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Determining the optimum drilling sites for groundwater wells based on the hydro-geoelectrical parameters and weighted overlay approach via GIS in Salah Al-Din area, central Iraq

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Abstract

Groundwater is one of the most precious assets for supplying water to the world's population. The main goal of this research paper is to use the GIS technique to determine the best drilling sites for new groundwater wells, based on hydro-geoelectrical factors and using a weighted overlay approach. Weighted Overlay Approach (WOA) assessment is a geographical approach for analysing multiclass charts, that are influenced by the various relevances of every layer as well as the classification of a layer. The advantage of WOA is its ability to makes the more favourable criteria with the higher values in the output raster, that help thereafter identifying those locations as the priority. The aquifer hydro-geoelectrical parameters such as resistivity, thickness, depth, and transmissivity.obtained by using the vertical electrical sounding (VES) technique allow together to determine the best locations for drilling.

The GIS technique is conjointly used herein to accurately identify the best location for the aquifers using the mentioned hydro-geoelectrical data. Weighted overlay has been applied to normalize the criteria layers, and blende to finally generate the suitability maps. The geospatial datasets are combined by using GIS to create and establish a suitability chart for determining efficient suitable locations for drilling successful water boreholes. The most suitable locations have been well recognized. The study area is divided into four categories: poorly suitable, fairly suitable, suitable, and excellently suitable. The different findings of this research can be consequently used to plan effective groundwater management in the region.

Keywords: GIS, hydro-geoelectrical parameters, suitable boreholes locations, VES, weighted overlay approach

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1 Introduction

Groundwater is an essential primary resource of national wealth and is a part of the human and economic development process (Naghibi et al, 2015; Mallick et al, 2019; Suliman and Ali, 2022). Groundwater in Iraq is a vital source of water usage both for domestic, agricultural, and industrial usage (Abdulrazzaq et al, 2020a), as Iraq's repeated losses from the Tigris and Euphrates rivers and their tributaries have reached frightening degrees in recent years, which left a detrimental influence on the sectors of agriculture, manufacturing, and other industries. The fluctuation and irregularity of rainfall transformed also the large areas of land into arid areas, and alarming levels, portending a dangerous future if they are not addressed and treated with comprehensive scientific and strategic plans. the mentioned reasons call and provoke us to think about alternative resources, particularly the Iraquian groundwater found in reservoirs of different hydraulic and hydrogeological properties. The hydrogeological system and the hydraulic properties of these reservoirs must be carefully evaluated to optimize the groundwater investment and to develop the suitable model management plans for the distribution of wells and pumping control. One of the most important methods adopted in this evaluation is the geophysical studies, considered the fastest technique in groundwater exploration and the cheapest one in correlation with drilling wells (Kosinski and Kelly, 1981).

Geophysical Surveys are one of the quickest methods for exploring groundwater, which is more affordable than the cost of drilling wells (Kosinski and Kelly, 1981). On the other hand, random drilling may lead to unproductive or low-productivity wells, or those wells may have weak hydraulic specifications, leading to wasted effort and large sums. It is therefore preferable to conduct multiple geophysical surveys before drilling wells to determine the depths and thickness of the related aquifers, their hydraulic properties, and the quality of their water. The resistivity method, the seismic refraction method, magnetic resonance sounding, and transient EM are several geophysical methods that can be used for groundwater investigation. The electrical resistivity approach, on the other hand, is widely used and applied in hydrogeological investigations (Keller, 1967), because of its cheap cost, ease of application, and its speed in giving the required results compared with other geophysical methods (Abdulrazzaq et al, 2020b).

Salah Al-Din Area, including the study area, is located in Baiji district and is considered an important agricultural area in Iraq (Alwan et al, 2019). The study areas have mainly been dependent on the groundwater, which led to the depletion of underground water reservoirs, which turned many of the wells into unproductive or poorly productive wells. There was therefore an urgent need and necessity to re-evaluate the hydraulic properties in the study region and nominate sites for drilling new wells with high productivity according to the available data used by this evaluation (Abdulrazzaq, 2011).

The process of nominating new well sites is not an easy task at all, where all the hydraulic properties and geological factors must be integrally considered. GIS technology, on the other hand, is considered one of the most reliable techniques that we use in the process of determining the most suitable sites. Suitable algorithms, mainly depending on the importance of a specific factor (criteria) are applied and used. Those algorithms deal with each criteria as a class within the selection and nomination mechanism (Chan, 2008). Several studies have used and invented the decision-making tool as a suitable approach for site selection (e.g., Abudeif et al, 2015; Gigović et al, 2017; Aziz et al, 2018; Agbasi et al, 2019; Falebita et al, 2020).

