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Integrated Geophysical Data and GIS Technique to Forecast the Potential Groundwater Locations in Part of South Eastern Nigeria

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Abstract

The objective of this research is to select the most suitable drilling location of new groundwater exploration wells, with a decision-making tool from Geographic Information System (GIS). The optimum location will be evaluated base on the hydro-geoelectrical parameter derived from Vertical Electrical Sound (VES) including Longitudinal Conductance, the thickness of the aquifer, the apparent resistivity and Transmissivity. From the Geo-electrical method (VES) the finds shows that the aquifers in the study area have Apparent Resistivity ranging from 0.32 to 40.24 Ωm, Thickness between 0.21 m to 15.06 m, Longitudinal Conductance ranging from 0.006 to 10.246Ω^{-1} and Transmissivity ranging from 0.14 to 10.38m^2/day. Hydro-geoelectrical data were integrated into GIS to precisely determine the best location for groundwater borehole. Finally, the study location was classified into three classes; not suitable, moderately suitable and highly suitability with respect to the input factors using the Fuzzy overly combing method. It's evident that the middle part of the area in study represents the optimum location for the drilling of groundwater boreholes.

Keywords: GIS, Hydro-geoelectrical Parameter; Location Selection, Spatial Analysis, Fuzzy Overlay.

1. Introduction

Water is essentially a vital natural resource, an utmost essential requirement of life next to air, availability of a reliable source of water is a vital necessity meant for maintainable advance both in domestic and industrial usage. It an indicator for measuring development. Water has no known auxiliary in many of its plentiful uses. Portable water is one that is harmless to drink, satisfying to taste buds and very un-objective and monochrome [1]. Water usage transcends domestic to food production, manufacturing, conservation of ecological unit, hydro-electric energy generation amid others [2- 7]. The above nevertheless, amplified quest for development affects natural water resources.

Moreso underground water aquifer is exhausted at a proportion quicker than the water can be rejuvenated, hence drains groundwater [4, 8], as a consequence of overpopulation and expanded exploitation of fresh water [9- 12].

Increase in population growth and urbanization puts a burden in the subsurface configuration (groundwater). In a settlement, potable water plays a major role in determining the growth and development of that settlement. According to Okechukwu and Etuk [13], groundwater occurs below the earth surface within saturated layers of sand, gravel and pore spaces in sedimentary as well as crystalline rocks. Groundwater potential valuation is compulsory for large-scale improvement of groundwater [14].

The environment can be evaluated without interfering with the hydrogeological system using geophysical studies [13]. Electrical resistivity method involving VES and GIS has demonstrated to be valuable in groundwater study; this technique has been extensively used in groundwater exploration to

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determine depth to water table, aquifer geometry, and groundwater feature by analyzing measured apparent resistivity field data [15]. The flora of the subsurface resources is of influence in the scheming of suitable groundwater management schemes in any geologic setting, whose properties (physical and chemical) and spatial circulation institutes the aim of all hydrogeological and hydro geophysical investigations [16, 17]. Groundwater flow in fractured aquifers is very complicated, and accuracy in the estimation of the hydraulic parameters depends on the hydraulic behavior in particular fractures, which is site-specific [18]. The gradation of this effect rest on the proportions, profile, location and bulk electrical resistivity of the subsurface strata. The bulk electrical resistivity depends on the mineralogy of the rocks and it is containing fluids [19].

GIS is the furthermost contemporary technology used to create three-dimensional/four-dimensional multi-criteria conclusions that target possible groundwater resources. GIS is used to carry out the fitness model for groundwater site choice via three-dimensional/four-dimension relationship, incorporating and weighting for all the datasets. Three-dimensional/four-dimension investigation is a procedure, which inspects the locations, connections between the structures and characteristics of a three-dimensional/four-dimension dataset. The core objective of this study is to finds optimum locations to drill new groundwater boreholes using GIS procedures to investigation the hydro-geophysical parameters (from Vertical Electrical Sounding, VES) data. The analysis of Geo-electrical method (VES) inversion of the resistivity data was used in mapping the best drilling location of new groundwater exploration boreholes. In recent times, geographic information systems (GIS) have been extensively used in groundwater vulnerability mapping [20- 28]. GIS procedure has permitted the formation of groundwater vulnerability maps that are founded on a parametric mapping.

