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Groundwater Detection in Basement Complex of Northwestern Nigeria using 2D Electrical Resistivity and OffsetWenner Techniques

Abdullahi N.K , Iheakanwa, A
Department of Applied Science, College of Science and Technology, Kaduna Polytechnic, Kaduna, Nigeria.

ABSTRACT

A two-dimensional resistivity survey of Kaduna Polytechnic Demonstration Secondary School, Northwest, Nigeria was conducted using the Wenner alpha electrode configuration. Measurements of three profiles separated by 20 m were investigated in the study area with the aid of an ABEM SAS 300C instrument. A manual data collection technique was employed with the aim of determining the groundwater potential of the study area by investigating the degree of weathering and fracturing in the weathered profile developed above the crystalline basement. The observed resistivity data were inverted using the RES2DINV code. Results from the 2D inverse models of resistivity variation with depth suggest the occurrence of potential aquifers mostly in weathered/fractured zones within the traps or below it. Also, the resistivity models produced indicate the presence of fracture zone that could be exploited for groundwater extraction. To verify the interpreted results (Fractures) from the 2D resistivity data, azimuthal resistivity measurement using the OffsetWenner technique was conducted beside the observed anomalous zone. Cartesians azimuthal graphs of R_{D1} and R_{D2} and coefficients of anisotropy (λ) obtained from the OffsetWenner VES measurements at greater depths (18 - 24 m) indicate homogeneously anisotropic ground suggesting fracturing at these depths, consequently, complimenting the 2D resistivity data.

Keywords: *2D resistivity survey, offsetWenner technique, anisotropy, fractures.*

1. INTRODUCTION

Water is an essential commodity to mankind and it is found everywhere in the earth's ecosystem. However the water, which exists in such abundance on the earth, is unevenly distributed in both time and space and in circulation (Ajayi et al, 1988). The search for groundwater has become quite intense in human history. This is due to the fact that government is unable to meet the ever-increasing water demand; inhabitants have had to look for alternative sources such as surface streams, shallow wells and boreholes. The amount of surface water available for domestic, industrial and agricultural use is insufficient to fulfill the current demand in the world. Therefore, exploration for groundwater is of vital importance. Groundwater is the water that lies beneath the ground surface, filling the pore spaces between grains in bodies of sediment and clastic sedimentary rock and filling cracks and crevices in all types of rock (Plummer et al., 1999). Groundwater exploration is gaining more and more importance in Kaduna owning to the ever increasing demand for water supply, especially in areas with inadequate pipe-borne and surface water supplies. With the advances in technology, hydrogeologists and geophysicists resorted to geophysical methods such as very low frequency, direct- current resistivity sounding, resistivity imaging, self-potential (SP), electro kinetic and magnetic methods to locate groundwater. Direct current resistivity sounding which uses four electrode configurations provides 1D model of resistivity variation with depth only below the central point of the array and this may hinder the efficiency of groundwater prospecting in dry metamorphic terrains. This type of electrical resistivity survey sometimes fails to locate water-bearing zones between two points of study. Therefore, a more accurate subsurface model would be the 2D model, where resistivity changes in the vertical as well as horizontal direction are presented. This problem is overcome by the development of 2D electrical resistivity imaging technique using multi-electrode electrical resistivity imaging (ERI) system and effective data processing software based on inversion techniques. The main advantages of the survey using multi-electrode ERI system are: (1) fast computer-controlled data acquisition, (2) simultaneous study of both lateral and vertical variation of resistivity below the entire spread length of the profile and (3) increased resolution of the computed images of the subsurface geological formation due to large amount of data acquisition. Such surveys are usually carried out using a large number of electrodes, 24, 48, 64 or more, connected to a multi-core cable. A laptop together with an electronic switching unit is used to automatically select the four relevant electrodes for each measurement. The ERI technique is being extensively used in groundwater prospecting, geotechnical problems and environmental studies (Ratnakumari et al, 2012). Azimuthal resistivity measurement is a modified resistivity method where the magnitude and direction of the electrical anisotropy are determined. An electrode array is rotated about its center so that the apparent resistivity is observed for several directions (Taylor and Flaming, 1988). It is generally assumed that the anisotropy is caused by presence of fluid – filled fractures in a relatively resistive rock or soil. It has been shown by (Odeyemi et al, 1985; Beeson and Jones, 1988; Okereke et al, 1993; Esu, 1993 and Edet et al., 1994) that the well yield in fractured rocks is directly related to the density, frequency, orientation and inter-connection of structural features at depth. One of the key problems with azimuthal resistivity method is its sensitivity to lateral heterogeneities. A site exhibiting significant lateral changes in resistivity can produce azimuthal resistivity measurements where the effects of anisotropy are entirely masked by the effects of heterogeneity. Much of the published work based on this method does not account for the possibility of data corruption from lateral changes in resistivity and in fact might be presenting erroneous conclusion (Watson and barker, 1999).Watson and Barker (1999) and Busby (2000) present argument that at site where the electrical anisotropy is to be determined based on single isolated measurements, only the offset Wenner electrode array should be used. The offset Wenner array identifies observations that only true electrical anisotropy is interpreted. The offset Wenner array does not, however, allow any interpretation of anisotropy at sites dominated by heterogeneity. The present work deals with the delineation of aquifers concealed within and below the traps in Precambrian terrain using 2D ERI and OffsetWenner techniques. Details about the study area are as follows.

