DC Resistivity Investigation of Anisotropy and Lateral Effect using Azimuthal Offset Wenner Array. a case Study of the University of Calabar, Nigeria

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Abstract
Azimuthal resistivity survey (ARS) was conducted using offset Wenner array to investigate anisotropy and lateral effect for the first time in the University of Calabar environment, Nigeria. Two (2) sites were surveyed within the study area. Data were collected using ABEM terrameter SAS 1000 and its accessories. From a reference point, azimuth was varied with an increment of 15^0 to 360^0. Analysis of azimuthal offset Wenner array resistivity data revealed that the study area is homogeneously anisotropic with no lateral effect in all azimuths. The apparent coefficient of anisotropy estimated from the field data ranged from 1.10 to 1.90 with anisotropy in (NW-SE), (NE-SW), (E-W) and (N-S) directions. The homogeneity index ranged from 4.71 to 9.60 and this indicates that the variation due to anisotropy is greater than that due to inhomogeneity within the study area.
Keywords: Anisotropy, Lateral effect, Azimuthal Resistivity Survey, Offset Wenner Array and homogeneity index.

1.1 Introduction

Anisotropy is a property of a rock which shows different measurements when measured along different axes. A rock is said to be electrically anisotropic if the value of vector measurement of its resistivity varies with direction (Taylor & Fleming, 1988; Watson & Barker, 1999). This is a common feature of all rock types and is exhibited by rocks in different scales.

Azimuthal resistivity method is an improvement of resistivity method where the magnitude and direction of the electrical anisotropy are determined. In this technique, an electrode is rotated about its centre so that apparent resistivity is observed for several directions (Taylor & Fleming 1988). It is generally believed that anisotropy is caused by the presence of fluid-filled fractures in relatively resistive rock or soil.

Electrical anisotropy studies has attracted the attention of many earth scientists such as Geophysicists, Geologists, Petrophysicists, Drillers, Reservoir engineers, Stratigrahers etc. Matias & Habberjam (1986), Watson & Barker (1999) and Busby (2000) have shown that when using azimuthal resistivity survey, any observed change in apparent resistivity

(ρ_a) is interpreted as an indication of fracture anisotropy, which in most cases might also be produced by the presence of a dipping bed or inhomogeneouties or lateral changes in apparent resistivity.

Ehirim & Essien (2009) stated that where electrical anisotropy exists, convenient assumptions fail, actual geological depths and structure are wrongly imaged, petrophysical parameters are wrongly estimated and drilling becomes more problematic because of loss in circulation of drilling fluids.

Azimuthal resistivity technique has also been used by other researchers to determine fracture geometry in crystalline rocks and glacial till (Ritzi & Andolsek 1992; Lane et al.1995 & Carlson *et al*. 1996), subsurface structures (Watson & Barker1999); fracture orientation (George *et al*. 2008), fracture in basement complex (Abdullah & Masanawa 2012).

Though anisotropy and lateral effect studies have been used by various researchers, but it has not been carried out in the University of Calabar environment. This study therefore investigates anisotropy and lateral effect for the first time in the University of Calabar, Nigeria.

1.2 Location and Geology of the Study area

The study area is the University of Calabar, Calabar. It is located between latitudes $4^0 30'$ and $4^0 40'$N and longitudes $08^0 5'$ and $8^0 15'$E with an elevation of about 15m above sea level (Figure 1). The area is accessible through tarred road from the University main gate.

Geologically, the study area falls within the coastal plain sands known as the Benin formation (Mbipom *et al*. 1996). The Benin formation is the upper most unit of the Niger Delta complex and overlies the Agbada formation. The coastal plain sands are made of alternating sequences of gravels and sands of different grain sizes, silt, clay and alluvium (Ugbaja & Edet 2004). Also Benin formation comprises sediments whose age is from tertiary to recent (Edet & Okereke 2002) (Figure 2). It consists of fine-medium coarse grained sands which sometimes are poorly sorted.