The purpose of this study is to select the preeminent drilling location of new groundwater exploration boreholes using Geographic Information System (GIS) as a decision-making tool. The optimum location will be selected depending on the geophysical data (1D electrical resistivity) comprising Longitudinal Conductance, the thickness of the aquifer, the apparent resistivity and Transmissivity. These parameters were unified with GIS and the location was more distinguished to accurately select the best locations. This research conferred how the incorporation among the geoelectrical parameters and hydrological data, could be used to define the best drilling location of new groundwater exploration boreholes. [29- 33].

2. Study Area

The study area is along the Imo River and close to the Abia State capital. The demand for groundwater is very high due to the industrious nature of the people in the study area, which they use for industrial and commercial purpose.

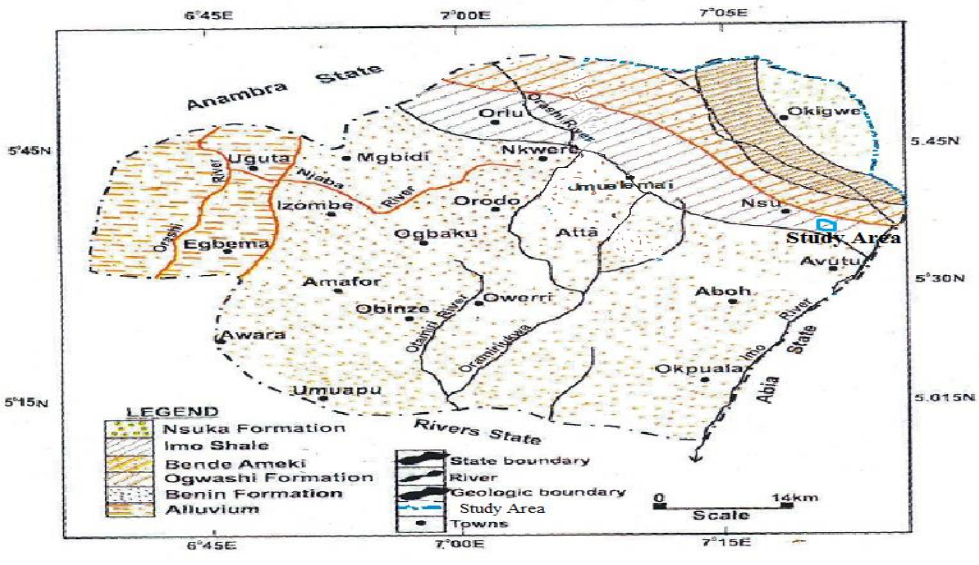

Figure 1-Geology map of Imo State, showing the location of study area.

The study region is an intricate geological setting in Imo State. The succeeding stratigraphic units lie beneath the area: the Benin Formation, the Ogwashi - Asaba Formation, the Bende-Ameki Formation, Imo Shale Formation, Nsukka Formation, and Ajali Formation. The Benin Formation comprises of coarse-grained gravelly sandstones by slight intercalations of shales and clay. The sand components, which are typically coarse-grained, pebbly and poorly sorted, comprise lenses of fine-grained sands. The Ogwashi-Asaba Formation is composited of a variable sequence of clays, sands, and grits with strata of lignite. The Ameki Formation comprises of greenish-grey clayey sandstones, shales, and mudstones by interbedded limestone. This Formation, in turn, superimposes the impermeable lmo Shale group categorized by horizontal and perpendicular variants in lithology. The lmo Shale of Paleocene age is laid down through the transgressive period that trailed the Cretaceous. It is triggered in succession by Nsukka Formation, Ajali Sandstones, and Nkporo Shales.

3. Methodology

The GIS methodology involved alphanumeric image processing aimed at the extraction of linear structures, GIS processing (with rasterization of vector layers and line density analysis) and analyses for the extraction of input layers from distantly sensed and numerous ancillary data (geological map, topographical map, soil map) and the evaluation (in terms of number and the characteristics of extracted lineaments) of distantly sensed data (DEMs and Landsat Imagery) as well as field studies. The groundwater parameters maps were drawn using the most appropriate technique. For this purpose, for each groundwater parameters, a suitable variogram model with respect to the spatial structure of each parameter event was fitted using GIS software (for the data which were not routinely distributed, the logarithm of data were used). Then by means of variogram representations and its parameters (nugget effect, sill, and the range) interpolation was carried out using the superlative kriging method.

