Integration of Geophysical Techniques for Groundwater Potential Investigation in Katsina-Ala, Benue State, Nigeria.

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ABSTRACT

Integrated geophysical techniques involving VLF-Electromagnetic and Electrical Resistivity sounding methods were carried out to investigate the groundwater potentials of selected areas in Katsina-Ala L.G.A of Benue State. The area is underlain by the crystalline basement complex of northeastern Nigeria with local geology predominantly granite. Measurements of the ground conductivity were carried out with Geonics EM 34-3 along eight traverses whose lengths varied between 220 and 520m. The qualitative interpretation of VLF-EM results identified areas of hydro-geologic importance and form basis for Vertical Electrical Sounding (VES) investigation.

Fifteen Vertical Electrical Soundings (VES) were carried out across the area using the Schlumberger electrode array configuration, with current electrode separation (AB) varying from 200m to 340m. The interpretation of the VES data assisted in the characterization of three to five geo-electric layers from which the aquifer unit was delineated. The geo-electric sections obtained from the sounding curves revealed 3-layer, 4-layer, and 5-layer earth models, respectively. The 3-layer model with 20% (percentage) of occurrence, the 4- layer (66.7%) and 5-layer (13.3%) models show the subsurface layers categorized into the topsoil, sandy-clay/clayey-sand, weathered/fractured layer, and the fresh bedrock. The weathered and/or the fractured basement are the aquifer types delineated across the area. The thickness of the weathered aquifer unit varies from 5.3m to 32.8m in the area. On the basis of geo-electric parameters the study area is zoned into high, intermediate and low groundwater potential zones.

(Keywords: Very Low Frequency Electromagnetic (VLF-EM), electrical resistivity, groundwater potential, aquifer, Katsina-Ala, Benue State, Nigeria)

INTRODUCTION

Groundwater is a mysterious nature's hidden treasure. Its exploitation has continued to remain an important issue due to its unalloyed needs. Though there are other sources of water; streams, rivers ponds, etc., none is as hygienic as groundwater because groundwater has an excellent natural microbiological quality and generally adequate chemical quality for most uses (Macdonald et al., 2002).

To unravel the mystery of groundwater, a detailed geophysical and hydro-geological understanding of the aquifer types and their spatial location are paramount in order to characterize the hydric zones in an area.

Katsina-Ala is underlain by the basement complex rocks of the northeastern Nigeria (Geological Survey of Nigeria, 1994), and groundwater in the crystalline basement is usually contained in the weathered and/or fractured basement rocks (Offodile, 1983), though problematic (Offodile, 2002). Consequently, such geologic setting requires a critical understanding of the hydro-geology and integration of geophysical data types to effectively characterize the hydro-geologic zones and to enhance successful identification of well locations (Omosuyi et al., 2008).

Olaleye (2005) noted that electromagnetic survey is best used in areas of crystalline basement rocks for mapping areas of fractures and/or weathered materials of the basement complex which are often the significant water bearing layers directly overlying the fresh basement rocks. Electromagnetic prospecting has been found useful as a reconnaissance survey in groundwater exploration Olaleye (2005), Amadi and Nurudeen (1990), and Adiat et al. (2009). Reconnaissance in the sense that it is fast, and requires less labor, and above all covers a large area in a short time.

Electromagnetic (EM) profiling and vertical electrical sounding (VES) geophysics have been complementarily used in the delineation of basement regolith, fissured media, and associated deep weathering (Beeson and Jones, 1988).

Though electrical resistivity method has been used immensely for hydro-geologic investigations Alile et al. (2008), Isife et al. (2000); Egwebe et al. (2004); Ajayi and Hassan (1990); and Olaleye (2005), the use of electromagnetic and resistivity methods for the study was justified by the geology of the area as noted by (Beeson and Jones, 1988).

In this study, integrated geophysical mapping of some selected areas in Katsina-Ala L.G.A of Benue State was carried out using both VLF-EM and Electrical Resistivity prospecting techniques with a view to investigating its groundwater potentials and most importantly recommend the most prolific aquifer type(s) capable of providing adequate and good quality water for the people of the area.

SITE DESCRIPTION AND GEOLOGY

The area under study is an extract from map sheet 272, Katsina-Ala NE (Federal Surveys Nigeria, 1975). It is bounded by latitudes 7°09' and 7°20' north of the equator and longitudes 9°15' and 9°30' east of the Greenwich Meridian (Figure 1). The area is generally low lying to gentle undulating terrain. The climate is sub-equatorial with average annual rainfall of about 2000mm-2500mm and a mean temperature of about 27°C-28°C (Olayinka, 2000). The area is drained by a major river: River Katsina-Ala (Figure 1). All the minor rivers and other drainages empty into River Katsina-Ala which empties into River Benue. The study area is underlain by the crystalline basement rocks of northeastern Nigeria comprising of mainly quartzites, siliciferous rocks, migmatite gneisses, older granites with other undifferentiated basement rocks (Offodile, 2002) which are overlain by the Lower Turonian Eze-Aku Shale group (Figure 1), which has lateral equivalence with Amaseri Sandstone (Reyment, 1965; Dessauvagie, 1975).

