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ASSESSMENT OF GROUNDWATER POTENTIALS USING 2D ELECTRICAL RESISTIVITY AND RADIAL VERTICAL ELECTRICAL SOUNDING TECHNIQUE IN DUSTEN-KURA-MAITUMBI MINNA, NORTH- CENTRAL NIGERIA

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ABSTRACT

The availability of sufficient fractures are the main features that enhance the development of groundwater resources in crystalline rocks of the Basement Complex. In order to achieve a better understanding of the groundwater potential of the study area, geologic mapping was conducted first, followed by Radial Vertical Electrical Sounding (RVES). These were complimented with a 2D electrical resistivity tomography (ERT) surveyso as to provide sufficient information about the subsurface structures and lithology ofDusten-Kura-Maitumbiin Minna, north-central Nigeria. RVES was carried out in four different stations along two profiles using a portable Geo-Sensor resistivity meter.Electrical resistivity sounding data obtained were used to produce Vertical Electrical Sounding (VES) curves, basement resistivity mapand depth to basement map. Coefficient of anisotropy polygons were produced using RVES data. The 2D ERT survey covered three profiles of 100 meach designed to be orthogonal to the predominant structural orientation of the area. Geologic map show that the area is composed of amphibolite schist which have been intruded by porphyritic older granite rocks.The VES model curves reveal that the area is generally characterised by three geoelectric layers. Resistivities and depths of top soil layer range from 64 Ωm to 333 Ωm and 1.1 m to 4.2 m respectively. The middle layer consisting of slightly weathered rocks have resistivity values ranging from 15 Ωm to 781 Ωm and depths of 1.0 m to 4.2 m. Generally, the area has not undergone appreciable weathering which is evident from the depth to basement map which indicate shallow overburden. The degree of fracturing as indicated by the anisotropy polygons show that there is a decrease in fracturing with increasing depth.The results of the 2D ERT show strong correlation with interpreted VES and anisotropy polygons. However, conclusions drawn from the research suggest a low groundwater potential for the area.This research has shown that a combination of RVES and 2D ERT surveys are good complementary tools in delineating groundwater potential in a basement terrain.

Keywords: Subsurface structures, Groundwater, Radial vertical electrical sounding, 2D electrical resistivity tomography, Anisotropy polygon

INTRODUCTION

Water is a universal solvent whose sources include rivers, springs, wells, seas, oceans groundwater, other freshwater bodies and the ocean. These sourcesprovide water for drinking, domestic, industrial and agricultural purposes. Different geological factors occurring within the Basement Complex are responsible for the occurrence, storage, and distribution of groundwater (Olurunfemi and Fasuyi, 1993). Most often, the occurrence of groundwater in Basement Complex terrains are localized and confined to weathered and fractured zones (Adiat*et al*., 2009).

Groundwater exploration in basement terrain isrelatively complex due largely to highly variable nature of the geology (Anbazhagan*et al*., 2011). There is need for detailed hydrogeological study/ assessment in the Basement Complex terrain to understand the geology that controls groundwater conditions (Solomon and Quiel 2006; Pradhan, 2009).Pipe borne water supply has become one of the most disturbing social amenities to be successfully achieved by government especially in Nigeria.Due to increased human activities and modern industrialization,its qualityand supply has been grossly inadequate to meet thevery increasing demand. Most parts of Minna central Nigeria rely heavily on groundwater to meet up with domestic requirements (Ejepu *et al.,*2014). InBasement Complex terrains, groundwater is foundin fractured and weathered crystalline rock formations.Exploration for groundwater in these terrains requires a proper understanding of the regional and local geology and a combination of appropriate geophysical methods which are able to enhance the subsurface geological structures where groundwater is likely to be hosted (Ejepu *et al.,* 2017).

Radial Vertical Electrical Sounding (RVES) survey is a modified resistivitytechnique wherein the magnitude, intensityanddirection of electrical anisotropy are determined (Olasehinde andBayewu, 2011).This method has been successfully used in thedelineation of subsurface geology and structures,especially for effective identification and delineationof strike (orientation) of fractures(Olasehinde, *et al.*,2013).Traditionally, Vertical Electrical Sounding (VES) which essentiallydetermines the vertical variation of resistivity within the subsurfacehas been very successful in delineating depth to fracture, overburden thickness and subsurface layering(Skjernaa and Jorgensen, 1993). However, one-dimensional (1D) interpretation of VES and does

not capture lateral variations in the subsurface resistivity.Thus, the use of 2D Electrical Resistivity Tomography (ERT) for groundwater exploration can greatly enhance the detectionand mapping of weathered and fractured zones and increase the chances of borehole drilling success in Basement Complex terrain (Singh *et al.*, 2006). This study employs RVES technique in combination with 2D ERT to characterise the subsurface fractures so as todelineate those with good groundwater potentialwithin the study area.

