Electrical Resistivity Mapping of Aquiferous Zones Within Gudi-takalau Area of Birnin Kebbi, Nigeria

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Abstract

Domestic water supply in Birnin Kebbi metropolis, Kebbi State of Nigeria comes majorly from groundwater. Birnin Kebbi is underlain by the sedimentary rock of Gwandu formation Northwestern, Nigeria. The zone constitutes the easternmost segment of the extensive Sokoto basin. A two-electrode (D.C) electrical resistivity survey was carried out at Gudi-Takalau area of Birnin Kebbi metropolis, Nigeria with the aim of determining the aquiferous zones within the Gudi-Takalau for future borehole drilling. Data obtained from the eleven Vertical Electrical Sounding (VES) station sounded were interpreted using the IPI2win resistivity and surfer V.12 software. An interpretation model was designed by sounding at a borehole site of known lithology log. The interpreted result suggested the existence of two major random geoelectric sections consisting of three to four subsurface layers: the top soil clay (the alluvium cover) with a resistivity range of 20Ωm to 450Ωm and thicknesses range of 3.5m to 10.5m, overlaying the weathered sandstone with a resistivity range of 450Ωm to 3000Ωm at a depth range of 3.5m to 20.4m. Other Sub-layers were identified as weathered, fractured and fresh zones and were also detected and interpreted as aquifers. Finally, regions of high groundwater potentials were identified as VES 04, 01, 09 and 08. A borehole of depth 3.4m to 38.5m is recommended.

***Keywords**: Mapping, Geoelectric Layers, Two-Electrode Resistivity Survey, Fractured and Aquifer.*

Introduction

Domestic water supply in Birnin Kebbi metropolis, Northwestern Geopolitical Zone of Nigeria comes majorly from groundwater. Birnin Kebbi is underlain by the sedimentary rock of Gwandu formation Northwestern, Nigeria. The zone constitutes the easternmost segment of the extensive Sokoto basin. Studies have shown that sedimentary basin generally contain enormous quantities of water (Alabi *et al.,* 2010; Aweto, 2011; Edet & Okereke, 2002; Omosuyi *et al.,* 2008). To realize this fact, several countries worldwide have engaged in extensive studies of basins within their frontiers, using geological/hydrogeological, geophysical, or chemical data, or a combination of the above, for proper identification and delineation of the water bearing units.

Some studies highlight the need for optimization and proper management of the basins in order to enhance safe discharge and appropriately safeguarding the quality status of the water. (Leit & Barker, 1978; Van Overmeeren 1989; El-Waheidi *et al.,* 1992; Keller & Frischknect, 1966; Ebraheem *et al.,* 1997; Choudhury *et al.,* 2001; Edet & Okereke, 2002; Lashkaripour, 2003), however, any rational development groundwater requires geophysical data input, among others. Aquifers in sedimentary terrains often occur at shallow depth, thus exposing the water to environmental risk, that is, vulnerable to surface or near-surface contaminants. Studies reveals that the people around Birnin Kebbi abstracts water from the unconsolidated materials overlying the bedrock through uncontrolled sinking of borehole, with glaring lack of concern for aquifer vulnerability to near-surface contaminants and quality status of the groundwater.

The electrical resistivity method is useful in this regards, it's an efficient and economical method for determining the presence of groundwater (Anomohanran, 2013). Geophysicist has also used it to determine the thickness of bedrock, clay aquitards, saltwater intrusion, the vertical extent of certain types of soil and the spread of groundwater contamination (Majumdar, 2011). The method can be used in a wide range of geophysical investigation, such as exploration for minerals, engineering investigation, geothermal studies, archeological surveys and geological mapping (Sirhan *et al.,* 2011).The method has been used extensively in Nigeria and other parts of the world to investigate the subsurface. Vertical Electrical Sounding

(VES) is commonly used in electrical resistivity surveys to determine the vertical variation between electrical resistivity below the Earth's surface and potential field generated by the current (Telford *et al.,* 1979).

The techniques involves inducing an electric current into the ground by means of two implanted electrodes and measuring the difference in potential between two other electrons referred to as the potential electrodes. The electric current used is the direct current provided by a dry cell. Therefore, analysis and interpretation of geoelectric data are on the basis on direct current (D.C) provided by dry cell. The resistivity computed from the measurement an induced current and potential difference is referred to as “apparent resistivity”. This measurement is based on the assumption that the ground is uniform.

However, in reality, the resistivity of the earth is determined by the inhomogeneties lithology and geological structures. Therefore, a graph of apparent resistivity against current electron spacing is used to determine the vertical variation in formation resistivity (Anomohanran, 2013). These properties affect the ability of an aquifer to store and transmit groundwater (Anomohanran, 2013; Tizro *et al.,* 2014). In order to guarantee good quality and sustainable groundwater, it is important to map aquiferous zones determined from the resistivity mapping within Gudi-Takalau area.

Hydrology and Hydrogeology of the Area

The water supply scheme of Gudi-Takalau is from the groundwater. A part from this groundwater there is no adequate surface water from the Duku-Tarasa Dam site available in the town during dry season except in the other rural areas, so mapping the aquiferous zones in some selected area of Gudi-Takalau therefore, remains an important to source the water in the area. However, high permeability can be encountered within the fractured and jointed units of the rock sedimentary terrain.

