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Assessment of Groundwater Yield Potentials Zones of Idi-Ayunre using Vertical Electrical Sounding and Geographic Information System (GIS)

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Abstract

To fully harness the increasing number of observations and variant data sets available and put them to efficient use in geological studies aimed at solving earth science-related problems, GIS technique is a veritable tool. The dynamic techniques and the complex nature of earth sciences is a serious cause for worry for geologists. In this work vertical electrical sounding (VES) was integrated with geographic information system (GIS) to delineate subsurface characteristics and evaluate groundwater potential zones in Idi Ayunre, Oluyole Local Government Area, Oyo State. The results of the VES curves obtained from the partial curve matching were used to constrain the interpretation by the computer using iteration software known as WINRESIST® and extended analysis on the data set was done using geostatistical analysis tool on archGIS 10.0®. The Root Mean Square (RMS) errors for the analysis were found to be very low with an average of 2.96% . This underscores the reliability of the analysis tool for this type of work. The area is dominated predominantly by Type-H curves which amassed twenty (20) out of the twenty-one (21) VES and one (1) VES producing a type-K curve. The VES results revealed a maximum of three geo-electric layers, viz: topsoil, weathered layer, bedrock respectively. The yields of wells dug in most of these locations may be insufficient, even for domestic use because of its relatively small thicknesses. However, at a depth of 7.8 m, a fractured zone occurs in VES 10 with resistivity value of 21.2 Ωm suggesting the presence of groundwater, which may be considered the main aquifer units suitable for groundwater exploration.

Keywords: Geographic information system; Aquifer; Vertical Electrical Sounding; Electrical Resistivity; Basement Complex.

I. Introduction

Groundwater is water that lies under the surface of the earth where it travels through and fills opening rock spaces to form aquifers. Water can also be obtained from the troposphere as precipitation which includes rain. The availability of water is limited because of its natural distribution on the earth surface which is not uneven [1];

97.5% of the global water is saline, existing in oceans and only 25% is considered to be available for biological use [2]. About 68.7% of the remaining 25% that is fresh is locked up in glaciers while 30.1% and 0.9% represents groundwater and other fresh water respectively. Global warming, climate, weather and human activities coupled with the explosion in population of many cities, towns and villages has led to surface water been highly insufficient in meeting the water supply needs of most communities which has led to the search for an alternative source of water.

Reference [3] affirms that globally, 26% of the renewable fresh water resources is from ground water. Groundwater therefore, has become a very viable alternative and has played vital role in developing industries, the agricultural and domestic sectors. The occurrence and development of groundwater is therefore, controlled by a variety of factors which includes but not limited to: Porosity and permeability of the surface, underlying rock formations. Variance in porosity and permeability therefore leads to changes in groundwater potentials [4]. Surface hydrological features such as topography, drainage density, water bodies etc. play important role in groundwater replenishment [2]. The types of geological materials contained in the lithologies determines the capacity of their permeability and porosity [5]. Geophysical techniques are successful and cost effective methods for groundwater investigations [6]. Methods such as Electrical resistivity method, Electromagnetic method have been used in the assessment of ground water potential.

In Nigeria, several studies [7]-[15] have been carried out to investigate groundwater potential yield. In these Studies, geophysical methods (vertical electrical sounding (VES) and Lineaments technique) and geospatial methods (Geographic Information Systems and Remote Sensing techniques) were employed.

Integration of technology is a part of modern day trends which cannot be overemphasized. Geographical information System (GIS) is integrated with vertical electrical sounding (VES) to delineate geo-electric characteristics and evaluate groundwater potential zones in the study area which will serve as a guide for future borehole development and water projects within the study area and its environs. There has not been any known case of a research which integrated GIS and Resistivity method (VES) being carried out massively in the study area to delineate subsurface structure and determine the groundwater potential zones. This study will therefore, serve such purposes as to provide useful information for borehole drilling and other water projects.