2. GEOLOGIC AND HYDROLOGIC SETTINGS OF THE STUDY AREA

The Geophysical investigation was carried out at the Kaduna Polytechnic Demonstration Secondary School in Kaduna North Local Government Area of Kaduna State. The area of the survey covered approximately 195 m^2 and bounded by latitude $10^o31'$ N and longitude 7^o25E.The study area is approximately 50 m south-west of Kaduna Polytechnic Main Campus. Precambrian basement complex rocks underlie the entire area of Kaduna (Figure 1) and they consist of migmatite gneiss complex, metasediments/metavulcanics (mostly schist, quartzite, amphibolites and banded iron formation, pan African granitoids and calc-alkaline granites, and volcanics of Jurassic age (McCurry, 1976). The relief of the area ranges between 370 and 650 m (Aboh, 2002: Mamman, 1992). Groundwater in the area has not been adequately developed and as such data relating to their magnitude and mode of formation are lacking. However in the Basement complex, the permeability and storativity of the groundwater system are dependent on structural features such as the extent, and volume of fractures together with thickness of weathering (Eduvie, 1998; Clark, 1985). The relatively high annual rainfall (1270 mm) and temperature (32^0C) in Kaduna, which has resulted in the formation of deep weathered zone in addition to high density of fractures have contributed tremendously to constituting large reservoirs of groundwater, good aquifers and high yields of boreholes (Eduvie, 2003). Geophysical investigation and borehole drilling reports have clearly established two major aquifers. These are the overburden weathered aquifer and the fractured crystalline aquifer (Eduvie, 1998; Dan-Hassan, et al, 1999). Both aquifers at some places are interconnected and form a hydro geological unit of water table surface.

3. METHODS OF STUDY

3.1 2D Electrical resistivity Imaging

A total of 3 multi-electrodes 2D geoelectrical resistivity imaging lines were measured with the aid of Abem SAS 300 model resistivity meter using the Wenner-alpha array. A manual data collection technique was employed (Fig.2). The length of the 2D traverses varies from 180.0 m to 145 m in length and the electrode spacing ranged from 3.0 to 39.0 m in an interval of 3.0 m, with a total of 61 and 57 electrode positions for traverse A, B and C respectively. This gives a total data level of 13 for each traverse so that data points of 146, 145 and 142 were observed for traverse lines A, B and C respectively.