The River Sokoto – River Rima System is the principal drainage network of the Kebbi State. The headwaters of the river Kebbi and Rima and their tributaries rise in pre-cretaceous crystalline rock terrain east of the Kebbi and flow west and south across a terrene underlain by sedimentary rocks of the Sagaldu, Indian water and Mashaya groups and the Tabkin Bature (Kebbi State Ministry of Environment & Solid Minerals).

The rivers Gagare, Maidiyaru, Wuyan Rai-Rai, Mashaya Gado, Gulka and Gayan Gulbinka are principle tributaries to the Kebbi, above its confluence with the river Chad. West of the Fadama of the river Kebbi, on the outcrop of the Dukku, surface drainage is largely ephemeral and poorly integrated.

Rainfall in this area percolates directly into the soil or flows in short streams to small closed basins where it infiltrates or evaporates. Streams discharge has been measured on a daily basis at a number of points on the Kebbi system. The hydrogeology, the Kebbi State, which constitutes the Nigerian sector of the Iullemeden sedimentary basins centered in Chad, is underlain by a sequence of interbedded with semi-consolidated gravel, sand, clay and some limestone. This sequence attains gross thickness of some 35m and ranges from cretaceous to quaternary in age.

Oldest rocks of the sedimentary sequence are terrestrial deposits of the Sagaldu and Indian water. The depositional environment change once again to terrestrial condition and beds of sand and massive clay was laid down constituting the Sagaldu and Indian water. Generally, the cretaceous and tertiary formation in the Kebbi State strike in a north eastern direction and dip about 20 m per mile to the northwest. These rivers also generally thicken down dip, but southward along the outcrop all become thinner and the Sagaldu groups pinch out completely.

Underlying the Fadama of Kebbi and its large tributaries are thin unconsolidated deposits of Alluvial sand, silt, and gravel of quaternary age. Groundwater in the study is found, both confined as artesian water or unconfined just beneath the water table, in most of the permeable members of the cretaceous – tertiary sedimentary sequence. Confined water occurs down dip and at depth in semi – consolidated sand or gravel of at least three important aquifers the water table condition occur in the outcrop area of all three aquifers. A local but important perched ground – water body is present in limestone of the outcrop area of the Dukku. Unconfined groundwater also occurs in the quaternary alluvial fill of the Fadamas of the river Kebbi and its large tributaries.

Geology of the Area

Birnin Kebbi is part of the Sokoto Basin of the Nigeria sector of the larger Iullemeden Basin; the Iullumeden Basin itself is a broader sedimentary basin covering most part of Algeria, Niger Republic, Benin

Republic, Mali, and Libya. The geology of Kebbi State is dominated by two formations Precambrian Basement complex in the South to southeast and young sedimentary rocks in the North. The basement complex region is composed of very old volcanic and metamorphic rocks such as granites, schist, gneisses, and quartzite consist of Gwandu, Illo and Rima group whose ages range from cretaceous to the Eocene (Fig. 1). The Gwandu group consists of massive of clay interbeded with sandstone while Illo and Rima group consist of Pebbly grits, sandstones and clays, mudstones and siltstones respectively mineral that can be found in the state include quarts, Kaolin, photolytic bauxite, clay, potassium, silica sand, and salt (Kogbe, 1979, 1981; Obaje *et al.,* 2013).