A. The Study Area

The study area (see Fig. 1) is the administrative headquarters of Oluyole local government area of Ibadan. Its geographical coordinates are 7°14'44" North and 3°51'21" East. The major rock associations of the study area makes up part of the Basement complex of Nigeria with an undulating topography. It is underlain by banded gneiss and granite gneiss. The minor rocks such as quartz vein and pegmatite occur as intrusions in the major rock types. The entire western part of the community in which the study area is located is underlain by banded gneiss while the eastern part is predominantly made up of granite gneiss [16]. IdI Ayunre is accessible by a major road, which is tarred.

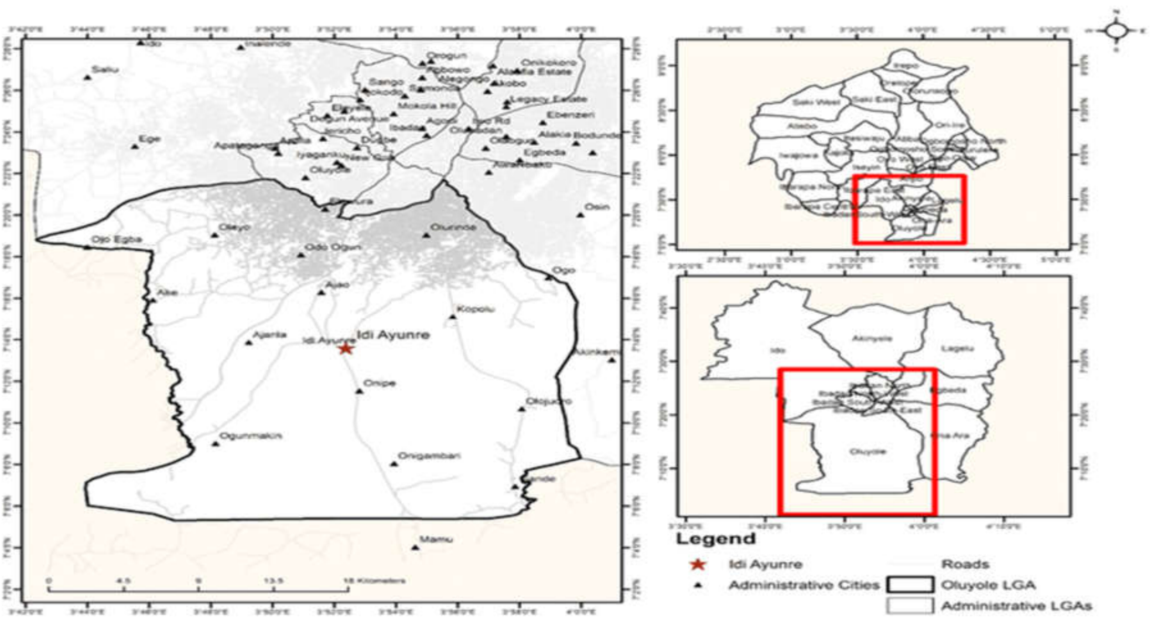

Fig. 1 Map showing Idi-Ayunre and its environs

II. MATERIALS AND METHOD

A. *Instrumentation*

Geoelectrical resistivity field data was acquired using earth's resistivity meter commonly referred to as Terrameter. The specific instrument used in this research is the Geopulse Tigre Resistivity meter (Fig. 2). The equipment is portable, light weight and cost effective when compared with other geophysical data acquisition equipments. The setup basically consists of a current source which is commonly a battery pack connected to a commutated DC circuit to change polarity of the current source, an ammeter which is used to measure the source current, a highly sensitive voltmeter that measures the response signal. A low frequency AC signal may be used as current source instead of a commutated DC source [17]. The impedance of the ammeter, connected in series with the current source, should be low so as to minimize its effect on the measuring circuit. Likewise, the voltmeter connected in parallel with the ammeter should have high input impedance in order to reduce any effect arising from the ammeter [18]. In general, the current source and both meters are usually housed in a single box.

