantities in some southern areas, at a percentage of about 5% (Nomas et al. 2023). According to the previously mentioned, the Al-Rifai Chibayish, and Souq Formation Holocene sediments has been rated a 3 on the geological map, whereas the Nasiriyah and Shastra Formations and Paleozoic sediments have been rated a 4.

Recent studies have highlighted the importance of integrating Geographic Information Systems (GIS) and Remote Sensing (RS) techniques for sustainable groundwater management in arid regions, especially in areas such as Thi-Qar. Some studies have shown that integrating these technologies can significantly increase the understanding of groundwater dynamics and support the development of effective management strategies in the region. Their results show that GIS and RS can be used to map groundwater resources and locate areas where extraction is safe, which is crucial for solving Thi-Qar's water problems.

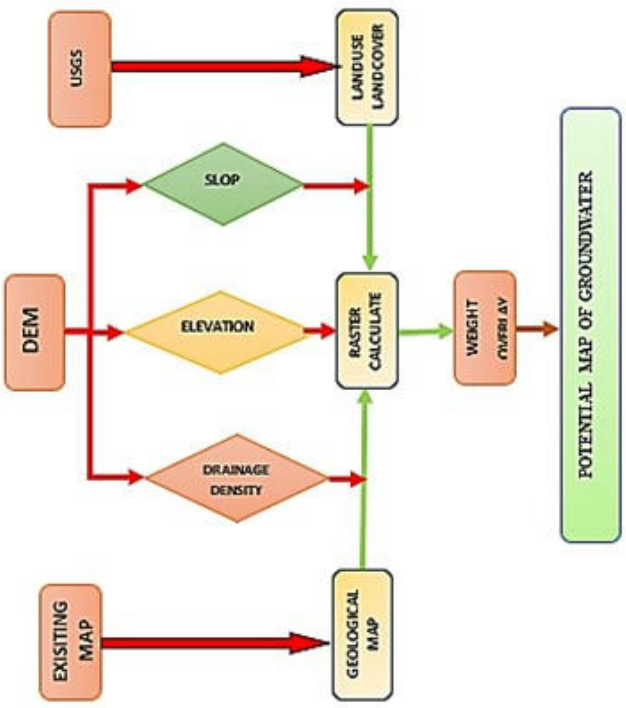

Figure 2. Data processing procedure

Elevation

Elevation affects how water enters aquifers in the Thi-Qar region, which is home to clayey soils and alluvial plains. Clayey soils can increase surface storage and reduce water infiltration in low-lying areas, while groundwater recharge increases in high-lying areas with permeable rocks (Al-Abas et al. 2022). Thi-Qar Governorate is located in the Iraqi alluvial plain region and is known for its relatively low and flat surface.

The elevations of the land surface in Thi-Qar range from 1 meter to 20 meters above sea level. Lowlands: They are mainly found in the southern and southeastern regions, where marshes such as Al-Chibayish and Al-Hammar Marshes are widespread. Relatively high areas: They appear in the northern and northwestern regions of the governorate, but they do not exceed 20 meters. The elevation map, as shown in Figure 4, was created by classifying it into five zones, where the lowest groundwater potential is represented by a value of 1 and the maximum by a value of 5. This chart indicates that high-elevation regions have a lower groundwater potential. On the other hand, the groundwater potential is higher in the lower elevation area.

Soil

A variety of soil types may be found in the Thi-Qar Governorate as a result of the influence of marshes, desert regions, and rivers like the Euphrates and Al-Gharraf. These soils have

Figure 3. The geological distribution model

significance for groundwater distribution, storage, and quality. Here is a thorough breakdown of Thi-Qar 's soil types and how they affect groundwater, as shown in Figure 5. Clay soil in the flood plains next to the Euphrates and Al-Gharraf Rivers. Because water finds it difficult to move through the clay layers, its effect on groundwater lowers groundwater recharge. sandy soil in the southeast and northwest parts of Al-Abas et al. 2022, particularly the desert and semi-arid sections, have sandy soil. regions close to the Basra and Muthanna desert borders (Muhaimeed et al. 2014). Because of its high permeability, its effects on groundwater greatly aid in groundwater recharging. Silty clay soil is widespread in the banks of major rivers such as the Euphrates and Al-Gharraf and areas exposed to