LITERATURE REVIEW

Olasehinde and Bayewu(2011)studied the electrical resistivity anisotropy in rocks of Odo Ara near Egbe, west-central Nigeria. The area comprises of the banded gneiss, amphibolites, schist and intrusive pegmatites. The aim of the study was to use the electrical resistivity anisotropy properties of the area to resolve its geological setup. The VES data showed a significant presence of electrical resistivity anisotropy. The VES curves obtained were predominantly of three geoelectric layers of H-type ($\rho_1 > \rho_2 < \rho_3$) curves; the topsoil, sandy clay/ clay layer and fractured basement.

Watson and Barker (1999) worked on differentiating anisotropy and lateral effects using azimuthal resistivity offset Wenner soundings.Their investigations revealed that electrical resistivity is measured as a function of azimuth about a fixed central point; any observed change in apparent resistivity with azimuth is interpreted as being indicative of fracture anisotropy. Analysis of data obtained using the azimuthal offset Wenner technique from their study have successfully identified subsurface structures and determined the anisotropy where it is present.

Olorunfemi and Okhue(1992) worked onelectrical resistivity survey involving 2D Dipole-Dipole subsurface imagery and 1D Vertical Electrical Sounding (VES) and an integrated magnetic and electrical resistivity survey involving magnetic profiling and 1D VES/2D electrical imagery technique;, within the Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria. The surveys were carried out with a view to delineate the subsurface layers and determine the geoelectrical characteristics; identify geological structures such as faults, fractured, jointed and sheared basement zones that are favourable to groundwater accumulation. The study demonstrated the effectiveness of integrated geophysical methods and techniques in providing information on the subsurface sequence and the structural disposition required for a successful groundwater development through borehole drilling, in a borehole-failure-prone Basement Complex terrain.

LOCATION AND GEOLOGY OF THE STUDY AREA

The study area covers Dustsen-Kura and Maitumbi areas in Minna, Niger State, north-central Nigeria. This area is part of Minna Sheet 164 SW. It lies within longitude 6°30′ 00″ E to 6°34′ 30″ E and latitude 9°36′ 00″ N and 9°38′ 30″N. The area is accessible by series of major roads such as Minna-Bida and Minna-Kontagora roads (Figure 1). There exists a fairly large network roads that link various settlements in the area. The area has a typical Guinea savannah climate with distinct wet and dry seasons: a dry season which usually last from December to March and rainy season last from April to October. Temperatures vary between 24°C around December/January and 32°C in March/April. Average annual rainfall for a thirty-year record in the area is about 1270 mm (NIMET, 2020).Geologically, the area falls within the Basement Complex Terrain of Nigeria. The Nigerian Basement Complex forms part of the ancient African shield, bordered tothe west by West African cratonic plate and underliesabout 60% of Nigeria's land mass. The Basement Complex has been described by Rahaman, (1988)as a heterogeneousassemblage of migmatites, para-gneisses, ortho-gneisses, quartzites, paraschists and a series ofbasic to ultrabasic metamorphic rocks. Pan AfricanGranites and other minor intrusions such as pegmatiteand aplite dykes and veins, quartz veins and extrusivediorites and dolerites have intruded these rocks. Thestudy area which is composed of amphibolite schist which have been intruded by porphyritic older granite rocks (Figure 2). The rocks have massive texture and lack anyform of faulting. Joints on the exposedoutcrops are few, shallow and tight.

