FRACTURE DELINEATION AND CHARACTERIZATION FOR GROUNDWATER STUDY USING AZIMUTHAL RESISTIVITY SURVEY: CASE STUDY OF PART OF UNIVERSITY OF ILORIN, SOUTHWESTERN, NIGERIA

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ABSTRACT

The usefulness of electrical resistivity anisotropy in rocks for improved geological mapping using electrical resistivity survey could not be over emphasized. Electrical resistivity survey was employed in delineation and characterization of the subsurface fractures within the migmatite and granite-gneiss rocks in a part of University of Ilorin, Nigeria. Sixteen radial vertical electrical soundings were analyzed with the aim of using electrical resistivity anisotropy properties to unravel the studied area geology or for groundwater exploration. Azimuthal resistivity soundings (ARS) was carried out at four locations and at different distances. Four of such distances were analyzed, making a total of sixteen points. Interpretations were both qualitative and quantitative involving radial plots, intensities of fracturing and computer iterations. Electrical resistivity anisotropy is inherent in this area as observed from the electrical resistivity data. The rose plot shows the preponderance of fractures in the N-S direction while the acquired data showed the predominance of fractures in the N-S followed by the NE-SW and then the NW-SE directions which agree with the geology of the study area and corroborate the fact that basement complex terrain of southwestern Nigeria is characterized by NE-SW and NW-SE lineaments which cut across the earlier Pan-African structures. Result from this study shows a fracture system that connote the study area as a reliable groundwater potential site. This is key to sustainable groundwater resources and further planning in this environment.

Keywords: azimuthal, fractures, groundwater, lineaments, radial, resistivity, sounding
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INTRODUCTION

Groundwater potential mapping in hard rock terrain is relatively complicated due to complex variability in the Basement terrain [1]. Hydrogeological investigations are required extensively in Basement Complex terrains for proper understanding of groundwater conditions [2, 3]. Evans and Myers [4] and Singh and Singh [5] noted that several techniques commonly employed in assessing groundwater potential of a terrain depends on the available data which includes remote sensing and Geographic Information System (GIS). Geophysical surveys are typically carried out for the purpose of determining the geoelectric parameters of formations, identifying aquifer units and determination of their depths and lateral extent. The radial vertical electrical soundings were employed with the aim of using the electrical resistivity anisotropy properties to study the groundwater potential. In areas underlain by crystalline rocks groundwater occurs in fracture zone or in highly weathered Basement Formation [6]. It has been proven that most river channels within the Basement Complex terrain are fracture controlled [7], this illustrates that drainage patterns within the Basement Complex are good indicators of fracture geometry in the area [8]. In the absence of river channels, other evidence of fracturing includes lineaments, lithologic contact, fault zone and luxurious vegetation growth [9, 10].

Study area

The study area is situated at the northern part of Ilorin Sheet 223 (Figure 1). The area mapped covers part of Ilorin south and lies within the University of Ilorin Main Campus. The area lies within Latitude 8.46666° – 8.48333° N and Longitude 4.67138° – 4.68333° E covering an area of 0.87 Km^2. The University of Ilorin lies within the Basement Complex terrain of southwestern Nigeria. The Basement Complex terrain is generally represented by series of older metasediments and gneisses that are known to be of Precambrian to Lower Paleozoic age [11]. This area is inhabited by a community of indigenous rural people and students of the University, who lack access to municipal water supply. The inhabitants rely mainly on low yield, pollution prone and annual shallow wells. Attempts to construct deeper borehole was made by the United Nations International Children's Emergency Fund (UNICEF)/Rural Water Sanitation (RUWATSAN), an organ of the Kwara State Government of Nigeria. The borehole drilled was successful and prolific but was not motorized, instead it was installed with a hand pump which could only allow one person at a time. A major step by the University of Ilorin at solving water problem was the construction of a dam across the major river that flows in a NE-SW direction (Figure 1) across the campus, which has actually assisted in meeting much of the water needs on the campus but yet there is still insufficient water supply as the population continues to grow at high rate [12, 13]. As a result of this, the need arises for a more detailed evaluation of the groundwater potential of the area. This research, which was aimed at determining the quantity and direction of fractures in the subsurface and provision of geological information, is part of the necessary work for future development of groundwater resources within the permanent site of the University.