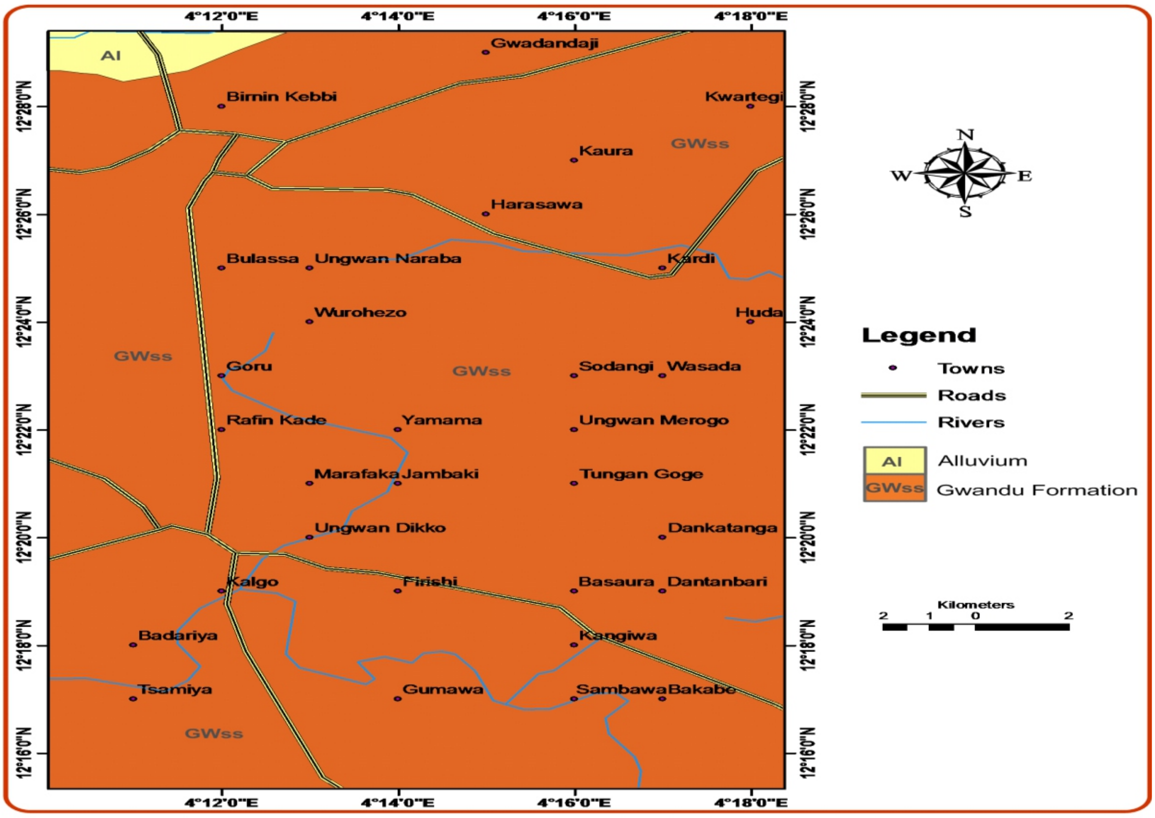


Fig.1: Geological Map of the Study Area Modified after Obaje *et al.,* (2013)

Materials and Method

The study was carried out in Gudi-Takalau Area of Birnin Kebbi, Nigeria, at latitude 4^0 $382'$ and 4^0 $031'$ N and longitude 12^0 $545'$ and 12^0 067' E with an average elevation of 369m above mean sea level (Fig. 2). The area is central to most major towns and communities in the district and experiences less of most water challenges. Eleven Vertical Electrical Sounding (VES) were conducted of the Schlumberger configuration for depth probing with a maximum current electrode separation of 50 m at random (Fig. 3). This technique was used because it is considered most appropriate in a sedimentary basin (Alabi *et al.,* 2010) and is simpler and more economical than other geophysical methods. ABEM Geosoft SAS 300 Terrameter was used to obtain the apparent resistivity at each VES point. The data were first interpreted by the conventional partial curve matching technique with two-layer master curves in conjunction with an auxiliary point diagram. This gave an estimate of the layer resistivity and thickness, which were used as input data for computer-assisted interpretation with IPI2win software to obtain the true resistivity and thickness of the various layers.

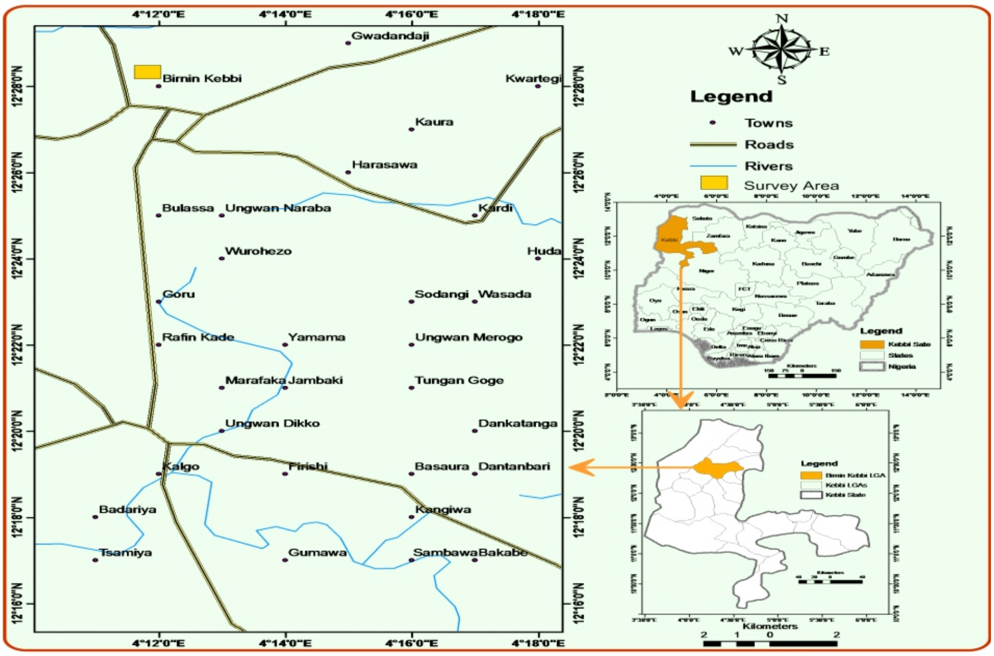


Fig.2: Location Map of the Study Area (Adopted from Google Earth Map, 2018)