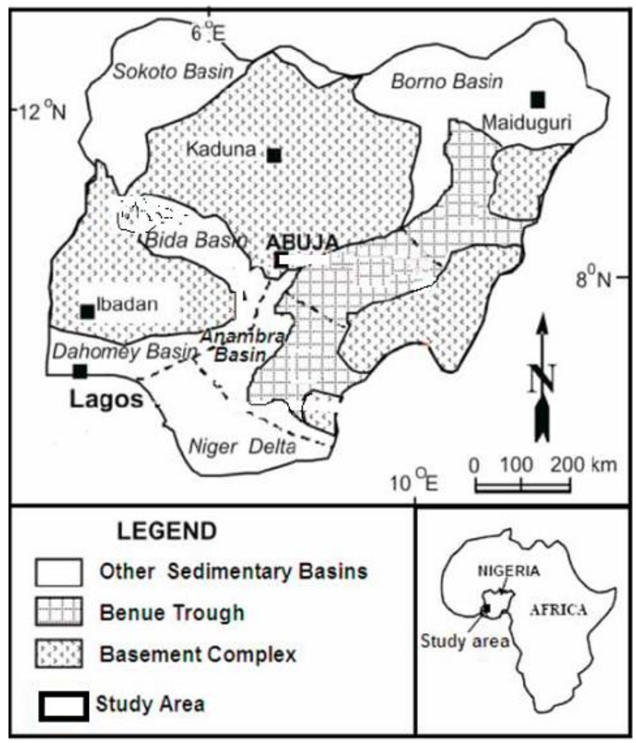

Figure 1. Geologic map of Nigeria showing the study area

The measurements commenced at the south end of each traverse with electrode spacing of 3.0 m at electrode positions 1, 2, 3 and 4 in each 2D traverse. Each electrode was then shifted a distance of 3.0 m (one unit electrode spacing), the active electrode positions being 2, 3, 4 and 5. The procedure was continued to the end of the traverse line with electrode positions for the last measurement being 159, 162, 165 and 168. The electrode spacing was then increased by 3.0 m, as noted above, for measurements of the next data level, such that the active electrode positions were 1, 3, 5 and 7. The procedure was then repeated by shifting each of the electrodes a distance of 3.0 m (one unit electrode spacing) and maintaining the electrode spacing for the data level until the electrodes were at electrode positions 144,150, 156, and 162. This procedure was continued until 13 data levels were observed, yielding a total of 146,145 and 142 data points in A, B and C traverses respectively. The resistivity meter was set on resistance mode and these readings were then recorded. The observed resistance values were used to compute the apparent resistivity values. The apparent resistivity values for each traverse were collated in a format that is acceptable by the RES2DINV inversion code. The data analysis was performed using the RES2DINV resistivity inversion processing software, which performs smoothness constrained inversion (automatic model interpretation) using finite difference forward modeling and quasi – Newton techniques (Loke and Barker 1996).