Structural elements

Lineaments may result from faults, joints, folds, contacts or other geological reasons, and are found in igneous, sedimentary and metamorphic rocks [14]. The rose plot of fractures in the study area as obtained from Aromoye *et al.* [16], shows the preponderance of fractures oriented in the NNE-SSW direction (Figure 2). Faults and lineament features form the major tectonic elements in this area and do not only structurally control the drainage system but also the morphology of the crystalline basement. They correlate with the general geologic strike of the West African craton and corroborate the fact that the Pan African in Nigeria was followed by conjugate strike slip fault systems which average in the NE-SW and NW-SE directions and showed dextral and sinisterly sense of displacement which cut across the earlier Pan African structures [17, 18].

METHODOLOGY

Radial Vertical Electrical Sounding (RVES) was carried out along the N-S, NE-SW and NW-SE directions at 10 different locations over the migmatite and granite-gneiss suites to observe the correlation between the measured structural directions and the plotted anisotropy polygons directions. The maximum spread of AB/2 in this area is 100m. When a formation is anisotropic due to the presence of fractures, the apparent resistivity (ρ_t) measured normal to its strike direction is greater than apparent resistivity (ρ_s) measured along the strike direction i.e. when Schlumberger or Werner array is used but contrary when

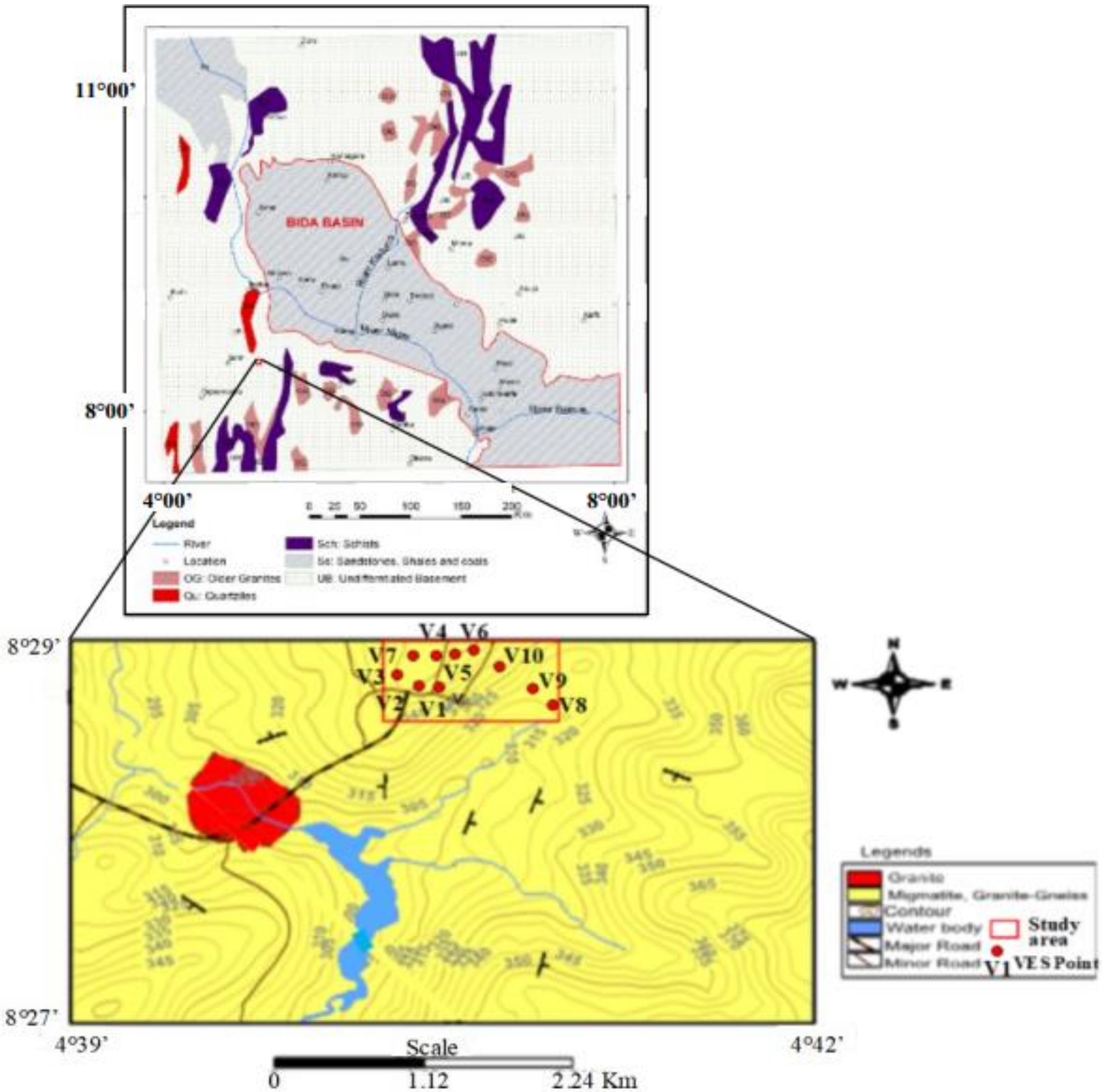

Figure 1: Geological map of University of Ilorin showing the study area

(Inset is the Geological Map of Bida Basin (Adapted from Obaje *et al.* [15]).