Fig. 2 Campus Geopulse Tigre Resistivity Meter

B. *Geostatistical Analysis*

Geostatistical analysis tool in the ARCGIS 10.0 software was used to interpolate the data from the field in the study area. Before using the interpolation techniques, the field data was explored using the exploratory spatial data analysis tools (ESDA). While setting up the framework for interpolation, histogram was used to examine the distribution and summary statistics of the dataset. Assessment of whether the data set is normally distributed and exploring whether two datasets have similar distribution was done using Normal QQ Plot and General QQ Plot. Voronoi Maps were used to visually examine the spatial variability and stationarity of the field dataset. Trend Analysis tool was used to Visualize and examine spatial trends in the dataset. Evaluation of the spatial dependence of the dataset was done using Semivariogram/ Covariance Cloud. The process of construction and evaluation of the performance of the interpolation model was done using geostatistical wizard which helped to guide through the process. The Geostatistical Wizard provides access to a number of interpolation techniques, which are divided into two main types: Deterministic and Geostatistical [19].

This Geostatistical Techniques assumes that at least some of the spatial variation observed in some natural phenomena can be modeled by random processes with spatial autocorrelation and require that the spatial autocorrelation be explicitly modeled [20]. Therefore, the Ordinary Kriging method was used for the purpose of this study to build an interpolation model and displaying them in ArcMap. Exploration of the data was done to examine the statistical and spatial properties of the datasets. Choice of an appropriate interpolation method was made and this was driven by the objectives of the study, understanding of the phenomenon, and the required model output. Performance diagnostics was done to cross check that the results are reasonable (expected), and evaluate the output surface using cross-validation and validation. The results are then embellished on a map and presented for interpretation.

C. *Other tools used in data collection*

1) Electrodes

Four stainless electrodes were used, having a pair as current electrodes and the other pair as potentials electrodes. Stainless steel was chosen for potential electrodes because it polarizes less than other metals. The current electrodes are used to pass current into the subsurface while the potential drop was measured through the potential electrodes.

2) Hammer

The hammers were used to drive both pairs of electrodes (Current and potential) into the ground.

3) Measuring tape

VES points spread were measured in metre with the aid the measuring tape.

4) Cables

Four reels of cables, for which a pair was connected to the current terminals on the resistivity metre and current electrodes while the other pair was connected to the potential terminals on the resistivity metre and potential electrodes.

5) Recording sheet

Field data and other import observations were recorded on the paper that contains the measured parameters.

6) Global Positioning System (GPS)

This is a space based radio navigation system, consisting of 24 satellites and ground support. It provides users with accurate information about their location and velocity anywhere on the earth surface. The coordinates of each grid point was obtained by the metre.

III. RESULTS AND DISCUSSION

The results of the VES curves obtained from the partial curve matching which indicated three layers were used to constrain the interpretation by the computer using iteration software known as WINRESIST® and extended analysis on the data set was done using geostatistical analysis tool on ArcGIS 10.0®. The Root Mean Square (RMS) errors for the analysis were found to be very low with an average of 2.96%. This underscores the reliability of the analysis tool for this type of work. The area is dominated predominantly by Type-H curves which amassed twenty (20) out of the twenty-one (21) VES and one (1) VES producing a type-K curve. Fig. 3, 4 and 5 are representative sample of the curves as stated.