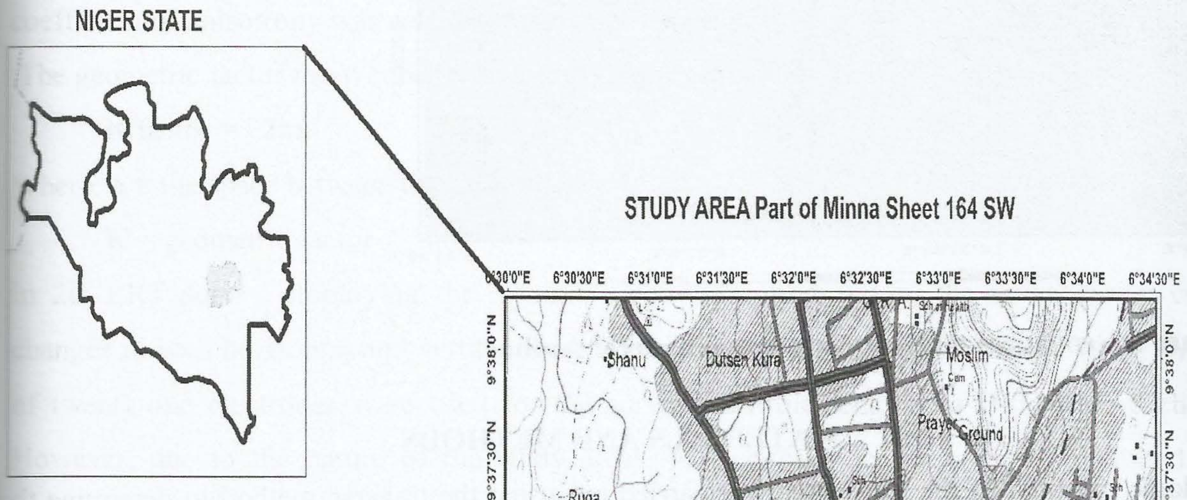


Figure 1: Location map of study area

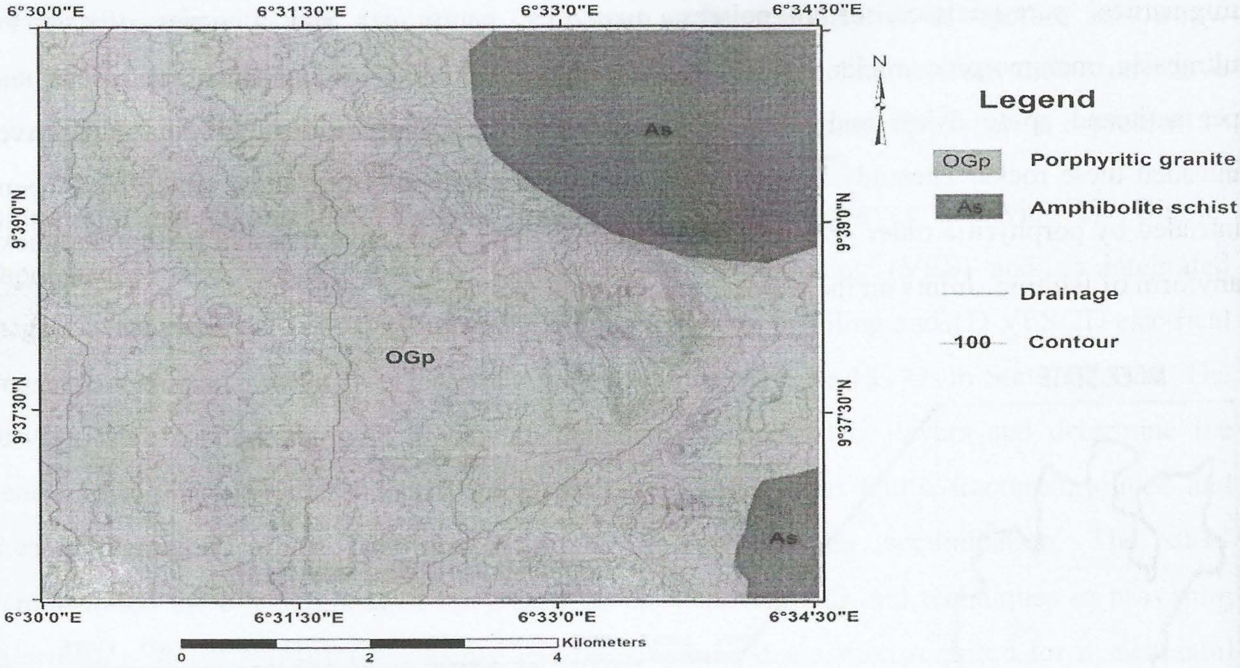


Figure 2.Geological map of study area. (Source: Author)

MATERIALS AND METHODS

Geologic mapping of the study area was carried out using the traverse method to determine the rock types and to obtain data to produce joint directions and rosette diagram. RVES and 2D ERT surveys were conducted using a portable Geo-Sensor resistivity meter. The instrument provides a digital readout of the current, resistance and selfpotential. Apparent resistivity was measured along three different azimuths; N-S (0°), NE-SW (60°) and NWSE (120°) for a given AB/2 separation and were plotted along their corresponding azimuths. Anisotropy polygons were generated from the apparent resistivity values at different AB/2 separations by joining lines of equal values along the different azimuths. The resistivity values were then multiplied by the calculated geometric factors to obtain the apparent resistivity values which were plotted against the electrode spacing (AB/2) using WINRESIST– an automatic resistivity inversion software (Vander-Velpen,2004). For an isotropic homogeneous formation, this polygon will assume a circular shape. Any deviation from a circle to an ellipse is indicative of anisotropic nature of the formation. The direction of the longest axis of the polygon shows that the strike (orientation) of the fracture, and the ratio of the long to short axis is an indication of the presence of fractures (faults and joints system) in an area if high, and otherwise if low (Skjernaa and Jorgensen,1993). A useful parameter in determining the coefficient of anisotropy (λ) for an anisotropic medium is calculated using: $= \sqrt{rt/rs}$. (λ=coefficient of anisotropy, rt=apparent resistivity measured normal to fracture strike direction, rs= apparent resistivity measured along the strike direction).