2.0 Materials and methods

The major instruments employed in the study include ABEM Terrameter SAS 1000, Global Positioning System (GPS), theodolite, and five electrodes. Other accessories used include ranging poles, pegs, measuring tape, hammer and umbrella for the terrameter.

The theodolite was used to map out the survey points about the centre, which is the reference point of the survey. It was ensured that the true North was first determined using the GPS on the centre point of electrode before taking out other angle measurements. An electrode spacing of 1.5m, 4m and 12m was used and each point was rotated in 15^0 increments about the centre point for a total of 360^0.

The offset Wenner array technique measures resistance using five equally spaced electrodes. Measurements of ground resistances are made using the left four electrodes, giving $R_{D1}$and then the right four electrodes, giving R_{D2}(Figure 3). This was repeated for the total azimuth of 360^0.

Analysis of the behavior of the two Wenner resistances as a function of both azimuthal and electrode spacing can enable differentiation between the true anisotropy and other geological models (Watson & Barker 1999).

Percentage Resistance as a function of azimuth in Cartesian and radial coordinates were plotted to produce polygons of anisotropy. Apparent coefficient of anisotropy was calculated using the equation (Mota *et al.* 2004):

$$\lambda_a = \sqrt{\frac{\rho_{\max}}{\rho_{\min}}} \tag{1}$$

Where $\rho_{\max}$ is the apparent resistivity measured along the ellipse major axis, $\rho_{\min}$ is the apparent resistivity measured along the ellipse minor axis direction.

Busby (2000) posited that for the rock mass to be considered an anisotropic and homogeneous, the anisotropy measure of dispersion is greater than the measure of dispersion caused by the homogeneity. This can be expressed by the simple dimensionless quotient:

$$\frac{\sigma(|\rho_D|)}{\sigma(|\rho_{D1}-\rho_{D2}|)} \tag{2}$$

Where $\sigma(|\rho_D|)$, is the standard deviation of the mean offset measurement and $\sigma(|\rho_{D1}-\rho_{D2}|)$ is the standard deviation of the absolute difference between the two offset measurements. When the measures of anisotropy and dispersion are equal, the quotient has a value of 1.0 and the variation due to anisotropy is equal to that due to inhomogeneity. A value greater than one shows the variation due to anisotropy is greater than that due to inhomogeneity, whereas values less than one show the reverse. Equation (2) is called the homogeneity index.

3.0 Results and discussion

Data collected at the two sites in the University of Calabar showed azimuthal graphs of R_{D1} and R_{D2} for electrode spacing of 1.5m, 4.0m and 12.0m (Figure 4 -6(a-c) and Figure 7-9 (a-c)).

In location 1 Staff Quarters Road by Palm Estate University of Calabar, the graphs (Cartesian) at 1.5m, 4.0m and 12.0m shows R_{D1} and R_{D2} rise and fall together as a function of azimuth(Figure 4-6(a)). This shows that the ground is homogeneously anisotropic in all electrode spacing but no lateral effect in any of these points of survey. According to Watson & Barker (1999), anisotropy occurs when R_{D1} and R_{D2} rise and fall together with rotation of the array. The apparent coefficient of anisotropy calculated at these points ranges from 1.57 to 1.90 (Table 1).The direction of maximum resistivity which is interpreted as the direction of electrical anisotropy (Habberjam 1975) and is found to lie NE-SW, NW-SE and N-S directions (black thick line) (Figure 4-6 (c) and Table 1). The homogeneity index calculated using equation (2) was 6.77, 9.60 and 5.34 at 1.50m, 4.0m and 12.0m spacing respectively. This suggests that the variation due to anisotropy is greater than that due to inhomogeneity (Busby 2000).

