

# Geophysical Investigation of Groundwater Potential and Aquifer Protective Capacity in Some Part Of Kafin Hausa Local Government, Jigawa State Using Electrical Resistivity Method

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## Abstract

*Geophysical survey using vertical electrical sounding (VES) was carried out in some part of kafin Hausa local government (Unguwan Kiginawa, opposite dan bartso dump site, Unguwan Kiginawa, Gambawa, Gambawa besides Dan-Modi rice mill, and Kiginawa Quarters). In order to investigate the aquiferous zones and groundwater potential in the area. The schlumberger electrode arrangement was used with a total of five VES point. Interpretation shows that VES 1, 3, 4 and 5 were all of poor protective capacity with a longitudinal value less than 0.1 whereas VES 2 is characterized as the area of moderate protective capacity. Also, in terms of groundwater potential, VES 2,3 and 4 were of high groundwater potential with a depth value of greater than 25m and VES 1 as a medium groundwater potential with a depth range of (10-25) m, whereas VES 5 With a depth of less than 10m is of low groundwater potential. It is recommended that Reliable borehole for good portable water should be sited in VES 2. Also recommended that most of VES site were not of good protective capacity and thus, a measure should be taken.*

**Keywords:** *Ground Water potential, aquifer protective capacity, electrical resistivity, Kafin Hausa.*

## 1. Introduction

Quality and abundance of groundwater are one of the nature's mysterious hidden treasures. The need for clean and portable groundwater remains one of the most important demands in the society we are living and the world at large. None of the alternative sources of water (e.g., streams, rivers, ponds, lakes, oceans, etc.) matches the hygienic quality of groundwater due to its excellent microbiological and chemical qualities that matches the satisfaction of our basic and domestic needs (MacDonald et al., 2002). Water remains one of the most vital elements to human existence and other natural environment (Alabi et al., 2010). The availability of groundwater in economic quantity from the subsurface strata solely depends on the distribution of the subsurface geo-materials called aquifers. As such, potentiality of groundwater may not be endowed enough in some given geographical areas, there may be either complete lack or insufficiency due to industrial or high domestic needs (Akpan and Goerge, 2010).

The exploitation success of groundwater in the basement terrain requires proper understanding of the geo-hydrological features of the aquifer units within the susceptibility of the basement environments (Abiola et al., 2009). One of the essential features for sustainable use of groundwater is to understand and delineate aquifer protective capacity. Aquifer vulnerability is one of the key expressions for quantifying aquifer protection, vulnerability indicates whether the biochemical and physical characteristics of the subsurface can prevent and/or favor the transport of pollutants in and into the aquifers (Bayewu et al., 2018).

By convention, the easiest and convenient way to satisfy public and domestic water demands are rivers and lakes, unfortunately these are only 0.001% of the world’s total water and less than 2% of world’s fresh water (Alabi et al., 2010). Groundwater accounts for 98% of world fresh water and its reserve is not likely to dry up under natural conditions within the crust and to the surface sources (Olusegun et al., 2016). However, detecting new locations of groundwater resources will not be enough to satisfy the social and domestic demands, the most challenging task is protecting the proven/delineated groundwater resource from potential pollutants. Considerations are not given to hydrogeological settings when it comes to sighting dumpsite areas and latrines thereby rendering the future of groundwater at risk (Ekwok et al., 2020). The widespread use of chemical products, coupled with the disposal of large volumes of waste materials, poses a danger potential for wide distribution of groundwater contamination (Ekwok et al., 2020).

Very few researches had been carried out in the study area which includes the work of Idris et al. (2019) where they determine the physico-chemical parameters of drinking water in Kafin-Hausa town. Suleiman et al. (2018) investigate the aquifer characteristics and ground water potential of Kafin-Hausa, Jigawa state using geo-electric method and Shitu et al. (2018) evaluate the subterranean condition of Sule Lamido University, Kafin-Hausa using geo-electric method. However, the interpretation used in the previous research involved large anomaly interpretation covering wide geographical area for the interpretation. Thus, this does not limit the information to more specific area of coverage. This research work chooses areas with the largest dumpsites and industrial activities within Kafin Hausa metropolis, in order to investigate the in fact of such activities to the ground water aquifers in the study area.