Table 1: Summary of Interpreted VES curves

VES Station	Layer Resistivity (Ωm)	Thickness (m)	Depth (m)	Curve Type	R.M.S Error	Layer Description
1	753.6	1.4	1.4	H	2.5	Top Soil
	413.1	43.1	44.4			Weathered Layer
	7218.6	------	-----			Bedrock
2	271.8	1.0	1.0	H	2.3	Top Soil
	105.4	5.4	6.3			Weathered Layer
	1262.6	-----	-----			Bedrock
3	333.9	0.8	0.8	H	3.1	Top Soil
	85.2	2.5	3.3			Weathered Layer
	1307.9	-----	-----			Bedrock
4	480.6	0.6	0.6	H	4.7	Top Soil
	106.3	1.1.	1.1			Weathered Layer
	1902.9	-----	------			Bedrock
5	456.2	0.6	0.6	H	2.1	Top Soil
	98.2	1.2	1.8			Weathered Layer
	1684.9	-----	-----			Bedrock
6	309.8	2.7	2.7	H	2.4	Top Soil
	68.5	1.6	4.4			Weathered Layer
	3218.0	-----	-------			Bedrock
7	881.0	0.4	0.4	H	2.7	Top Soil
	152.2	4.6	5.0			Weathered Layer
	1394.7	------	------			Bedrock
8	485.9	0.6	0.6	H	1.9	Top Soil
	101.1	2.9	3.5			Weathered Layer
	760.2	------	------			Bedrock
9	516.1	0.7	0.7	H	5.6	Top Soil
	196.9	5.3	6.0			Weathered Layer
	1526.2	-----	------			Bedrock
10	69.1	3.0	3.0	H	3.4	Top Soil
	21.2	7.8	10.9			Weathered Layer
	1191.7	----	-----			Bedrock
11	133.7	1.0	1.0	H	2.5	Top Soil
	13.6	6.2	7.2			Weathered Layer
	625.7	-----				Bedrock
12	395.7	1.9	1.9	H	6.3	Top Soil
	12.8	5.6	7.5			Weathered Layer
	155.9	-----	-----			Bedrock
13	308.3	0.8	0.8	H	11.8	Top Soil
	13.4	2.2	3.0			Weathered Layer
	6948.5	-----	-----			Bedrock
14	202.5	1.0	1.0	H	2.5	Top Soil
	30.9	7.9	8.9			Weathered Layer
	2464.8	-----	------			Bedrock
15	45.7	1.3	1.3	H	2.5	Top Soil
	16.9	0.8	2.1			Weathered Layer
	1694.4	-----	-----			Bedrock
16	135.4	1.1	1.1	H	1.5	Top Soil
	78.6	16.4	17.5			Weathered Layer
	169.7	-------	-----			Bedrock
17	210.6	0.4	0.4	H	2.5	Top Soil
	79.2	5.1	5.4			Weathered Layer
	1506.0	------	------			Bedrock
18	200.1	0.4	0.4	H	1.9	Top Soil
	84.5	5.2	5.5			Weathered Layer
	247.2	-------	------			Bedrock
19	155.5	0.4	0.4	H	3.9	Top Soil
	29.6	2.2	2.5			Weathered Layer
	131.0	-----	----			Bedrock
20	589.3	0.9	0.9	K	3.3	Top Soil
	1264.3	2.6	3.4			Weathered Layer
	281.2	------	-----			Bedrock
21	259.4	0.9	0.9	H	3.1	Top Soil
	243.9	33.5	34.4			Weathered Layer
	4758.7	-----	------			Bedrock