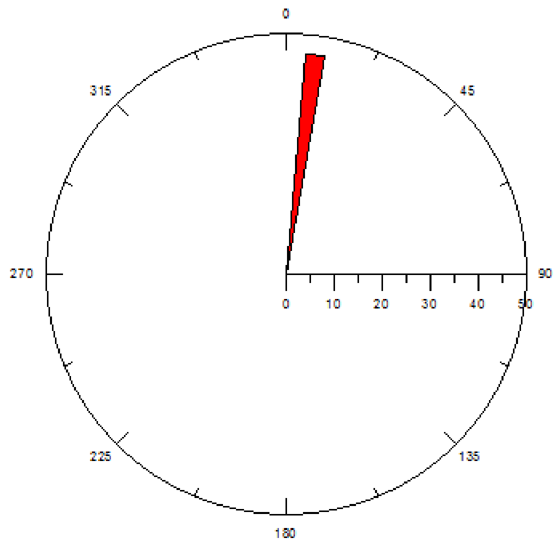

Figure 2: Rose diagram of lineaments at University of Ilorin (Adapted from Aromoye *et al.* [16]).

crossed square array is employed [19, 20]. The apparent resistivity was measured along N-S, NE-SW and NW-SE directions for a given AB/2 separation (e.g. 20, 30, 60 and 80m) and were plotted along their corresponding azimuths (0-180°, 60-240° and 120-300°), while lines having the same resistivity value along different azimuths were joined together to produce a polygon. A set of such polygons obtained corresponding to different AB/2 separations is known as a polar diagram or anisotropy polygon [20].

The major or longest axis of the ellipse, which can fit any of such anisotropic polygon gives the strike direction of the fracture. The coefficient of apparent anisotropy (λ_a) (i.e. degree of fracturing) is calculated from each anisotropy ellipse (obtained from each polygon) using the relationship [21]:

$$\lambda_a = \frac{a}{b} \quad (1)$$

where a and b are the semi major and semi minor axis of the element. The values of λ_a are then plotted against the corresponding AB/2 separations to obtain the behavior of rock fracturing (qualitatively) at various depths based on their variation. The apparent resistivity anisotropy polygon of the four (4) RVES surveys done was plotted and the coefficient of anisotropy was calculated for each station as described in Habberjam [22] and Lane *et al.* [19]. The preliminary interpretation was done using partial curve matching and computer iteration. Areas with the presence of two or more interconnected fractures and high co-efficient of anisotropy indicate intense fracturing, thus, a potential site for the drilling of water borehole [23, 24].