The purpose of this project paper is to use the Geographic information system as a decision-making technique to find and locate the best boring site for water wells. The new locations are chosen based on the primary hydro-geophysical characteristics acquired from vertical electrical sounding (VES) data, which include mainly the aquifer depth, resistivity, thickness, and transmissivity. The findings of this research study will certainly help in the planning of effective groundwater management in the region.

2 The study area

Salah Al-Din area is situated on the western bank of the Tigris River, within longitudes 43o 56'-43o 40' E and latitude 34o 35'-34o 54' N. The Tigris River surrounds it on the east, the Tikrit subsurface anticline (TSA) on the west, Wadi Shishen on the south, and shorelines on the north and north-west (Fig.1). east. The most visible geomorphologic characteristics are seasonal valleys, which are divided into two processes: denidritic valleys and parallel valleys. These valleys are gently sloping and filled with fine-grained sediments. The area is distinguished by less prominent valleys that finish in depressions within the study area to absorb precipitation and replenish subsurface aquifers (Al-Jobori, 2011). Numerous geomorphological features occur, such as crests and collapsing masses in the Tigris River, as well as natural dunes and sand sheets (Al-Ani, 1997).

The study area is tectonically located inside the Mesopotamian zone, Ammara–Tikrit secondary subzone, and is a part of the instability shelf (Buday and Jassim, 1984). Excluding the NW-SE Tikrit subsurface anticline along the western edge of the region, there are no visible marks to suggest structural processes. The topography is influenced by this underlying structure, with a fault crossing the Tikrit structure. This deep-seated fault has spanned Jurassic to Miocene rock (Al-Ani, 1997).

It is expected to be numerous subterranean faults in the region that have a significant impact on aquifer characteristics owing to the hydraulic connection, caused by cracking and faults that change from confined to semi-confined and unconfined types. Because of the aquifers' longitudinal and lateral complexity, the region's aquifers are considered a systematic hydrogeological system. This variability leads the aquifer characteristics to shift from unconfined to semi-and confined (Abdulrazzaq et al, 2022).

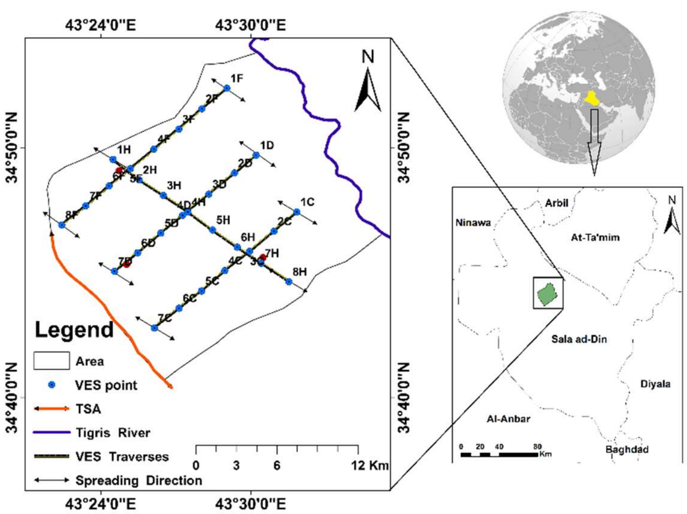

Figure 1. Location of the study region, showing the VES points.

2 Hydro-geophysical data

The hydro-geophysical data used in this research include baisically the geoelectrical and hydraulics characteristics. The bulk resistivity and thickness of the aquifer are the main geoelectrical characteristics acquired from the vertical electrical sounding (VES) analysis (Fig. 2). The aquifer depth (watertable depth) represents the depth of the projected dig to access the groundwater, where its hydraulic parameters are established by pumping test results via nearby wells. Transmissivity (T) is one of the most significant hydraulic factors, characterized as the capacity of the aquifer to flow water through a square area unit cross-sectional area of the aquifer at the prevalent temperature. Transmissivity is equal to the product of hydraulic conductivity (K) by the saturated thickness of the aquifer (H). As a result, this is the frequency of flow of water at a hydrostatic pressure through the full saturated thickness of the aquifer either through a cross-section of a breadth unit. The aquifer's hydro-geophysical data for the study region comprise resistivity, depth, thickness, and transmissivity (Table 1). The available geoelectrical and hydraulic parameters of the four VES points (1D) curves interpretation, located about one km away from four observed wells in the study area aquifer are conjointly used to get more precise empirical relationships between them(Fig. 3). The transmissivity values shown in Table 1 were obtained from the experiment pumping test results using Jackob's method, carried out by (Al-joburi, 2011), for the four mentioned wells.