In location 2, within University of Calabar Teaching Hospital (UCTH), the graphs (Cartesian) indicate that at all spacing there is a rise and fall of R_{D1} and R_{D2} as a function of azimuth (Figure 7-9(a)). This shows that the ground is homogeneously anisotropic and lateral effect is not observed. The apparent coefficient of anisotropy lies between 1.10 and 1.69 and the anisotropy lie in NE-SW, N-S and E-W directions (black thick line) (Figure 9-11(c) and Table 1). The homogeneity index calculated was 4.71, 9.57 and 6.30 at 1.50m, 4.0m and 12.0m spacing respectively. This also indicates that the variation due to anisotropy is greater than that due to inhomogeneity.

The source of electrical anisotropy in the study area is suggested to be probably due to formation layering or bedding laminations, preferred mineral grain orientations, grain boundary cracks and other lateral inhomogeneities in the subsurface at the depth of investigation (Ehirim & Essien 2009).

4.0 Conclusion

Azimuthal resistivity survey (ARS) using offset Wenner array was conducted at two (2) locations in the University of Calabar, Nigeria in order to investigate anisotropy and lateral effect within the area for the first time. The study revealed that in both locations at all points the ground is homogeneously anisotropic with no lateral effect observed. The apparent coefficient of anisotropy calculated ranged from 1.10 to 1.90.The homogeneity index ranged from 4.71 to 9.60 and this indicates that the variation due to anisotropy is greater than that due to inhomogeneity within the study area.

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References

Taylor, R.W. & Fleming, A.H (1988). Characterizing jointed systems by azimuthal resistivity surveys. *Ground Water*, 26(4): 464-474.

Watson, K.A. & Barker, R.D. (1999). Differentiating anisotropy and lateral effects using azimuthal resistivity offset Wenner soundings. *Geophysics*, 64(3): 739-745.

Busby, J.P., (2000). The effectiveness of azimuthal apparent-resistivity measurements as a method for determining fracture strike orientations. *Geophysical Prospecting*, 48(4): 677-695.

Ritzi, R.W. & Andolsek, R.H. (1992). Relation between anisotropic transmissivity and azimuthal resistivity surveys in shallow, fractured, carbonate flow systems. *Ground Water*, 30(5): 774-780.

Carlson, D.A., Taylor, R.W. & Cherkauer, D.A. (1996). Azimuthal Electrical Resistivity as a tool for determination of the orientation of preferred hydraulic transmissivity for a Dolomite Aquifer in Southeastern Wisconsin. SAGEEP 1996Meeting, Keystone, Colorado, USDA, *Expanded Abstracts*.

Lane Jr., J.W., Haeni, F.P. & Watson, W.M. (1995). Use of a square-array and direct-current resistivity method to detect fractures in crystalline bedrock in New Hampshire. *Ground Water*, 33(3): 476-485.

George, A.M.., Okwueze, E.E., Akpan, A.E & Uchegbu, C.J (2008). Comparative VES studies for the determination of fracture orientation using azimuthal square array and Schlumberger array data in Awi within the Oban Massif, SE Nigeria. *Nigerian Journal of Physics* 20(1)*:*136-144

Matias, M.J.S & Habberjam, G.M (1986). The effect of structure and anisotropy resistivity measurements. *Geophysics*, 51, 964-971.

Ehirim, C.N & Essien, E.E (2009). Comparative investigation of offset Wenner, square and Schlumberger arrays in electrical anisotropy studies. *Scientia Africa*, 8(2):53-60.

Abdullahi, N.K., Batu, M.A & Masanawa, A. A (2012). Fracture determination using azimuthal, Schlumberger and offset Wenner array in Basement complex of Northern Nigeria. *Research Journal of Environment and Earth Sciences* 4(7):747-755.

Mbipom, E. M. Okwueze E. E. & Onwuegbuche, A. A (1996) Estimation of Transmissivity Using VES Data from the Mbaise Area of Nigeria, *Nigerian Journal of Physics*, 85, 1996, 28-32

Ugbaja, A.N. & Edet, A.E (2004) Groundwater Pollution near Shallow Waste Dumps in Southern Calabar, South- Eastern Nigeria, *Global Journal of Geological Sciences*, 2(2): 199-206.