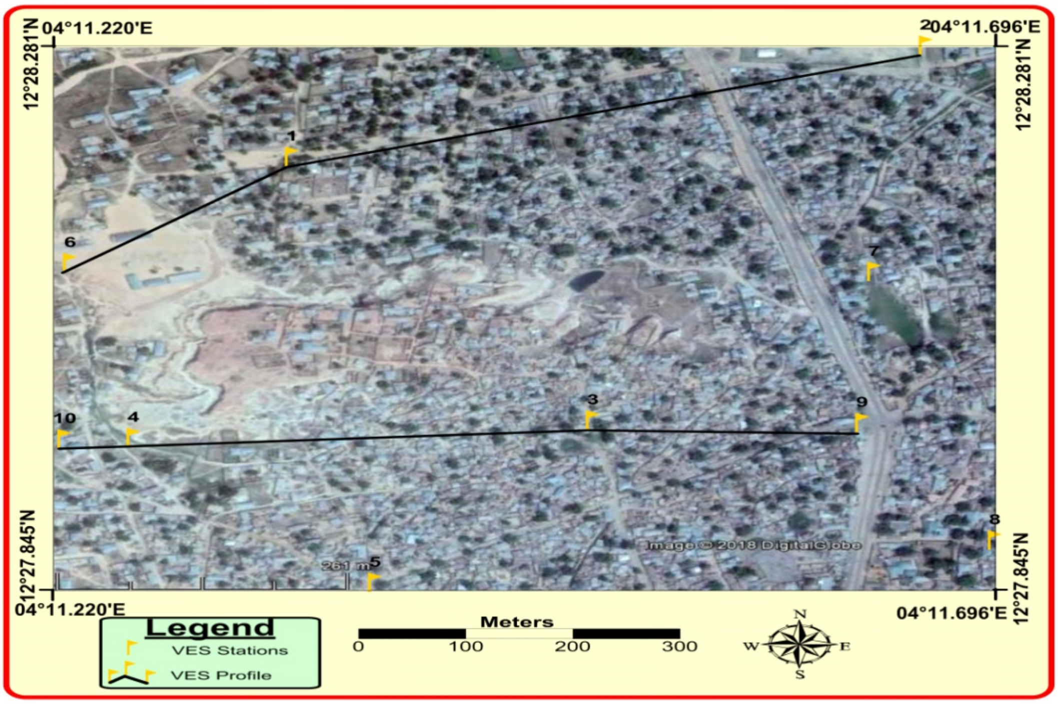


Fig. 3: Established VES Stations on Google Earth Map within the Study Area

Methodology

Symmetrical Schlumberger Electrodes Configuration

In this array, the current electrodes are spaced much further apart than the potential electrodes. The electric field is measured approximately. The two- electrode D.C. resistivity method popularly known as schlumberger Vertical Electrical Sounding method is used for this work. The method is based on the elementary principle of Ohm's law which states that the current that passed through a metallic conductor is directly proportional to the potential difference provided temperature and other physical parameters are kept constant, as applied to the measurement of resistance and hence resistivity of an ohmic conductor of a given length and cross sectional area. The theory can be found in (Telford *et al.,* 1979). The apparent resistivity of the theoretical earth model is given as:

$$\rho_a = \pi\left(\frac{l^2}{2b} - \frac{b}{2}\right)\frac{\Delta V}{I} \quad \text{............ (1)}$$

Where l is the distance of the current electrode from the Sounding, point and b is the potential electrode distance from the sounding point. sounding, the potential electrodes are fixed while the current electrode separation is increased symmetrically about the Centre of the spread, Schlumberger soundings are carried out under the constraint potential electrode spacing (MN) is small compared to the current electrode spacing (AB) i.e MN < AB/2 (Fig. 4).

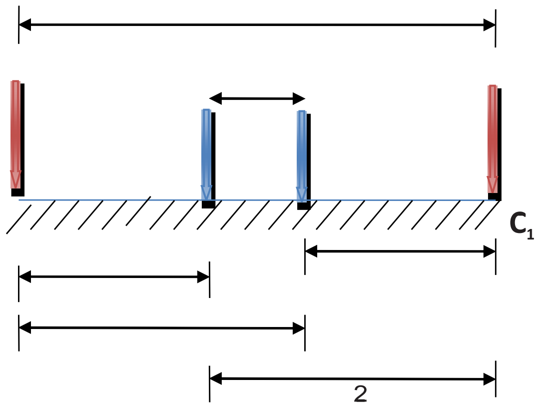


Fig. 4: The Schlumberger Array

Where A and B are current electrodes while M and N are potential electrodes.

Field Equipment

The materials used for this survey consist of the Geopulse Terrameter SAS 300, four steel electrodes, field hammers, measuring tape and reels of wire. The Geopulse Terrameter SAS 300 measures the resistance and displays on its screen board depending on its magnitude, it may be in kilo ohms, ohm or milliohms. The Geopulse Terrameter SAS 300 contains three basic sub-units; a microprocessor for monitoring, control and computation; an electrically isolated transmitter for the supply of defined regulated signal current. It can operate at frequency as low as 4 cycles per second; this property makes it suitable for greater depth of investigation. It is portable. It carries out signal averaging by taking consecutive readings automatically and displaying the average result. This makes it possible for the Terrameter to extract the signal from any of noise. See plate I, II, III, IV, V & VI on Appendices III.

Field Procedures and Data Collection

There are two procedures for carrying out the resistivity field survey depending on whether one is interested in resistivity variations with depth or with lateral extent, and these are the vertical electric sounding and the horizontal electrical profiling. So for this research the VES was carried out to investigate the variations with depth in order to map the aquiferous zones within the Gudi-Takalau area of Birnin Kebbi.

Vertical Electrical Sounding Data Collection

A total of 11 Vertical Electrical Soundings (VES) were taken at random on the surface of the area within the Gudi-Takalau community area of Birnin Kebbi (Fig. 3). A maximum current electrode spacing (AB) of

200m was used with the aim of probing a depth of at least ¼ of AB (Gholam and Nad, 2005). In this method, a fixed point called the VES station was marked and noted. Two current electrodes C_1 and C_2 of equal distance on the opposite sides of the VES station were measured and driven into the ground with the aid of sledge hammer for proper contact to be made with the ground. Similarly, two other electrodes called the potential electrodes P_1 and P_2 of equal distance from the sounding point and between the current electrodes were measured and driven into the ground with the aid of the sledge hammer for proper contact to be made also with the ground. The arrangements of the current and potential electrodes were in such a way as to maintain a straight line.