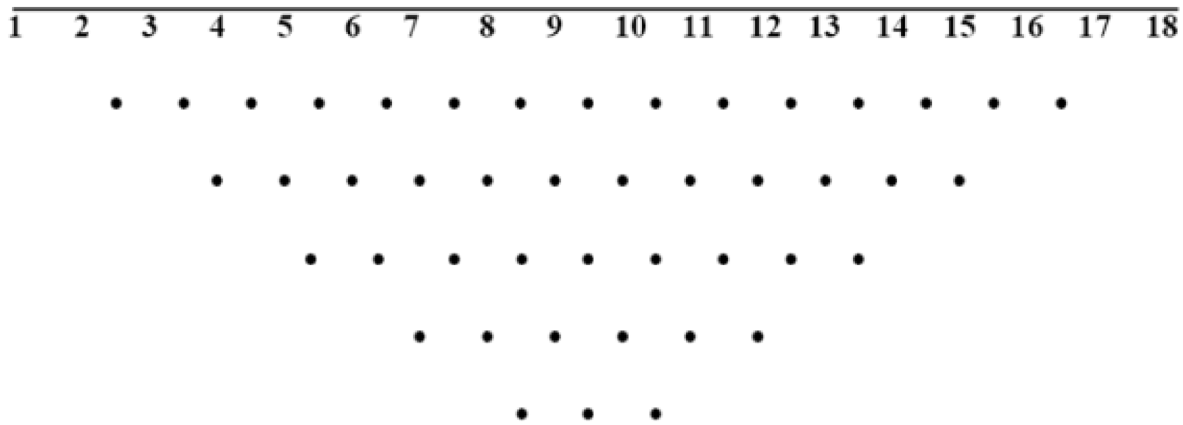

Figure 2. The arrangement of electrodes for a 2-D electrical survey and the sequence of measurements used to build up a pseudosection (After Aizebeokhai, 2010)

3.2 OffsetWenner Array

The offset Wenner method is an improvement of the Wenner array which 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} (Fig. 3). Analysis of the behavior of these two Wenner resistances as a function of both the azimuthal and electrode spacing can enable differentiation between the true anisotropy and other geological models (Watson and Barker, 1999). A maximum of 24 m electrode separation (a) was used for the offset Wenner array due to space constrain and the data was investigated for eight azimuthal directions (30 ^{0}interval). Apparent coefficient of anisotropy was calculated using the relationship (Mota et al., 2004):

$$\lambda_a = \sqrt{\rho_{max}/\rho_{min}} \quad (1)$$

Where ρ_{max} is the apparent resistivity measure along the ellipse major axis; ρ_{max} apparent resistivity measure along the ellipse minor axis direction. Resistivity, as a function of azimuth in Cartesian coordinates, were plotted to produce polygons of anisotropy.

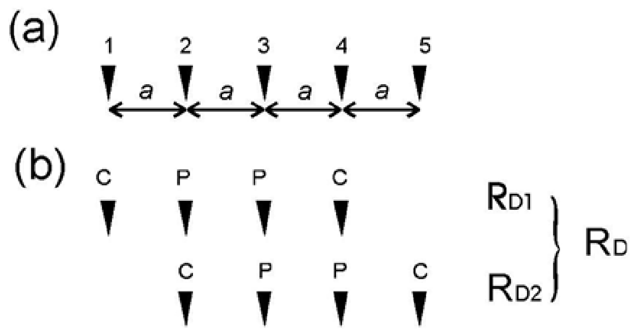

Figure 3. Offset Wenner electrode arrangement and resistance measurement.
a) The five equally spaced electrodes,
b) the measurement of the two resistances R_{D1} and R_{D2}, the average of which provides R_D. P and C are potential and current electrodes respectively and a is the electrode spacing(After Watson and Barker, 2005)

4. RESULTS AND DISCUSSIONS

Fig 4 shows the result of the 2D resistivity data collected with minimum electrode spacing of 3m. The length of the profile is 196 m. The inverse resistivity model section shows high resistivity at *x* = 59 m, with resistivity value of 1977 ohm-m. The depth to basement at this point is shallow about 6 m. This zone is interpreted as the Fresh Basement (Granite) rock. There are low resistivity zones between *x* = 9 m to 42 m as well as between *x* =108 m to

141 m with resistivity values ranging from 50 ohm-m to 144 ohm-m. This is interpreted as medium to coarse sand.