The optimum groundwater location will be selected based on the available hydro-geophysical data (Table- 1), aquifer resistivity, aquifer thickness, Longitudinal Conductance, and transmissivity. Figure- 2 explains the methodology flowchart.

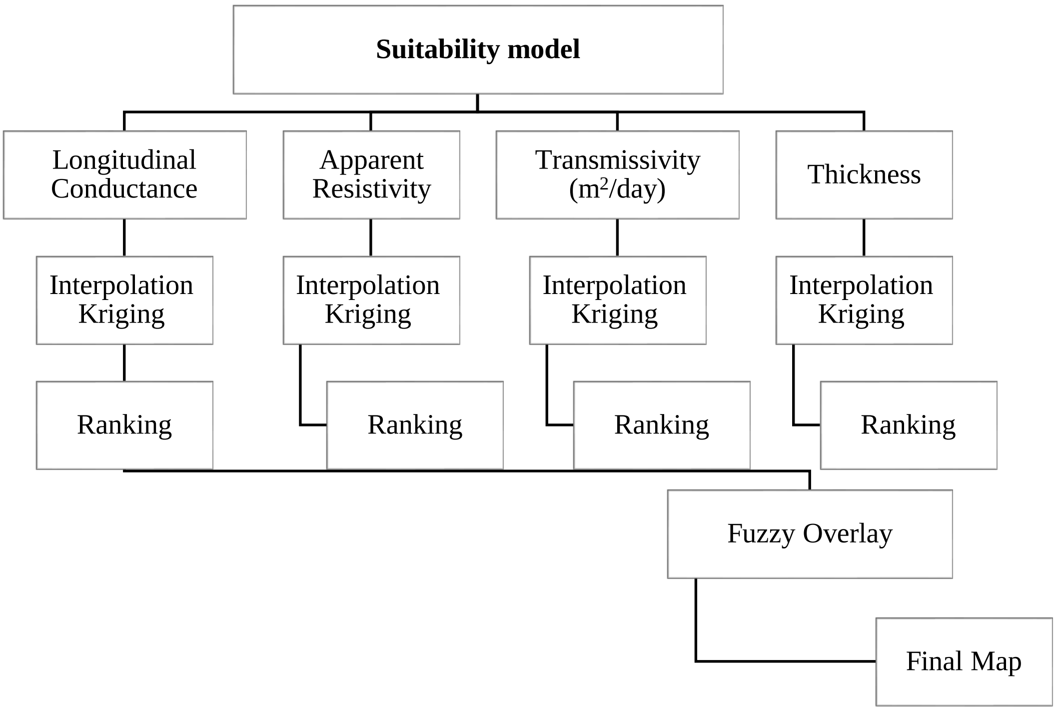

Figure 2-Flowchart for Suitability Model.

Table 1-Hydro-geophysical Data of Aquifer

VES No.	Latitude	Longitude	Apparent Resistivity (Ωm)	Thickness (m)	Longitudinal Conductance (Ω^{-1})	Transmissivity (m^2/day)
1	5.604219	7.320564	1.35	3.89	2.881481481	2.684053350
2	5.603579	7.320285	0.65	6.66	10.24615385	4.599503777
3	5.601048	7.320285	2.55	12.91	5.062745098	8.893859932
4	5.60344	7.317302	1.00	5.30	5.300000000	3.658600726
5	5.593189	7.324169	1.34	10.41	7.768656716	7.182868538
6	5.605148	7.31816	3.98	3.14	0.788944724	2.159167517
7	5.605575	7.32846	31.37	0.21	0.006694294	0.139351633
8	5.590968	7.327945	3.40	7.50	2.205882353	5.161137284
9	5.599083	7.313697	5.93	4.65	0.784148398	3.189397917
10	5.601859	7.318289	3.02	4.20	1.390728477	2.891665009
11	5.605874	7.320306	4.30	11.57	2.690697674	7.952604457
12	5.558128	7.326786	0.32	2.77	8.656250000	1.913827682
13	5.586932	7.303011	40.24	1.78	0.044234592	1.167629124
14	5.605041	7.335284	2.48	15.06	6.072580645	10.37596590

3.1 Reclassifying Datasets

The procedure involved for building a suitability model is to derive the reclassification databases, in this tactic for every criteria input, each cell in the study area will have a dissimilar value for each layer. The suitability map will then be created by the combination of the resulting datasets in order to recognize the potential locations for drilling new boreholes [34].