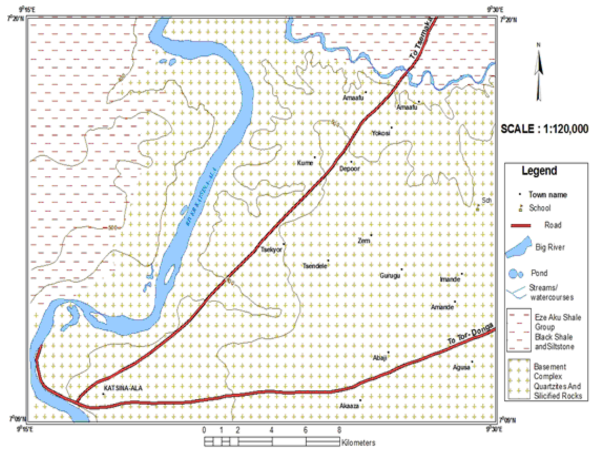

Figure 1: Geological Map of the Study Area (after Geological Survey of Nigeria (GSA) Sheet, 1994).

The sediments of the Eze-Aku shale group were formed during the Turonian time a period of marine transgression in Nigeria when the sea covered large parts of the eastern and northern Nigeria (Reyment, 1965). The sediments are mainly flaggy, calcareous shale and siltstone, grey or black in color containing frequent impressions of *Inoceramus.* The aquifer units in the area and other similar Basement Complex areas are believed to be derived essentially from the weathered rocks Offodile (1983), though problematic.

DATA ACQUISITION AND ANALYSIS

The EM response was measured using Geonics EM34-3 instrument. The measurements of the ground conductivity were as detailed in McNeil (1980b). EM does not require contact with the ground Mamah and Eze, (1988); McNeill, (1983) therefore the speed with which EM can be operated is much faster than other electrical methods. EM data were collected at 20m intervals along eight (8) traverses, whose traverse lengths varied between 220m to 520m (Figure 2).

The EM data (vertical and horizontal coil resolutions) were presented as conductivity profiles against station intervals. The section shows plots of field gradient against station positions with their corresponding pseudo-section (Figures 3 and 4). The EM profiles were qualitatively analyzed.

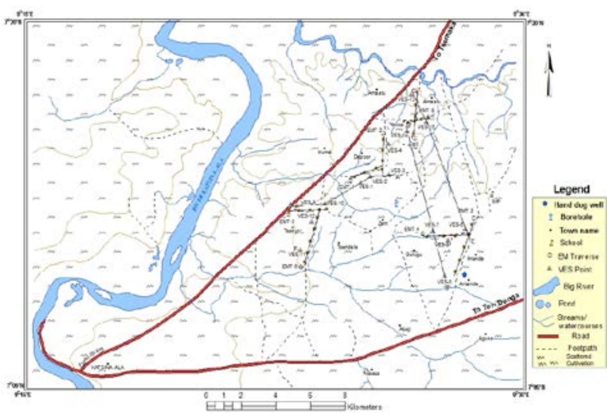

Figure 2: Location Map of the Study Area showing the VES points and EM Traverse (after Federal Survey of Nigeria (FSN), Sheet 272, Katsina-Ala, 1975).

The qualitative analysis enabled the identification of inflection points of the vertical dipole which were considered as priority areas for vertical electrical sounding (Figures 3 and 4). The ABEM Terrameter SAS300C was used for resistance measurements, employing Schlumberger array configuration.

The depth soundings were conducted at points of inflection (anomaly) qualitatively delineated from the EM profiles. Fifteen (15) depth soundings were conducted, with current electrode spacing (AB) ranging from 200-340m. The field curves were interpreted using Win Resist computer iterative modeling (Vander Velpen, 2004). Through an iterative process, the program varies the number of layers, thickness and electrical resistivity of each layer, until it finds a final geo-electric model that satisfactorily best fits the data (Figure 5).