Therefore, this study is aimed at investigating the groundwater potential and aquifer protective capacity in some parts of Kafin Hausa local government area, Jigawa State, Nigeria using vertical electrical sounding (VES) with Schlumberger electrode configuration, in order to provide information about the subsurface layers, assess the aquifer protection, and determine the electrical properties and thickness of the subsurface layers within study area.

**1.2 Location of the Study Area**

Kafin Hausa is situated in the north-eastern part of Jigawa state between latitude of 12,2406 (1214`26.160` N) and longitude of 9, 91331 (954`47.016` E). The Study area is made up of sedimentary rocks (Shitu et al., 2018). Kafin Hausa is bounded close to the hydrological divide within a Chad formation which occupies the north-eastern part of the state (www.Jigawastate.net, 2017). The main rivers that lie within the study area are Hadejia, Kafin Hausa and Iggi Rivers with number of tributaries feeding many marshlands in the north-eastern area of the state. Hadejia-Kafin Hausa Rivers traverse the state from west to east through the Hadejia-Nguru wetlands. (www.Jigawastate.net, 2017).

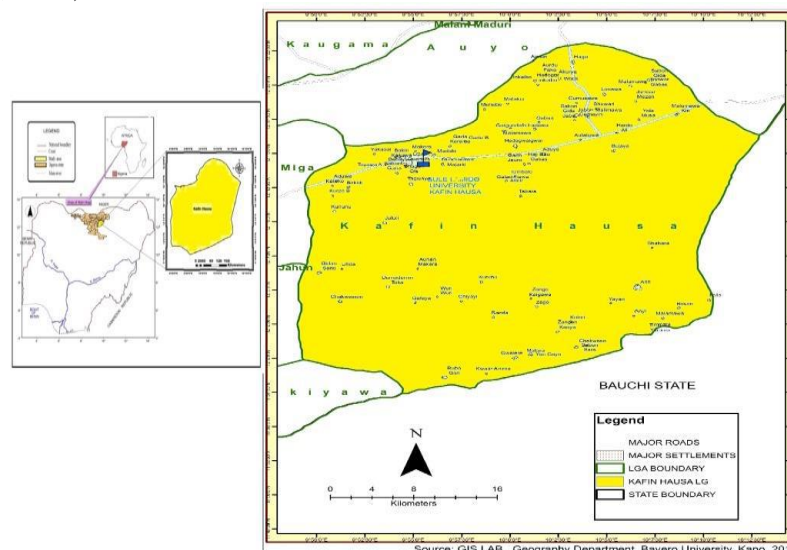


Figure 1: Location map of Kafin-Hausa Local Government (Adopted from Suleiman *et al.*, 2018).

## 2. Materials and Methods

This research work employs the use of electrical resistivity method (vertical electrical sounding using schlumberger electrode configuration) due to the recognition that it received by expert and leading researchers as an effective, quick and economic means of obtaining details about the location, depth or thickness and apparent resistivity of the subsurface formation. Determination of the subsurface geologic characteristics of the investigated area was determine using apparent resistivity of the subsurface geologic material. In this research work, five (5) VES stations were used and taken at different locations within the study area using Schlumberger array configuration.

Current electrode was used to pass currents into the ground and the resultant resistance were obtained through pair of potential electrodes which was subsequently recorded on the resistivity recording sheets. An iron rod is driven into the ground within the chosen stations which marks the base station used as a mid-point from where  $MN/2 \cdot AB/2$  (potential electrode). Then, spacing are measured in both direction using the marked mid-point and measuring tape. The depth range increases by changing the spacing between potential electrodes at which current penetrates, the apparent resistivity is then plotted against the corresponding half electrode spacing ( $AB/2$ ) on a bi-log paper. Quantitative and qualitative interpretation was used in for the interpretation of the curve types. The partial curve matching and the iteration using the IP2WIN software are used as qualitative interpretation, while the inspection of the curve types was used as quantitative interpretations. The ABEM SAS 1000 terameter provides the resistance, voltage and the current which are symbolized as  $R, V, I$  respectively. The apparent resistivity was computed when the values are given using the given equation below.