Results and Discussion

Results

Available geological controls such as borehole data (Fig. 5.), hand dug wells, exposed sections of the rock formations and resistivity values of earth materials compiled are used in order to have a meaningful interpretation (Saleko, 2013). Assumption has been made in the interpretation of Vertical Electrical Sounding (VES) data that: (a) the various geoelectric layers encountered are electrically homogeneous and isotropic. However, because of the existence of lateral variation in resistivity within a layer, possibility of error in interpretation is present, (b) the principle of equivalence that is, non unique solution for a number of types of a typical three layer curve which are only distinguished by the resistivity value of their second layer in a relation to the value of either the first or third layer. Typical examples are type A ($\rho_1 < \rho_2 < \rho_3$) and type H ($\rho_1 > \rho_2 < \rho_3$) curves.

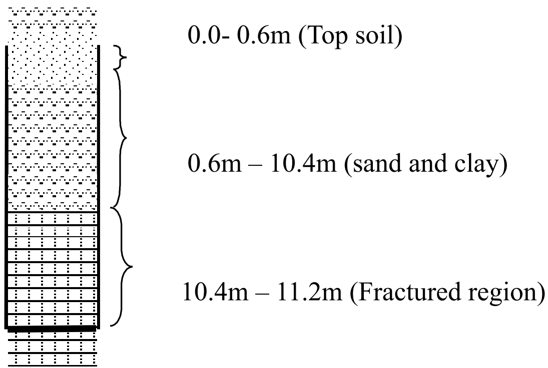


Fig. 5: Borehole Log Data Drilled Near the Study Area, (After Saleko Nig. Ltd., 2013)

Determination of Resistivity Values

A method developed by the first author (Zohdy, 1965) known as Schlumberger Vertical Electrical Sounding method was used to complete the resistivity of each geoelectric layer. This method involves "stripping" the effect of the overlaying layer in order to determine the resistivity of the layer of interest. The principle behind the method is that if the layer concerned were of the same material (same resistivity value) as that above it, the log-log plot would be a continuation of the segment representing the layer above it (Salami, 2002).

Interpretation Model

The sounding at the side of an existing borehole is aimed at developing an interpretation model for the work. Fig. 5 above is the lithological log, of the borehole from a drilling firm. It can be observed that the earth surface within the borehole site consists of three major geologic layers, the topsoil (0.0-0.6m), the sand and clay (0.6m-10.4m) and fractured region (10.4m-11.2m). This result is in close agreement with the resistivity log obtained by curve matching techniques (Fig. 6a). Thus, the two geoelectric sections correspond to the major geologic layers on the log which are the topsoil, sand and clay as well as weathered-fractured region of varying grain sizes with little intercalations of shale/clayey sand.

A close look at Table 1 and Fig. 6 suggest that there are local deviations with depth within the line BC. This is an indication of the variation in resistivity within the sandstone unit. Local variation in resistivity within the sandstone was separated from the observed resistivity variation deviation existing within the zone BC. Positive variation suggest the existence of material of resistivity higher than the average resistivity of the main sandstone while negative deviation suggest that the resistivity of the material is lower than the average resistivity of the sandstone. The deviations were plotted with the borehole log at the depth were they occur in order to see what type of lithology the resistivity represents (Fig. 6).

Resistivity of various subsurface layers within and the magnitude of the resistivity values obtained from the interpreted VES data compared with the lithology log obtained at the borehole site as a standard. The geoelectric sections were derived for the random sampling point profiles VES points 01, 02, 04 e.t.c. shown in (Fig. 7 and 8) based on the interpretation of the semi log plot which indicates two major geoelectric layers down to the maximum depth of investigation. The geoelectric of the sandstone unit for all the 11 random sounded stations were similarly obtained.

Table 1: Data of VES POINT 01, 12^0 28' 19.2" N, 4^0 11' 34.1" E

AB/2 (m)	MN/2 (m)	K-FACTOR (m)	RES (ohms)	APP RES (ohm-m)
1	0.5	2.4	26.8	64.9096
1.5	0.5	6.0	13.24	79.44
2	0.5	12.0	7.88	94.56
3	0.5	27.0	4.01	108.27
5	0.5	78	1.79	139.62
5	1	38	4.03	153.14
7	1	75	2.20	165.00
10	1	156	1.02	159.12
10	3	48	2.84	136.32
15	3	113	0.907	102.491
20	3	205	0.843	170.815
25	3	320	0.56	180.88
30	3	67	0.45	210.15
30	10	126	0.145	144.27
35	10	177	0.99	175.23
40	10	236	0.86	202.96
50	10	377	0.36	135.72