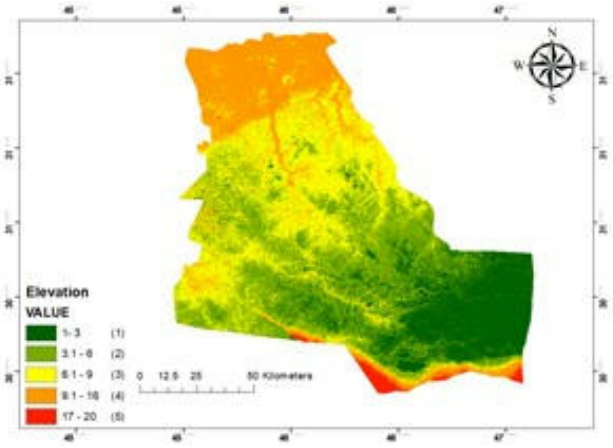

Figure 4. The elevation distribution model

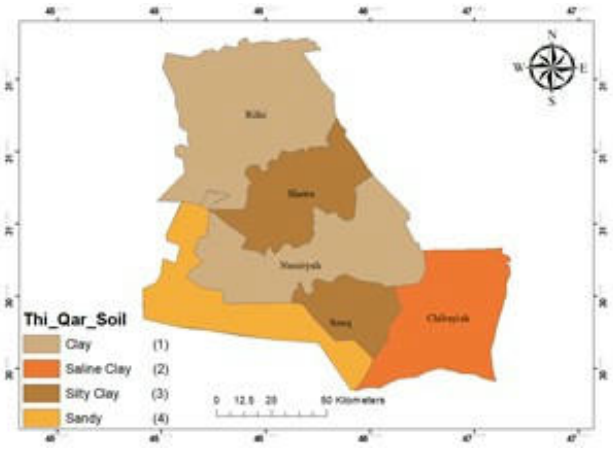

Figure 5. The Soil distribution model

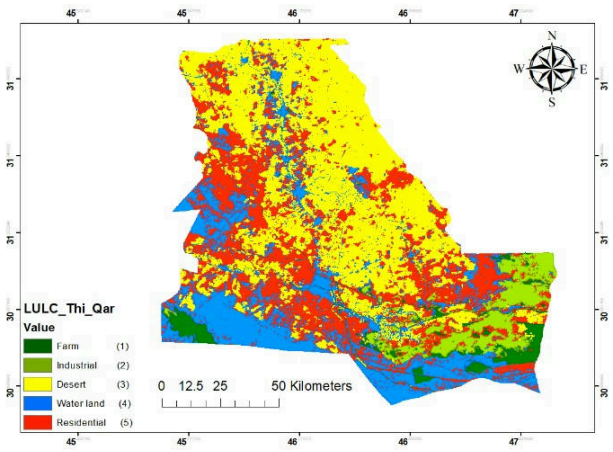

Figure 6. The land use and land covers model

seasonal floods such as agricultural areas in Shatrah and Souq Al-Shuyukh (Al-Abas et al. 2022). It contributes to feeding groundwater reservoirs moderately. Saline clay soils are found in low-lying areas, especially in the old marshlands or areas that have been exposed to heavy water evaporation, such as Al-Chibayash and areas near Nasiriyah. Infiltration rate was used to determine the soil rating; clay received a rating of (1), whereas sandy received a grade of (4).

Land Use and Land covers

The Thi-Qar Governorate is distinguished by its variety of land uses and land cover, which includes agricultural areas dispersed along rivers like the Euphrates and Gharraf Rivers, particularly in Shatrah, Al-Rifai, and Souq Al-Shuyukh, as shown in Figure 6. Approximately 30% of the governorate's total area is made up of agricultural lands. Marshes are concentrated in the southeast of Thi-Qar, especially in Al-Chibayish and Al-Hammar Marshes, where they constitute about 15% of the area of the governorate (Abdullah et al., 2023; Al-Obaidi, 2017). Urban lands are concentrated in the main cities, such as Nasiriyah (the capital of the governorate), Shatrah, Souq Al-Shuyukh, Al-Chibayish, and Al-Rifai, where they constitute about 10% of the area of the governorate.

Desert lands are found in the southwestern and northwestern regions of the governorate, where desert and pastoral lands cover more than 40% of the area of the governorate. Land uses and types of coverage greatly affect the distribution and quality of groundwater in Thi-Qar , which requires balanced management to maintain the sustainability of resources. The rating value is assigned to the following factors: Residential (5), Water lands (4), and Farm (1); the rating value is assigned to the factors of Industrial (2). A rating of Desert (3) encompasses most of the sub-basin.

Drainage Density

The total length of stream segments of all sorts per unit area is referred to as drainage density. The spatial analysis was used to create a drainage density map as illustrated in Figure 7. The soil's ability to absorb water is negatively correlated with drainage density. Five separate zones with values ranging from 0 to 2 were identified on the resulting map. Drainage areas with high densities were rated lowest (5), while those with low densities were rated highest (1). With a few isolated exceptions, it is clear from the sub-basin's drainage density map that groundwater potential is often low throughout the majority of the area.