RESULTS AND DISCUSSION

Geophysical investigations

Figures 3 and 4 are the plots of apparent resistivity values versus AB/2 along different azimuths in some chosen locations within the study area. The geometry of the wiggles representing the apparent resistivity variations have shown a considerable presence of anisotropy as the resistivity varies with azimuth at each location. The results show that the KH curve types are predominant with about fifty percent in the study area, followed by the H and A type which form about 25 percent each.

Figures 5 to 8 show the plots of anisotropy polygons for apparent resistivity at each depth with respect to AB/2 in metres. Table 1 contains the result of the interpreted fracture directions. The major or longest axis of the ellipse which can fit any of such anisotropic polygons, gives the strike direction of the fracture [20, 24]. The general trend of the strike is in the N-S direction followed by the NE-SW and then the NW-SE directions (Table 1 and Figures 5-8). This agrees with the geology of the study area and corroborates the fact that, ‘the effects of Pan African orogeny in Nigeria include the conjugate strike slip fault systems which trend in the NE-SW and NW-SE directions, which show dextral and sinistral sense of displacement, and which cut across the earlier Pan African structures [17, 18].
The degree of fracturing at depths 5, 7.5, 15 and 20 m (i.e. AB/2 = 20, 30, 60 and 80m respectively) for locations 3, 8, 9 and 10 have been interpreted and included in Table 1. The intensity of fracturing is generally high near the surface but attenuates at depth, a

situation that is expected to suit hydrogeological purposes or groundwater resources development.

Table 2 contains the **c**oefficient of apparent anisotropy (**λ**a) values used for the scatter diagrams that shows the degree of fracturing at depth with respect to electrode spacing AB/2 for each location and along different azimuths in the study area. Figures 9 (a) and (b) are the scatter diagrams for locations 3 and 8 respectively. Their intensity of fracturing is prominent at 2.5 m,

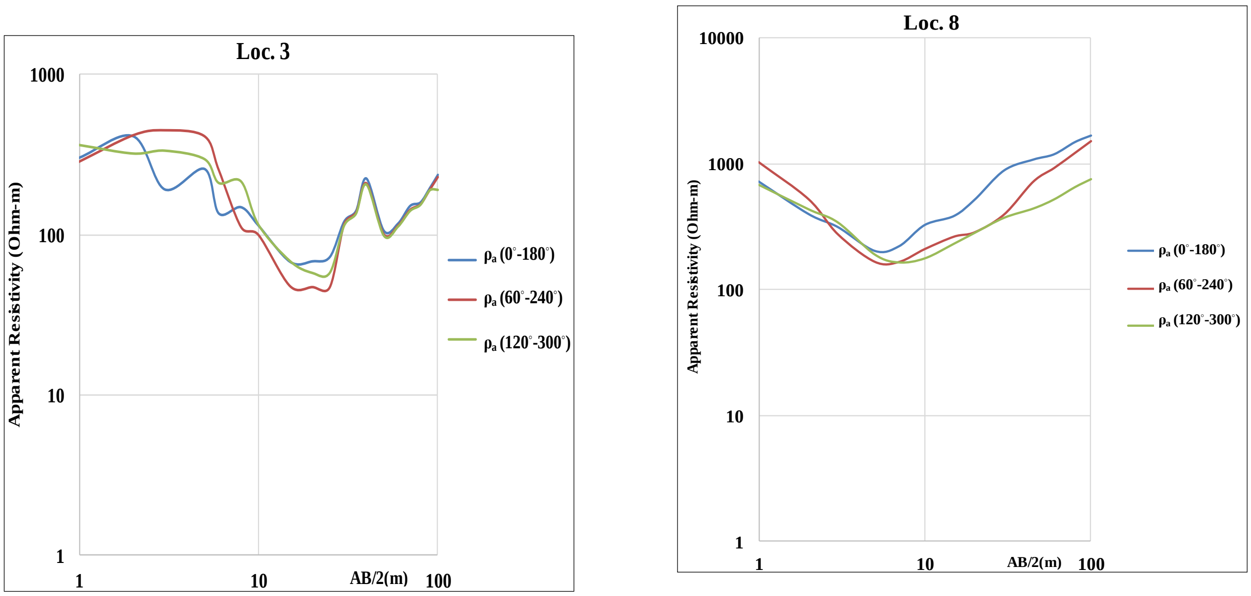

Figure 3: Diagrams of Apparent Resistivity versus AB/2 at different Azimuths in locations 3 and 8