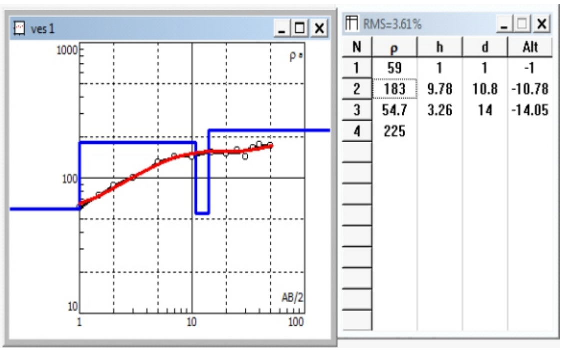


Fig. 6a: The Graph of VES Point 01

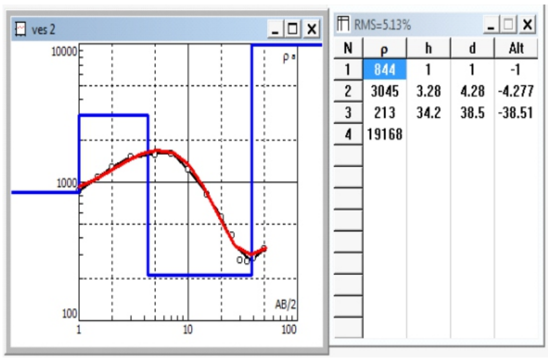
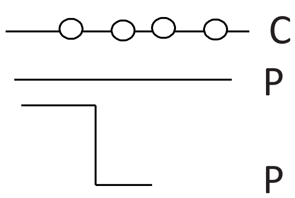


Fig. 6b: The Graph of VES Point 02



ρ – Layer resistivity in Ohm-metre

h – Layer thickness in metres

d – Depth to interface in metres

N – Layer number

Fig. 6: Example of Resistivity Sounding Curve Types Obtained from the Study Area and their Model Interpretation

Geoelectric Sections within the Study Area

Geoelectric Section along VES 03, 04, 09 & 10

Figure 7 shows the geoelectric section along VES 03, 04, 09 & 10. Four lithological layers are distinguished. The top soil has resistivity ranging from 30 - 850 ohm-m and an average thickness of 2.4 m. this layer consists of laterite, clay and silt. Underlying the above layer is a formation where the resistivity is between 100 – 1000 ohm-m and average thickness of 15.2 m. this is likely the weathered region. The third layer has resistivity range of 536 – 1256 ohm-m and thickness varying from 15.2 to 28 m; this layer is presumably the fractured region. The last layer of infinite thickness has resistivity greater than 500 ohm-m. This is probably the fresh zone.

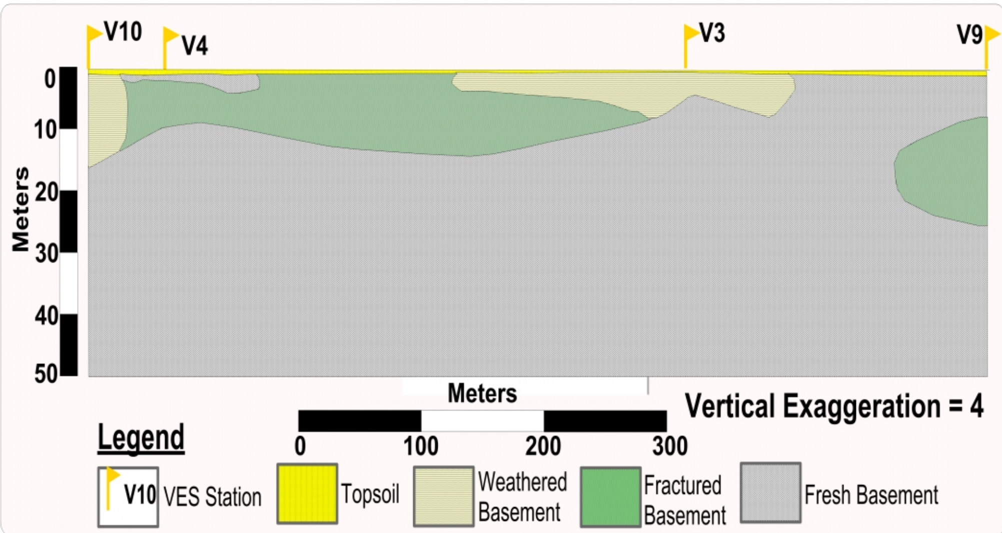


Fig. 7b: Geoelectric Section along VES 03, 04, 09 & 10

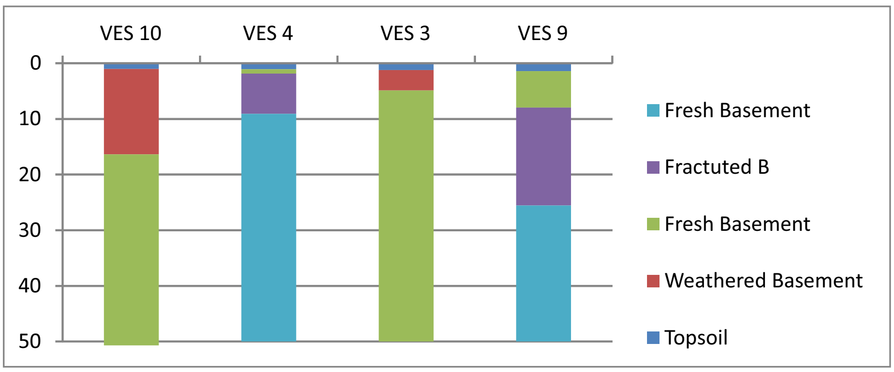


Fig. 7c: Histogram Plot Analysis of VES 03, 04, 09 & 10

Geoelectric Section along VES 01, 02 & 06

Geoelectric section along VES 01, 02 & 06 has three subsurface layers (Fig. 8). The top soil layer has value ranging from 90 – 450 ohm-m and average thickness of 1.8 m. the presence of lateritic around VES 01 may be responsible for the low resistivity value. The second layer resistivity varies from 50 – 740 ohm-m and average thickness of 13 – 35 m. the values are low compared to other layers and may be consisting of clay lenses. This layer is presumably the fractured region. The third layer whose resistivity value is greater than 800 ohm-m with infinite thickness is probably the fresh basement.