From the RVES survey carried out, the apparent resistivity anisotropy polygon was plotted and coefficient of anisotropy was calculated for each station.

The geometric factor for Wenner array can be expressed as;

K factor = $\mathbf{2\pi a}$

Where: **a** = the space between the electrodes

K = geometric factor

In 2D ERT survey employing the Wenner electrode configuration, the investigation covers changes in both horizontal and vertical directions along the survey profile (Loke, 1999). A total of twenty-one electrodes were used for the survey. Profile lengths of 200 m were chosen. However, due to the nature of the study areas, some profile lengths (L) were limited to a continuous intermittent break of 100m covering the entire area. For the first sequence of measurements, the spacing between adjacent electrodes (a) at 1a was set at 5m. For the first measurement electrodes numbers 1, 2, 3and 4 served as C1, P1, P2 and C2 respectively. For the second measurement, electrodes numbers 2, 3, 4 and 5 servers as C1, P1, P2 and C2 respectively. This sequence was carried on until electrodes 18, 19, 20 and 21 served as C1, P1, P2 and C2 respectively. Eighteen total mid-points were measured at the end of 1a sequence. The next sequence of measurement with 2a was made. The adjacent spacing between electrodes was increased from 5m to 10m, but still maintaining the overlapping horizontal electrode movement of 5m. Electrodes 1, 3, 5 and 7 were used as C1, P1, P2 and C2 respectively for the first sets of measurement. Electrodes 2, 4, 6, and 8 were used for the second sets of measurement. This sequence was repeated down the profile line until electrodes 15, 17, 19 and 21which formed the last measurement in the 2a sequence. The whole measurement procedure was repeated for 3a, 4a, 5a, and 6a spacing. From the first sequence of measurement 1a, a total of 18 mid-points were obtainedand the mid-point reduces by three in subsequently measurement sequences. At 2a, mid-points =15, at 3a=12, 4a=9, 5a=6 and 6a=3. The number of measurements decreases with increase in electrode spacing. The total probe depth is about 18m from the surface. This depth varies from site to site as each site have been excavated to a certain degree for borrow material. The excavated based used as the survey for the electrode spray ranges from 4 to about 13 meters.

RESULTS AND INTERPRETATION

Rosette diagram

A plot of joint directions data from the field reveal that that the principal joint direction in the area isNNE-SSW (Figure 3). The minor joint directions in thearea are not very distinct. The NNE-SSW fracturing pattern revealed by the rosette diagram depict the fracturing pattern of the surfacewhich is likely to change with increase in depth.This is the major reason why more analytical methods are required to reveal the subsurface structural pattern of an area.