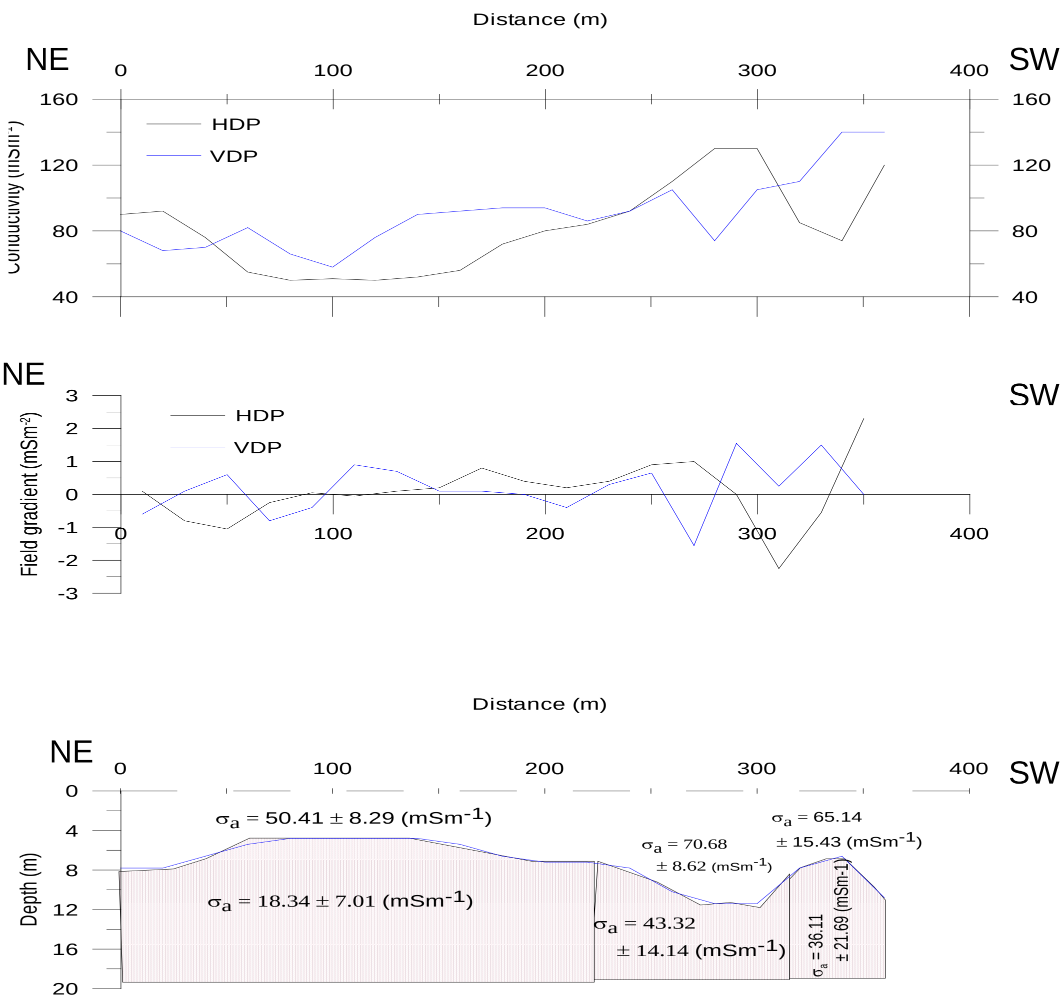

Figure 3: Typical Interpretive EM Profile across the Area**:** a) Conductivity profile, b) Vertical and Horizontal Dipole Field Gradient and c) Inverted Pseudo Section along EM t 1.

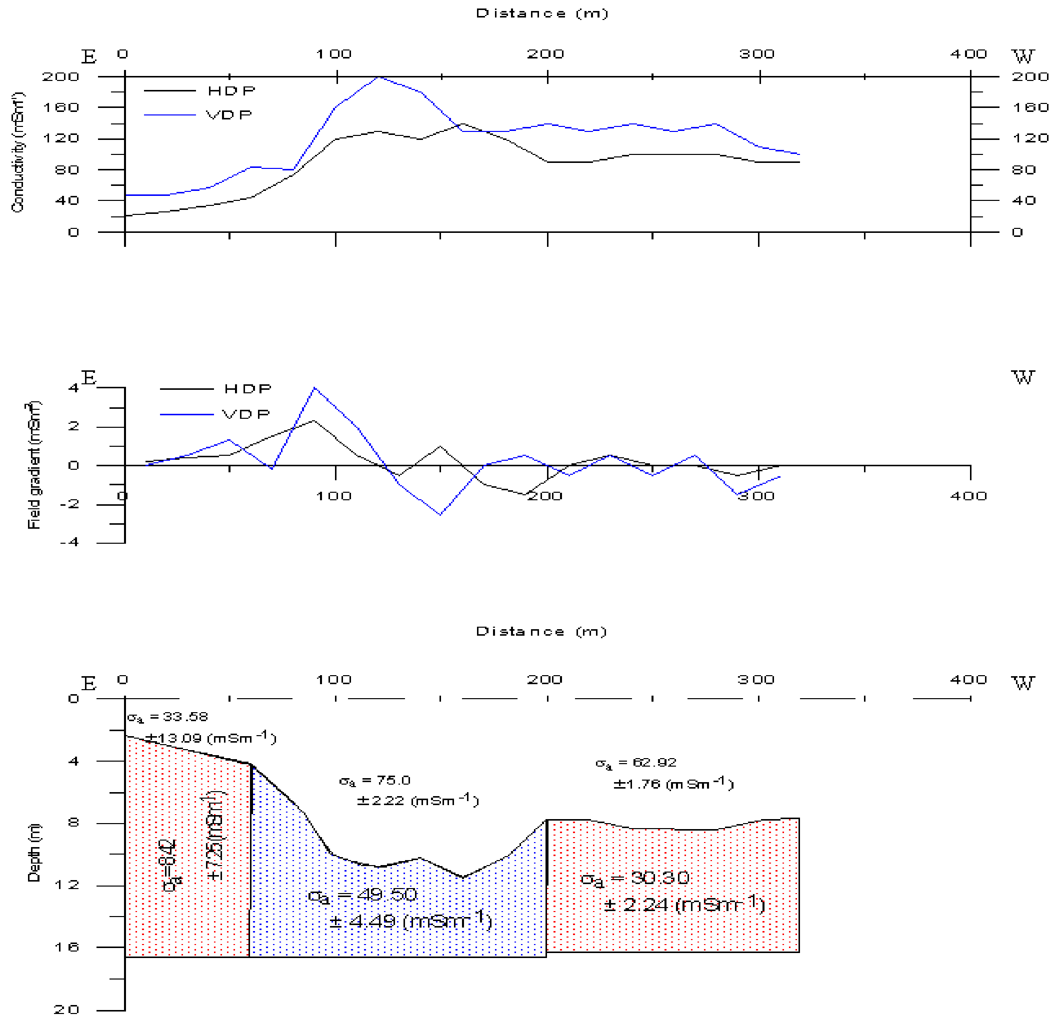

Figure 4: Typical Interpretive EM Profile across the Area**:** a) Conductivity Profile, b) Vertical and Horizontal Dipole Field Gradient, and c) Inverted Pseudo Section along EM t-5.

RESULTS AND DISCUSSIONS

VLF-EM Profiles: The VLF electromagnetic profiling data are presented as plots of conductivity (in mS/m) against station intervals (in m). Typical EM profiles from the study area are shown in Figures 3 and 4. The EM anomalies vary significantly; some are sharp while others are broad (Omosuyi et al., 2008).