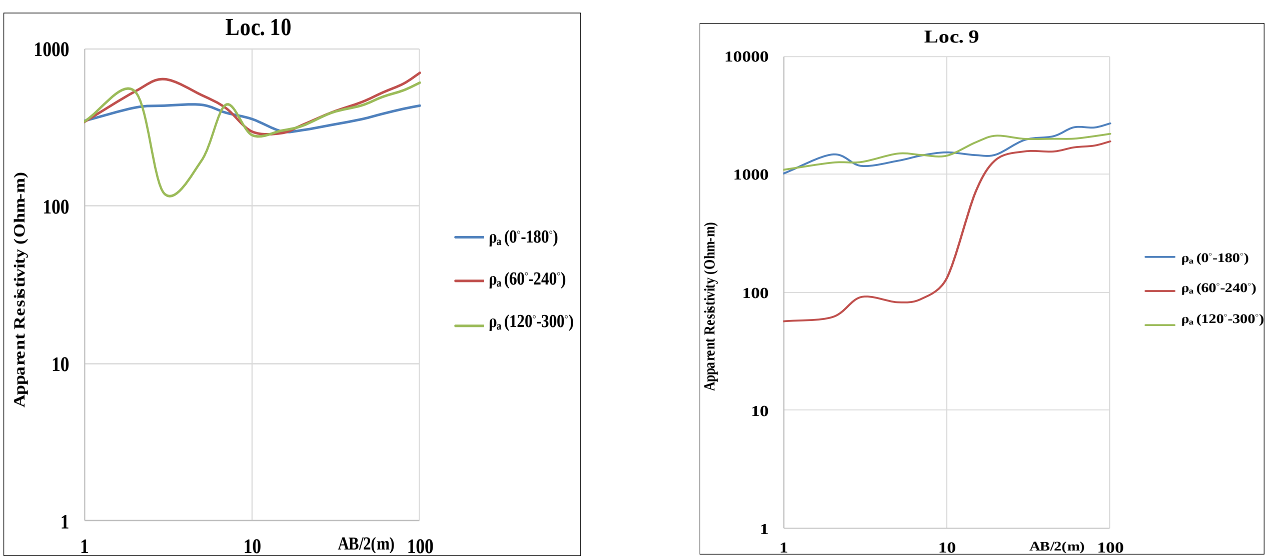

Figure 4: Diagrams of Apparent Resistivity versus AB/2 at different Azimuths in locations 9 and 10