$$\rho_a = k \frac{V}{I} \tag{1}$$

Where  $k$  is the geometric factor of the electrode arrangement in case of schlumberger electrode configuration, which is given by the equation below;

$$k = \pi \left[ \left( \frac{AB}{2} \right) - \left( \frac{MN}{2} \right) \right] \tag{2}$$

Where  $\pi = 3.142$ ;  $AB$  = Current Electrode Separation;  $MN$  = Potential Electrode

### 2.1 Longitudinal conductance (S)

Groundwater potential targets are define using the geoelectric parameter called “Longitudinal conductance (S)”. Relatively thick successions are indicated by having high values of longitudinal conductance, these high values of “S” determines the highest priority in terms of groundwater potential (Olusegun *et al.*, 2016).

$$S = \frac{h}{\rho_a} \tag{3}$$

Where  $S$  is the longitudinal conductance,  $h$  is thickness and  $\rho_a$  is apparent resistivity of the aquiferous layer.

### 2.2 Transverse resistance (R)

$R$  is a parameter that is used to defined a good groundwater potential area that matches the observation/investigation targets. The aquifer and/or aquiferous zones transmissivity values are determined by highest values of transverse resistance ( $R$ ).

$$R = h \cdot \rho_a \tag{4}$$

Where  $R$  is the transverse resistance,  $h$  is thickness and  $\rho_a$  is apparent resistivity of the aquiferous layer

3. Result

Table 1: Results Table for Computer Interpretation of VES Data for Profile 1, 2, 3, 4 & 5

VES Points	Location	Latitude	Longitude	$\rho(\Omega m)$	h(m)	Lc	Tr	Errors	Curve Type
1	Unguwar Kiginawa Opposite Dan Bortso dumpsite	12.24225°	9.91444°	968.9	0.238	0.00245	230.59	2.93	HQA
				968.9	0.357	0.00368	345.88		
				968.8	0.893	0.2442	865.19		
				18.3	4.47	0.0092	81.801		
				2.87	3.62	1.2613	10.389		
2	Unguwar Kiginawa	12.24128°	9.914833°	10.7	1.42	0.1327	15.194	11.7	HQA
				4.1	1.34	0.3268	5.494		
				1.65	1.63	0.9878	2.6895		
				52.8	2.45	0.046	129.36		
				0.109	4.6	133.94	1.5914		
3	Gamabawa	12.23919°	9.915278°	164	0.448	0.0027	73.472	3.54	QKA
				164	0.672	0.0041	110.21		
				26.3	1.25	0.0475	32.875		
				174	1.3	0.0074	226.2		
				4.7	34.7	7.3829	163.09		
4	Gamabawa Beside Dan-Modi Rice Mills	12.23686°	9.916778°	177	1.17	0.00661	207.09	3.64	QKA
				20.1	0.784	0.039	15.785		
				105	2.05	0.0195	215.25		
				105	3.05	0.029	329.25		
				10.9	5.37	0.4926	58.533		
5	Kiginawa Quarters	12.24189°	9.913944°	12.64	0.0715	0.0057	0.9045	13	A
				12.68	6.000	0.0085	1.356		
				12.76	0.1073	0.0212	3.3913		
				12.64	0.2683	0.0531	8.4802		
				25.31	0.6709	0.1795	86.712		

Key: Lc = Longitudinal Conductance, Tr = Transverse Resistance.

Table 2. Showing Aquifer Protective Rating (Olusegun *et al.*, 2016)

Ratings	Remarks
Greater than 10	Excellent
5 to 10	Very Good
0.2 to 4.9	Moderate
0.1 to 0.19	Weak
Less than 0.1	Poor

Below are the models resulting from the computer-based interpretation of sounding data of VES profile 1, 2, 3, 4 and 5.