Zones with peak positive vertical dipole anomalies are inferred conductive, typical of water–filled fissures (Alvin et al., 1997), or effect of appreciable weathering (Beeson and Jones, 1988). The higher the peak the deeper the rock fractured (Ugwu and Nwosu, 2009). These zones are considered priority areas for depth sounding. Figure 3 is a typical conductivity profile across the study area at EMT_1 conducted NE-SW of Depoor. At a distance of about 340m- 360m and 160m-180m along the section shows points of inflections.

The two depth soundings (VES 1 and 2) conducted along this profile respectively to determine the possible depth to the aquifer layer and the bed rock for which information was not provided with the EM34-3, weathered layer/ fracture was delineated only in VES 1.

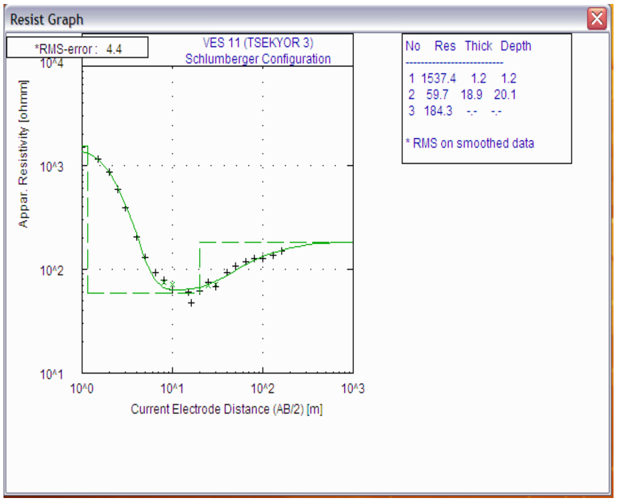

Figure 5a: Typical 3-Layer Curve from the Study Area.

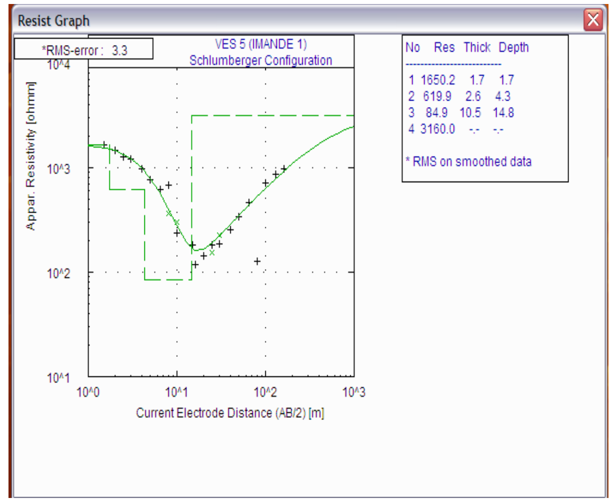

Figure 5b: Typical 4-Layer Curve from the Study Area.

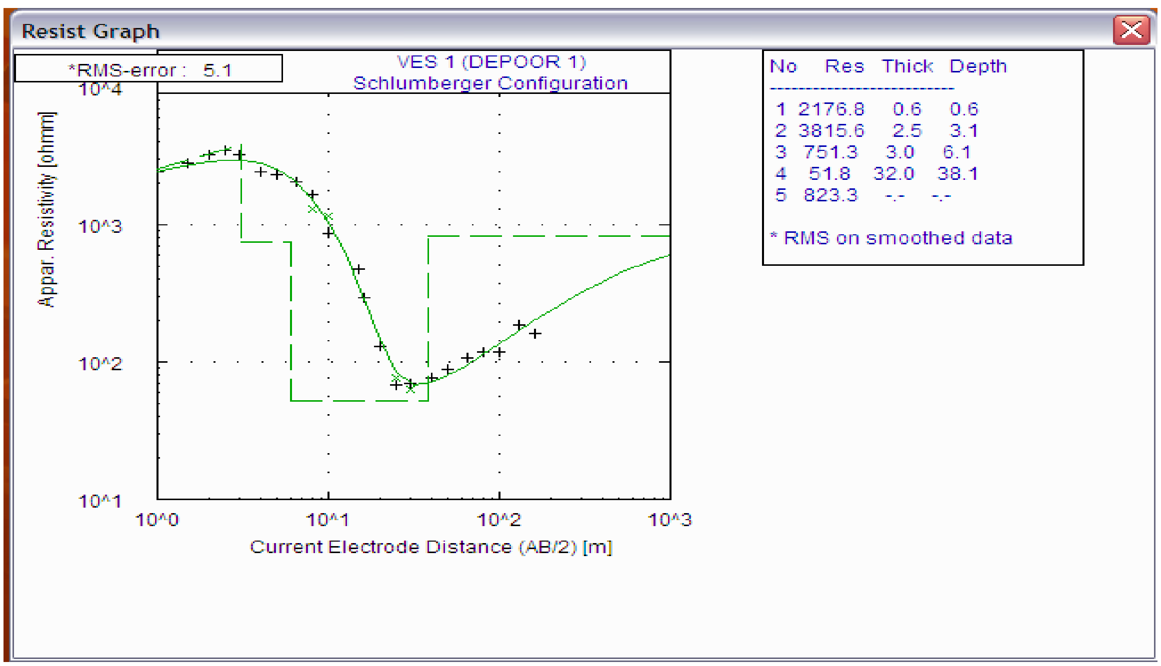

Figure 5c: Typical 5-Layer Curve from the Area.