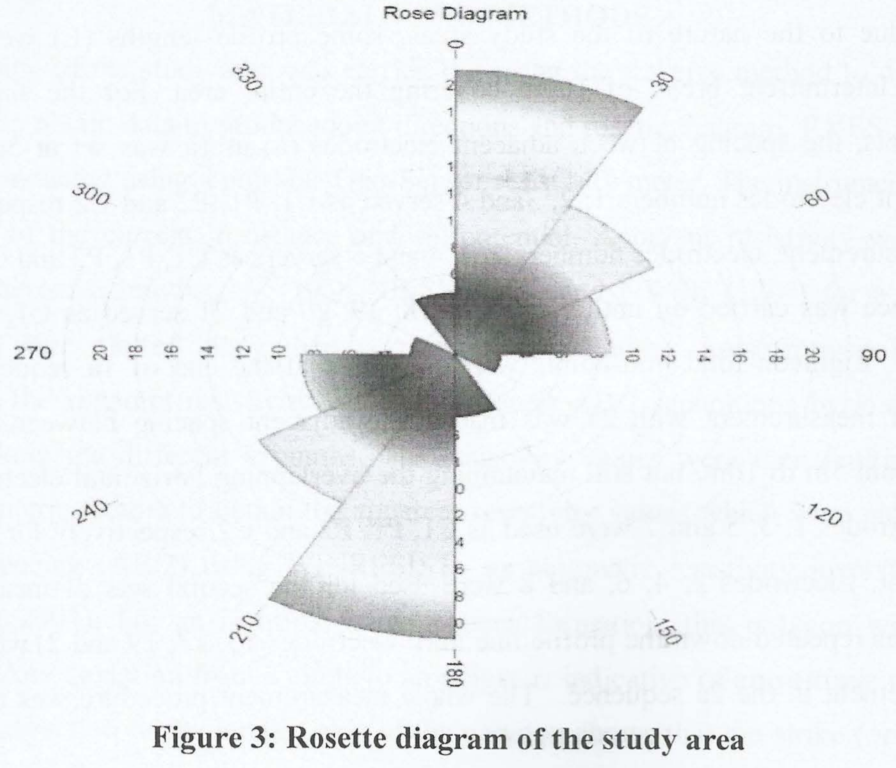
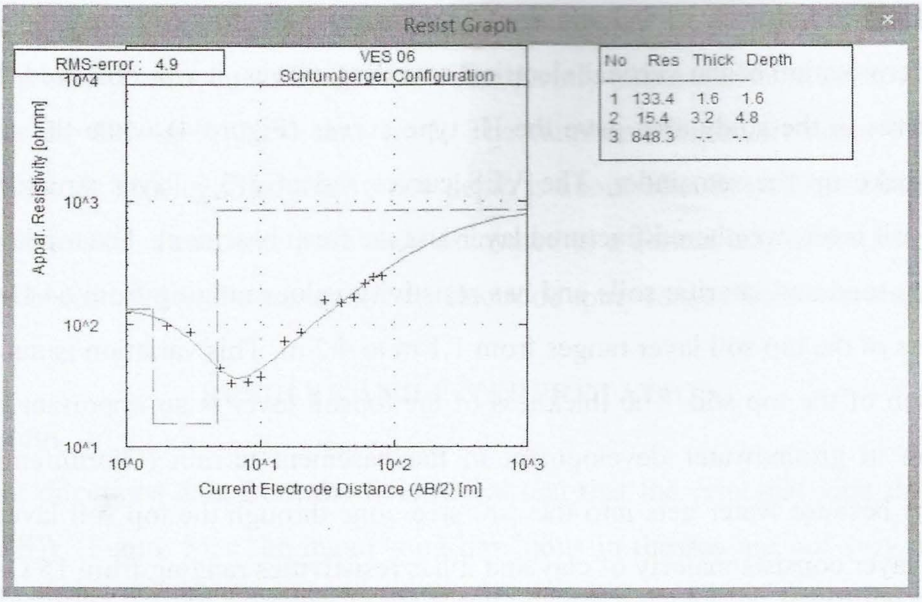


Figure 3: Rosette diagram of the study area

Description of VES curves

From the interpretation of the vertical electrical sounding curves, it was observed that 60% of all the VES curves in the study area gave the H- type curves (Figure 4) while the A– type curves (Figure 5) make up the remainder. The VES curves reflect a 3 – layer structure. The layers include top soil layer, weathered/fractured layer and the fresh basement. The top layer consists of sandy, clayey sand and lateritic soils and has resistivity values ranging from 64 Ωm to 333 Ωm. The thickness of the top soil layer ranges from 1.1 m to 4.2 m. This variation is due to the degree of compaction of the top soil. The thickness of the topsoil layer is an important hydrogeologic consideration in groundwater development in the basement terrain (Olorunfemi and Okhue, 1992*)*. This is because water gets into the saturated zone through the top soil layer. The second geo-electric layer consists majorly of clay and it has resistivities ranging from 15 Ωm to 831 Ωm. The thickness of this layer varies from 2.3 m to 27.9 m.

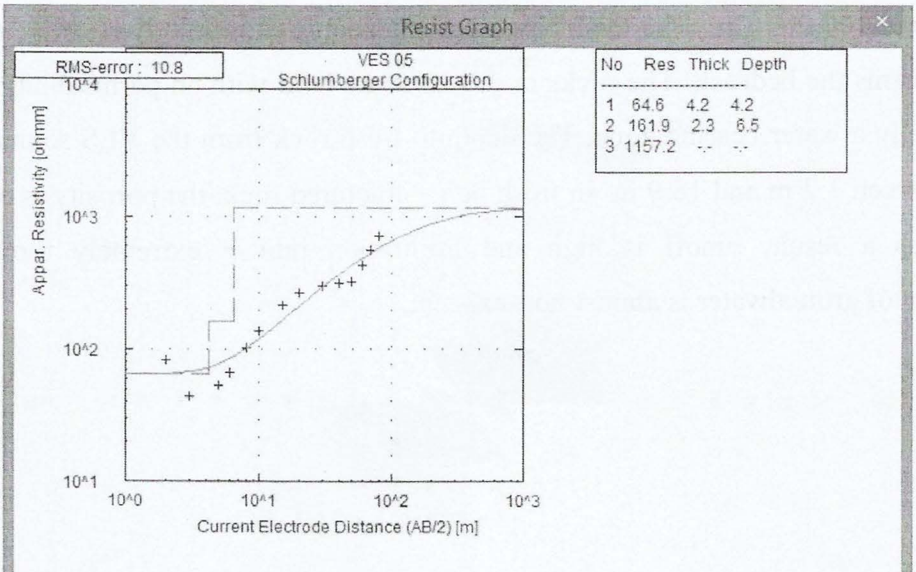
The Fresh basement layer is the third geo-electric layer and it is characterized by high resistivity values of up to 100,000 Ωm. The fresh basement is made up of infinitely resistive rock in all the stations. It forms the bedrock. The rocks in this zone are hard with no permeability and hence, it is not normally a water bearing zone. The depth to fresh rock from the VES soundings is found to range between 3.7 m and 16.9 m. In fresh non – fractured rock, the porosity is often less than 2.5% and as a result, runoff is high and infiltration rate is extremely too low. Hence, accumulation of groundwater is almost non-existent.