Edet, A. E. & Okereke, C. S (2002) Delineation of Shallow Groundwater Aquifers in the Coastal Plain Sand of Calabar Area Using Surface Resistivity and Hydro-Geological, *Journal of African Earth Sciences*, Vol. 35(3): 433-441.

Mota, R. S., Monteiro, A., Mateus, F.O., Marques, A., Conclaves, Figueiras, J. & Amaral, H (2004). Granite fracturing and incipient pollution beneath a recent landfill facility as detected by geoelectrical surveys. *Journal of Applied Geophysics*, 57(1): 11-22.

Habberjam, G.M., (1975). Apparent resistivity, anisotropy and measurements. *Geophysical Prospecting*, 23(2): 211-247.

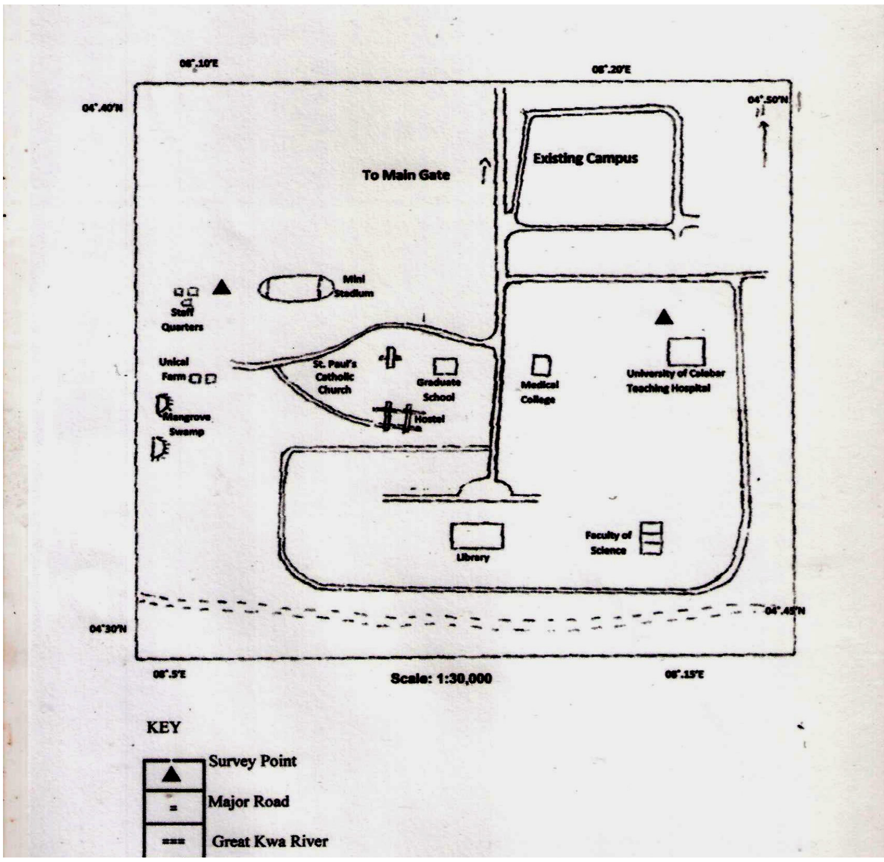


Figure 1: Location map of the study area

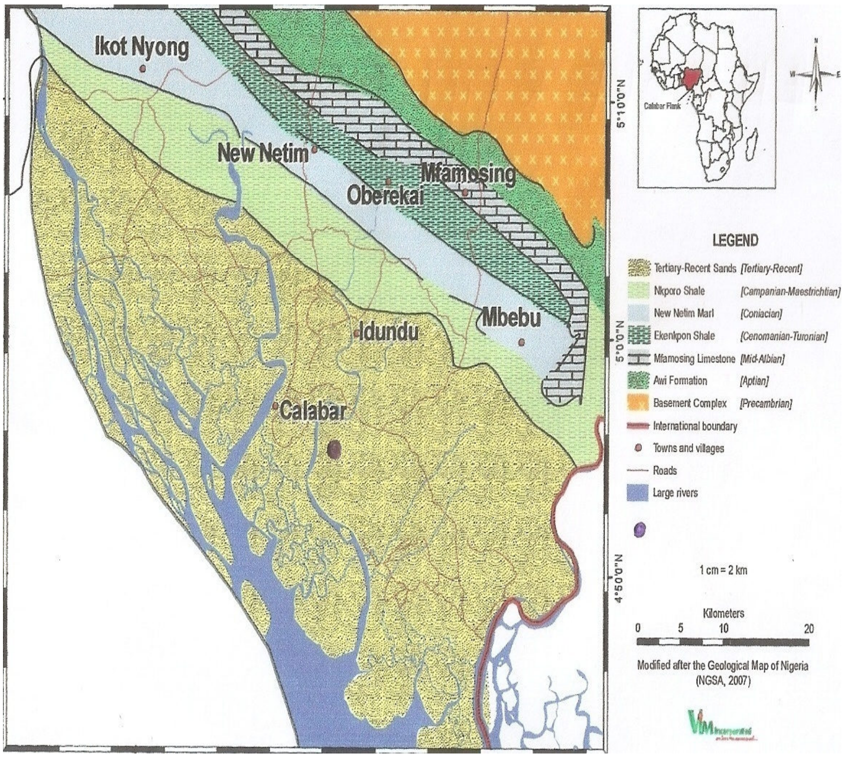
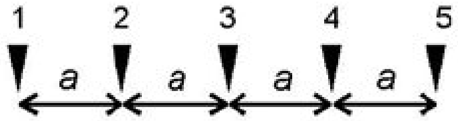