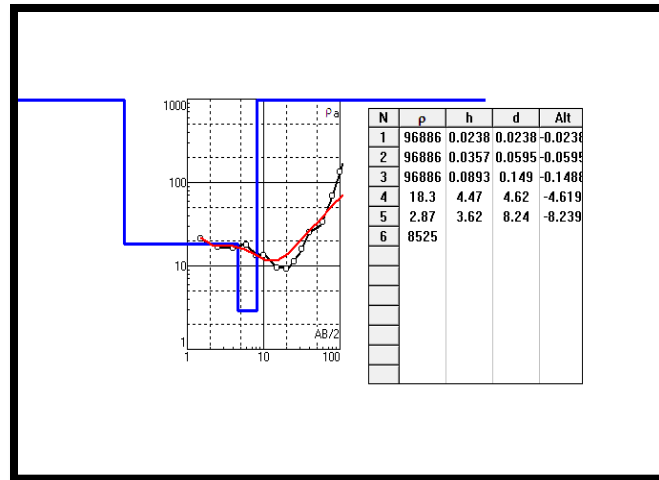


Figure 2: Resistivity Curve for VES 1 (Unguan Kiginawa, Opposite Dan Bortso dumpsite)

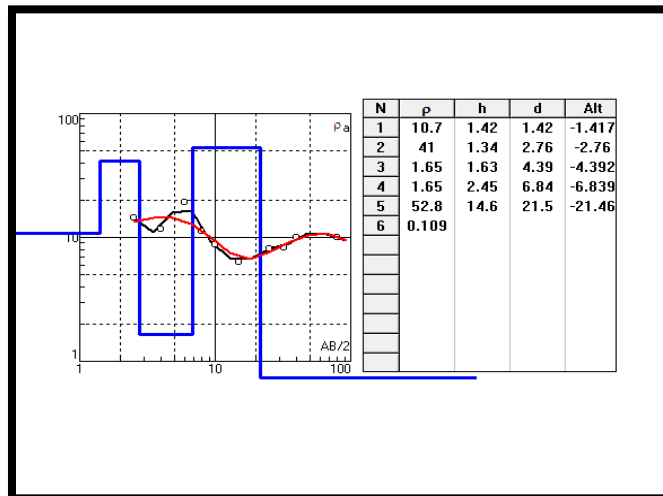


Figure 3: Resistivity Curve for VES 2 (Unguan Kiginawa)

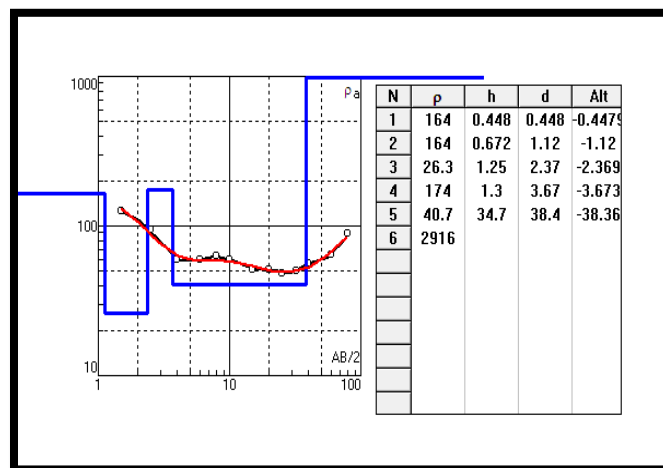


Figure 4: Resistivity Curve for VES 3 (Gambawa)

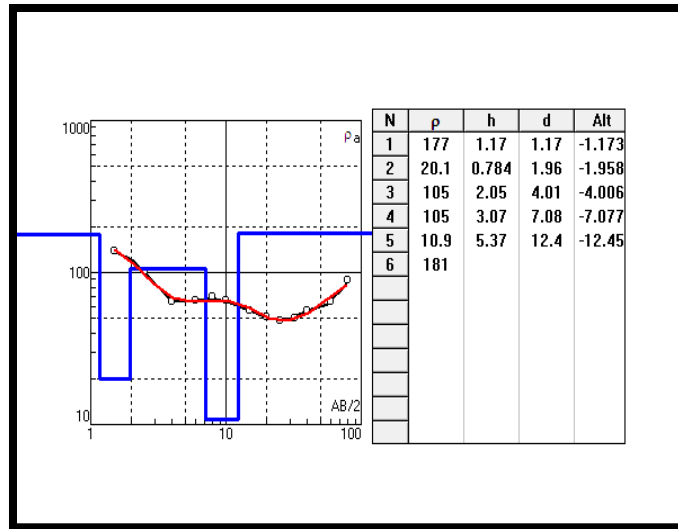


Figure 5: Resistivity Curve for VES 4 (Gambawa besides Dan-Modi rice mill)

