Application Of Electromagnetic Method And Electrical Resistivity Sounding In Hydrogeological Studies, A Case Study Of Vandeikya Area, Central Nigeria

Jika, H.T, Mamah, L.I

Abstract: VLF-EM profiles and Schlumberger depth soundings were carried out in Vandeikya area of Central Benue Trough of Nigeria. The area is underlain by both sedimentary and Basement complex rocks.Groundwater potential and aquifer characteristics of the area were analized using Dar Zarrouk parameters. The geoelectric data acquired were interpreted using partial curve matching, IX1D, Surfer, Grapher and Win-Resist software programmes. The qualitative interpretation of VLF-EM results identifies areas of hydro-geologic importance and forms basis for Schlumberger depth soundings. The study shows that most aquifers in the area lie between the second and the third layer with resistivity varying from 29.5-232.7Ωm. The thicknesses of aquifers in the area vary between 7.3-38.0m. Overburden thicknesses in the area vary between 0.9-6.7m. The study shows that aquifers in the area are prolific with the exception of VES 8 and VES 10 with poor hydrogeologic significance. Dar Zarrouk parameter of longitudinal conductance revealed that transmissivity within the area ranges from 0.49-13.99m^2/day.However hydraulic conductivity in the area ranges from 0.0671-1.7124. Correlation coefficient between the modeled transmissivity and hydraulic conductivity gave R^2 value of 0.8249 which signifies a perfect correlation.

Key words:VLF Electromagnetic method,resistivity sounding,Dar Zarrouk parameters,Transmissivity,aquifer thickness, overburden thickness and Central Benue Trough.

1.0Introduction

Groundwater has been identified as the best source for rural water supply in most rural communities in Vandeikya, Central Nigeria because it eliminates the problems of waterborne diseases which have affected communities in the region over the years. Waterborne diseases are not totally eradicated in the area and there are signals that its occurrence will be increasing in the near future if adequate measures are not implemented to curtail the problem. It is on this basis that this study was carried out to determine the groundwater potential of the area. In the field of geophysics different geophysical methods respond differently to certain parameters. Seismic method respond to differences in acoustic impedance in the different geologic layers, gravity respond to differences in density contrast, magnetic method respond to differences in magnetic susceptibility of the rock unit, electrical method respond to differences in resistivity while electromagnetic method respond to differences in conductivity of rocks Telford etal (1990).The resistivity of subsurface materials depends more on the pore volume including fractures, degree of saturation, weathering and conductivity of the saturant than on the rock type. The resistivity method is used to determine the depth to the aquifer, thickness of the aquifer and quality of groundwater Badmus etal (2010).In the study of basement terrain in North Western Nigeria revealed that crystalline basement in this region can only be exploited for hydrogeology where there are fractures and faults Edet (1990). Boreholes sited on high conductivity anomalies penetrates thicker regolith and with high yield while those on conductivity lows penetrates a thinner regolith with relatively lower yield Olayinka (1990). Chemical characteristics of groundwater from different parts of the basement complex rocks of the area were studied. Groundwater samples were collected from boreholes in the basement complex rocks of the area. The results were evaluated with a view to determine its quality and portability. Generally, these chemical characteristics compare well with those of the groundwater from other basement areas but differ in many respects from those in sedimentary terrain (Ushie and Amadi, 2008). Zohdy (1989) developed a fully automatic method for the interpretation of Wenner and Schlumberger sounding curves, which produces a model with a multilayered variation of the resistivity with depth. The model consists of horizontal layers where the number of layers is equal to the number of data points on the sounding curve. If a line of soundings is measured, the resulting models combined to produce a contoured section of the subsurface. Hydraulic conductivity of clayey sediment could be linked to electrical resistivity through the concept of clay content and that high clay contents generally correspond with low resistivity and hydraulic conductivity Henriet (1976).Transverse resistance is the dominant parameter for a layer when electrical current tends to flow perpendicular to the bedding and therefore controls the shape of a K-shaped sounding curve, where the middle of the three layers is of higher resistivity, besides when electrical current flows parallel to the bedding as in an H-type curve, the longitudinal conductance is the dominant parameter Frohlich et al (1985)

1.1 Location of the study area

The area of the present study is situated in South Eastern part of Benue State. It is bounded by longitudes 9^0 00´00"E and 9^0 11´00"E and latitudes 6^0 38´00"N and 6^0 59´00"N (fig.1). The area is dominated by undulating terrain with much of the area being below 183M (600ft) above sea level and some parts higher than the stated value. The study area is drained by numerous small streams. In the northern part of the area, it is drained by River Sambe, flowing from east to west. In the Central part and the southern part of the study area, it is being drain by River Be and River Aya, which flows east to West and Northwest to southwest respectively. The drainage pattern is controlled by the undulating nature of the area.