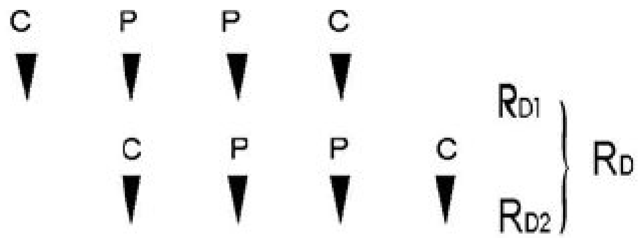


Figure 2: Geologic map of the study area



(a) Five – electrode array sounding technique



(b) Offset Wenner measurements

C = Current electrode P = Potential electrode a = electrode spacing, R_D = mean Resistance

Figure 3: Principles of the offset Wenner five-electrode array (Watson & Barker 1999).

Table I: Summary of anisotropic parameters obtained using azimuthal offset Wenner array

SITE	**Spacing (m)**	**Apparent coefficient of anisotropy (λ_a)**	**Direction of anisotropy**	**Homogeneity Index(HI)**
LOCATION 1 Staff Quarters Road by Palm Estate University of Calabar	1.50	1.57	NE-SW	6.77
	4.00	1.64	NW-SE	9.60
	12.00	1.90	N-S	5.34
LOCATION 2 University of Calabar Teaching Hospital, Calabar	1.50	1.23	NE-SW	4.71
	4.00	1.10	N-S	9.57
	12.00	1.69	E-W	6.30