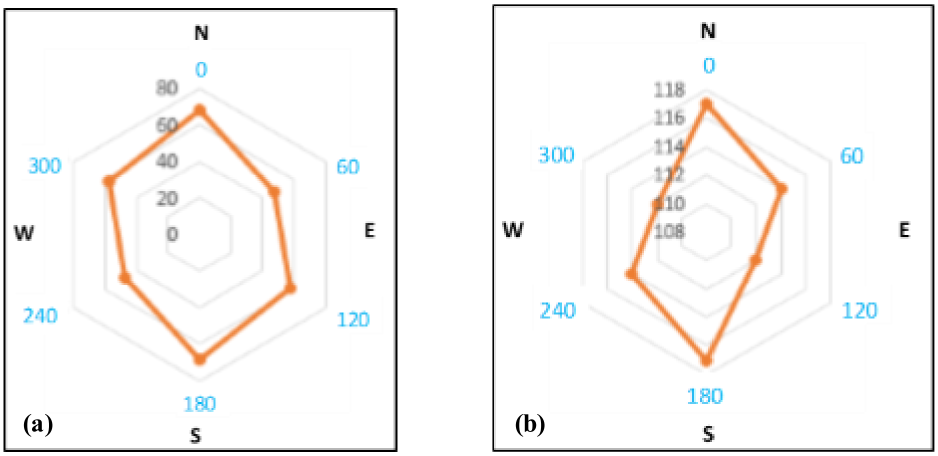

Figure 5: Typical Radial Plots at Location 3 (a) AB/2 =20 m (b) AB/2 =60 m

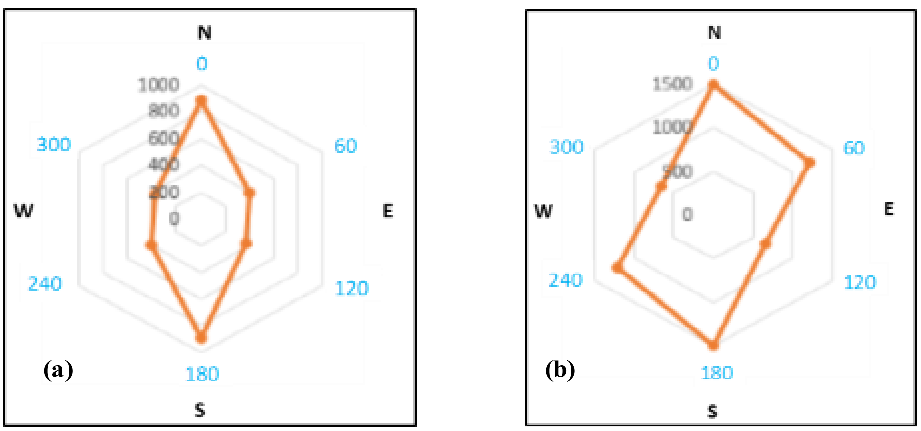

Figure 6: Typical Radial Plots at Location 8 (a) AB/2 =30 m (b) AB/2 =80 m

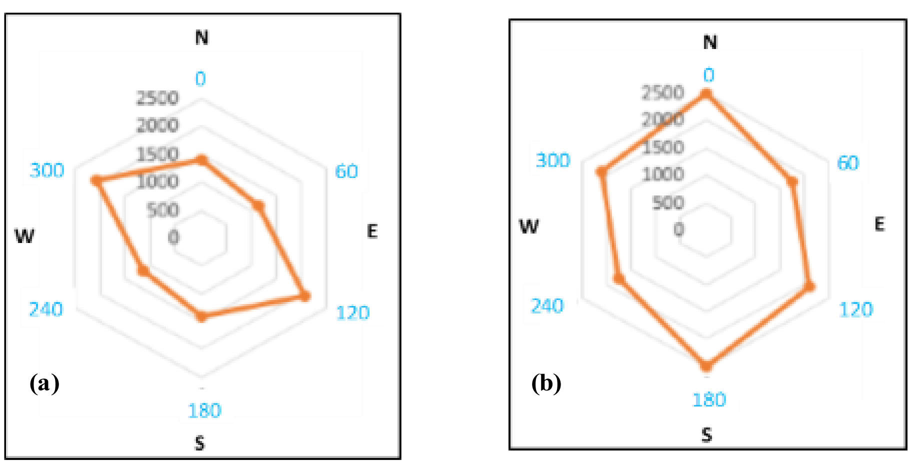

Figure 7: Typical Radial Plots at Location 9 (a) AB/2 =20 m (b) AB/2 =80 m

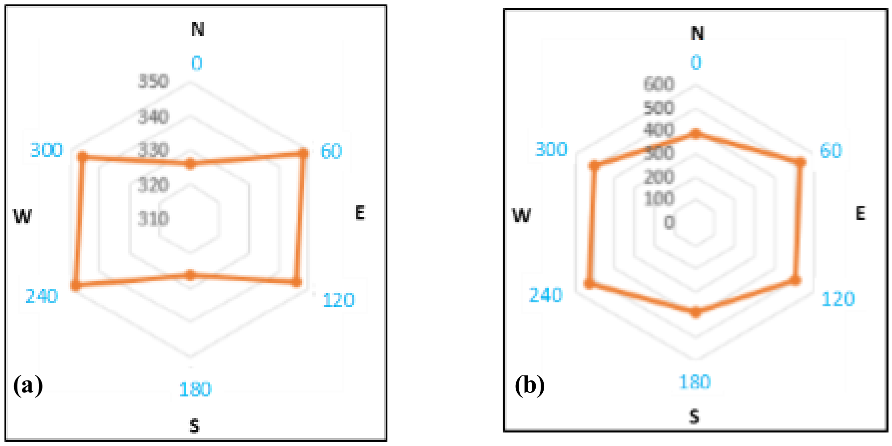

Figure 8: Typical Radial Plots at Location 10 (a) AB/2 =20 m (b) AB/2 =60 m

Table 1: Selected Values for Radial Plots and Interpretation of Fracture Direction