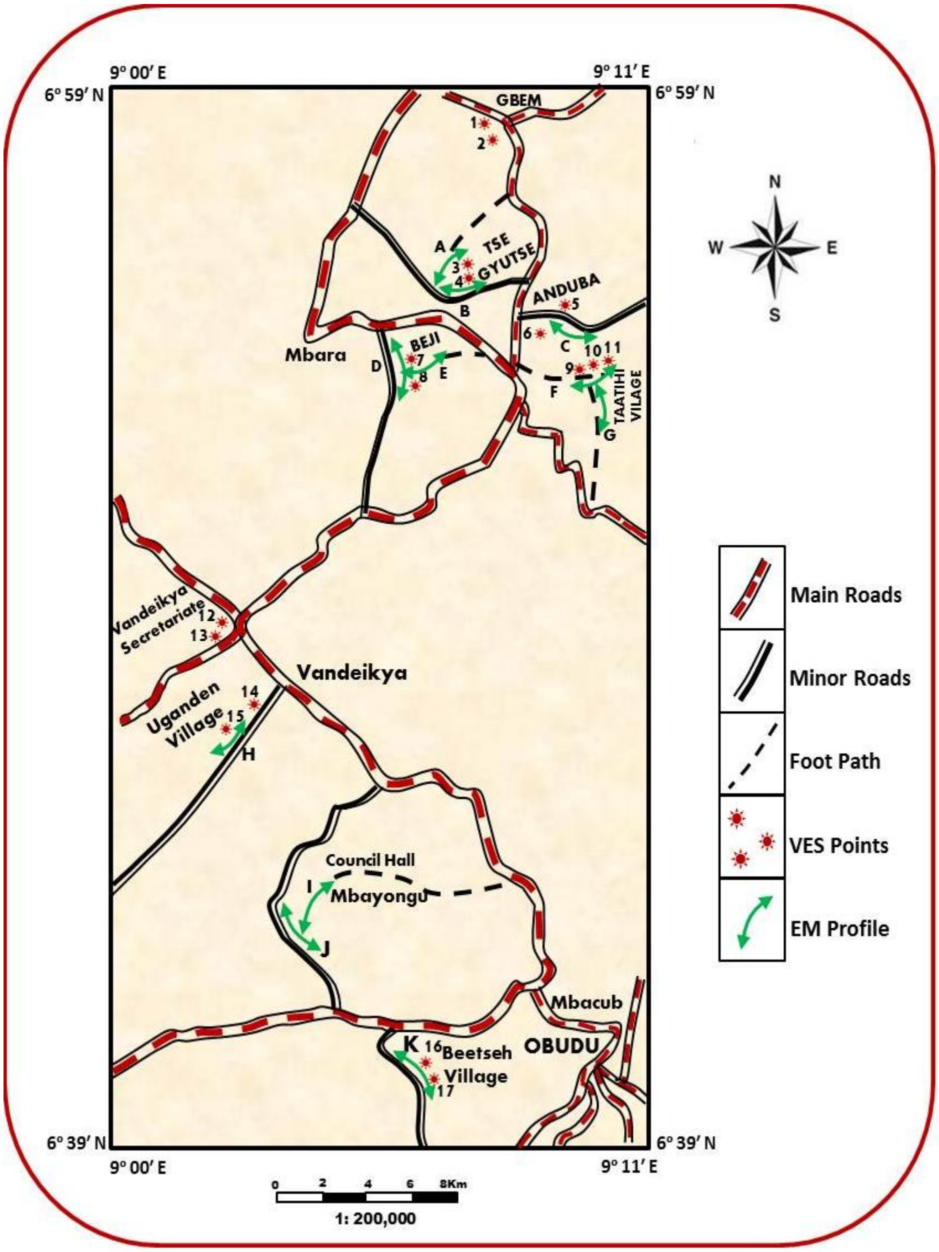

Fig. 1 Map showing location of EM profiles and VES points in the study area

1.2 Geologic Setting

Geologically the area comprises of both sedimentary and basement complex rocks (fig.2). The sedimentary terrain falls within the Central Benue trough of Nigeria which is believed to be structurally developed. The basement complex rocks of the study area were formed during the Pan African Orogeny with the following rock units; granite gneiss, migmatites, charnockitic and gneiss Kogbe etal (1989). The oldest Aptian-Cenomanian successions of the Asu River Group consists of arkosic sandstones, volcaniclastics, marine shales, siltstones and limestones which overly the Pre-Cambrian to Lower Paleozoic crystalline basement rocks. The arkosic sediments were derived principally from the extensive weathering of the basement rocks which were invaded by alkaline basaltic rocks prior to the initial rapid marine flooding of the Middle Albian times. This first Albian-Cenomanian successions are overlain by the Eze-Aku and Awgu Formations (Turonian-Coniancian) consisting predominantly of marine shales, calcareous siltstones, limestones and marls Akande etal (2011).

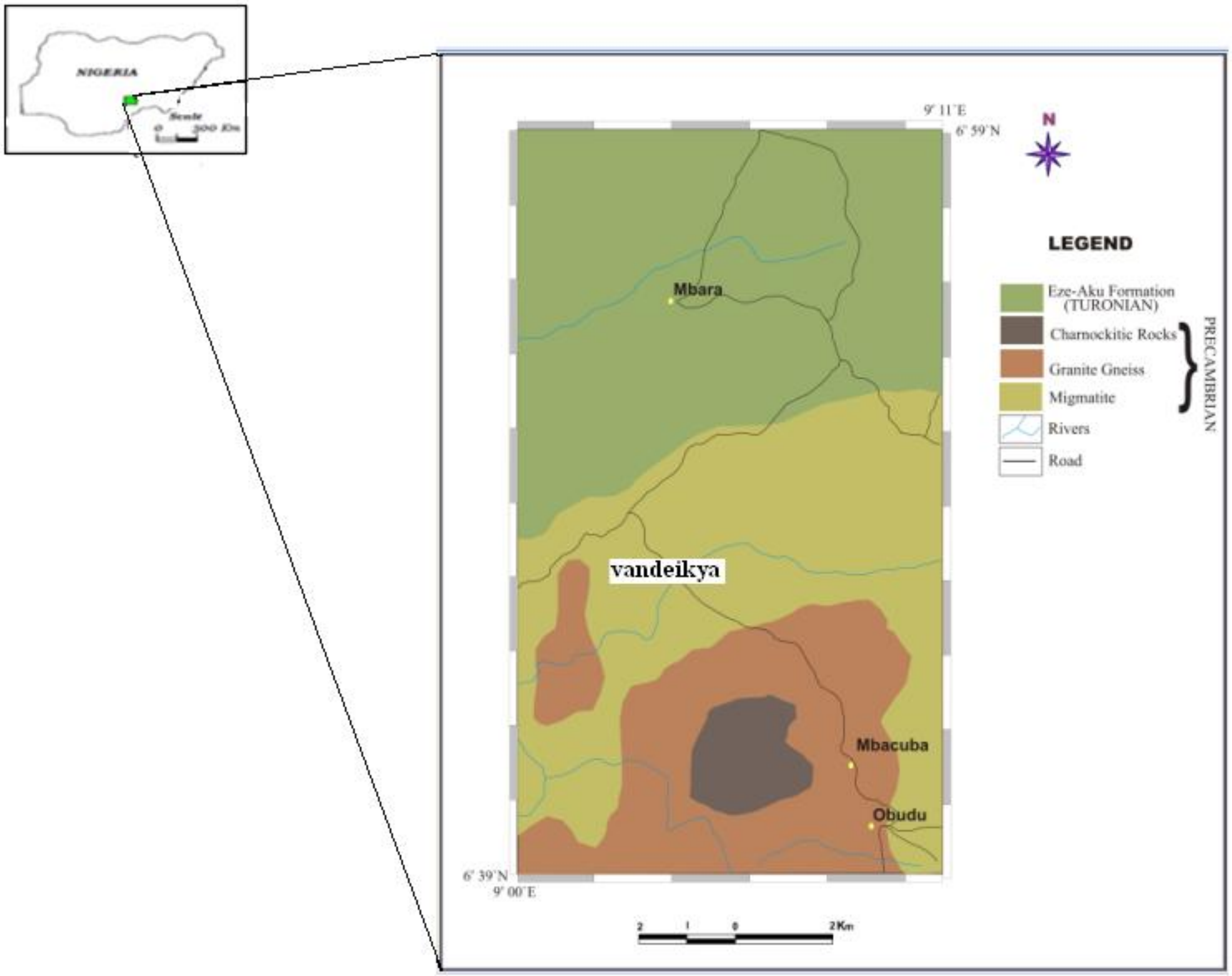

Fig. 2 Geology map of the study area (Modified from Nigerian Geological Map of Benue State 2004)

2.0 Materials and Methods

The Geonics EM-34 conductivity meter was used in the study to take profiles in some selected communities in the area with inter-coil spacing of 20m. Areas of conductivity highs were basis for sounding using ABEM Terrameter SAS 300C and employing Schlumberger electrode configuration.

2.1 Basic principles of electromagnetic surveying

Electromagnetic field is generated by passing an AC through a wire coil {transmitter}. EM field propagates above and below ground. If there is conductive material in the ground, magnetic component of the EM wave induces eddy currents {AC} in the conductor. The eddy currents produce a secondary EM field which is detected by the receiver (Klein and Lajoie, 1980).The receiver also detects the primary field {the resultant field is a combination of primary and secondary which differs from primary field in phase and amplitude}.The Out of phase {or quadrature phase} component, using certain simplifying assumptions, can be converted to a measure of apparent ground conductivity.