The transverse resistivity is directly proportional to the transmissivity and is linked with it by the following equation with a confidence coefficient (R^2=0.93).

$$\rho_t = 2.627\,(T) - 55.975 \qquad (1)$$

Where: ρt is the transverse resistivity, which can be defined as the resistance that obstructs the path of the current.

It is perpendicular to the application plane and can be obtained from the product of multiplying the aquifer thickness by its resistivity. T is the transmissivity.

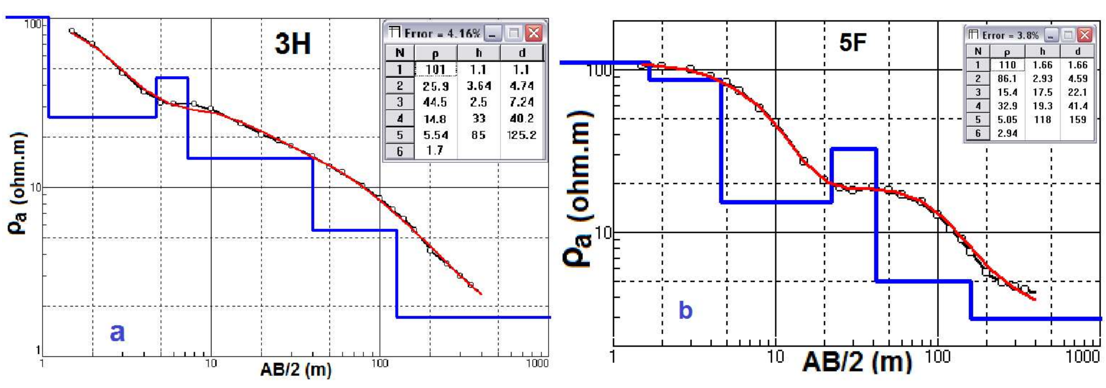

Figure 2. Some soundings curves, a- near an expected area with good productivity, b- near an expected area with excellent productivity.

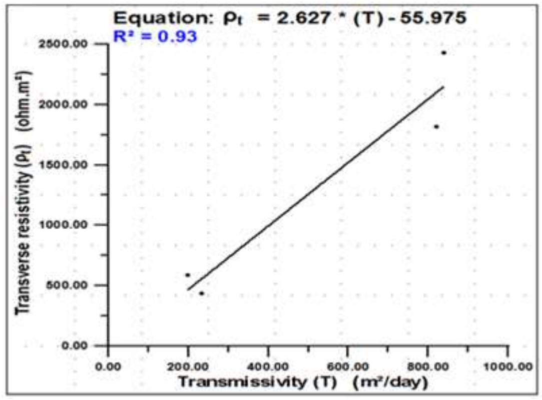

Figure 3. An empirical relation between the transverse resistivity and the transmissivity.

3 Methodology

Weighted overlay approach (WOA) assessment is a geographical approach for analyzing multiclass charts that are influenced by various relevance of every layer, as well as the classification of a layer using GIS softwares (Chaudhari et al, 2018). WOA makes the criteria more favorable with higher values in the output raster, which allows to identify thereafter these locations as the priority. WOA incorporates also several weights into the multicriteria geoprocessing. It differs from traditional multicriteria evaluation (MCE) procedures, through which one evaluates the effect of every criterion, and assigns ratings inside a given range of classes (Vázquez-Quintero et al, 2020). The superlative location will be chosen and decided based on the hydro-geophysical data analysis (Table 1). Fig. 4 depicts a flowchart of the classification process.

3.1 Dataset Reclassification

The reclassification reclassifies or rescales each dataset to a common scale (for example, 1 to 10), giving higher values to more suitable attributes. All reclassification methods are applied to each cell within a zone. The first step in elaborating the suitability model is to develop a database, such as depth.Each cell in this classification technique has in the research region a numerical significance for each layer for each criterion input.

An appropriate map may be built as a result of combining the produced datasets to indicate the suitable drilling areas for future wells. Although those individual maps cannot be combined in their current state, the subsequent stages are used to categorize the prior maps into five related classes that share a unique value. The ideal decided regions for drilling a well are given and labeled as number five on the maps, whereas the unfavorable areas are labeled as number one.