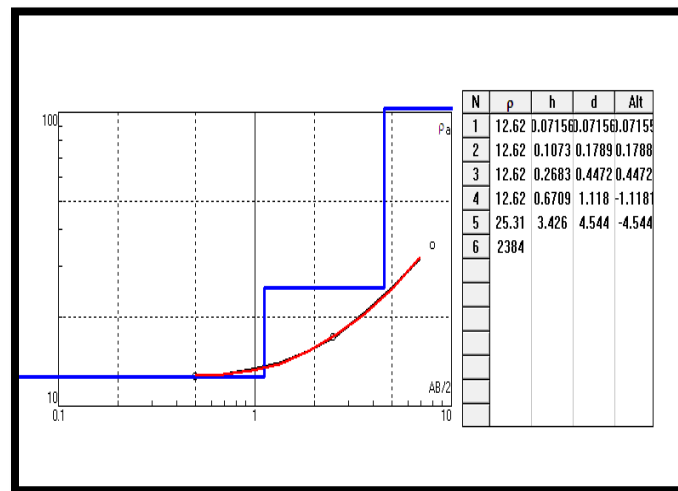


Figure 6: Resistivity Curve for VES 5 (Kiginawa Quarters)

Table 3. Shows the Longitudinal Conductance and Transverse Resistance Aquifer

VES Points	Location	Lc	Tr
1	Unguar Kiginawa Opposite Dan Bortso dumpsite	0.002834	14509.0948
2	Unguar Kiginawa	0.244	847.746
3	Gamabawa	0.0674	1855.045
4	Gamabawa Beside Dan-Modi Rice Mills	0.02977	638.9814
5	Kiginawa Quarters	0.059995	1.8145595

Key: Lc = Longitudinal Conductance, Tr = Transverse Resistance.