Loc-ation	**Distance AB/2 (m)**	**Values**			**Coefficient of Apparent Aniso-tropy (λa)**	**Fracture Direction**	**Intensity of Fracture with Electrode Spacing and the Geological Application**
		0°	60°	120°			
3	20	68	47	58	1.6	N/S	Intensity of Fracture increases with increase in electrode spacing. The intensity of fracture is high for AB/2= 30-80 m. Suitable for hydrogeological purposes
	30	119	116	113	2.8	N/S	
	60	117	114	112	2.25	N/S	
	80	158	155	153	2.5	N/S	
8	20	549	256	262	2.4	N/S	Intensity of fracture is highest at AB/2= 30 m but closes up at depth. Suitable for hydrogeological purposes.
	30	893	395	371	2.76	N/S	
	60	1201	921	520	2.1	N/S	
	80	1500	1210	650	2.12	N/S	
9	20	1410	1138	2070	2.0	NW/SE	Intensity of fracture is high near the surface but closes up at depth. Suitable for hydrogeological purposes.
	30	1952	1563	1991	1.29	N/S	
	60	2500	1690	2000	1.86	N/S	
	80	2490	1750	2100	1.54	N/S	
10	20	326	348	346	2.25	NE/SW	Intensity of fracture closes up with depth. Suitable for hydrogeological purposes but caution must be taken.
	30	331	395	395	2.25	NE/SW and NW/SE	
	60	390	530	499	1.33	NE/SW	
	80	420	605	550	1.4	NE/SW	

7.5 m and 11.25 m (i.e. depths corresponding to AB/2 of 10, 30 and 45 m) with orientations in the N-S direction. Figure 9 (c) is the scatter diagram for location 9. The intensity of fracturing is prominent at 0.25 m to 2.5 m (i.e. depths corresponding to AB/2 of 1 to 10m) before a gradual attenuation with depth and with orientations in the N-S, NE-SW and NW-SE directions. Figure 9 (d) is the scatter diagram for location 10. The intensity of fracturing is prominent at 0.75 m, 1.25 m and 2.5 m (i.e. depths corresponding to AB/2 of 3, 5 and 10 m) followed by a gradual attenuation with depth and having orientations in the NE-SW and NW-SE directions. The degree and manner of fracturing is generally expected to suit groundwater resources planning and hydrogeological purposes.

Table 2: Coefficient of Apparent Anisotropy **(λa)** Values Used for Scatter Diagrams

Distance AB/2 (m)	**Location 3**	**Location 8**	**Location 9**	**Location 10**
1	1.4	1.5	7.0	2.6
2	1.2	1.45	7.0	1.2
3	1.75	1.2	5.3	4.3
5	1.6	1.35	5.7	4.3
7	1.68	1.62	5.3	2.5
10	2.67	2.47	6.2	1.55
10	1.63	1.88	6.25	2.8
15	1.45	1.76	2.5	2.4
20	1.6	2.4	2	2.25
30	2.8	2.76	1.29	2.25
45	2.67	2.69	1.5	1.35
60	2.25	2.1	1.86	1.33
60	2.4	2.5	1.76	1.35
80	2.5	2.12	1.54	1.4
100	1.17	2.2	1.59	1.45