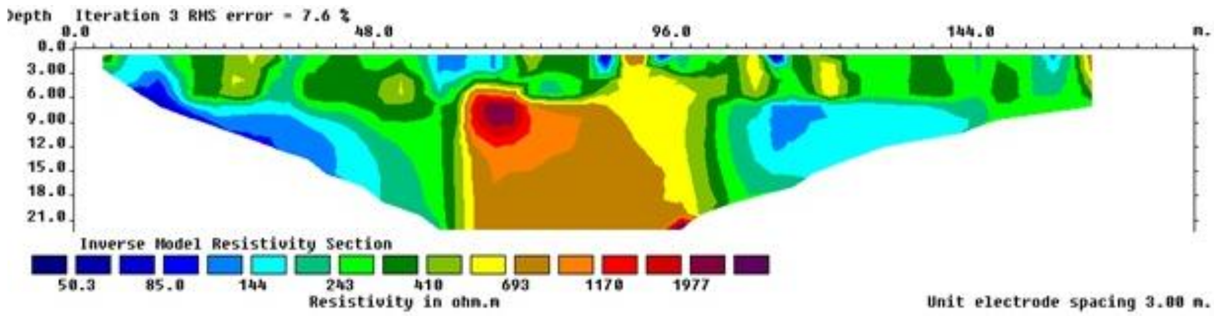

Fig. 4 2D resistivity model along traverse A

The resistivity image profile for traverse B shows significant, well-defined geological features (Fig 5). Rocks with low resistivity were observed at depths of 0 m to about 6 m area of the profile (from a distance of 0 m to about 100 m). This is likely wet soil. At profile position *x* = 78m – 102 m there is high resistivity zone at depth of 21 m. With a resistivity value 1488 ohm-m, it could represent granite rock.

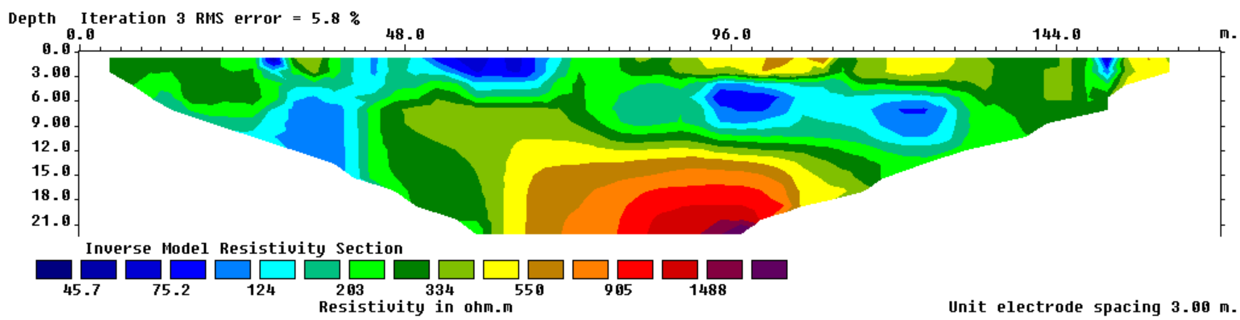

Fig. 5. 2D resistivity model along traverse B

Figure 6 shows the result of 2D resistivity data collected with minimum electrode spacing of 3m along profile C. The length of the profile is 162 m, and the inverse model shows four resistivity zones. Looking at the invers resistivity model from the surface down to about 9 m depth, there is a low resistivity zone. This zone with resistivity value of 15.4 ohm-m is typical of unconsolidated wet clay. At a distance of about 66 m to 87 m, a possible fracture in the profile can be inferred. On these positions, there is low resistivity zone flanked on both side by high resistivity zone (1798 -3978 ohm-m).