The previous maps were classified into a comparative friction of five (5) classes, to have a communal value. In the classified maps, the number 1, indicated good areas to drill groundwater borehole, the higher the value, the lower the indication of a good area to drill a groundwater borehole.

3.2 Suitability Model

All the reclassified datasets have been reclassified to a mutual measurement scale (more appropriate cells have lower values). To estimate the optimum location to drill groundwater boreholes, we would combine all the hydro-geoelectrical parameter reclassified datasets. The suitability analysis was established using GIS methods dependent on a number of thematic layers [35]. The Fuzzy overlay instrument permits the inquiry of the option of a phenomenon fitting to numerous sets in multi-criteria overlay analysis. Furthermore, this equation is used to acquire a suitability significance for every cell on the map [36].

$$S = \sum W_i X_i$$

Where,
W_i=The weight of the I factor map.
X_i = Criteria class score of factor i
S = Suitability index for each pixel in the map.

The obtainable methods are fuzzy And, fuzzy Or, fuzzy Product, fuzzy Sum, and fuzzy Gamma. Individual approach offers a different feature of individually cell's membership to the multiple input criteria. In this study fuzzy AND was used. The fuzzy And intersection category will return the smallest assessment of the sets the cell location belongs to. This procedure is valuable once you want to recognize the least mutual denominator for the membership of all the input criteria. Fuzzy And uses the following function in the evaluation:

Fuzzy And Value = min (arg1, ..., arg n)

In this study, all the thematic layers were incorporated into ArcGIS 10.2 platform in order to make a map illustrating appropriate location to drill a new groundwater borehole.

4. Results and Discussion

The input layers have been used to assess the outcomes from Integration between GIS and hydro-geophysical parameters. By intersection grouping technique in GIS (i.e Values of Aquifer Resistivity, Aquifer Depth, Aquifer Thickness Aquifer Longitudinal Conductance and Aquifer transmissivity).

4.1 Reclassifying the Aquifer Resistivity Map

Aquifer Resistivity map was reclassified to integer values as an alternative of arrays to be used as inputs in the weighted model. One (1) was allocated to the best suitable series and five (5) to the least suitable range. From Figures- 3a and 3b as shown below are the apparent resistivity map and the reclassified apparent resistivity map respectively.