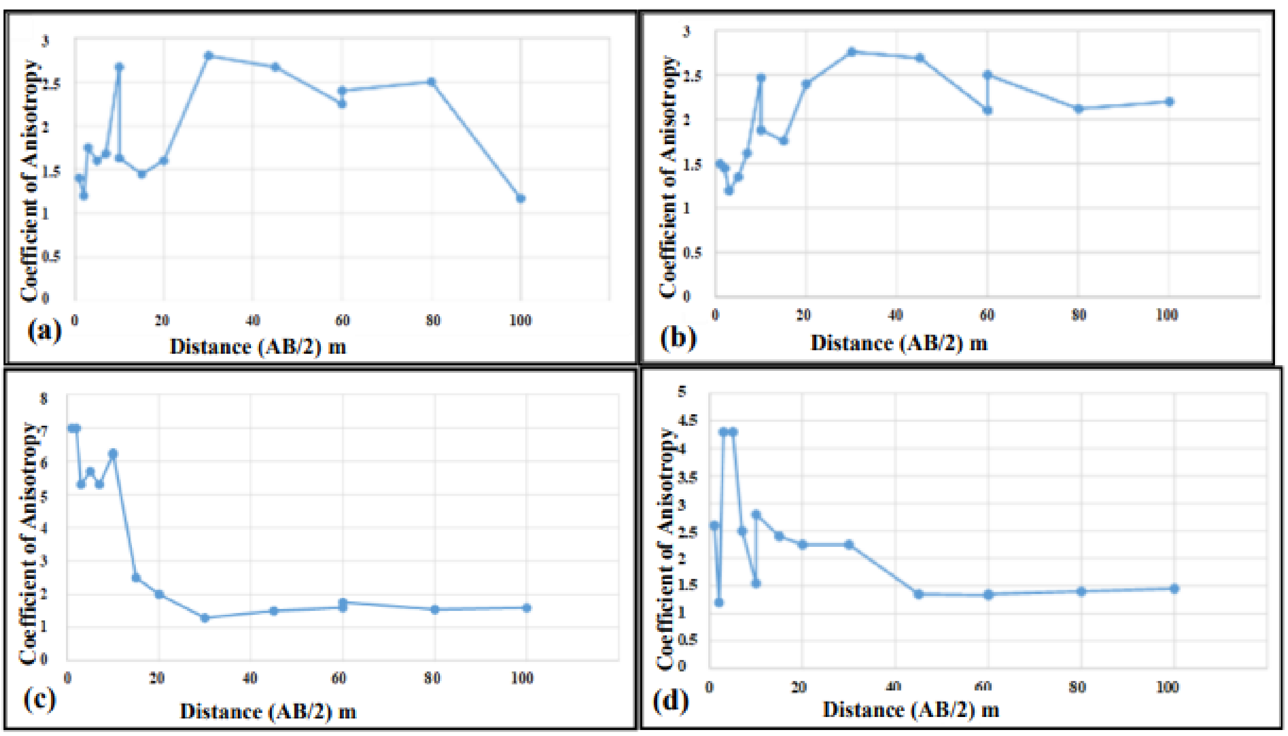

Figure 9: Scatter Diagram for Locations: (a) 3, (b) 8, (c) 9 and (d) 10.

CONCLUSION.

Part of the permanent site of University of Ilorin, Southwestern Nigeria has been investigated with RVES techniques in delineating and correlating the subsurface fractures as well as their orientations and depth. From the rose plot of the fractures in the study area and the RVES that delineated the subsurface fractures and their orientations, anisotropy was established in the study area with fractures oriented prominently in the N-S followed by the NE-SW and then NW-SE directions characteristic of the basement complex terrain of southwestern Nigeria [15, 16].

The intensity of fracturing at locations 3, 8, 9 and 10 (Table 1) is generally highest near the surface (7.5 m) but attenuates with depth (e.g. 20m). The **c**oefficient of apparent anisotropy (**λ**a) values used for the scatter diagrams (Table 2), show that intensity of fracturing is prominent at depths of 2.5 m, 7.5 m and 11.25 m (locations 3 and 8) and 0.25 m to 2.5 m (location 9) and 0.75 m, 1.25 m and 2.5 m (location 10) before a gradual attenuation with depth along different directions. The degree and manner of fracturing in the study area show that groundwater potential is high and the aquiferous layers are generally close to the surface but the amount of water is expected to decrease with depth.

This study has demonstrated the usefulness of azimuthal resistivity survey in structural study in the research for groundwater potential thereby reducing the uncertainties in decision making while choosing sites for groundwater resources development.

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