Figure 3b is the corresponding field gradient along the section, points of inflexion at about 320m-350m and 130m-140m agree with the locations of VES1 and 2, respectively, which are presumed to be a contact zone which may act as a suitable aquifer (MacDonald et al. 2005). This was confirmed from the geo-electric section AA[1] (Figure 4) which runs along the same axis with fractured and fairly thick weathered layer at VES 1. On the contrary, between the distance of about 140m-260m, the conductivity values didn't change much depicting that the rock was not generally fractured (Ugwu and Nwosu, 2009) or a linear conductor, (McNeill, 1980b). Figure 3c is the corresponding pseudo-section of the traverse which provides the pictorial or diagnostic information about current with depth.

The inverted conductivity values are shown with the most conductive layers having a value of about 50.41mSm^{-1}-70.68mSm^{-1} which could probably be a fractured/weathered layer.

The conductivity of 18.34mSm^{-1}-36mSm^{-1} which is lower is suspected to be fairly weathered zone. The conductivity profile along EM traverse-5 (Figure 4a) which runs along E-W of the study area shows a peak conductivity anomaly at a distance of about 120m and a broad anomaly at about 200-280m. On this account VES 9 and 10 were conducted along the profile and VES 9 with peak inflection; fracture (Ugwu and Nwosu, 2009), or effect of appreciable weathering was confirmed with depth sounding. Figures 4b and 4c showed similar inference.

Resistivity Sounding Curves: The resistivity sounding curves obtained from the surveyed area vary from 3, 4 layer (H type), or 5-layer (KH) as shown in Figure 5. The H-type curve with about 86.7% of occurrence and KH-type curve with about 13.3% of occurrence were deduced from the area. Worthington (1977) showed that field curves often mirror image geo-electrically the nature of the successive lithologic sequence in an area and hence can be used qualitatively to assess the groundwater prospect of an area. The H and KH curves which are often associated with groundwater possibilities (Omosuyi, 2010) are pertinent to the study area. The geo-electric parameters of the lithologic units were delineated from the interpreted sounding curves and shown on Table 1.

Geo-electric Sections, Characterization and Lithologic Delineation: Electrical resistivity methods primarily reflect variations in ground resistivity (Omosuyi et al., 2008).

Table 1: Summary of the Geo-Electric Parameters and Model Theoretical Resistivity Curve Types Over the Study Area.

Geo-electric earth layer model type	Curve Type	VES No.	Layer Resistivity (Ohm-m)	Layer Thickness (m)	No. of occurrence	Perct. of occurrence (%)	Layer	Resistivity Range (Ohm-m)	Thickness Range (m)
3-Layer	H	11	1537,60,184	1.2,18.9	3	20	1	509-1537	1.2-3.4
	H	14	509,41,4429	3.4,10.3			2	28-60	8.8-18.9
	H	15	527,28,3444	2.9,8.8			3	184-4429	∞
4-Layer	H	2	6137,886,58,1754	2.1,7.2,18.5	10	66.7	1	323-6137	0.3-2.6
	H	4	2103,358,77,1001	2.6,8.3,25.0			2	103-886	1.6-8.2
	H	5	1650,620,85,3160	1.7,2.6,10.5			3	29-85	5.3-32.8
	H	6	2489,296,53,1978	2.6,2.8,5.3			4	109-3160	∞
	H	7	1507,205,52,1167	2.5,2.0,8.0					
	H	8	1445,401,83,1215	1.9,4.1,6.9					
	H	9	1069,300,46,751	2.2,2.0,29.2					
	H	10	1950,176,31,1802	1.7,4.5,32.8					
	H	12	1212,138,35,1570	0.9,3.0,25.2					
	H	13	323,103,29,109	0.3,1.6,19.4					
5-Layer	KH	1	2177,3816,751,52,823	0.6,2.5,3.0,3.2	2	13.3	1	760-2177	0.5-0.6
							2	1577-3816	
								461-751	2.3-2.5
	KH	3	760,1577,461,45,4549	0.5,2.3,6.0,16.4			3	45-52	
							4	823-4549	
							5		3.0-6.0
									3.2-16.4
									∞

These variations in ground resistivity exist across lithologic interfaces or geo-electric boundaries in the subsurface. Their disparity is the yardstick on which the aquiferrous and non aquiferrous units can hence be delineated. The 2 dimensional view of the geo-electric parameters (resistivity and thickness) obtained from the inversion of the electrical resistivity sounding data were used to adjudge the aquiferrous or non aquiferrous layers and reliable geological deductions.

The geo-electric sections (Figures 6 and 7) of the various VES stations in the study area are created to indicate the various geo-electric layers, their thicknesses within the depths penetrated with their characteristics resistivity values and probable geo-electric connotations. The profiles were taken along the NE-SW; AA[1], and BB[1] NW-SE directions.