Potential Map for Groundwater

Evaluating the potential for groundwater in Thi-Qar , an area with important water issues, is the aim of this project. to ascertain whether the current study's results correspond with a significant number of previous studies on the subject. The results of this research indicate that there might be groundwater in because several sites with varying depths of

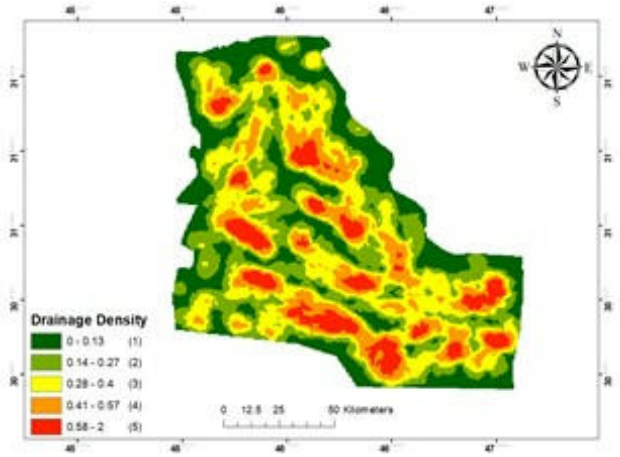

Figure 7. The drainage density model

Table 2. Potential Zones for Groundwater.

Color	Range (km²)	Groundwater potential
	59.58	Very Low
	50.05	Low
	46.71	Moderate to High
	43.49	High
	38.58	Very High

groundwater availability were discovered. when contrasting their results with those of Alrakabi, M. H. (2017), Al-Dabbas et al. (2020) and Ali et al. (2022). An elemental examination of the groundwater, marshes, and rivers in the Thi-Qar region of Iraq. Researchers discovered that groundwater levels at different areas were comparable. For instance, "The results of the study suggest that there may be groundwater in Thi-Qar since a number of locations were found that showed groundwater availability at different depths in southern Iraq. Using the overweight method, a groundwater potential map was created for each of the six layers. The sub-basin's groundwater potential, Figure 8 was divided into five zones as shown below.

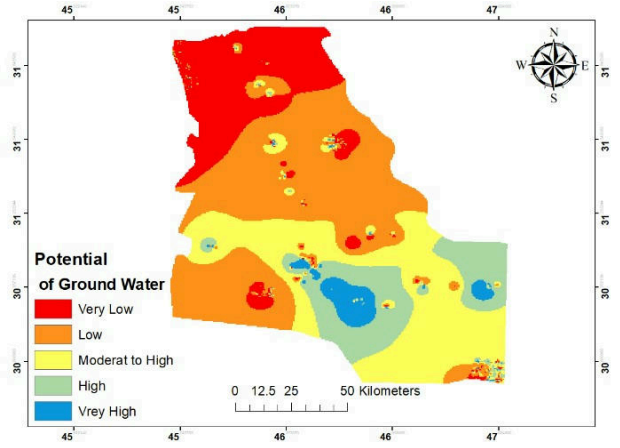

Figure 8. Potential Map of Groundwater

It mainly exists in the marshland areas (Al-Hammar, Al-Chibayish) in the southern and southeast parts of the Thi-Qar Governorate. These locations have surface groundwater reservoirs that are the result of filtration from marsh water; however, they are frequently salty or of low quality. Since the northern and northeastern regions represented by Al-Rifai and Al-Shatra are higher in elevation and have less saline water, there is less chance of groundwater. Regarding the governorate's center (Al-Nasiriyah), there is a moderate chance of groundwater and a low proportion of salts in the water.

Conclusion

The results of this study illustrated that the southern and southwestern regions (marshlands) of Thi-Qar are considered to be areas with high and very high potential for groundwater due to several reasons. The nature of the alluvial and clayey soils in the marshes retains moisture and allows water to gradually seep into the lower groundwater layers. Despite the low permeability in the clayey soil, the sandy layers beneath it facilitates the movement of water into the groundwater reservoirs. In addition, the low topography in the marshes is located in low areas, which leads to the accumulation of surface water, thus increasing the possibility of the presence of groundwater reservoirs close to the surface. While the eastern and northeastern regions have a low to very low potential for groundwater, the reason is that the soil in the northern regions of Thi-Qar (such as Shatra and Al-Rifai) is often heavy clay soil with low permeability, which hinders water infiltration into the groundwater layers, in addition to the absence of sand layers that enhance groundwater movement. Also, the topography of the land in the northern regions is characterized by a relatively higher topography compared to the southern regions, which limits water accumulation on the surface and its penetration into the lower layers. Surface water tends to flow towards the low-lying areas to the south, leaving the northern regions with weak groundwater recharge.

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