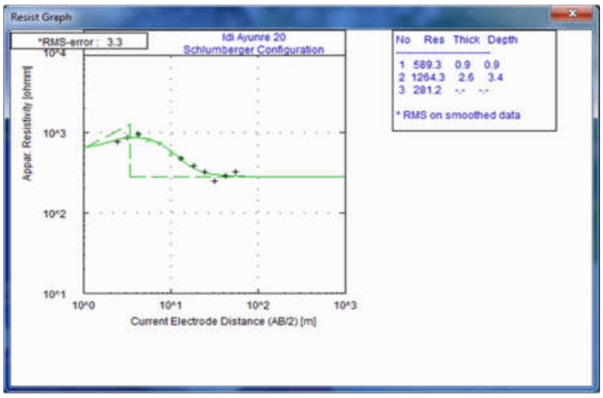

Fig. 3 Typical K-Curve

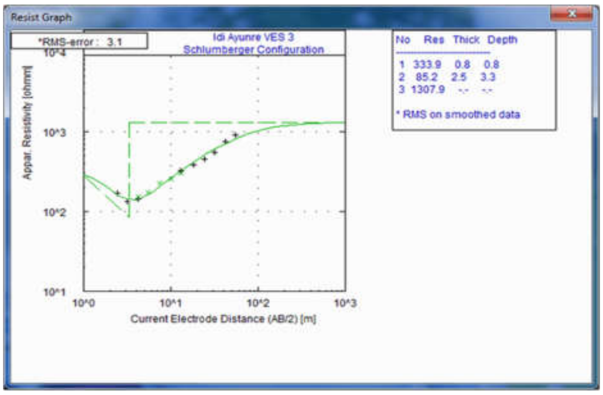

Fig. 4 Typical H-Curve

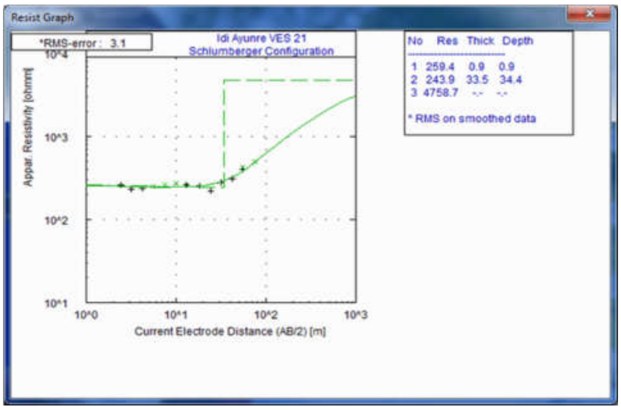

Fig. 5 Typical H-Curve

A. *Overburden Thickness*

Fig. 6 shows the overburden thickness map of the study area. The overburden as used in this work includes all material above the presumably fractured/fresh bedrock. The map shows overburden thickness ranging between 1.1 m and 44.4 m. Generally, the overburden is relatively shallow within the study area with average overburden thickness of 8.7 m. The overburden within the south-western and south-eastern part of the study area is thick with overburden thickness of about 44.4 m, and 34.4 m, respectively, while the other parts of the area have shallow overburden thickness which means that basement is thick in all this area.

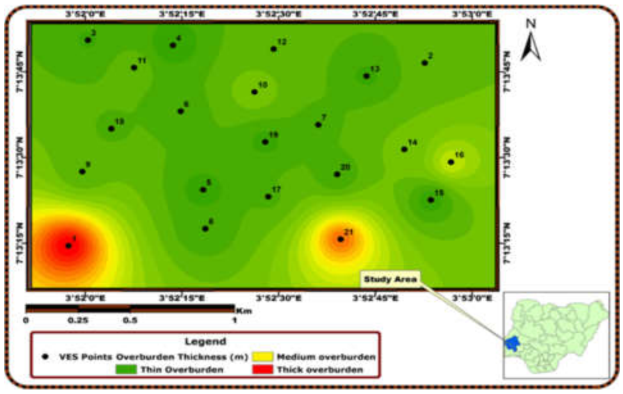

Fig. 6 Overburden Thickness Map

B. *Weathered Basement Resistivity*

The weathered basement resistivity map Fig. 7 shows the resistivity variation within the weathered basement of the study area. The resistivity values range is between 12.8 Ω m to 1264.3 Ω m with a mean value of 153 Ω m. The resistivity is highest at the south-eastern part of the study area and progressively decreases from the south-western parts to other parts of the study area. The weathered basement in the study area has a mean thickness of 7.7 m. Generally, the area is characterized by very thin weathered basement except in few areas with thickness of 43.1 m, 33.5 m, and 16.4 m respectively.

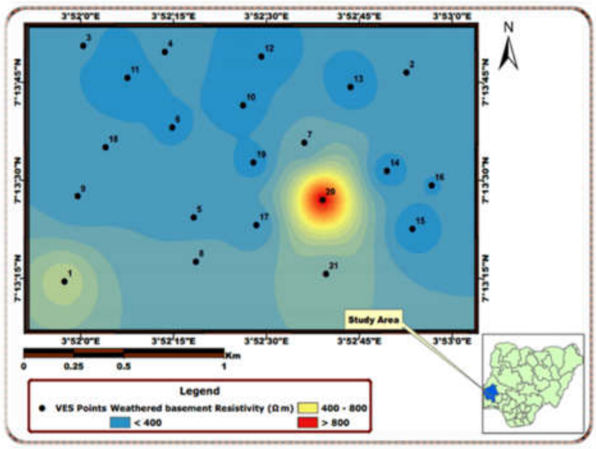

Fig. 7 Weathered Basement Resistivity Map

C. *Bedrock Relief/Topography*

Fig. 8 shows the bedrock relief/Topography of the study area. This bedrock relief map shows the basement topography, its structural resolution and also the degree of weathering of the basement. The hydro geologic importance of this has been identified by [21].Topography troughs, ridges and plains are identified in the bedrock relief map. The troughs are characterized by the thick overburden as seen in the part of the south-western part of the map while ridges and plains are noted for thin overburden cover as seen in the map which means that the overburden is shallow and any runoff that infiltrate to the basement will flow to another location where there might be troughs that will serve as water collecting centre.