2.2 Basic Principles of DC Resistivity Method

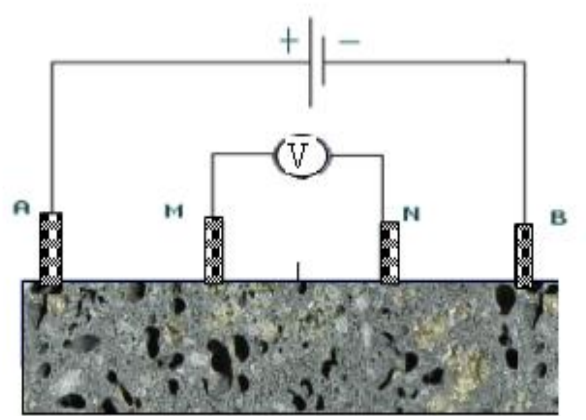

Fig. 3 Electrodes arragement for a dc resistivity survey

Surface electrical resistivity surveying is based on the principle that the distribution of electrical potential in the ground around a current-carrying electrode depends on the electrical resistivity and the distribution of surrounding soils and rocks. The usual practice in the field is to apply an electrical direct current (DC) between two electrodes implanted in the ground at positions A and B and to measure the difference in potential between two additional electrodes that do not carry current M and N (fig.3). Usually the potential electrodes are inline between the current electrodes, but in principle they can be located anywhere. The current used is either direct current, commutated direct current (i.e., a square-wave alternating current), an AC of low frequency (typically about 20HZ). In 1827, George Ohm defined an empirical relationship between the current flowing through a wire and the voltage potential required to drive that current.

$$R = \frac{V}{I} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \{1.1\}$$

Where I, is the current, V, is the voltage and R, is the resistance.

The resistance of a wire is also directly proportional to the distance between the electrodes and inversely proportional to the cross-sectional area and the relationship is given by

$$R = \frac{\rho L}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \{1.2\}$$

ρ= Constant of proportionality {resistivity}; L= Distance between the electrodes; A= Cross-sectional area.
Combining equations 1.1 and 1.2

$$\frac{V}{I} = \frac{\rho L}{A}$$

From the above relationship the potential at any point is given by

$$V = \frac{\rho IL}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \{1.3\}$$

Since the wire is cylindrical in shape, hence

The area =2ΠrL =A……………………………… {1.4}

Substituting for A in equation {1.3}

$$V = \frac{\rho IL}{2\pi rL}$$

$$V = \frac{\rho I}{2\pi r} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \{1.5\}$$

V is the potential in volts, ρ is the apparent resistivity and r is the distance from the electrode.

2.3 Dar Zarrouk Parameters in Aquifer Characterization

Dar Zarrouk parameters consist of the transverse resistance (R_T) and longitudinal conductance (L_C). For a horizontal, homogeneous and isotropic layer, the transverse resistance R_T (Ωm^2) is given by

$R_T = \rho h$ .... {1.6}

While the longitudinal conductance L_C (mho) is given by

(L_C) =h/... {1.7}

Where R_T= Transverse resistance (Ωm^2); ρ= Resistivity (Ωm); h=Thickness of layer (m); L_C= Longitudinal conductance (mho)

Establishing a relationship from Darcy's law

T=Kh...{1.8}

Where T= Transmissivity {m^2/day}; K= hydraulic conductivity; h= Thickness of the layer

Solving for h in equation {1.6} and {1.7} and substituting in equation {1.8}, thus we have

T=K/ρ *R_T..{1.9}

T=KρL_C……………………................................{2.0}

In other words in a clay rich aquifer hydraulic conductivity is directly proportional to resistivity, thus

K∞ρ

K/ρ=C1……..{2.1}

C1= Constant

In an unconsolidated, sandy, clay-free aquifer, a direct relationship exist between hydraulic conductivity and porosity (K∞Ø), while an inverse relationship exist between porosity and resistivity (Ø∞1/ρ) (Frohlich and Kelly. 1985), thus

Kρ=C2………..{2.2}

C2= Constant

Substitute equation {2.1} in to equation {1.9} and equation {2.2} in to equation {2.0} we have

T=R_TC1……...{2.3}

T=L_CC2…..{2.4}

3.0 Results and Discussion

The electromagnetic profiles were carried out in different directions in the area fig. 1. The data were plotted using grapher and surfer software programme to give a conductivity contour map of the area. Thus, areas with conductivity high in the Vertical dipole mode (VDM) signify fractures or weathered zones at depth while areas with conductivity high in the Horizontal dipole mode (HDM) signifies lateral extend of conductivity; fig. 4a, 4b, 5a and 5b. Areas of conductivity high were then selected for schlumberger depth sounding. The data were plotted with Sufer 10 software programme. The result obtained from the EM profiles revealed different conductivity layers represented in colour code fig. 4b and 5b. However, the result obtained from vertical electrical sounding revealed 3-4 geoelectric layers with Winresist software programme fig. 6, 7a and 7b. Thus most of the aquifer in the area lies in the second and third layer with resistivity values varying from 29.5-232.7Ωm.The aquifer thicknesses varying from 7.3-38.0m and overburden thickness of 0.9-6.7m.Inferred geologic section were produced from the resistivity data using grapher software programme fig.8 and 9. Borehole log correlated well with resistivity data (Figure 10).Furthermore, the result obtained from the study is presented in Table 1 and Table 2; however the result revealed that transmissivity with in the area ranges from 0.49-13.99m^2/day. Transmissivity distribution contour map was produced for area (Fig. 12).The transmissivity map revealed that some areas in SW and NE have good transmissivity (Fig. 12). A good correlation coexist between hydraulic conductivity and transmissivity given the correlation coefficient of R^2=0.8249 this signifies that hydraulic conductivity is directly proportional to transmissivity (Fig. 11).