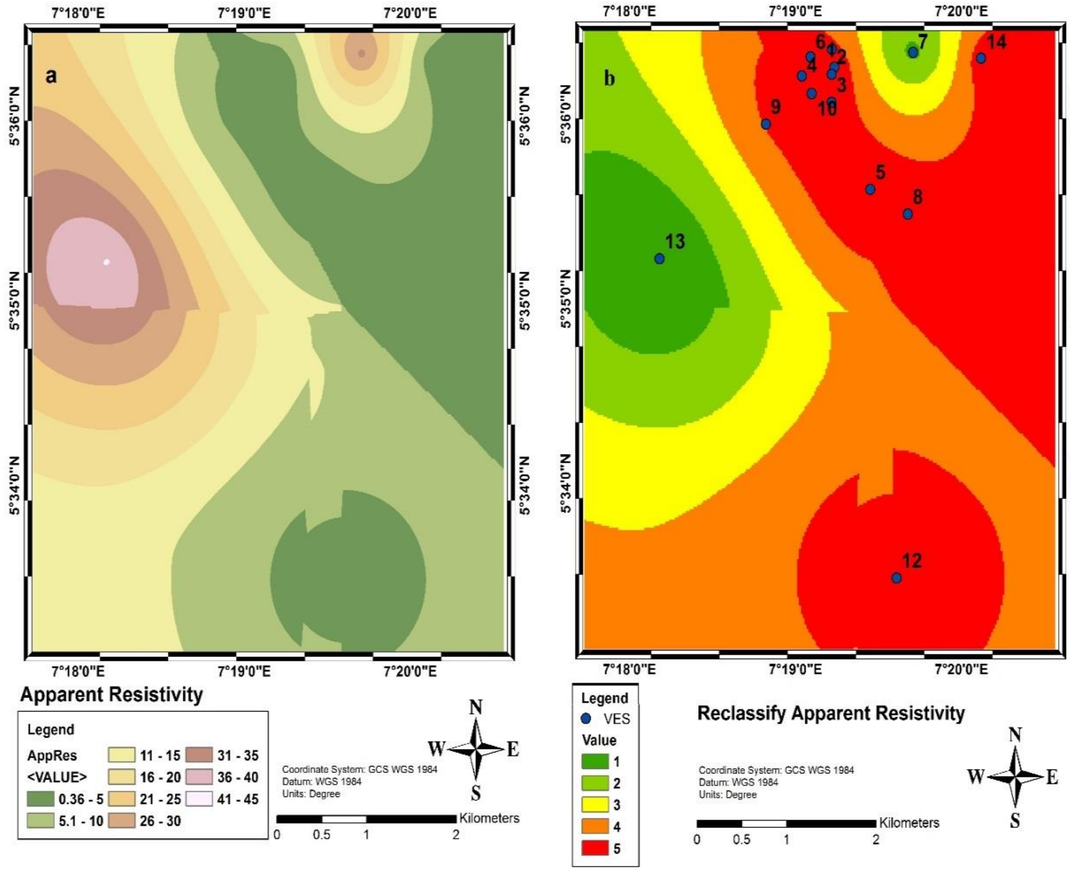

Figure 3-(a) The Resistivity Map (b) The Reclassified Apparent Resistivity Map.

4.2 Reclassifying the Aquifer thickness Map

Aquifer Thickness map was reclassified to integer values as an alternative of arrays to be used as inputs in the weighted model. One (1) was assigned to the most suitable range and five (5) to the least suitable range. Figures-(4a and 4b) below shows the aquifer thickness map and the aquifer thickness reclassified map respectively.