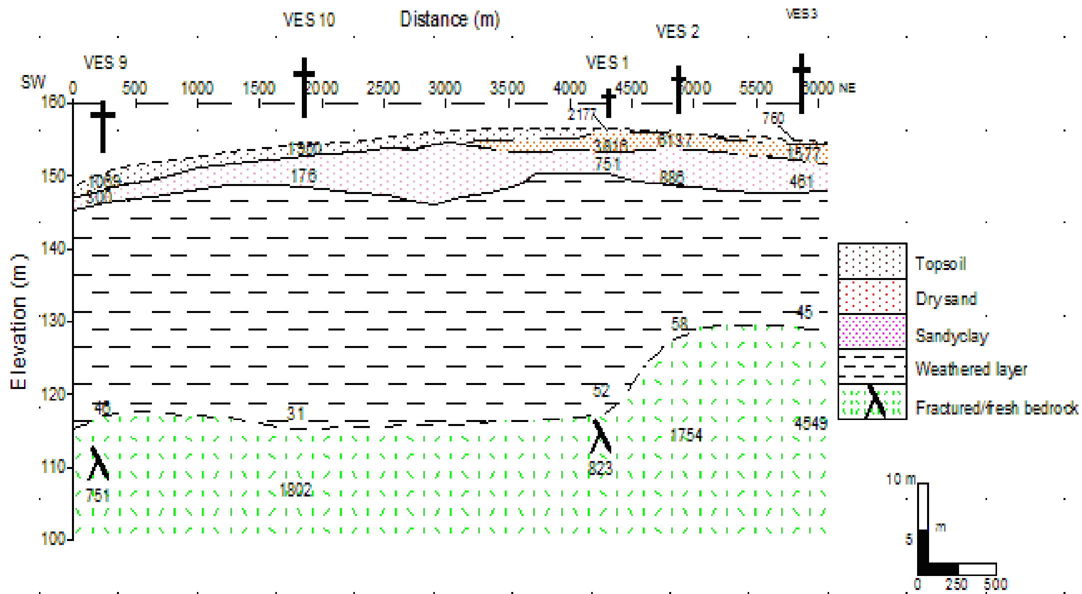

Figure 6: Geo-Electric Section AA$^{/}$ across VES 9, 10,1, 2, and 3.

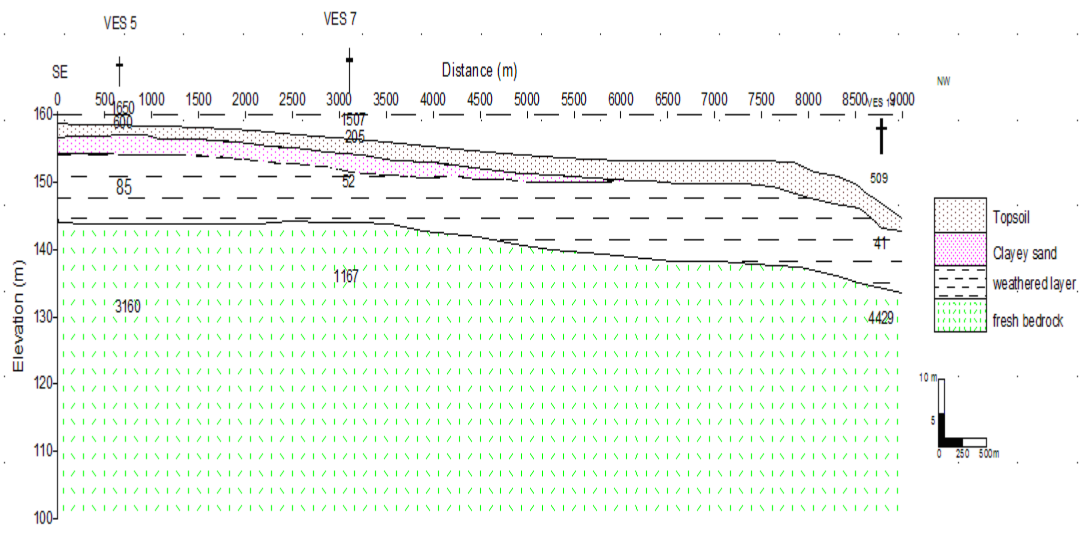

Figure 7: Geo-Electric Section BB$^{/}$ across VES 5, 7, and 14.

The geo-electric section (Figure 6) AA[1] which runs across NE-SW direction of the study area is smade up of data from VES 1, 2, 3, 9, and 10. The interpretative cross section AA[1] shows four geo-electric layers in VES 2, 9, and 10 and five layers in VES 1 and 3. The topsoil which is relatively thin is characterized by resistivity values ranging from 760 ohm-m to 2177ohm-meter with a thickness that varies from 0.5m to 2.2m, and is composed of predominantly laterite, and clay towards the northeastern part. The second layer has resistivity values that vary from 1577-6137ohm-m at the northeastern part and terminated in VES 9 and 10. The next layer with resistivity range of 176-886 ohm-m and a thickness between 2.0m- 7.2m is presumed to be sandy-clay. The third layer which is probably conductive and reflects the layer identified as the aquifer unit characterized by resistivity values between 31 ohm-m and 58 ohm-m with thickness values of 16.4m−32.8m is diagnostic of extensive weathered bedrock which are subject to groundwater development (Ajayi and Hassan, 1990; Oyedele and Adeyemo, 2001). The last layer with resistivity values that vary from 751-4549 ohm-m with infinite thickness is suggestive of fractured or fresh basement, respectively.

The geo-electric section BB[1] across NW-SE direction (Figure 7) is made up of data from VES 5, 7, and 14. The cross section shows three to four geo-electric layers. The topsoil has resistivity value ranging from 509ohm-m to 1650ohm-m with thickness varying from 1.7m-3.4m characteristic of lateritic sand at the southeastern part and sandy-clay at VES14. Beneath the topsoil layer towards the southeastern part, the relatively low resistivity value of 205ohm-m observed under the topsoil which does not extend to VES 14 is characteristic of clayey-sand. The next layer which is recognized as the aquifer layer with resistivity range of 41ohm-m – 85ohm-m with thickness of 8.0m-10.5m is the presumed weathered layer. The underlying bedrock is characterized by resistivity values ranging from 1167ohm-m to 4429ohm-m.

Geo-Electric-Litho-Log Correlation: A borehole outside the project area; at Kasar but located in a similar geologic setting yielded the following information (Daagu, personal communication).

The close correlation between the geological interpretation of the sounding data and the borehole lithology (Table 2) gave enough confidence on the reliability of the results. Thus the geo-electric sections compare well with the geology of the area and as well the lithologic log close to the area.