(a) Cartesian Azimuthal Graphs	(b) Polar Azimuthal Graphs	(c) Polar Graph of R_o

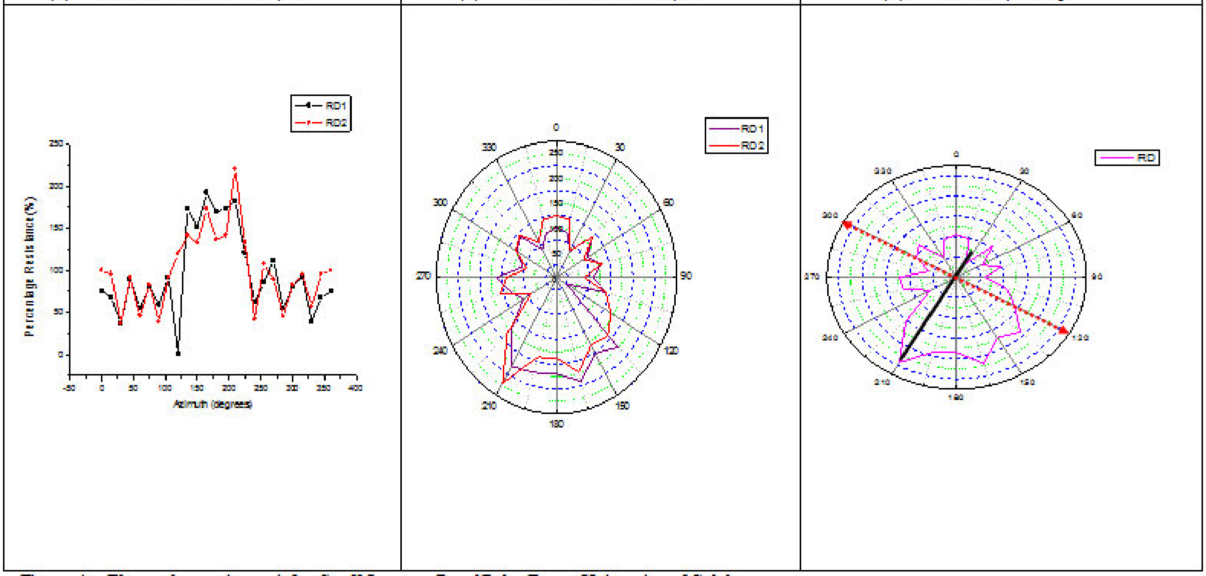


Figure 4: Electrode spacing at 1.5m Staff Quarters Road Palm Estate University of Calabar