RMS-error : 4.9

No	Res	Thick	Depth
1	133.4	1.6	1.6
2	15.4	3.2	4.8
3	848.3	-.-	-.-

Figure 4: Typical H curve of the study area



RMS-error : 10.8

No	Res	Thick	Depth
1	64.6	4.2	4.2
2	161.9	2.3	6.5
3	1157.2	-.-	-.-

Figure 5: Typical A curve of the study area

2D Electrical Resistivity Result

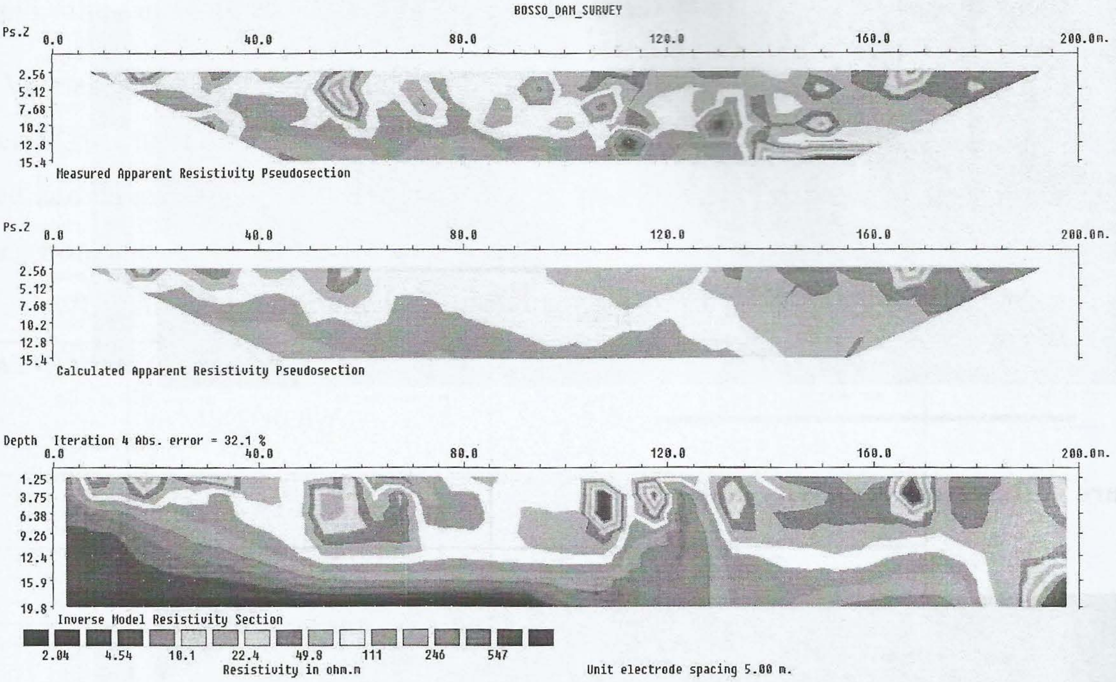


Figure 6:2D Electrical Resistivity Tomography inverse model for profile 1

Figure 6 shows a 2D interpretation for a profile within the study area covering a distance of 100m. The top layer from the inverse model shows low resistivity value of 22Ωm to 50 Ωm at a depth of about 4m to about 10m at right flank of the section. This resistivity value can be interpreted as lateritic clay/sandy clay. The second layer has resistivity values of about 200Ωm which can be interpreted as weathered/ fractured basement. This layer has a depth of 4-12m which are seen to be deeper towards the right flank. The resistivity value of greater than 500 Ωm is seen at the bottom of the section and is interpreted as fresh basement with little thickness of about 10m. Towards the right flank of the section, between the layer 1 and layer 2 at about 100 – 110m, 112-120m and 164 – 170m along the profile respectively there are indications of very low resistivity values; this could indicate a discontinuity which can be interpreted as saturated material such as wet/saturated clay.