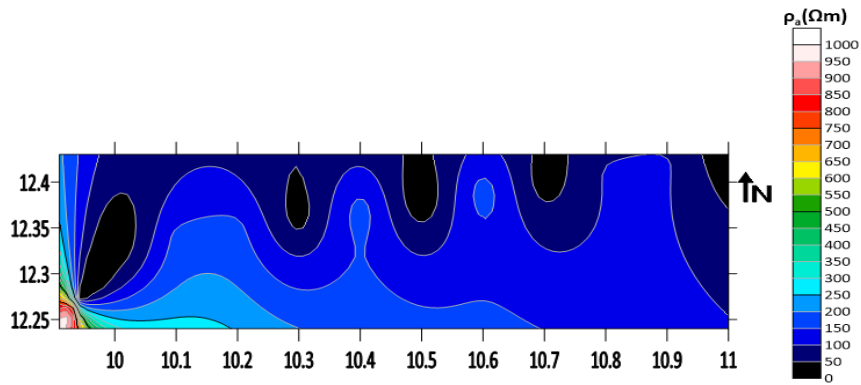


Figure 7: Color Shaded Resistivity map of the study area

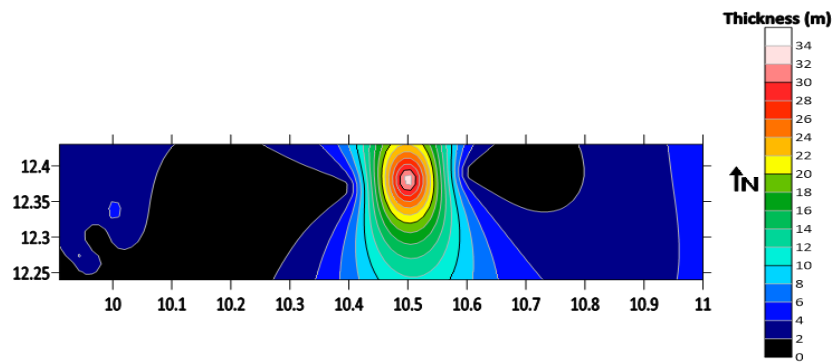


Figure 8: Color shaded depth map for the study area

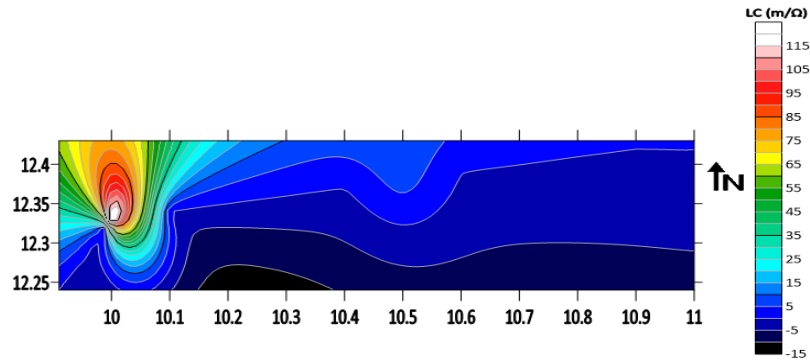


Figure 9: Color shaded Longitudinal Conductance map of the study area

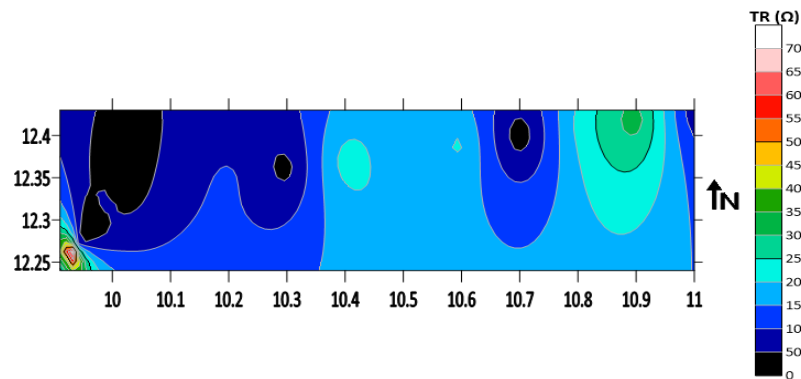


Figure 10: Color shaded Transverse resistance map of the study area.

## 4. Discussion

### 4.1 Interpretation of Vertical Electrical Sounding (VES) and Curves types in the study area

The analyses of the VES survey data were performed using the computer software IP2 win. The summary of the resistivity and thicknesses of the geo-electric/lithological layers within the subsurface are presented in table 1. Table 2 shows the aquifer protective capacity as modified by Olusegun *et al.* (2016) while shows the longitudinal conductance and transverse resistance aquifer are presented in table 3. The iterative curves generated for the apparent resistivity data using IP2 win software are presented in Figure 2 – 6 for VES carried out in the study area. The curves obtained for the electrical resistivity survey are HQA, HQA, QKA, QKA and A indicating the presence five layers in the study area whereas as the color shaded 2D surface map are presented in Figure 7 – 10 respectively.

Resistivity curves obtained in the study area were classified into four distinct classes. Increase in the resistivity values from the top soil to the basement rocks are classified as class 1 type curve representing the subsurface layers' conditions, example is the **A-type** curve. Class 2 curve types are usually clayey and of low resistivity values especially when the upper horizons are not leached. Example of class 2 is the **H-type** curve which is characterized with high porosity, low resistivity, low specific yield and low permeability aquiferous zone and thus, is characterized as fresh basement. This classic architecture of the profile was found to be the most predominant in the study area. Class 3 curve types, are typically a succession of relatively low and high resistivity layers. The **K-type** curve is a curve with highly resistive lateritic layer which underlies low resistivity clayey top soil and weathered zone in turn underlies the former (Obiora *et al.*, 2015). Class 4 curve is the succession of the subsurface layers which starts with highly resistive top soil followed by more conductive horizon and then another less conductive layer underlies the later, example is the **HKH-type** curve.