Table 2: Borehole Data from Kasar.

Static water level	3.0m
Dynamic water level	6.0m
Yield	140.00 liters per minute
The borehole lithology was as follows:	
Depth(m)	Lithology
0.1	Laterite
1-3	Lateritic clay
3-6	Sandy clay
6-11	Micaceous clay
11-17	Weathered crystalline basement
17-18	Fresh basement

Hydro-Geological Zoning: Electrical resistivity depth sounding is useful in locating areas of maximum aquifer thickness and serves as a good predictive tool for estimation of borehole depth (Omosuyi, 2010). To zone the area into groundwater prospects, the ideas of Ameloko and Rotimi, (2010), Lenkey et al. (2005), and Omosuyi et al. (2008) were adopted. Several maps were produced using SURFER8 program to monitor the trend of resistivity, thickness and conductance variation with a view of assessing the sub-surface lithology suitable for low, intermediate or high groundwater potentials.

Isopach, Iso-Resistivity, and Longitudinal Unit Conductance Maps: Figure 8 shows the isopach map distribution of the main aquifer unit (weathered layer) that varies from 5.3m to 32.8m. Based on the weathered layer thickness, the central (Depoor), and south western (Tsekyor) parts of the area can probably support intermediate-high groundwater potentials whereas the southeastern part (Imande) and a patch of northeastern areas show an indication of low – intermediate groundwater potential.

With regards to significant role plays by thickness in groundwater abstraction (Adiat et al. 2009; Omosuyi et al. 2008) areas characterized by thickness between 10.6 – 32.8m were accorded more preference in groundwater development.

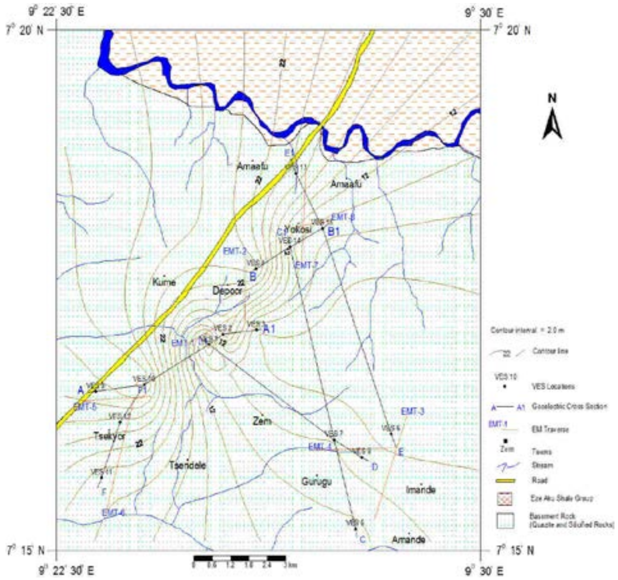

Figure 8: Iso-pach Map of the Aquifer Unit in the Study Area.

Figure 9 is the iso-resistivity map of the layer considered as the main aquifer in the area. The resistivity value of the (weathered) layer lies between 28 ohm-m and 83 ohm-m while the most frequently occurring resistivity values are between 41 ohm-m and 58 ohm-m suggestive of materials of most likely slight clayey and/or saturated with water (Ajayi and Hassan, 1990); typical of clay which may be constantly saturated but poorly permeable to the interstitial formation water for abstraction (Abiola et al., 2009).

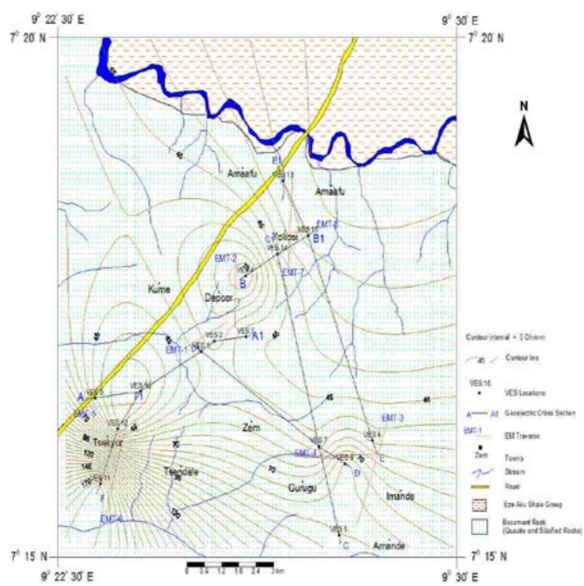

Figure 9: Iso-Resistivity Map of the Aquifer Unit in the Study Area.

Although aquifer thickness alone cannot be considered as the yardstick for groundwater prospect evaluation, resistivity and lithology amongst others are relevant considerations. Consequently, the longitudinal unit conductance map of the study area (Figure 10) was generated from the data calculated from the model parameter:

$$S = \sum_{i=1}^{n} hi / \rho i \text{ (Abiola et al. 2009)}$$

and shown in Table 3 for all the VES locations.

The longitudinal unit conductance, S values obtained from the study area ranged from 0.0947 to 1.083mhos. From the map (Figure 10), the northern and a patch of southwestern region have over 0.5 mhom. The southeastern and southern parts have conductance values lower than 0.5mhoms which is probably responsible for low groundwater potential across those parts (Figure 11). This is because the earth medium acts as a conductor especially when it contains fluid. Its ability to conduct current is a measure of its conductance capacity and invariable its resistive capacity as well.