3.2 The Suitability Model with Weighted Overlay

The classed datasets should be combined to discover the best place for drilling new wells. All the datasets are reclassified to the same descriptive statistic to generate an integrative study for the values of different and dissimilar inputs (the suitable cell has a higher value). The input layer has been assigned a weight based on its significance and degree of effect, where 10% is assigned for depth, 20% for thickness, 30% and 40% are for aquifer resistivity and transmissivity, respectively. These criteria have been developed according to our experience and the available information about the region and the impact of each parameter. The larger the proportion, the greater the significance of a specific input on the suitability model. GIS techniques are used to create the weighted suitability analysis premised on

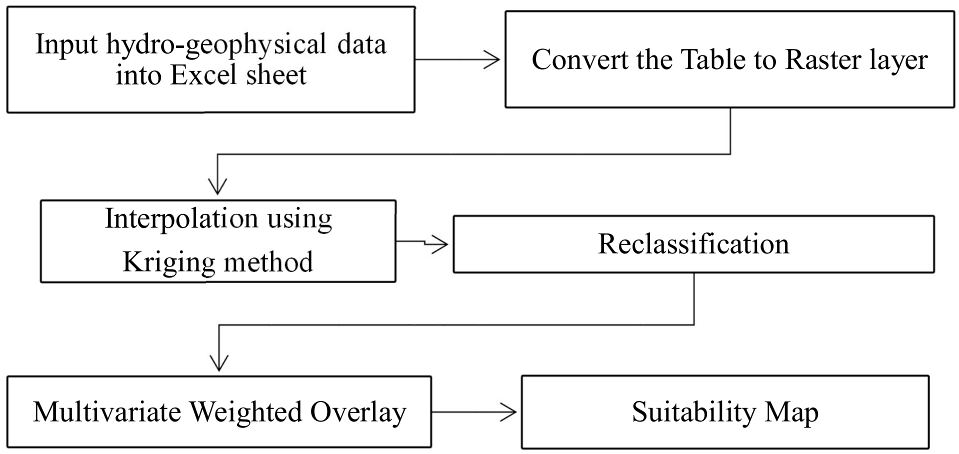

Figure 4. Flowchart of the multivariate of thematic maps.

Table 1. The hydro-geophysical data of the aquifer.

VES Name	Longitude (UTM)	Latitude (UTM)	Resistivity (ohm.m)	Thickness (m)	Depth (m)	Transmissivity (m^2/d)
1C	365568	3850779	9.14	79.50	28.0	356.69
2C	364151	3849363	12.60	75.55	30.0	474.61
3C	362643	3847900	20.50	76.66	27.0	693.49
4C	361110	3846507	11.50	79.44	26.0	456.65
5C	359670	3845020	8.50	90.40	19.0	381.1
6C	358277	3843766	10.70	84.57	21.0	452.49
7C	356744	3842327	9.14	79.53	26.0	356.86
1D	363153	3855006	6.73	68.63	35.0	158.86
2D	361807	3853705	13.80	79.75	33.0	537.95
3D	360227	3852173	8.58	87.00	27.0	368.45
4D	358602	3850640	10.20	80.00	24.0	407.34
5D	357255	3849340	7.55	81.54	24.0	284.31
6D	355815	3847900	10.7	61.00	23.0	309.84
7D	354376	3846553	8.37	70.00	24.0	262.70
1F	361435	3859975	8.81	79.23	23.4	339.15
2F	359902	3858489	6.12	117.00	30.4	350.28
3F	358463	3857003	9.58	124.23	19.4	572.11
4F	356930	3855563	6.67	147.00	26.0	487.51
5F	355467	3854123	5.05	137.40	22.0	336.55
6F	354143	3852869	5.93	132.65	22.0	391.32
7F	352704	3851429	5.05	96.30	30.6	181.37
8F	351218	3850036	14.00	99.00	29.0	638.64
1H	354422	3854820	14.10	129.00	22.0	757.31
2H	356001	3853287	6.27	107.00	24.3	321.85
3H	357441	3852126	5.54	85.00	40.2	167.30
4H	358927	3850872	10.46	50.80	35.1	220.05
5H	360413	3849525	9.47	59.30	24.0	244.19
6H	361899	3848225	10.20	68.53	27.0	339.77
7H	363339	3847017	7.60	62.80	25.0	173.18
8H	365011	3845624	7.23	72.60	39.0	214.70

Table 2. Aquifer factor weight.