(a) Cartesian Azimuthal Graphs	(b) Polar Azimuthal Graphs	(c) Polar Graph of R_o

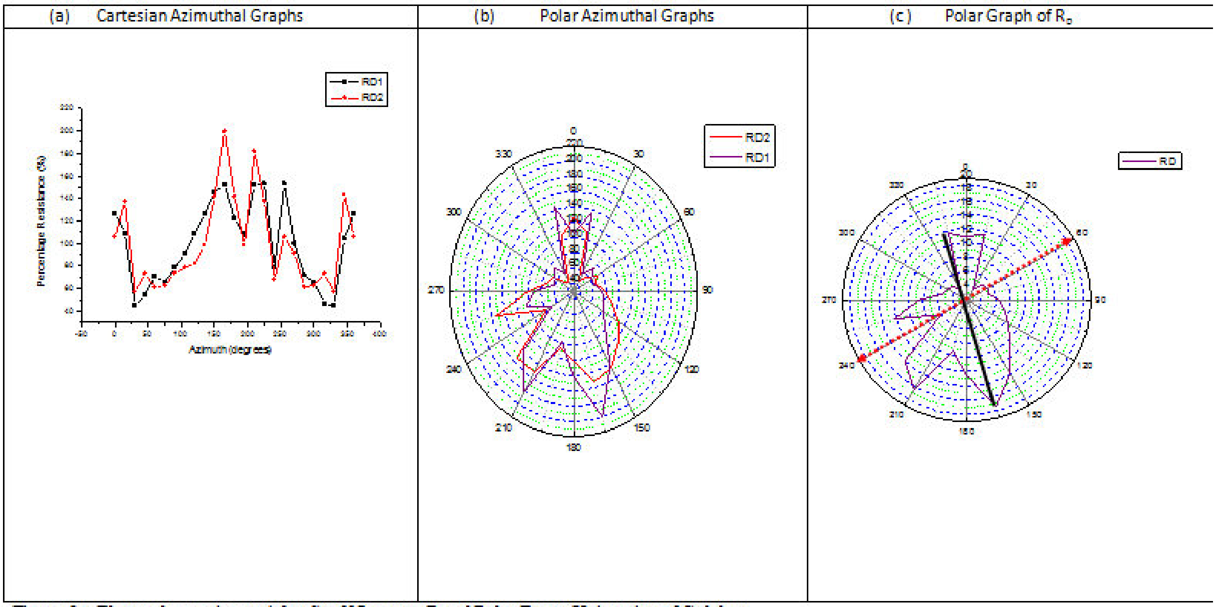


Figure 5: Electrode spacing at 4.0m Staff Quarters Road Palm Estate University of Calabar

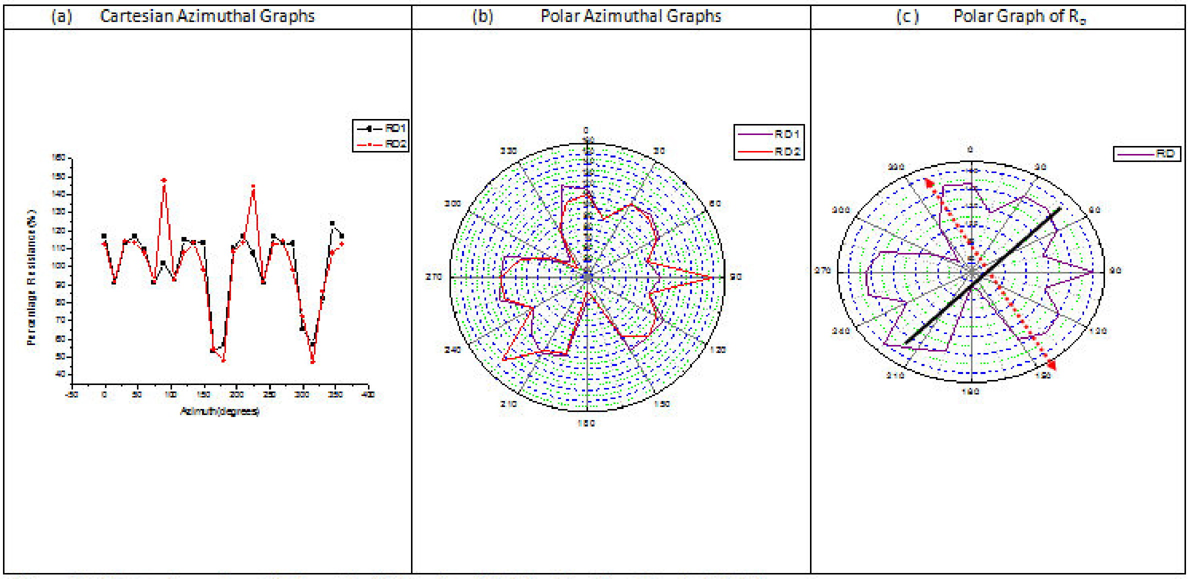


Figure 7: Electrode spacing at 1.5m at the University of Calabar Teaching Hospital, Calabar