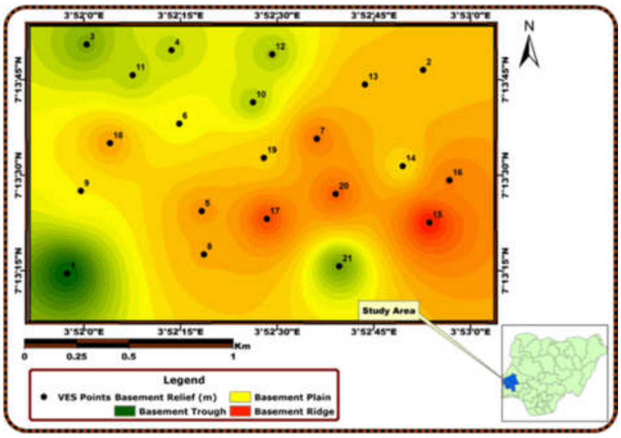

Fig. 8 Basement Relief Map

D. Basement Resistivity

Fig. 9 shows the bedrock/basement resistivity map of the study area. The resistivity values of the basement vary between 131 Ωm – 7218.6 Ωm. According to [22], the basement resistivity values that exceed 1000 Ωm is of fresh bedrock but where the resistivity values are less than 1000 Ωm, the bedrock is fractured and saturated with freshwater. From the map generated, the presence of fractured bedrock (<1000 Ωm) is considerably present within the study area with predominant occurrence of fresh bedrock (>1000 Ωm) in the south-western and north-eastern part of the area.

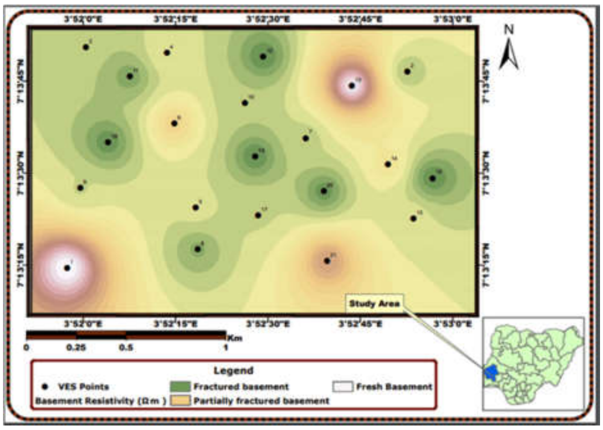

Fig. 9 Basement Resistivity Map

E. Reflection Coefficient

Fig. 10 shows the reflection coefficient map. The calculation of the reflection coefficient r for each of the VES point was done using the method adopted by [22].

$$r = \left\{\frac{\rho_n - \rho(n-1)}{\rho_n + \rho(n-1)}\right. \quad (1)$$

Where ρ_n is the layer resistivity of the nth layer and $\rho(n-1)$ is the layer resistivity overlying the nth layer. The freshness of the basement increases as the value of the reflection coefficient tends to the maximum value of 1. Reference [22] observed that the resistivity of the basement cannot be solely relied on to identified areas of promising aquifer within the basement terrain, hence, the consideration of its reflection coefficient which brought a better result which shows the degree of fracturing underlying the basement.