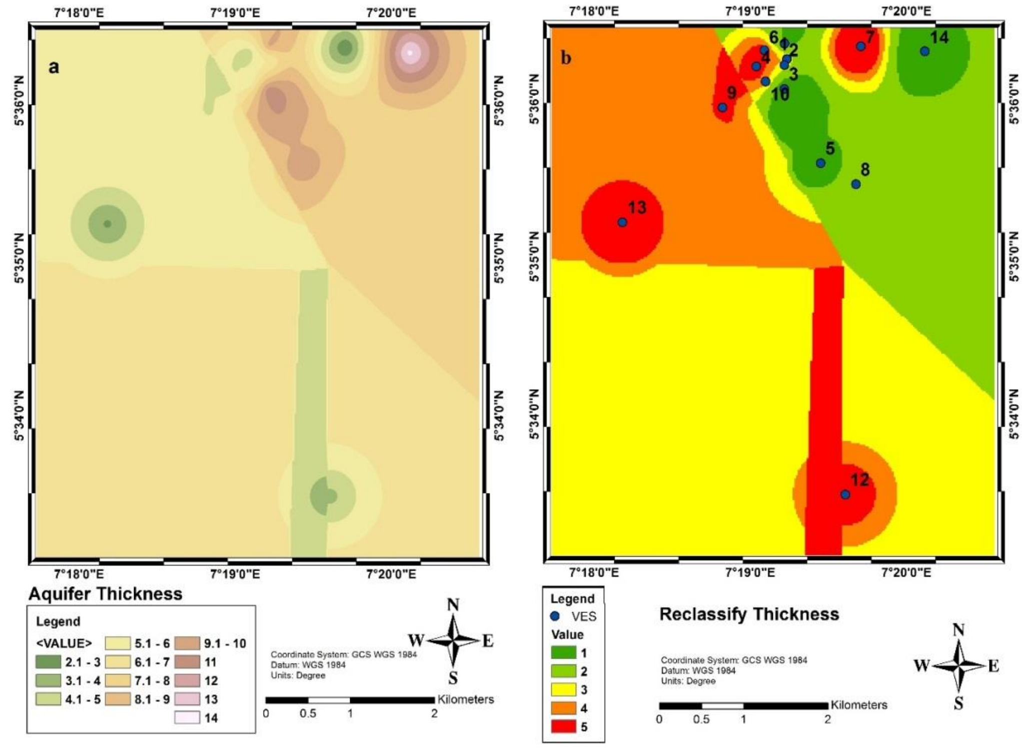

Figure 4-(a) The Aquifer Thickness Map (b) The Aquifer Thickness Reclassified Map.

4.3 Reclassifying the Aquifer transmissivity map

Aquifer Transmissivity map was reclassified to integer values as an alternative of arrays to be used as inputs in the weighted model. One (1) was assigned to the most suitable range and five (5) to the least suitable range. Figures 5a and 5b below shows the aquifer transmissivity map and the aquifer transmissivity reclassified map respectively.

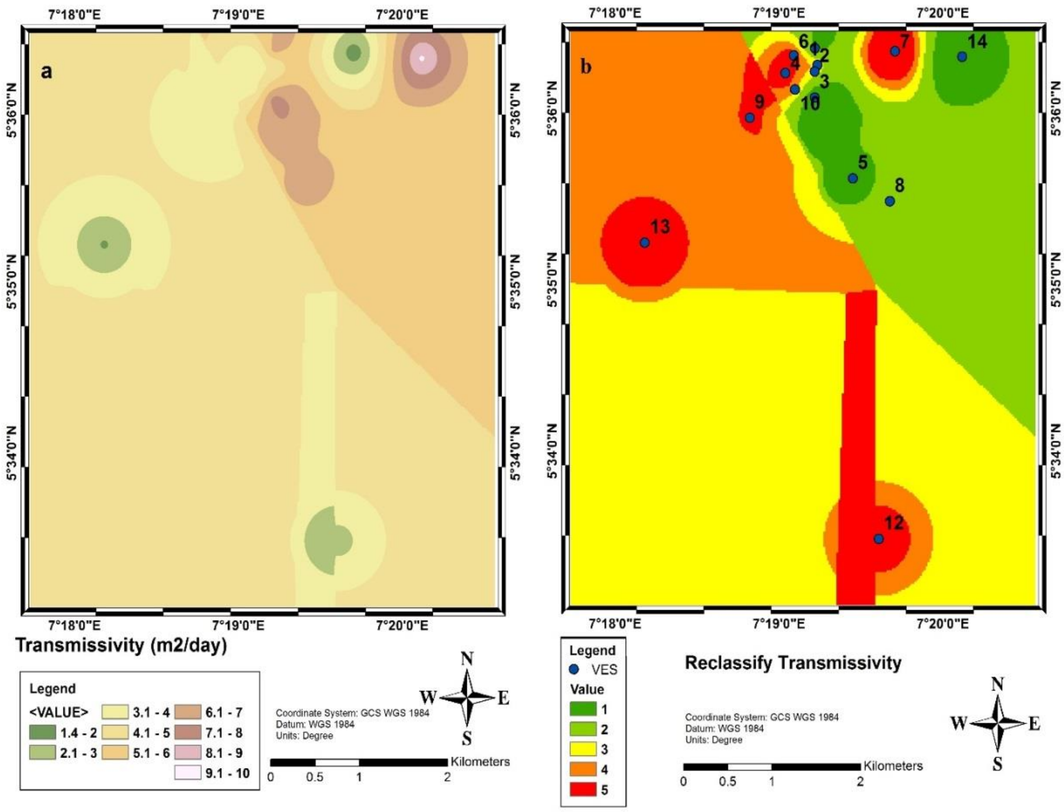

Figure 5-(a) The Aquifer Transmissivity Map (b) The Aquifer Transmissivity Reclassified Map

4.4 Reclassifying the Aquifer Longitudinal Conductance map

Aquifer Longitudinal conductance map was reclassified to integer values as an alternative of arrays to be used as inputs in the weighted model. One (1) was assigned to the most suitable range and five (5) to the least suitable range. Figures 6a and 6b below shows the aquifer longitudinal conductance map and the aquifer longitudinal conductance reclassified map respectively.