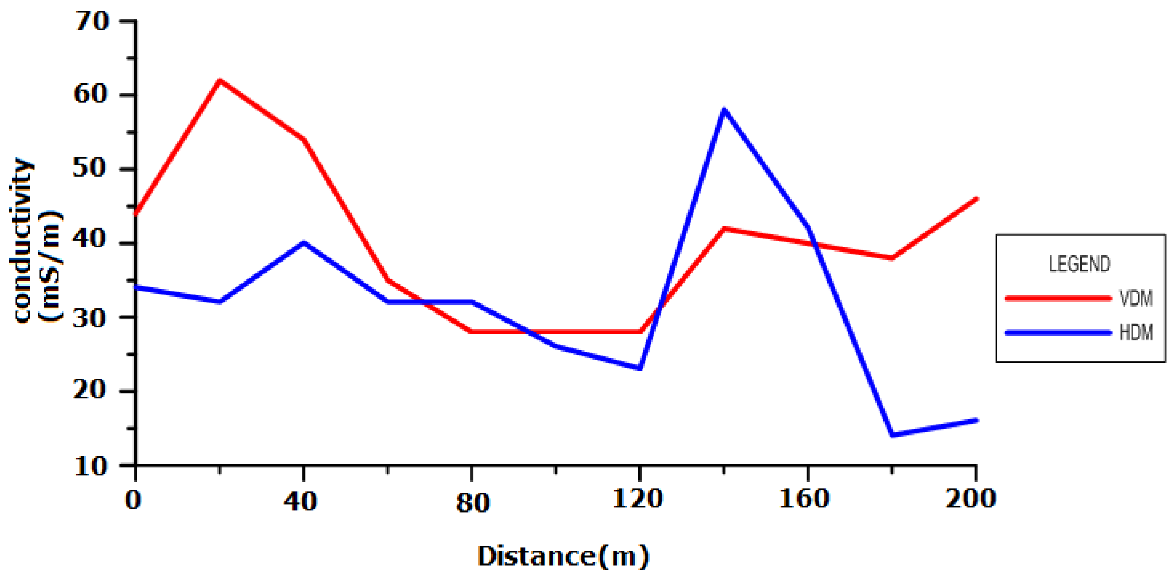

Fig. 4a VLF-EM profile A in Tse Gyutse Community

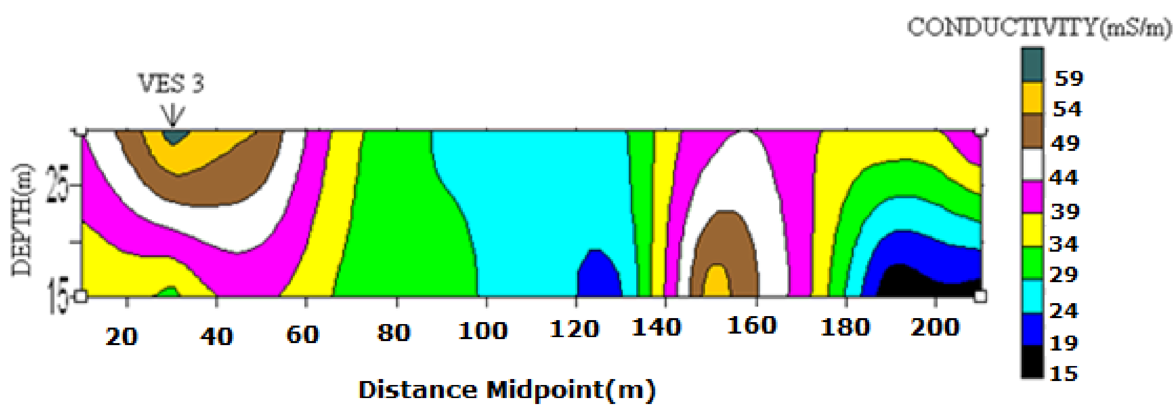

Fig. 4b Conductivity contour map along VLF-EM profile A

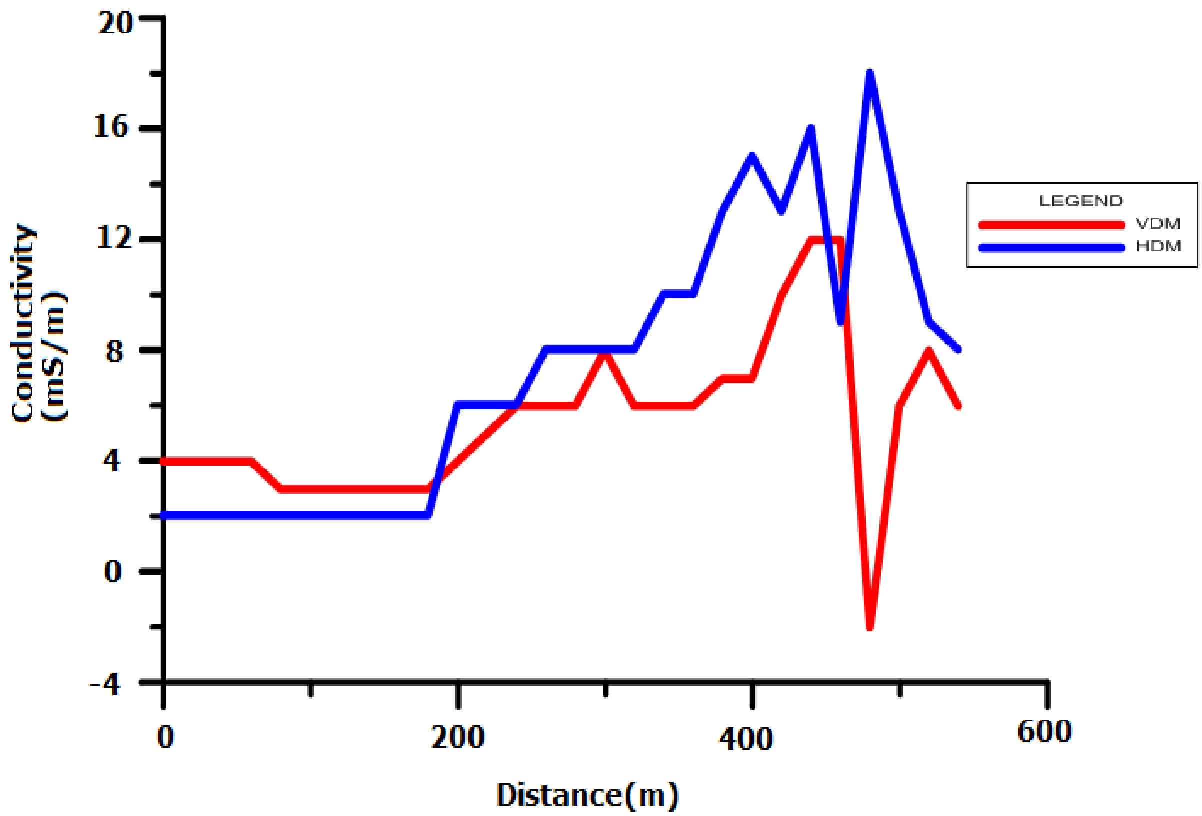

Fig. 5a VLF-EM profile K in Beetseh Community

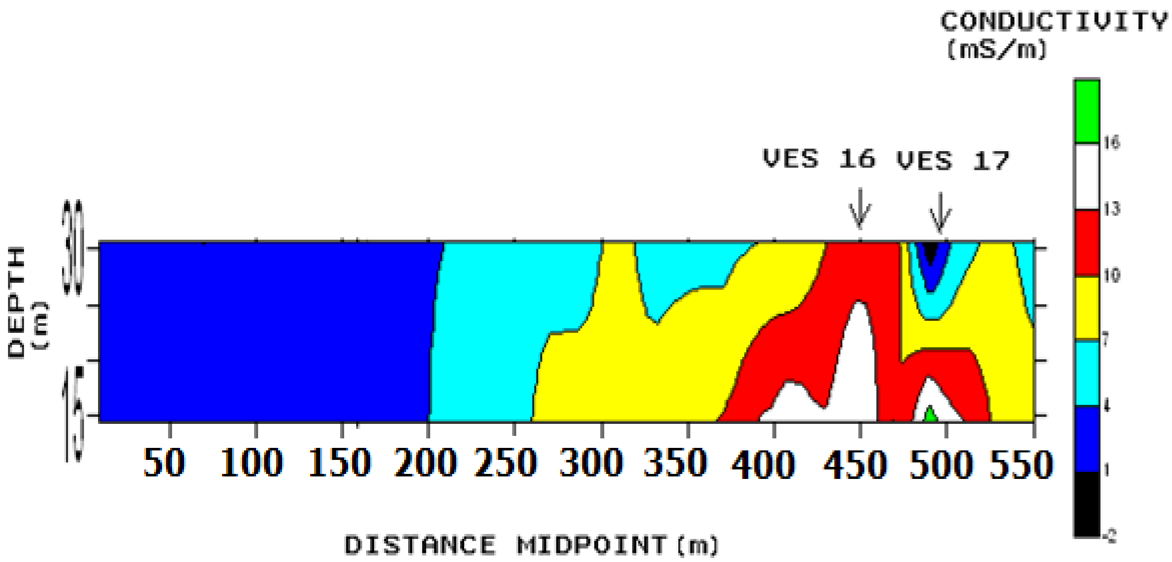

Fig. 5b Conductivity contour map along VLF-EM profile K

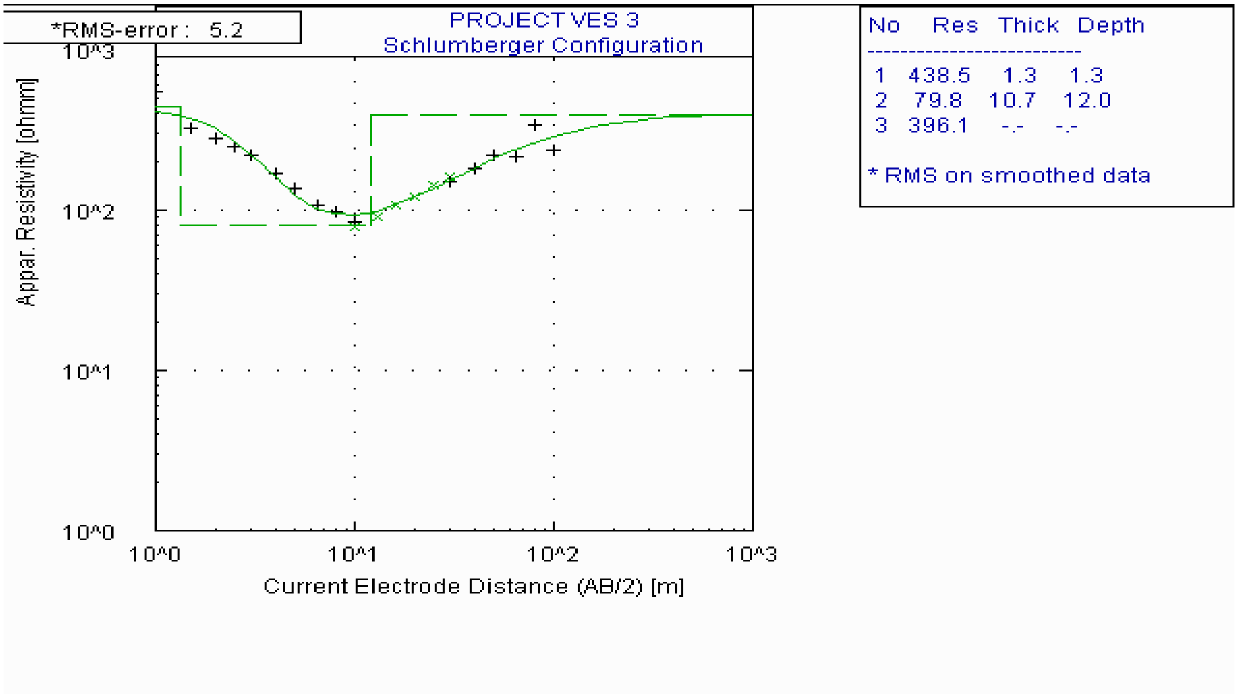

Fig. 6 Inverse model of VES 3 in Tse-Gyutse community

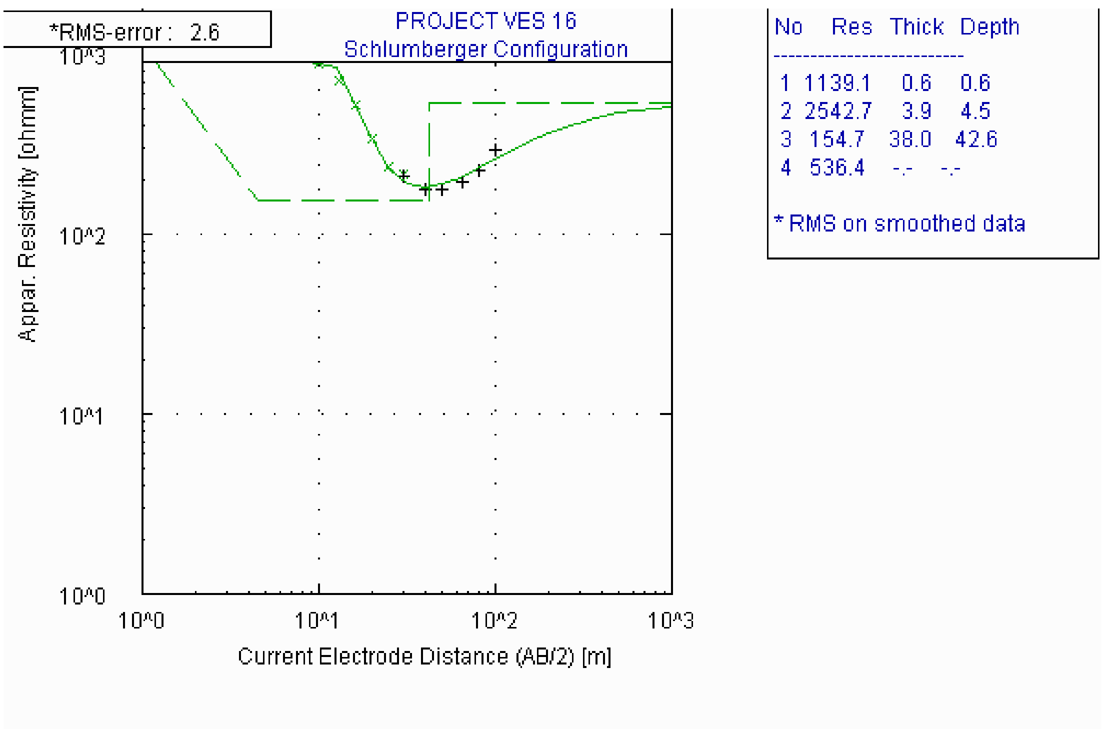