Aquifer factor	Weight (%)
Transmissivity (TA)	40
Resistivity (RA)	30
Thickness (ZA)	20
Depth (DA)	10

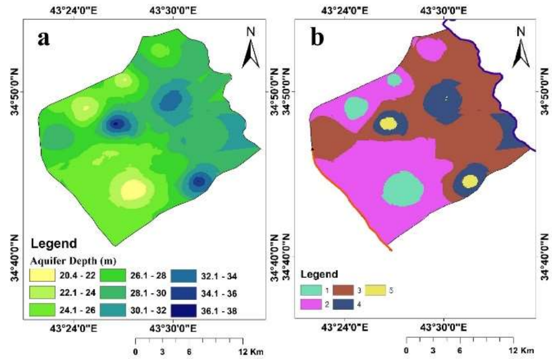

Figure 5. Aquifer depth map of the study area. a- Interpolation map, b- Reclassification map.

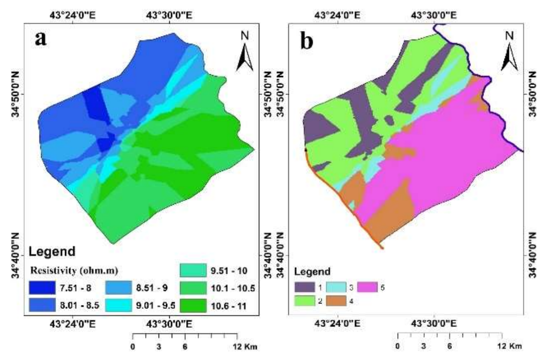

Figure 6. Aquifer resistivity map of the study area. a- Interpolation map, b- Reclassification map.

several thematic maps. Layers of input might, as a result, not even be equally significant. Each unit in the binary image is classified into appropriateness units.They are therefore computed as the sum to designate a degree of significance to each, and the total weight is consequently calculated. This following equation can also be used to calculate the appropriateness of each cell on the map.

$$S_i = \sum W_i Y_i \quad (2)$$

Where,

S_i=The significance of the i major consideration map

W_i=Major consideration i's criterion class score

Y_i=Suitability index for each pixel in the map.

All the thematic layers are o combined in this research in the ArcGIS 10.2 platform to create a map, that will indicate a good location for drilling a new water well. The previous equation (2) is used to calculate the cumulative weights of every pixel in the final incorporated layer;

$$S = (DA_w DA_r + RA_w RA_r + ZA_w ZA_r + TA_w TA_r) \quad (3)$$

Where,

S=Dimensionless to every pixel in the final integrated layer's new well location index.

DA=Depth of the aquifer

RA=Resistivity of the aquifer

ZA=Thickness of the aquifer

TA=Transmissivity of the aquifer

w=The weight of each class

r=The data value for each class

Table 2 illustrate the factor and weight for the suitability model. The transmissivity is assigned a higher percentage weight (40%), because of its strong and tight association with water volume and availability, as well as the prospect of rejuvenation. On the other hand, the aquifer resistivity

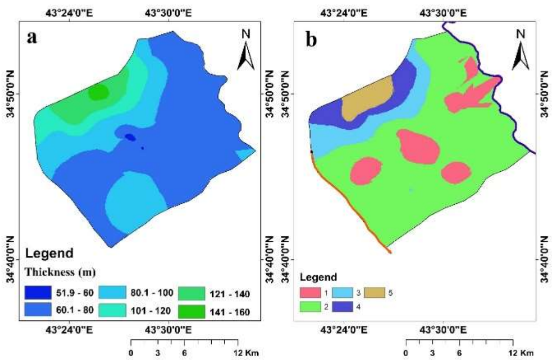

Figure 7. Aquifer thickness map of the study area. a- Interpolation map, b- Reclassification map.

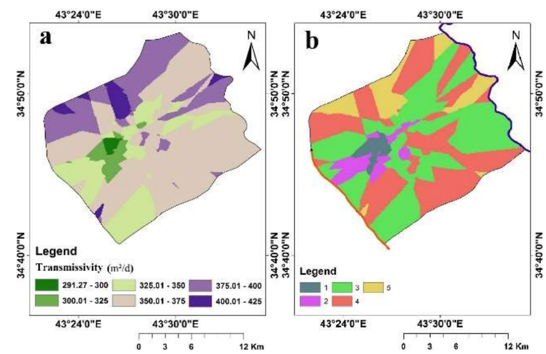

Figure 8. Aquifer transmissivity map of the study area. a- Interpolation map, b- Reclassification map.

aspect being related to water freshness (salinity) is allotted a 30% weight, where resistivity decreases as salt content increases. The aquifer thickness (20%) and aquifer depth (10%) have been given the smallest percentage weights since they are significant in predicting the volume of water and in the expenditure of drilling wells.