Figure 7: Basement resistivity map

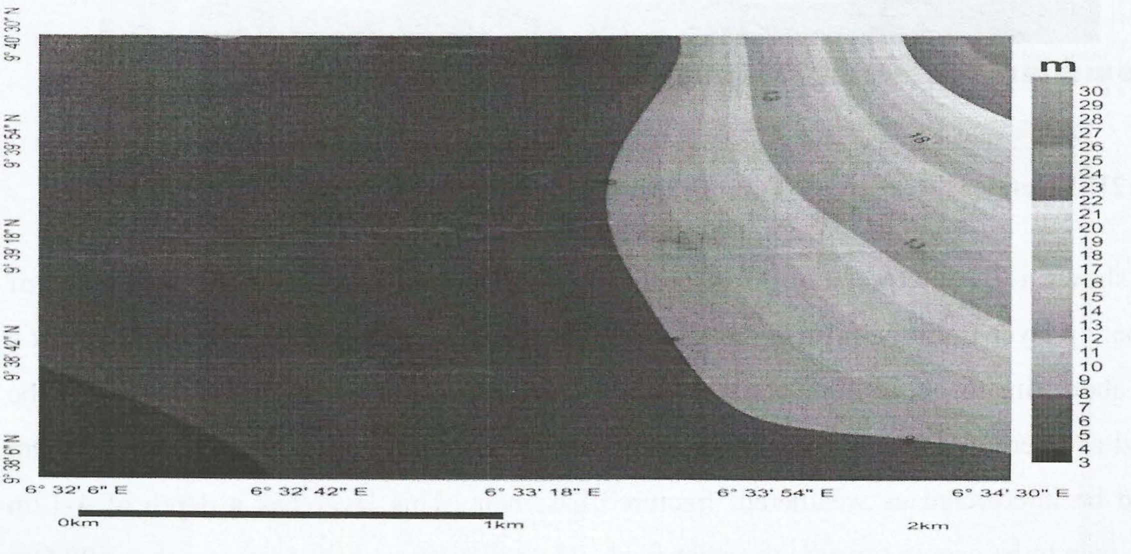


Figure 8: Depth to basement map

The basement resistivity increases towards the SE portion and is lower towards the NW portion of the study area (Figure 7). Generally, the shallower the depth, the higher the resistivity. The study area has shallow depths of overburden thickness ranging from 6m to 10m as indicated by the depth to basement map (Figure 8). This is also an indication of very low amount of weathered and fractured rock. Deep areas are found in the north-eastern portion of the study area with depth values up to 30m.

Radial Vertical Electrical Sounding

The inferred structural trends and the coefficient of anisotropy are presented in Table 1. They are classified into threeaxis: N-S, NE-SW and NW-SE. Morphology of curves and degree of fracturing from anisotropy values were analysed.

Table 1: Coefficient of anisotropy and inferred structural trends of the study area.

LOCATIONS	COEFFIENT OF ANISOTROPY	INFERRED STRUCTURAL TREND
1	1.6	N-S-SE
2	1.5	NW-SE,N-S
3	1.7	NE-SW
4	1.8	N-S

Coefficient of anisotropy and anisotropy polygon

The arrangement of inferred structural orientation and the coefficient of anisotropy of allthe sounding station are presented in Table 1: three axes are classified N-S, NE-SW, NW-SE. The direction of estimated long axis of the anisotropy corresponds to the orientation of fracture. A high ratio of the long to short axis indicate the presence of fracture. If it is low, fractures are not significant or entirely absent. The direction of electrical anisotropy lay N-S (Figure 9).

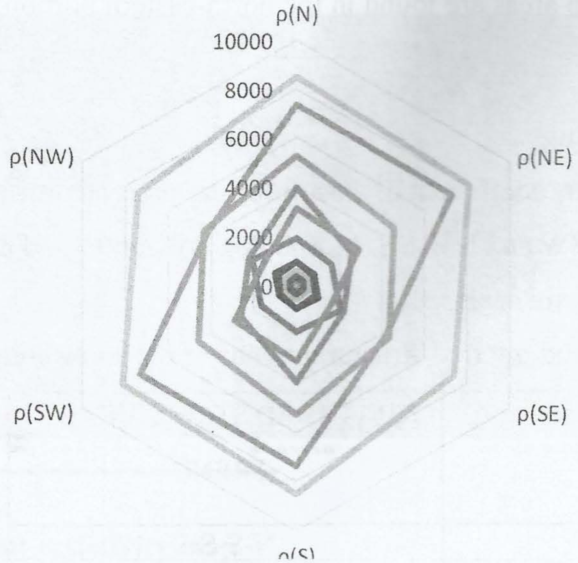


Figure 9: Coefficient of anisotropy polygon

Morphology of the Curve

The effect of anisotropy of the subsurface reveal the morphology of the RVES curve. A change in the shape of the curve indicate change in values of the resistivity. This is a proof of the anisotropic nature of the subsurface (Figure 10).