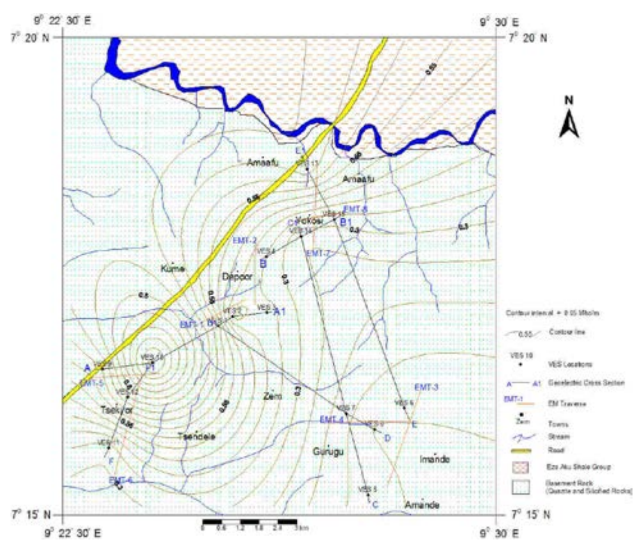

Figure 10: Longitudinal Unit Conductance Map of the Study Area.

Groundwater potential evaluation: At large the groundwater potential evaluation of the study area is based on various categories of maps, namely, iso-pach and iso-resistivity maps of the

Table 3: Aquifer Parameters of the Sounding Locations.

Bulk rest. (ohm-m) ρ_h	Aquifer resist. (ohm-m) ρ_a	Aquifer thick (m)	Trans. resist. R_t	Long. cond. (mS/m)
7619	52	32	1664	0.62031003405
8835	58	18.5	1073	0.3274341147712
7392	45	16.4	738	0.3795859889978
3539	77	25.0	1925	0.349096011294
5515	85	10.5	829.5	0.12875326321
4816	53	5.3	280.9	0.110504055682
2931	52	8	416	0.165261176378
3144	83	6.9	572.7	0.094671847913
2166	46	29.2	1343.2	0.643507173496
3959	31	32.8	1016.8	1.08371987743621
1781	60	18.9	1134	0.3157807417046
2955	35	25.2	882	0.7424817046874
564	29	19.4	562.6	0.6854282903497
4979	41	10.3	422.3	0.257899276444
3999	28	8.8	246.4	0.3197885606

weathered layer (aquifer), and the longitudinal unit conductance map of the aquifer unit in preparing the groundwater potential map of the area as deduced from the geo-electric parameters (resistivity and thickness) and longitudinal conductance obtained from interpreted VES results. The groundwater potential map Figure 11 was used to classify the study area into high, intermediate, and low groundwater potential zones. In view of groundwater abstraction, areas with intermediate to high notation are accorded more preference to well development.

CONCLUSIONS AND RECOMMENDATIONS

The integrated geophysical methods used in this study have assisted as a good alternative to investigating the groundwater potential of some selected areas in Katsina-Ala in Benue State. Both the VLF-EM and Electrical resistivity data over the area were inverted and interpreted in terms of the distribution of the geo-electric parameters in the area. Interpretation of the EM profiles identified some conductive zones which were considered as priority areas for depth sounding.

The geo-electric parameters obtained from the inverted Vertical Electrical resistivity sounding data were used to delineate the aquifer types of the area: fractured bedrock and/or weathered bed rock. Also cross- sections and contoured maps which were analyzed based on hydro-geological importance of the study area were evolved.

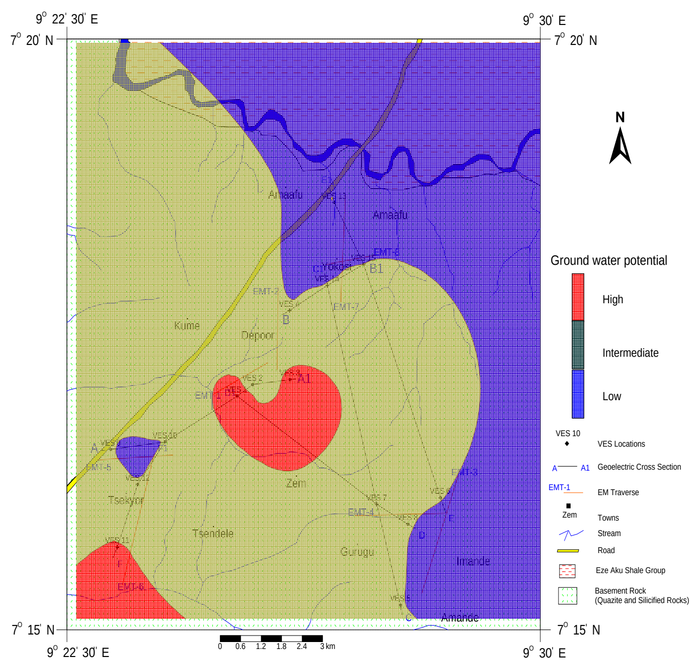

Figure 11: Groundwater Potential Map of the Study Area.

Based on these, the area was categorized into high, intermediate and low groundwater potential. Analysis of the geophysical survey data revealed that the study area could play a significant role in providing adequate portable water for the rural dwellers.

It is, however, recommended that more sophisticated and effective geophysical methods such as aerial remote sensing, seismic refraction, electrical tomography and depth probing electromagnetic instrument: ABEM WADI VLF instrument which detects fractures, the depth to the conductive zone and its dip and electrical resistivity sounding equipment: SAS 4000 (Lund Imaging System) for better imaging of the subsurface and to obtain data of better quality. Above all, development of some of the sites investigated (VES 1, 4, 10, 12, 13) will encourage the dwellers to adopt irrigation farming thereby improving their socio-economic and agricultural status.

ACKNOWLEDGEMENTS

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