Fig. 7a Inverse model of VES 16, Beetseh Village

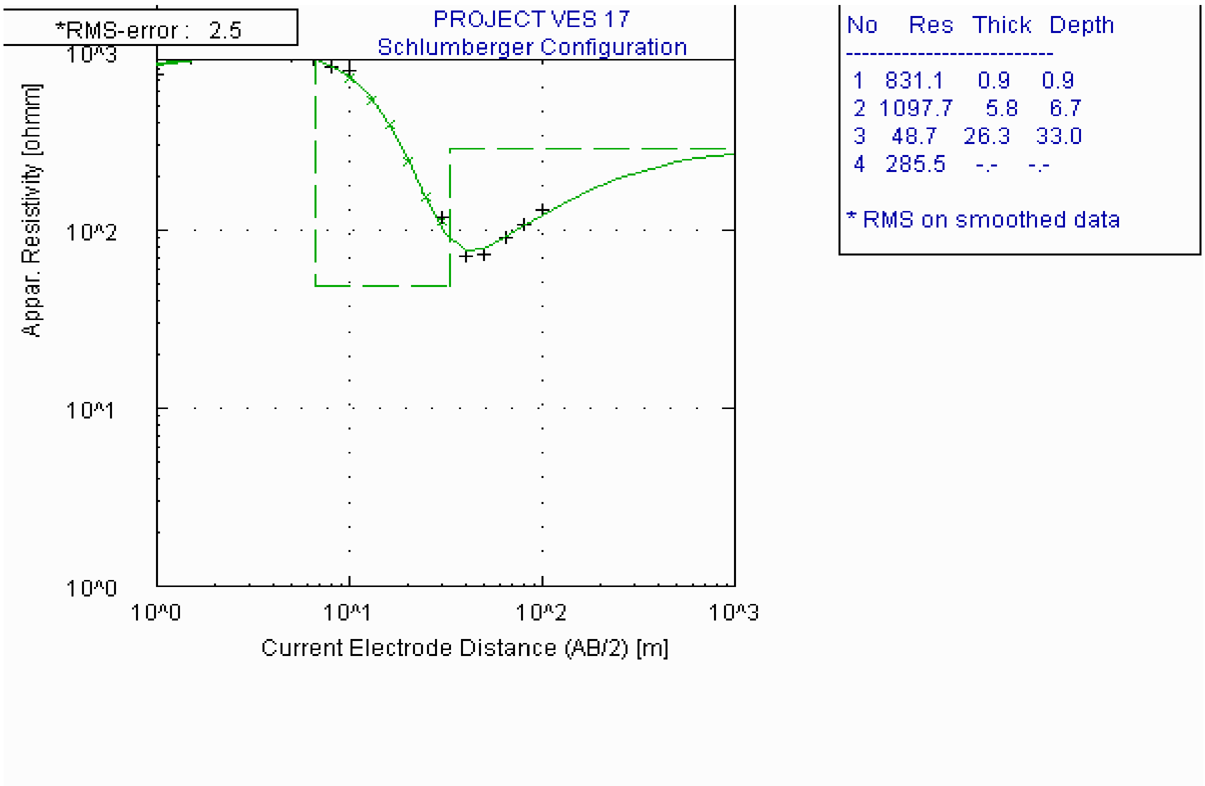

Fig. 7b Inverse model of VES 17 in Beetseh community

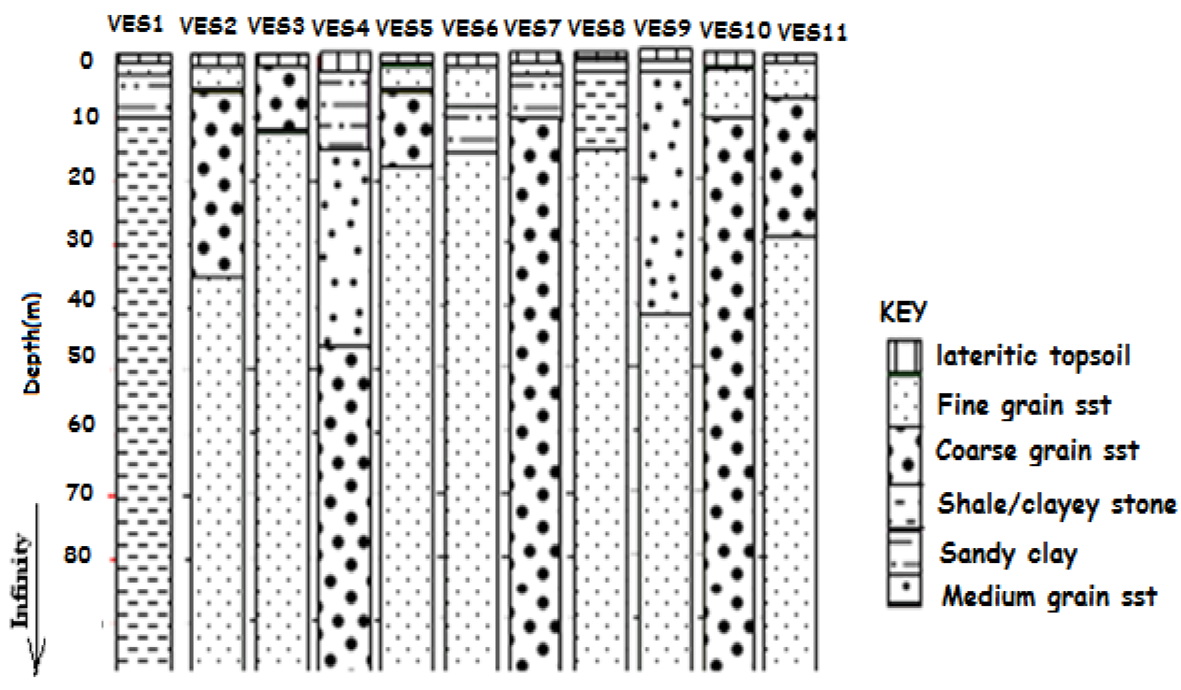

Fig. 8 Inferred lithology in the sedimentary terrain

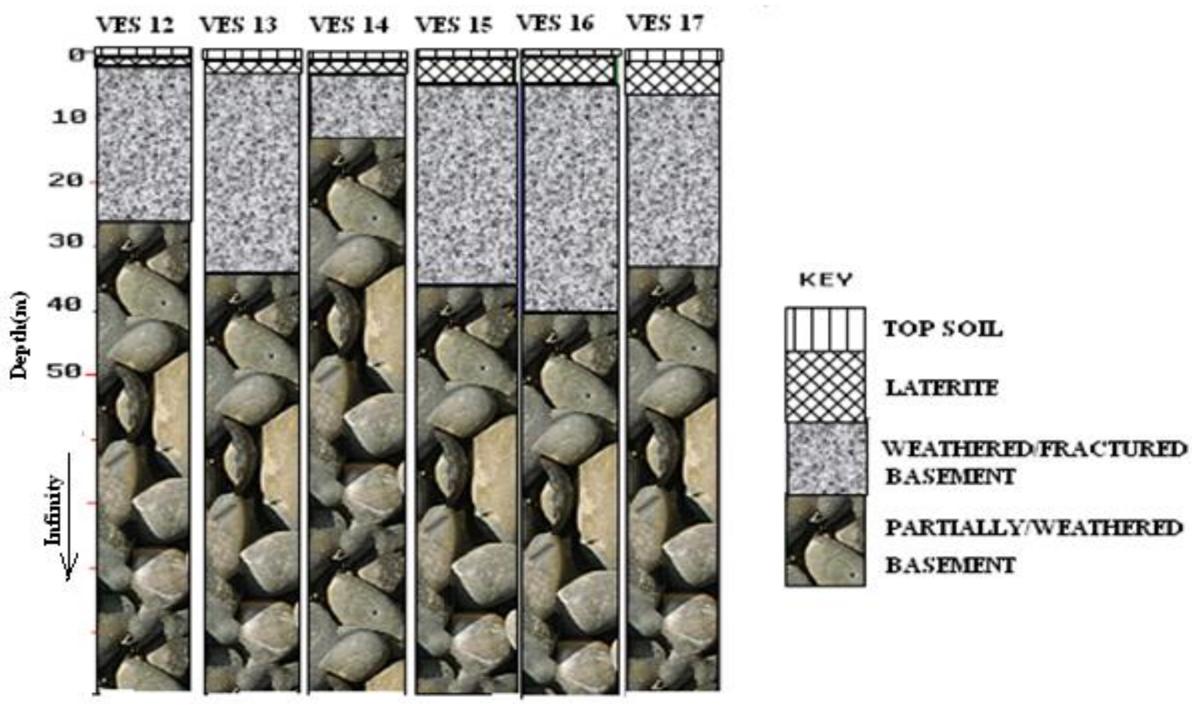

Fig. 9 Inferred lithology in the basement complex terrain

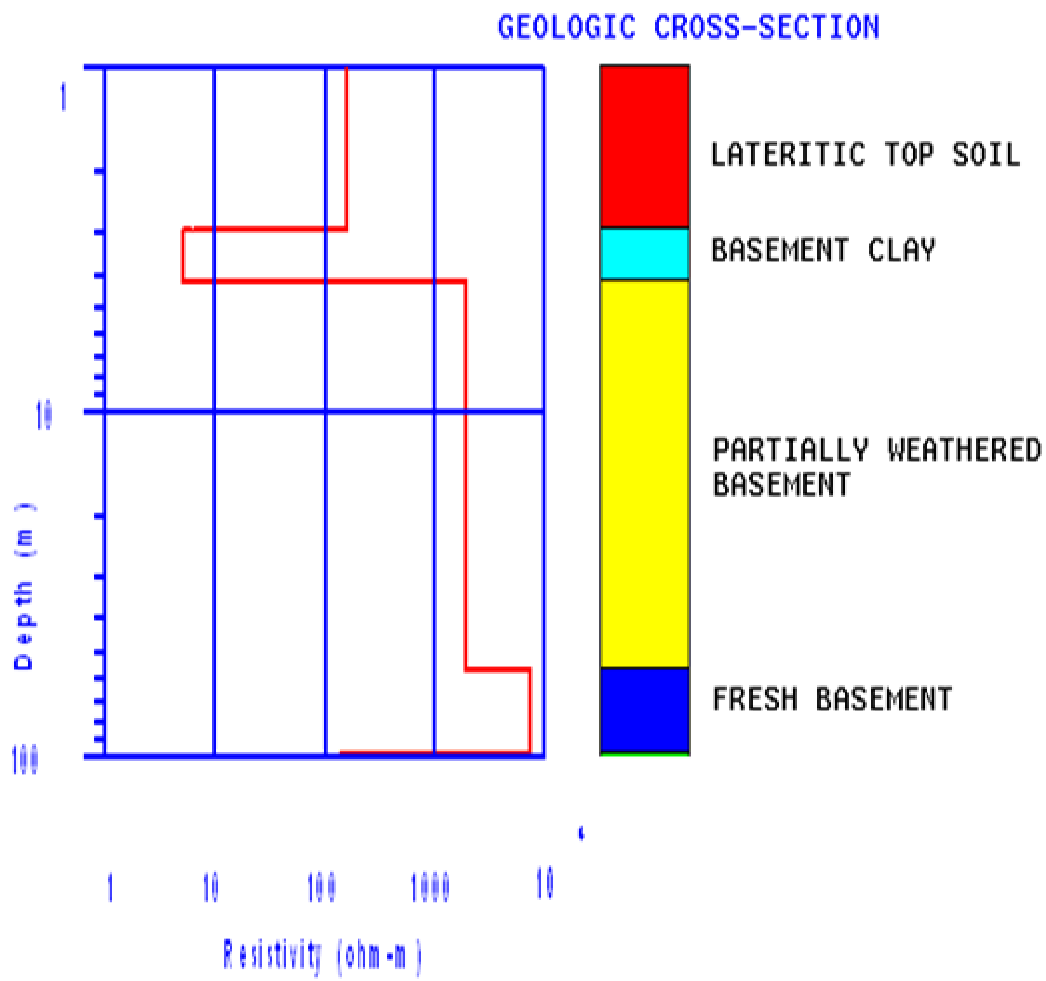

Fig. 10 Geological/Resistivity Correlation at Beetseh Village borehole site (VES 17) using IX1D Software

Table 1 Estimated Modeled Transmissivity from Dar Zarrouk Parameters