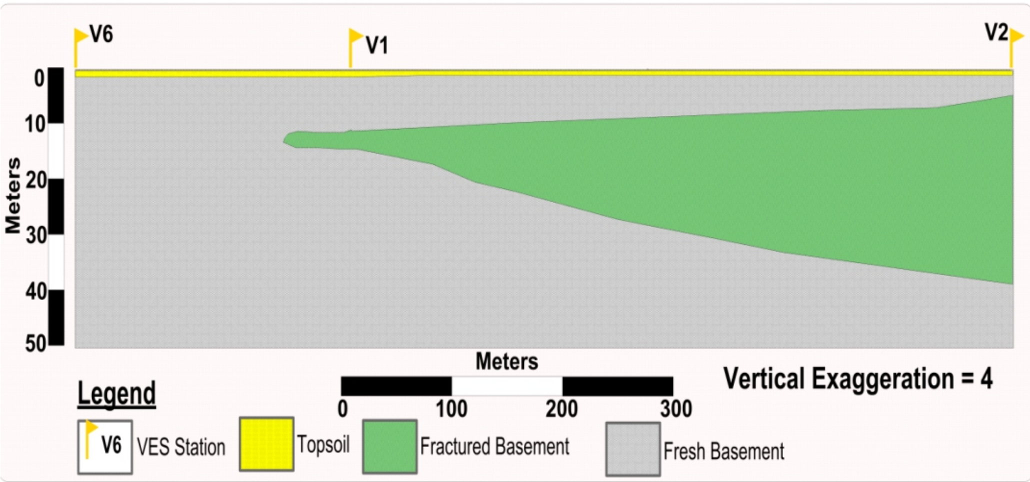


Fig. 8a: Geoelectric Section along VES 01, 02 & 06

Delineation of Aquifer

According to Eduvie (2000), water within the sandstone in the sedimentary terrain occurs at the fractured and jointed units of the medium grained and fine to medium grained sandstone. Thus fractured zones within the sandstone of (fig.7a & 8a) unit are considered as aquiferous zones. According to Chii (2002), fractures are detected on a semi log plot as scattered points. The depth of the fractures is given by the range of AB/2 within the scattered points. Salami (2002) also agreed that the presence of fractures is observed in a semi log plot as scattering of the plotted points at the point at which the fractures occur. Consider the typical interpretation curve for the sounding at the borehole site shown in (Fig.6a & 6b) fractures occur between the depth ranges of 10.4 to 14m and 4.28 to 38.5m.

Iso-Resistivity Contour Map

The map was produced by contouring the resistivity values of the overburden at all the random 11 VES points within the study area. The map and the surface plot are shown in (Fig. 9). A contour interval of 50 m was used for the map. The resistivity values of the top soil vary between 100 – 467 ohm-m. The N-W area has lower resistivity value.

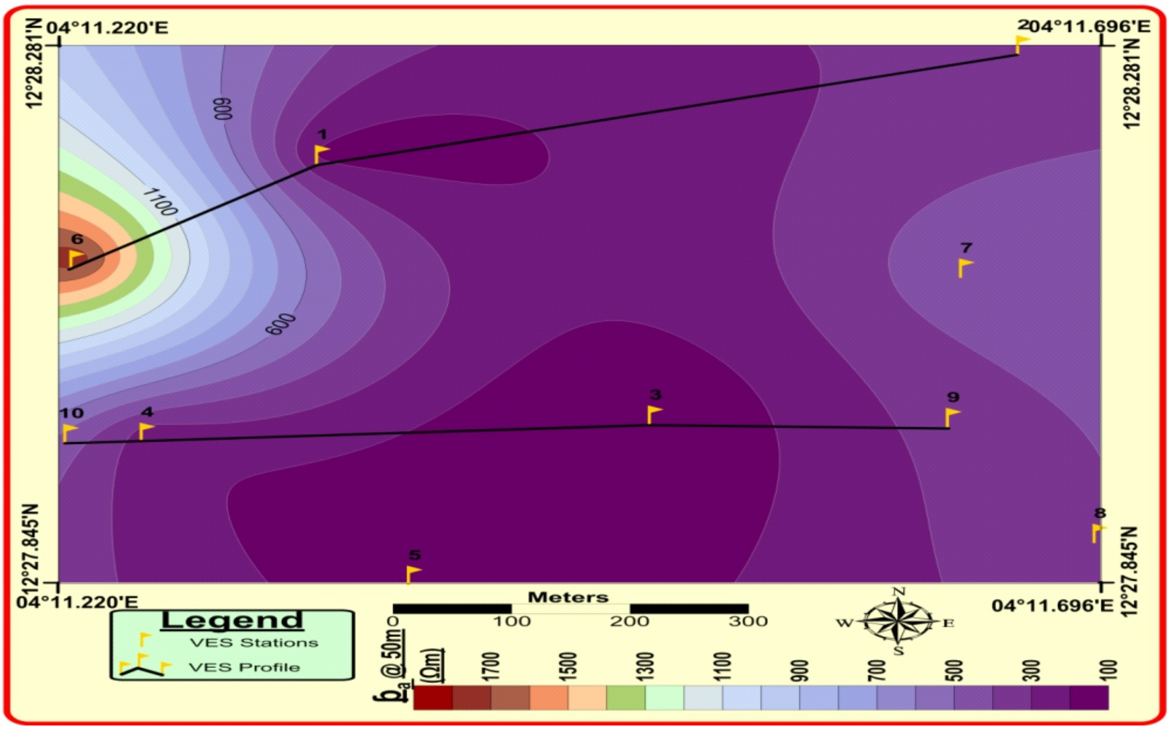


Fig. 9: Iso-resistivity Map of Overburden (Contour interval 50 meters)