4 Results and Discussion

The results of integrating GIS and hydrogeophysical data are analyzed in this research paper to perform the input layers, where the overlay combination (values of the aquifer's depth, thickness, resistivity, and transmissivity) in the GIS approach is used.

4.1 The Aquifer Depth Map's Reclassification

The weighted model is used to reclassify the aquifer depth map using numerical value rather than varies as inputs. The reclassify function is used to reclassify this map. The most appropriate range (low depth value) receive a score of five, while the least appropriate range receives a score of one (high depth value). The classes on each layer have to be the same (1 to 5). Fig. 5a depicts the aquifer depth map, while Fig. 5b depicts the recategorized version of this map.

4.2 The reclassification of the aquifer resistivity map

The aquifer resistivity map has been reclassified, using integer values rather than ranges as inputs in the weighted model. This map is reclassified using the reclassify function. The most suitable range (low depth value) receives a value of five, while the least suitable range receives a value of one (high depth value). Each layer should have the same classes (1 to 5). Fig. 6a, shows the aquifer resistivity map, while Fig. 6b, shows the reclassified version of this map.

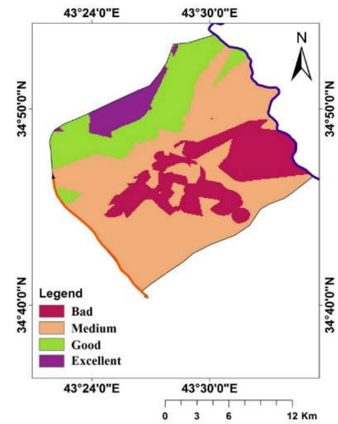

Figure 9. Resulting appropriateness map of the study area.

4.3 The reclassification of the aquifer thickness map

For use as parameter in the weighted model, the aquifer thickness (the aquiferous unit thickness from the watertable to basement) map has been reclassified to integer values rather than ranges. The most appropriate range (high value) receives a value of 5, while the least appropriate range receives a value of one (low value). The thickness map is depicted in Fig. 7a, while the classed version is depicted in Fig. 7b.

4.4 The reclassification of the aquifer transmissivity map

For the input in the weighted model, the aquifer resistivity map has been reclassified to integer values rather than ranges. The most suitable range (high transmissivity rating) is assigned a value of five, while the least favorable range is assigned a value of one (low transmissivity value). The transmissivity map is depicted in Fig. 8a, while a reclassified version of the same map is depicted in Fig. 8b.

4.5 Choosing the best successful locations

Each pixel has now in the resulting map a value reflecting its appropriateness. Pixels with a value of three are ideal. The best site location for drilling new wells has, as a result, a value of three. Several locations are chosen and decided as the best locations during the process based on the input variables. Groundwater explorative borehole locations are identified and explored by utilizing the obtainable hydro-geophysical data, such as (aquifer thickness, resistivity, depth, and transmissivity). GIS is an effective tool for incorporating spatial analysis datasets into a suitability map for determining the efficient groundwater well places. The most suitable locations are identified. The above technique is lively and could be improved by incorporating additional data layers to extract extra important factors for developing groundwater potential. The findings map in this paper (Fig. 9) allows decision-makers to quickly determine the best location for groundwater wells.

5 Conclusion

The best location for groundwater wells is determined by using hydro-geoelectrical data and the GIS approach.

The weighted overlay approach was thereafter used to normalize the criterion layers, which were consequently merged with the overlay function to produce the feasibility maps. The geospatial datasets are combined with GIS to create a suitability map for determining efficient groundwater well locations. The most suitable locations have been identified. The study area was accordingly divided into four categories: poorly appropriate, moderately appropriate, good appropriate, and excellently appropriate. The findings of this research can be therefore used to plan effective groundwater management in the study region. The available data was used as input, recorded, combined, and evaluated using the GIS. All of the images with attribute values in the ArcGIS suitability map might be transferred; thus, all image features can be used as an input layer, where a precise result for the whole maps could be acquired. This research study highlights the effectiveness of GIS-based suitability analysis in locating ideal locations for drilling new groundwater wells. The use of groundwater suitability analysis immediately helps the community to deal easily with the water situation. The GIS-based weighted overlay approach is efficacy applied, based on geo-hydraulic factors, to select the best areas and to bore new groundwater reservoirs.

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