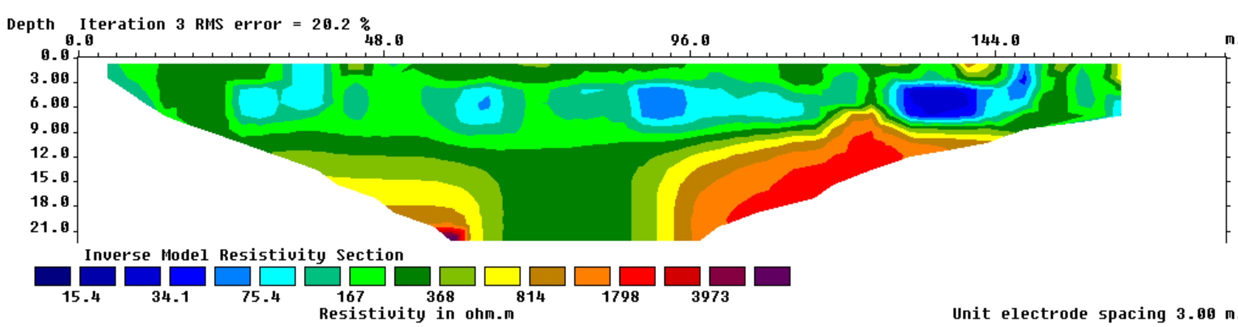

Figure 6. 2D resistivity model along traverse C

Figure 7 presents the results of the Offset-Wenner azimuthal resistivity survey besides the inferred fracture along traverse C (between x = 66 m to 87 m).Cartesian azimuthal graphs using the Offset Wenner data at the 18 m & 24 m electrode spacings were produced (Fig 7a). From the Figures, it is apparent that the ground is homogeneously anisotropic as the values of R_{D1} and R_{D2} for both electrode spacings rise and fall together according to the orientation of the configuration. The maximum variations delineating the strike of the beds occurred at 60°/240° for both the electrode spacings respectively. Figure 7b is the corresponding Offset Wenner array radial graphs of R_D (obtained from the mean of R_{D1} and R_{D2}).The figures produced are generally elliptical, which are departures from the circular pattern characteristics of a homogeneously isotopic subsurface. The coefficient of anisotropy (λ_a) varies from 1.42 and 1.95. These values are diagnostic of anisotropic medium given that for homogeneously isotropic medium, λ_a = 1. The direction of maximum apparent resistivity which is interpreted as the principal axis of fracturing anisotropy is observed to lie in the NE-SW direction for both electrode spacings (18 and 24 m). This conforms to the major geologic trends in basement complex of north western Nigeria.

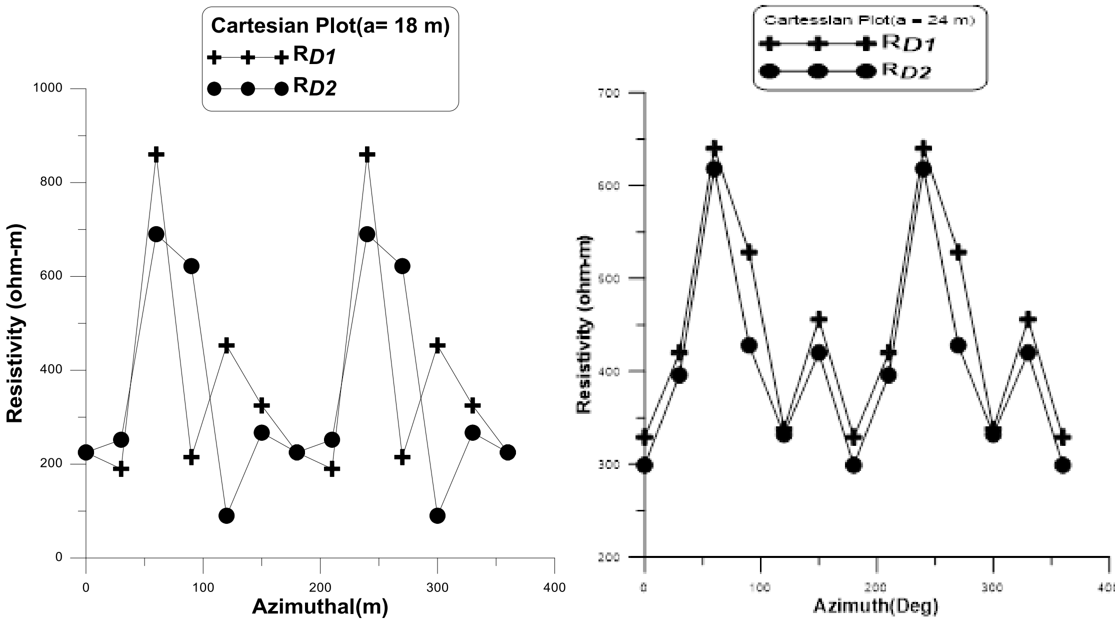

Fig.7b: Cartesian graphs of electrode spacing of a = 18 and 24 m along traverse C