Aquifer Thickness Contour Map

In the sedimentary terrain environment the main aquifer system lie within the fractured region, however, other formations such as gravel layer may serve as underground water bearing layer. The aquifer thickness map was produced from the interpreted data of the weathered and fractured layer thickness for all the VES points at an interval of 2m. The map of (Fig. 10) show the variation of aquifer thickness varies from one place to another. The aquifer thickness varies from 1 to 38m. The aquifer thickness maps correlate to Isoresistivity map as the low thickness values correspond to areas of shallow zones.

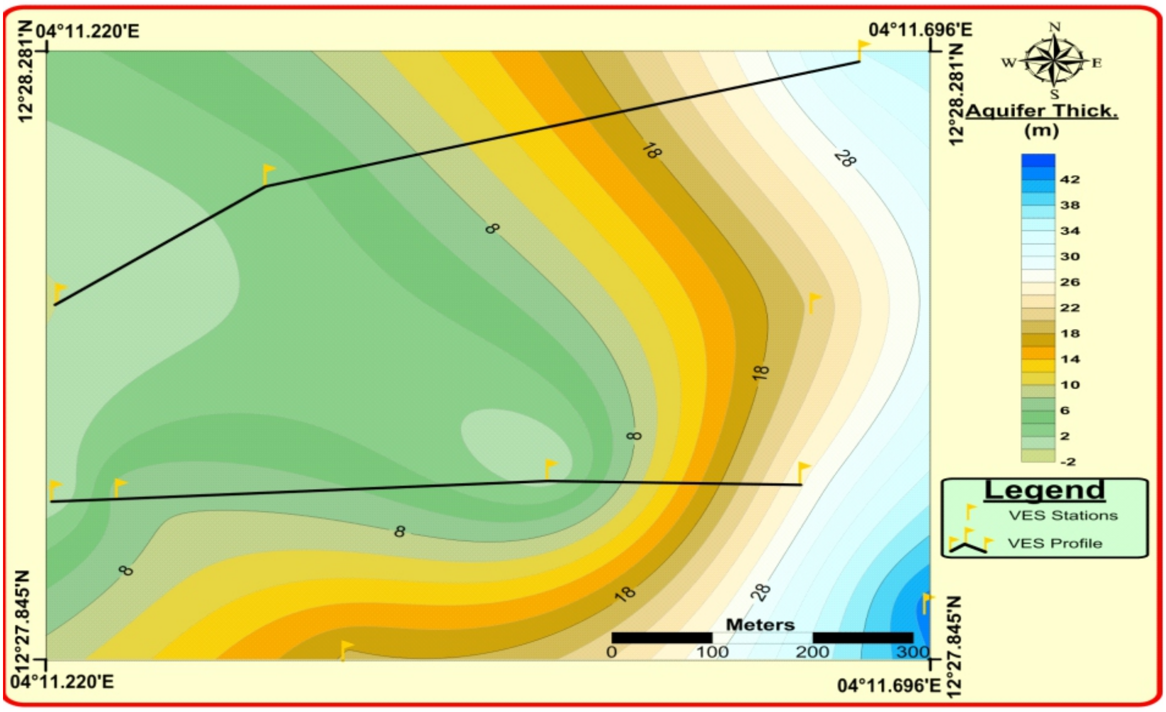


Fig. 10: Aquifer Thickness Map of the Study Area

Conclusion

In this research work, Schlumberger two electrode resistivity technique (VES) was used to map out the aquiferous zones within the Gudi-Takalau area of Birnin Kebbi. The work is considered as an appraisal of the performance of the technique on a sedimentary formation. Vertical Electrical Sounding method was used in determining the resistivity of various layers. Two aquiferous zones were detected. They are the fractured and weathered regions within Gudi-Takalau, which consist of fine to medium, and medium to coarse grained in size. Region of high groundwater potentials were therefore indicated. The best yielding borehole is however the one that penetrates at least the main aquifer so that the potentials of aquifer could sufficiently be tapped.

Recommendation

The following recommendations are offered for effective exploitation of groundwater resources within the Gudi-Takalau community;

- The most promising regions for underground water exploitation lie within the aquifers.
- The electrical resistivity method is a reconnaissance tool; however it is also suitable for the detailed study of problem areas that have been selected using other techniques, such as Seismic, Gravity, Magnetic

and Electromagnetic (EM) methods or resistivity traversing.

- Very Low Frequency (VLF) survey should also be employed for the purpose of detecting fractures, faults and shear zones within the sandstone beds, which are the best yielding zones.
- A better policy for water management should be adopted for effective exploitation of available water resources.
- Collaborative efforts should be made to standardize the method by applying it at various fields in diverse geologic formations and greater depth of investigation.

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