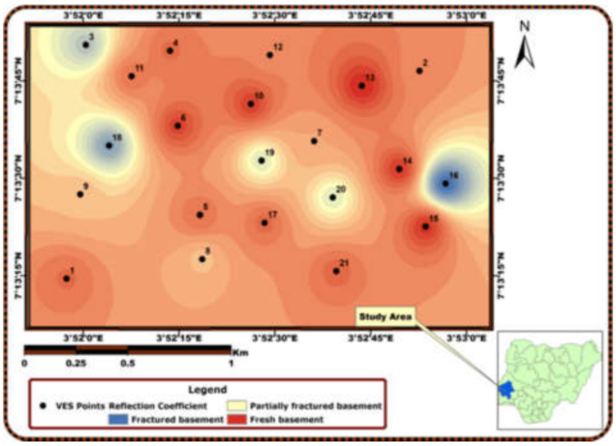

Fig. 10 Reflection Coefficient Map

F. Groundwater Potential Evaluation

The groundwater potential of Idi Ayunre, Ibadan was evaluated based on the integration of the weathered layer resistivity, overburden thickness, basement resistivity, bedrock relief and reflection coefficient maps. The groundwater prolific area have thick overburden > 10 m [23], the basement resistivity < 1000 Ω m which represent fractured basement, and weathered basement resistivity ranging from 50 Ω m to 300 Ω m [23]. In addition, groundwater potential is characterized by troughs on the basement topography map while the reflection coefficient of the area is less than 7.5 which represent fractured basement [24]. These maps were produced and interpolated for the production of the groundwater potential map, which was finally used to classify the study area into high, medium and low/poor groundwater potential zones. From the groundwater potential map it was observed the north-eastern flank and southern part of the area is characterized by low aquifer potential. On the other hand, the central part and towards the end of the north-western region was characterized by moderate aquifer potentials. The central towards eastern part of the area was characterized by high or good aquifer potential (see Fig. 11).

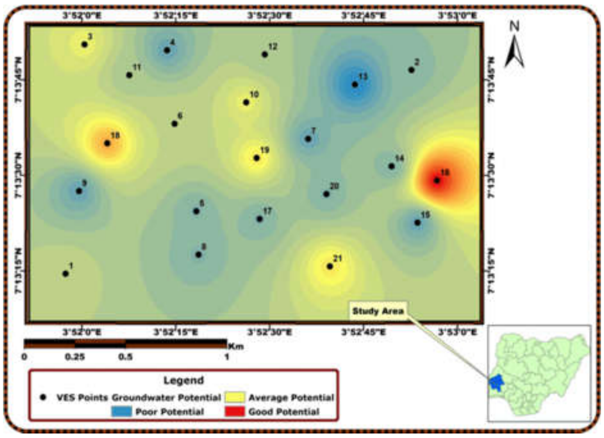

Fig. 11 Groundwater Potential Map

IV. CONCLUSION

The research shows that the shortage of water or drying up of boreholes within the study location is as a result of the unfavorable groundwater potential condition of the area. It was also observed that no borehole cited in the small portion of the study area favors groundwater. Generally, the overburden of the study area is shallow compared to the range given by [22]. Based on the overburden thickness, the groundwater abstraction from this study area may not be too feasible because of the occurrence of shallow overburden. The southwestern part of the study area which has a thick overburden may be good for groundwater abstraction. In addition to being characterized by thick overburden which is between 1.1 m and 44.4 m, basement troughs also constitute groundwater collection, especially the water displaced from the bedrock crest. Generally, fresh basement dominates the study area with resistivity values greater than or equal to 1000 Ωm mostly in the southwestern and Northeastern part of the study area. In basement terrain, good aquiferous zones are usually found either where the overburden is relatively thick and or where the reflection coefficient is low (< 0.75). The area which falls within this category is less than 19% of the area investigated which indicates that the basement may be fresh and the weathering is not deep.

In conclusion, the groundwater potential of the study area is low which has contributed immensely to the shortage of water during the dry season with more than 80% of the study area having low groundwater potential, during the raining season groundwater is more abundant especially during periods of heavy rainfall. Having said that, the high groundwater zones are located in the eastern part of the study area.

The findings in this work shows that electrical resistivity is still one of the best geophysical methods to characterize groundwater potential and an integration with others tools helps in building a better perspective and understanding. In view of the persisting groundwater scarcity faced in the study area, the following recommendations may be considered:

1. More geophysical investigations of the area be carried out with emphasis on increasing the electrode separation and VES points to allow detailed probing of the subsurface in order to delineate high yielding potential groundwater zones.

2. A detailed 2D survey is also encouraged in order to reveal the true image of the sub-surface both vertically and laterally, which will give an insight to the continuity of the various units of the subsurface.

3. The eastern part of the study area is recommended for consideration for water projects such as siting boreholes.

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