### 4.2 VES Resistivity Curve Interpretation

Figure 2 shows that VES 1 is HQA curve. The curve revealed five resistivity layers for VES 1. The first layer which is the top soil has resistivity value of 968.86  $\Omega\text{m}$  with thickness 0.238 m. This layer is interpreted as basement complex (Idris *et al.*, 2018) with a moderate protective capacity (Olusegun *et al.*, 2016). And according to Obiora *et al.* (2015) the layer is characterized as a layer of low groundwater potential with a depth value of <10.

Figure 3 shows that VES 2 is also HQA curve. The curve shown the five resistivity layers for VES 2. The first layer has a resistivity of 10.7  $\Omega\text{m}$  with a thickness of 1.42 and the longitudinal and transverse resistance of 0.1329 and 15.194 respectively. Thus, according to (Idris *et al.*, 2018) the layer is classified to be clayed sand and with a poor protective capacity (Olusegun *et al.*, 2016). And according to Obiora *et al.* (2015) the layer is characterized as a layer of low groundwater potential with a depth value <10.

Figure 4 shows that VES 3 is a QKA curve. The curve publicized the five resistivity layers for VES 3. The fifth layer has a resistivity of 4.7 and a thickness of 34.7 with a longitudinal and transverse resistance value of 7.3829 and 163.09 respectively. Therefore, according to (Idris *et al.*, 2018) the layer is characterized to be a clayed sand and with an excellent protective capacity (Olusegun *et al.*, 2016). The layer is characterized as a layer of high groundwater potential with a depth value of >25.

Figure 5 shows that VES 4 is also a QKA curve. The curve exposed the five resistivity layers for VES 4. The third layer has a resistivity of 105 and a thickness of 2.05 with a longitudinal and transverse resistance value of 0.0195 and 215.25 respectively. Therefore, according to (Idris *et al.*, 2018) the layer can be considered to be a medium sand with a coarse sand and with a week protective capacity (Olusegun *et al.*, 2016). The layer is characterized as a layer of low groundwater potential with a depth value < 10.

Figure 6 shows that VES 5 is an A curve. The second layer has a resistivity of 12.64 and a thickness of 0.1073 with a longitudinal and transverse resistance value of 0.008483 and 1.356272 respectively. Hence, according to (Idris *et al.*, 2019) the layer is regarded as clayed sand and with a moderate protective capacity (Olusegun *et al.*, 2016). The layer is characterized as a layer of low groundwater potential with a depth value < 10.



Most of the result obtain agrees fairly well with the previous work (Idris *et al.*, 2019; Suleiman *et al.*, 2018) conducted within the vicinities of the study area.

#### 4.3 Resultant Longitudinal conductance (Lc) and Transverse resistance (Tr) interpretation

Table 3 shows the resultant longitudinal and transverse resistance for the five respective VES points. However, VES 1, 3, 4, and 5 corresponding to “Unguwar Kiginawa Opposite Dan Bortso dumpsite, Unguwar Gambawa, Unguwar Gambawa besides Dan-Modi rice mill, and Unguwar Kiginawa” respectively, were all found to have poor aquifer protective capacity with a longitudinal value less than 0.1 ( $L_c < 0.1$ ) based on the recommendation of Idris *et al.* (2019) and Olusegun *et al.* (2016). Whereas, VES 2 corresponding to “Kiginawa Quarters” is characterized as the area of moderate protective capacity. The result obtained agree fairly with the work of Idris *et al.* (2019) and that of Suleiman *et al.* (2018).

#### 4.4 Interpretation of 2D surface maps of the study area

The color shaded map of the resistivity  $\rho(\Omega m)$  values for the study area is represented in Figure 7 Portions on the map that were shaded pink and red represent areas of high electrical resistivity whereas those portions in blue and black corresponds to areas of low electrical resistivity values. In between these are intermediate colors of yellow and green representing areas of intermediate resistivity intensities. Generally, the resistivity map (Figure 7) of the study area showed varying resistivity values ranging from 968.9 to 0.109  $\Omega m$ . high resistivity values (968.9 – 177  $\Omega m$ ) are predominantly observed in extreme south-western (SW) corner of the study area, low resistivity values (0.109 – 4.70  $\Omega m$ ) are predominantly observed in the north-east (NE), north-west (NW) and south-western (SW) part of the study area while areas with intermediate resistivity values are observed predominantly extreme south-western corner of the study area.