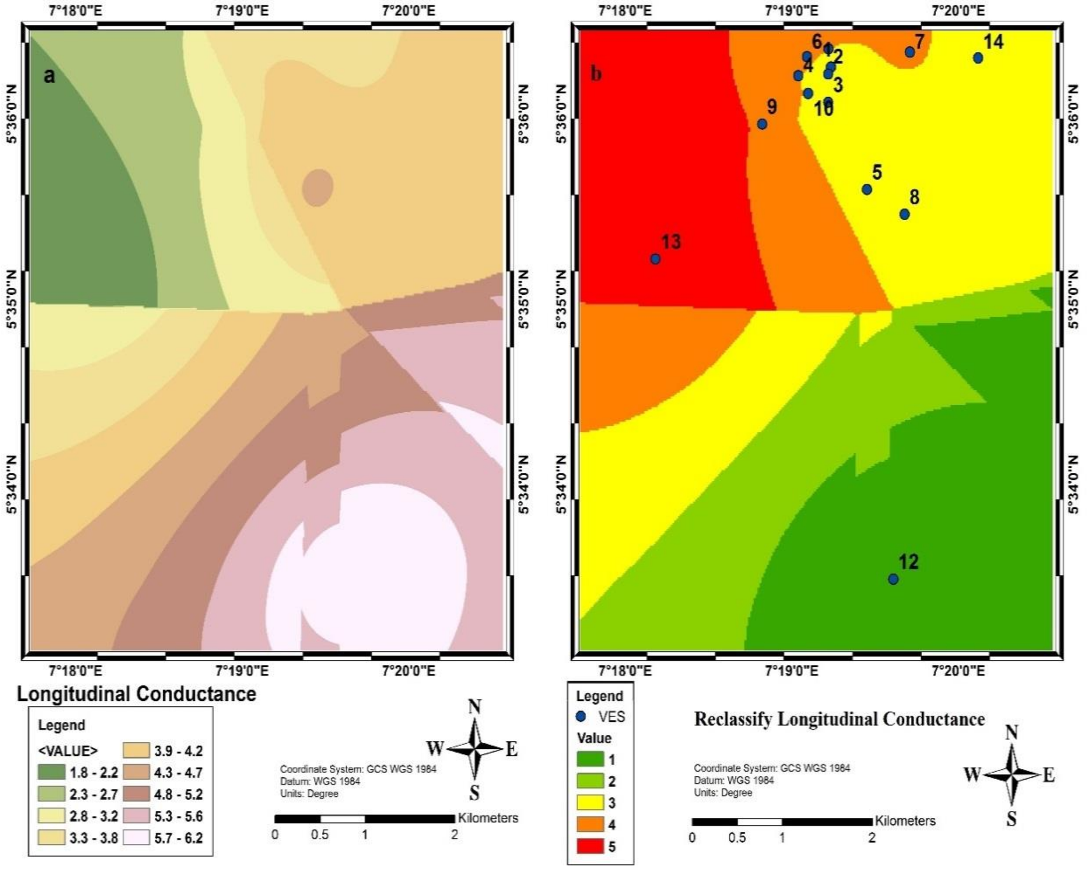

Figure 6-(a) The Aquifer Longitudinal Conductance Map (b) The Aquifer Longitudinal Conductance Reclassified Map

4.5 The Optimum Location Selection

Pixel is used to represented suitability on the reclassified maps, as can be seen in figures 3b, 4b, 5b and 6b, each pixel has a value it represents between 1 and 5. Pixels with the value of (3) three is most appropriate. Consequently, the optimum location to drill a groundwater borehole has the value of three.

Groundwater investigative boring locations were explored and recognized using the available Hydro-geophysical data comprising of thickness, resistivity, depth, longitudinal conductance and transmissivity of the aquifer), GIS was used to assimilate these geospatial datasets in a fitness map aimed at choosing optimum groundwater well locations. The optimum locations have been identified as seen in figure 7 below. Figure-7 would help for easy decision making to find the unsurpassed location for drilling of groundwater.