S/N	EASTINGS	NORTHINGS	AQUIFER RESISTIVITY (Ωm)	AQUIFER THICKNESS (m)	LONGITUDINAL CONDUCTANCE (mho)	TRANSMISSIVITY (m^2/day)
1	9.13583	6.96972	232.7	7.3	0.03137	0.49
2	9.13833	6.96777	52.1	29.3	0.56238	8.86
3	9.12833	6.925	79.8	10.7	0.13409	2.11
4	9.13083	6.91888	147.4	30.3	0.20556	3.24
5	9.16416	6.90972	84	13.8	0.16429	2.59
6	9.15166	6.90333	37	10.9	0.29459	4.64
7	9.105	6.89194	29.5	7.8	0.26441	4.17
8	9.10583	6.88666	9.2	12.1	Not an Aquifer	Not an Aquifer
9	9.1675	6.88666	202.6	38	0.18756	2.96
10	9.17166	6.89111	160.5	-	-	-
11	9.18055	6.8875	162.7	26.2	0.16103	2.54
12	9.03555	6.81166	37.6	23.8	0.63298	9.97
13	9.03417	6.80333	39.4	35	0.88832	13.99
14	9.0475	6.78111	89.8	9.8	0.10913	1.72
15	9.03888	6.77222	166.2	33.5	0.20156	3.18
16	9.1	6.66472	154.7	38	0.24564	3.87
17	9.10083	6.65833	48.7	26.3	0.54004	8.51

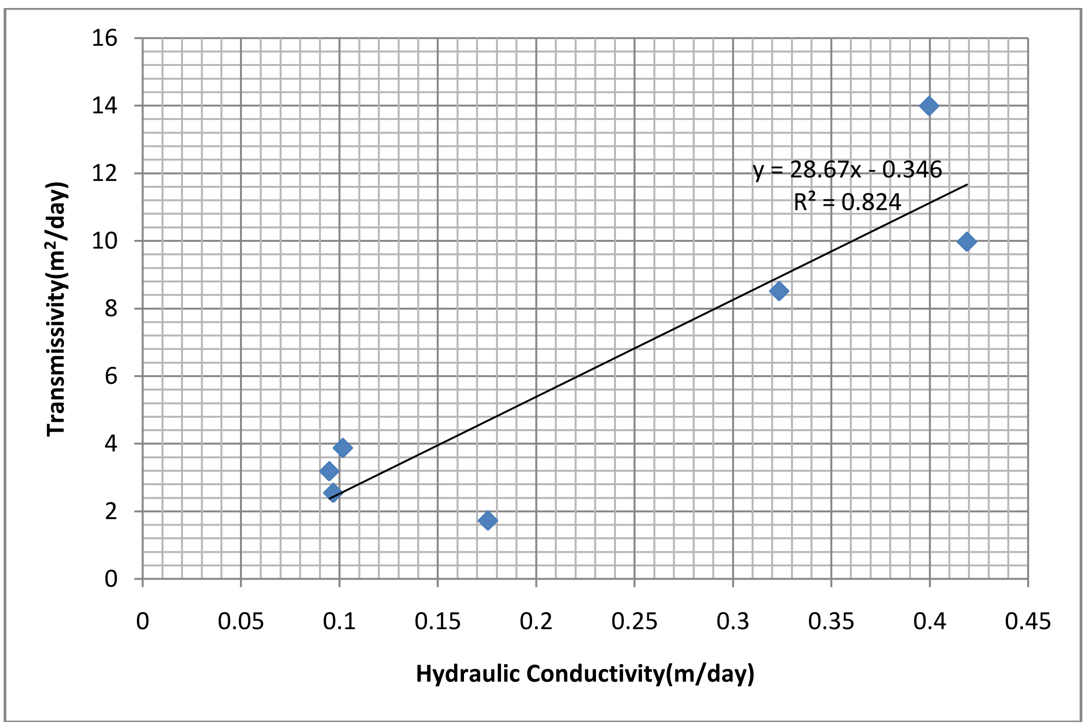

Fig. 11 Correlation of modeled transmissivity and hydraulic conductivity

Table 2 Overburden and aquifer thickness inferred from resistivity data interpretation