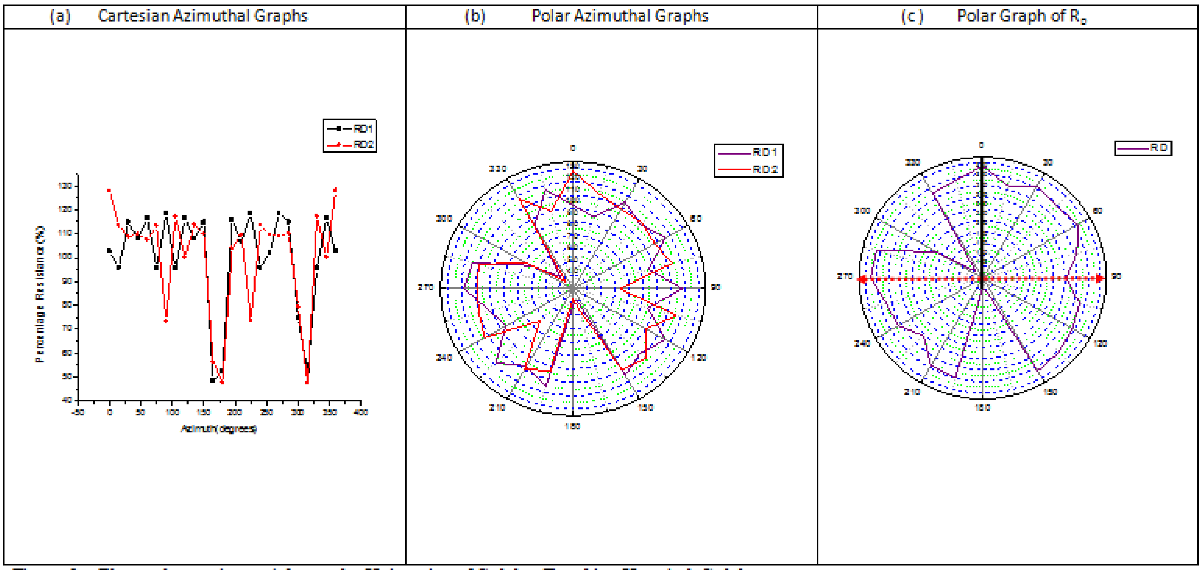


Figure 8: Electrode spacing at 4.0m at the University of Calabar Teaching Hospital, Calabar

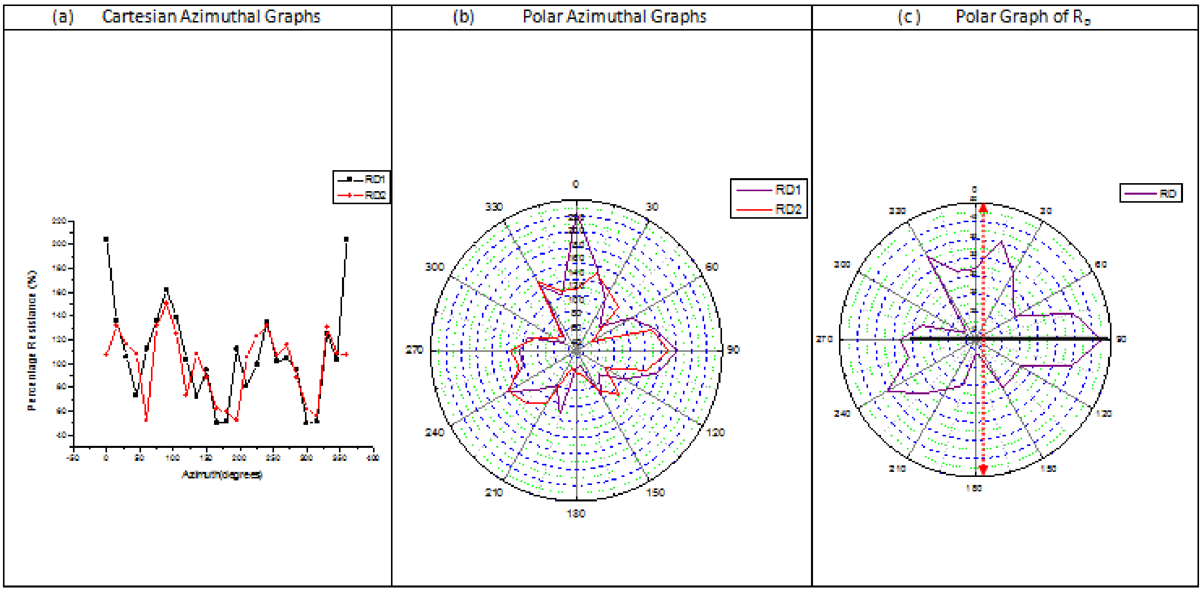


Figure 9: Electrode spacing at 12.0m at the University of Calabar Teaching Hospital, Calabar