The color shaded depth map of the study area is represented in Figure 8. Portions on the map that were shaded pink and red represent areas of high thickness whereas those portions in blue and black corresponds to areas of low thickness (thin) values. In between these are intermediate colors of yellow and green representing areas of intermediate thickness. The depths values within the study area showed varying depth ranging from 0.1073 – 34.70 m. The thickness map (Figure 8) displays an increase in positive thickness values (34.70 – 24.5 m) towards the central parts, and decreases towards eastern and western parts of the study area. However, areas of low thickness occurrences (0.1073 – 1.63 m) occupied north-west (NW), north-east (NE), south-west (SW), and south-eastern (SE) parts of the study area. High thickness values increase towards the north-west (NW), north-east (NE), and south-eastern (SE) parts of the study area.

The color shaded Longitudinal Conductance (Lc) and Transverse resistance (Tr) maps of the study area are represented in (Figure 9 and 10) respectively. Portions on the maps that were shaded pink and red represent areas of high longitudinal conductance and transverse resistance whereas those portions in blue and black corresponds to areas of low longitudinal conductance and transverse resistance values. In between these are intermediate colors of yellow and green representing areas of intermediate longitudinal conductance and transverse resistance values. Areas with high Lc values are predominantly in the North-Western (NW) parts of the study area, areas with low Lc values are predominantly within the South-West (SW) and South-Eastern (SE) parts. Areas with intermediate Lc are predominantly observed within the South-West (SW) and North-Western parts of the study area. It could be said that Lc decreases towards the South-west (SW) and South-Eastern (SE) parts. Conversely, the Lc increase towards the NW and SW parts of the study area. Areas with high Tr values are predominantly observed within the extreme corner of the South-Western (SW) part of the study area, areas with intermediate Tr are predominantly observed within the central parts and North-Eastern (NE) parts of the study area. Areas with low Tr values are predominantly observed within North-West (NW), South-West (SW) and North-Central (NC) parts of the study areas. It could be said that the Tr increases towards the SW part and decreases towards the NW parts of the study area. It could be observed that there exists an inverse relationship between Lc and Tr, dominant areas of high Lc values correspond to areas of low Tr values and vice versa.

## 5. Conclusion

The study has shown that the area is underlined by five (5) geo-electric layers within the depth penetrated. The research has enabled the determination of the depth to aquifer, aquifer thickness, and sub-surfaces geology of the study area thus revealing its aquifer distribution. Areas of low clay content with resistivity values greater than 100 W/m and high values of overburden thickness greater than 25 m were considered as zones with high ground water potential, whereas areas with low overburden thickness values ranging from 10 – 25 m were classified as zones with medium groundwater potentials while areas with less than 10 m over burden thickness values were classified as zones of low groundwater potential. The quality assessment criteria of aquifer protective capacity are based on the values of the longitudinal unit conductance of the overburden rock units in the area. The geophysical subsurface layers with longitudinal unit conductance values greater than 0.7 ohms were classified as zones of good aquifer protective capacity whereas portions with conductance value ranging between 0.2 and 0.69 ohms were classified as zones of moderately protective capacity while zones with conductance values ranging from 0.1 and 0.19 ohms were classified as zones of weak protective capacity and where it is less than 0.1 mhos is considered as poor aquifer protective capacity (Obiora *et al.*, 2015).

## 6. Recommendation

Reliable borehole for good portable water should be sited in VES 2, boreholes of moderate quality should be sited in VES 3 and 4 locations. It is also recommended that most of VES site were not of good protective capacity and thus, a measure should be taken while siting and drilling the boreholes. A preliminary and more advanced geophysical survey using at least two methods and more sophisticated instrument are therefore recommended. For example, resistivity method with spontaneous polarization methods should be carried out within these areas for a better and wide-reaching result.

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