S/N	EASTINGS	NORTHINGS	AQUIFER RESISTIVITY(Ωm)	AQUIFER THICKNESS(m)	OVERBURDEN THICKNESS(m)
1	9.13583	6.96972	232.7	7.3	2.2
2	9.13833	6.96777	52.1	29.3	5.3
3	9.12833	6.92500	79.8	10.7	1.3
4	9.13083	6.91888	147.4	30.3	1.3
5	9.16416	6.90972	84	13.8	0.9
6	9.15166	6.90333	37	10.9	1.3
7	9.10500	6.89194	29.5	7.8	0.9
8	9.10583	6.88666	9.2	12.1	2.8
9	9.16750	6.88666	202.6	38	2.9
10	9.17166	6.89111	160.5	-	1.0
11	9.18055	6.88750	162.7	26.2	3.2
12	9.03555	6.81166	37.6	23.8	1.8
13	9.03417	6.80333	39.4	35	1.7
14	9.04750	6.78111	89.8	9.8	3.4
15	9.03888	6.77222	166.2	33.5	4.5
16	9.10000	6.66472	154.7	38	4.5
17	9.10083	6.65833	48.7	26.3	6.7

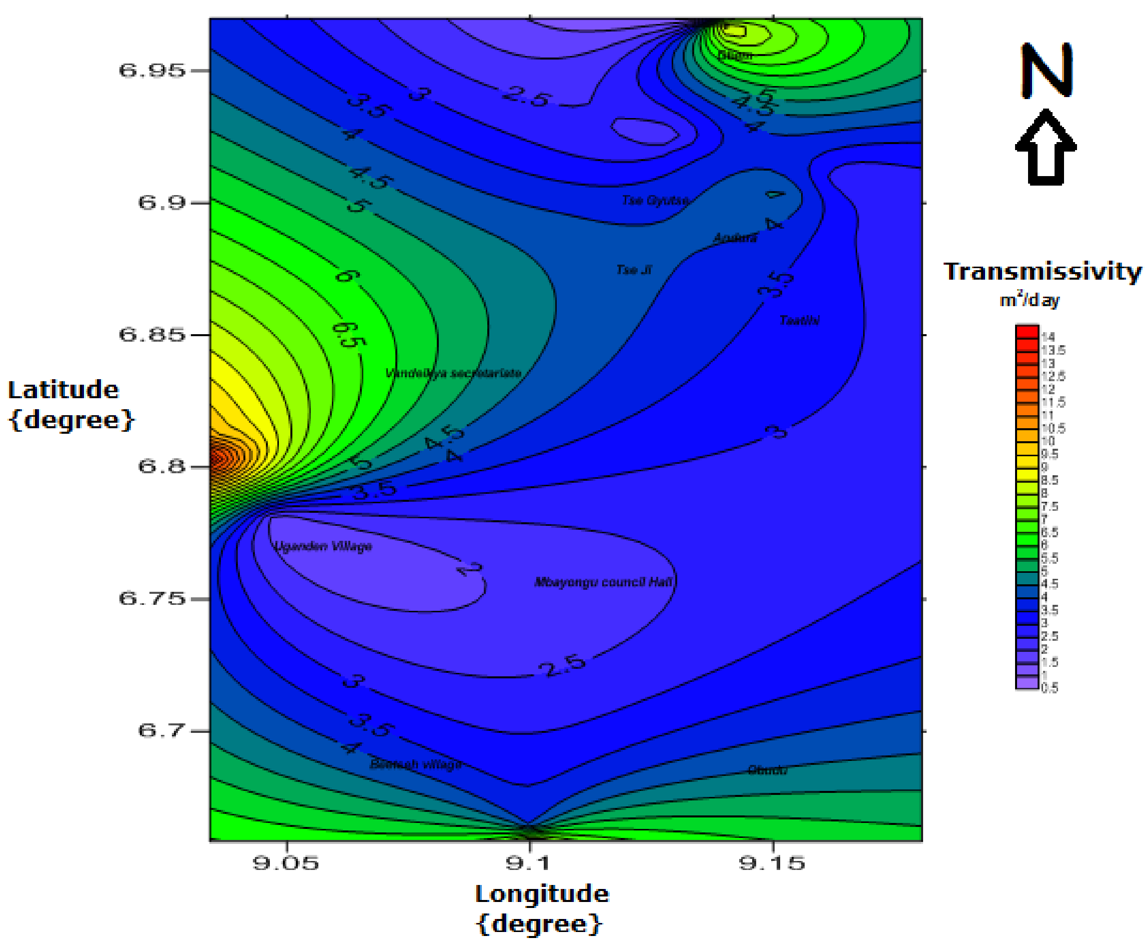

Fig. 12 Transmissivity distribution in the study area estimated from Dar Zarrouk parameter

4.0 Conclusion

The geophysical methods used in this study have greatly assisted in evaluating groundwater potential of Vandeikya and its environs, a town in Central Nigeria. Both the VLF – EM and Electrical resistivity probing data over the area were inverted and interpreted in terms of the distribution of the geoelectrical parameters in the area. Interpretation of both the EM profiles identified some areas of hydrogeologic importance in form of fractures and permeable zones and were produce on a conductivity contour map, which were further probed using the Electrical Resistivity survey. The geoelectric parameters obtained from the inverted Vertical Electrical resistivity sounding data were used to evolve various maps ranging from transmissivity contour map obtained from Dar Zarrouk parameter and the resistivity data were correlated with well data. The result revealed that most part of the study area is of hydrogeologic significance.

REFERENCE

[1]. Akande,S.O.,Ojo,O.J.,Adekeye,O.A.,Egenhoff,S.O. ,Obaje,N.G. and Erdtmann,B.D.(2011). Stratigraphic Evolution and Petroleum Potential of Middle Cretaceous Sediments in the Lower and Middle Benue Trough, Nigeria: Insights from New Source Rock Facies Evaluation.Petroleum Technology Development Journal Vol.1 pp.1-34.

[2]. Badmus, B.S. and Olatinsu, O.B. (2010). Aquifer characteristics and groundwater recharge pattern in a typical basement complex, South Western Nigeria. African Journal of Environmental Science and Technology Vol.4 (6), pp. 328-342.

[3]. Edet, A.E. (1990). Application of photo-geologic and Electromagnetic Techniques to Groundwater Exploration in North-Western Nigeria. Journal of African Earth Sciences, Vol.11, No ¾, pp.321-328.

[4]. Frohlick, R.K. and Kelly, W.E. (1985). The relation between Hydraulic transmissivity and transverse resistance in a complicated Aquifer of Glacial Outwash Deposits. Journal of Hydrology, Vol.79, N0. 3-4, pp 529-556.

[5]. Henriet, J.P. (1976). Direct Application of Dar Zarrouk parameters in Groundwater Surveys. Geophysical Prospecting Vol.24, N0.2, pp 344-353.

[6]. Klein, Jan. and Lajoie, Jules. (1980). Electromagnetic prospecting for minerals, practical Geophysics for the Exploration Geologist, Northwest Mining Association, Spokane,WA, pp 239-290.

[7]. Kogbe, C.A. (1989). Geology of Nigeria. Rock View (Nig). First published 1975, pp. 39-56.

[8]. Nigerian Geological Survey (2004): Geology and Mineral Map of Benue State.

[9]. Olayinka, A.I. (1990). Electromagnetic Profiling for Groundwater in Precambrian Basement Complex Areas of Nigeria. Nordic Hydrology Vol.21, pp. 205-216.

[10]. Telford, W. M., Gel dart, L.P. and Sheriff, R.E. (1990). Applied Geophysics 2nd Ed., Cambridge.

[11]. Ushie, F.A. and Amadi, P.A.(2008). Chemical characteristics of Groundwater from parts of the basement complex of Oban Massif and Obudu Plateau, South Eastern Nigeria. Scientia Africana, Vol.7 (No.), pp.81-88.

[12]. Zohdy, A.A.R. (1989). A new method for the automatic interpretation of Schlumberger and Wenner Sounding curves.Geophysics.54: 245-253.