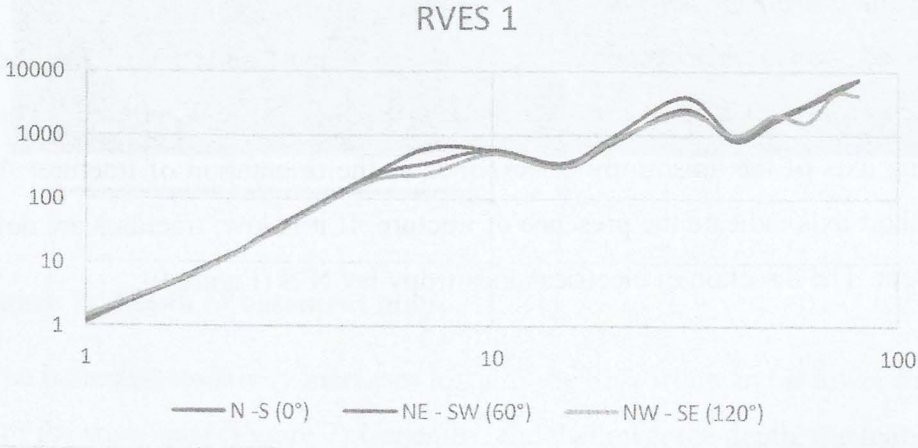


Figure 10: Change in morphology of VES values at a point in different directions depicting anisotropy of the subsurface.

Coefficient of Apparent Anisotropy Values (λa) Against Ab/2

Graphical plot of coefficient of apparent value (λa) against various depth equivalents to different AB/2 separation is shown in Figure 11. The degree of rock fracturing at various depth can be understood quantitatively. It might be observed from these fracturing existing in depth of 30m to 80m in all locations. This increase terminated at approximately AB/2= 80m starteddecreasing from this depth. Anisotropy decrease indicate diminution of fracture with depth (Olasehinde 1999).

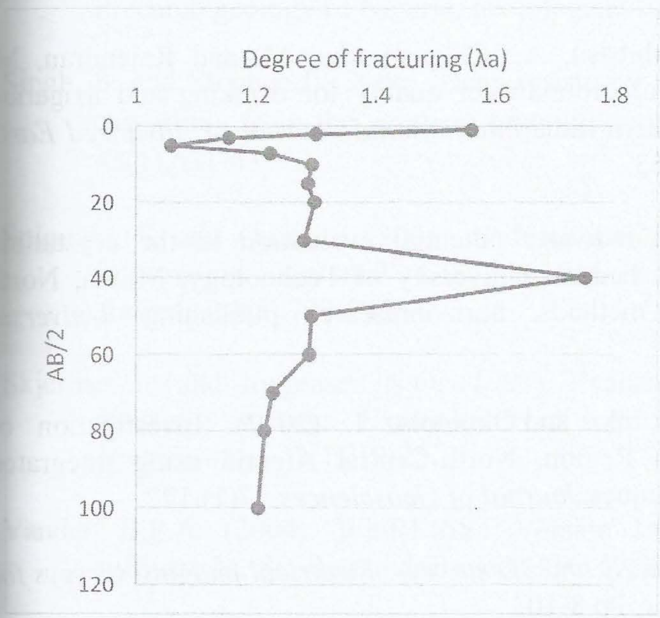


Figure 11: Degree of rock fracturing with respect to depth.

CONCLUSION

Geologic mapping revealed a general fracture pattern of NE-SW observed at thesurface in the study area from the rose diagram plotted. This has a fair correlation with fracture directions that were obtained using radial geo-electric soundingtechnique with coefficient of anisotropy of 1.7. The degree of fracturing as indicated from the coefficient of apparent anisotropy is low to medium. The 2D electrical modelling reveals low resistivity values towards the NE-SW with resistivity values ranging from 2 Ωm to 10 Ωm. This indicates groundwater development potentials of the study area as not being too viable. However, appreciable success can be achieved in some stations especially in station 4.It has also shown that integrating geologic mapping, RVES and 2D ERT surveys enhances understanding of the assessment of groundwater potential of the area.

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