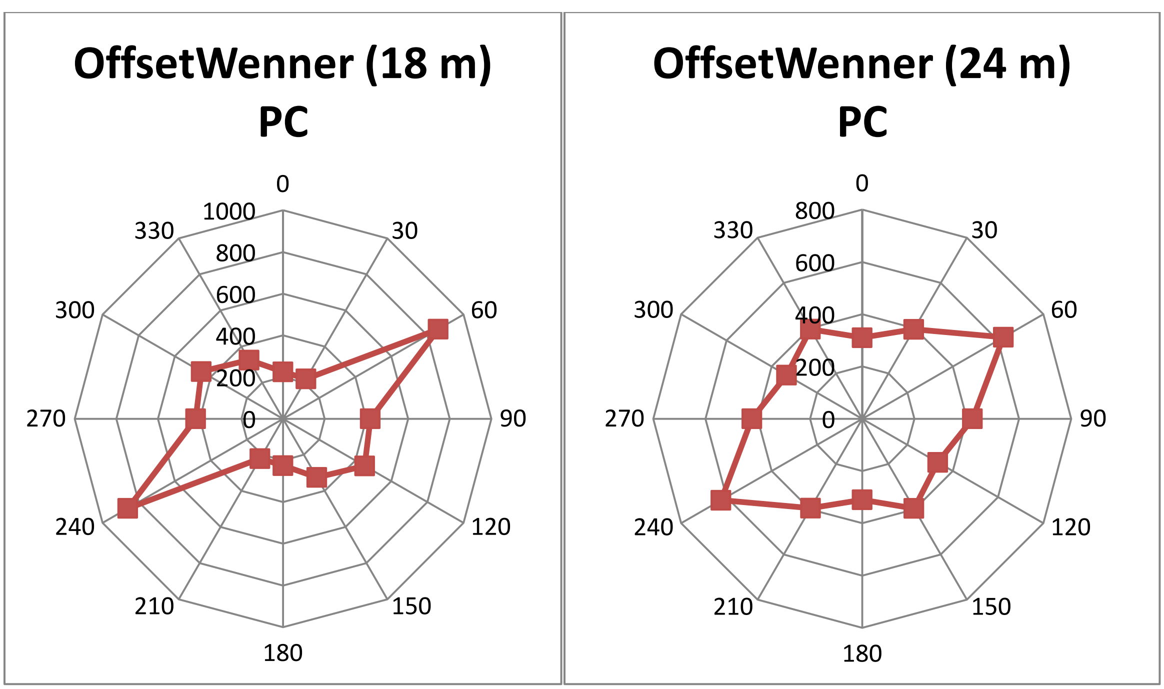

Figure. 7b: Offset Wenner sounding diagrams of azimuthal resistivity survey along traverse C

5. CONCLUSION

Resistivity models suggest that the hydrogeology of the studied area is highly complex and the 2D electrical survey has successfully identified potential zones of groundwater in such a heterogeneous environment. Resistivity models produced by inverse modeling of measured apparent resistivity data indicate the presence of fracture zone along traverse C that could be exploited for groundwater extraction. The Azimuthal offsetWenner techniques conducted besides the inferred fractured zone supported the conclusion of existence of fracture zone in the study area. Strong anisotropic effect is observed at electrode spacing of 24 m. The coefficient of anisotropy is significant at this depth with λ_a equal to 1.42. Principal axis of fracturing anisotropy is observed to lie in the NE-SW direction in the study area.

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