The results of the Geo-electrical method (VES) shows that the aquifers in the study area have a thickness between 0.21 m to 15.06 m, Apparent Resistivity ranging from 0.32 to 40.24 Ωm, Longitudinal Conductance ranging from 0.006 to 10.246$\Omega^{-1}$and Transmissivity ranging from 0.14 to 10.38m^2/day.

It's evident that the central part of the study area represents the optimum location for the drilling of groundwater boreholes.

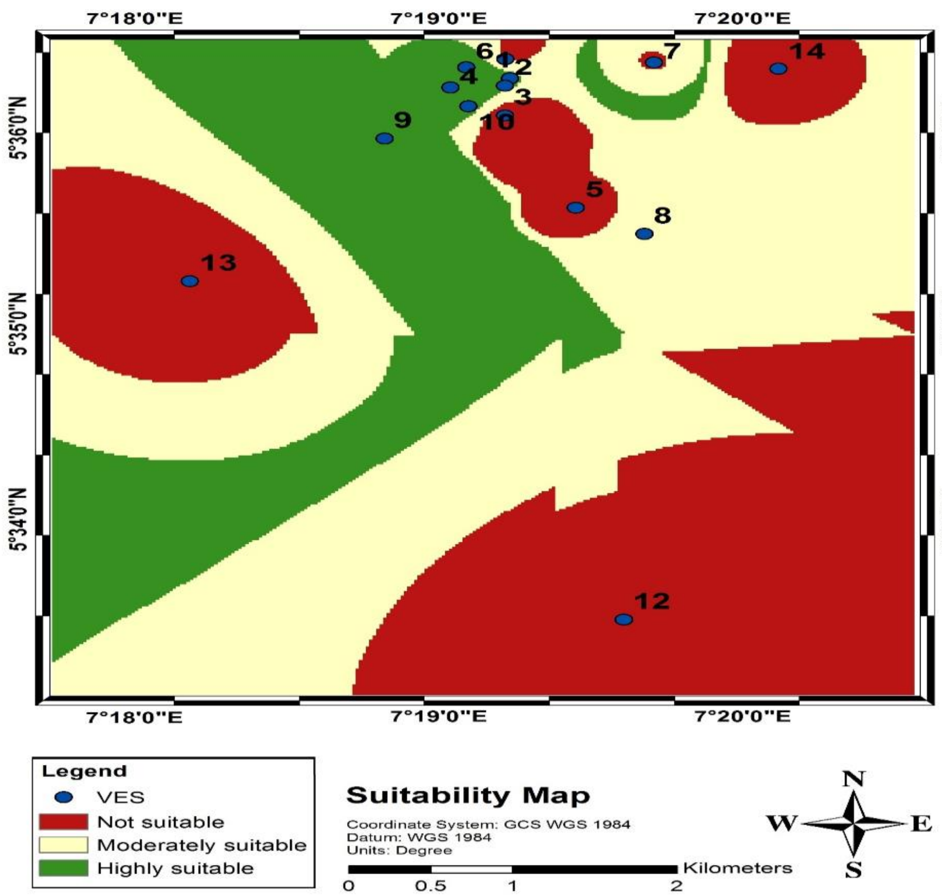

Figure 7-Final Location Evaluation.

5. Conclusion

Geo-hydraulic parameters and geographic information systems (GIS) are an efficacious method for classify of the optimum locations for groundwater.

The study location was distributed into three classes; not suitable moderately, suitable and highly suitability rendering to the input influences by means of an overly combing method. The fuzzy overlay method by ArcGIS is contemplated to be an operational device in handling, preparation a geospatial data, spatially in location suitability studies. The GIS has been used to input, store, consolidate and evaluate the available data.

A methodological technique in accompanying a research by means of GIS was presented to be used in choosing the optimum position of groundwater boreholes, where the three-dimensional/four-dimension analysis, imagining and enquiry competences of GIS engaged in selecting the groundwater well locations for a prerequisite set of criteria. Characteristic values of all the pixels in the fitness map of ArcGIS could be exported; hence, all the pixels features might be used as an input layer, a precise result could be acquired for the entire map.

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