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Geological and Hydrogeophysical Investigation of Angwan Zakara, Keffi Sheet 208N.E of North Central Nigeria

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ABSTRACT: *The geological and hydrogeophysical assessment of the groundwater prospect/potential in Angwan Zakara and its environs, Karu Local Government, Nasarawa State, North-Central, Nigeria has been carried out in this study. The study area covers 25km^2.The area is underlain by the Basement Complex of the North-Central Nigeria consisting of Medium grained biotite granite, biotite gneiss, phyllite and un-mappable muscovite schist with structural features such as joints, veins, foliation, faults, and xenoliths trending NW-SE direction. Forty Nine (49) Vertical Electrical Sounding were carried out in the study area using Omega Resistivity Terrameter, GPS12 Garmix with a maximum cable spread of AB/2=100m and MN/2=5m. The results obtained from the field data were interpreted using IXID Software for quantitative analysis. True resistivity map, piezometric map, basement resistivity map and depth to basement map were prepared and interpreted using computer software for qualitative analysis (SURFER 8). From the IXID interpreted results, five (5) curve types were obtained from the acquired data namely A, H, KH, AH, and HK curve types are the dominant. The study area showed depth to basement ranges from 20-90m. That revealed good groundwater potential. The study area revealed 4-7 lithologic sequences consisting of top soil, laterite, clay, weathered/ fractured basement however the host rocks in the study area are biotite granite, quartzite and schistose-gneiss. The results obtained shows that the direction of water flows revealed five ridges R1-R5 and four depressions D1-D4 with receptacles trends of the ridges are R1 and R2:NW-SE; R3 N-S, R4 : NE-SW and R5; E-W. The geoelectric sections were produced and correlated with the geology of the study area and it was found to be in conformity with the each other. Based on this, the study area is zoned into three namely good, moderate and poor groundwater potential zones.*

KEYWORDS: Geologic, hydrogeophysical, assessment, groundwater, potential, quantitative and qualitative

INTRODUCTION

Groundwater is an essential replenishable resource whose occurrence and distribution greatly varies according to the local as well as regional geology, hydrogeologic setting and to an extent the nature of human activities on the land. Groundwater in a Precambrian Basement terrain is hosted within zones of weathering and fracturing which often are not continuous in vertical and lateral extent (Jeff, 2006). There is a steady rise in the demand for groundwater in most hard rock areas most of which cannot boast of any constant surface source of water supply

(Adanu, 1994). The failure rate in most groundwater project recorded in Basement Complex aquifers has informed the general acceptance of a geophysical survey as a compulsory prerequisite to any successful water well drilling project (Dan Hassan & Olurunfemi, 1999). The electrical resistivity method involving the vertical electrical sounding (VES) technique is extensively gaining application in environmental, groundwater and engineering geophysical investigations (Olorufemi *et al.*, 1993 & 2004). In this study geological mapping and detailed hydrogeophysical investigation was carried out in Angwan Zakara and environs, Keffi sheet 208NE Central Nigeria. Qualitative and quantitative analysis to provide detailed information that will help researchers and developers in understanding the aquifer potential of the study area to determine the rock types, the geoelectrical characteristics of the aquifer present in the study area, correlate the vertical electrical sounding (VES) curves with various rock types and relate them to the aquifer potential, estimate the depth to basement in the area, the overburden thickness of the layers and correlate the VES with geology. The study area is AngwanZakara and its environ is located in Keffi Local Government Area and part of Karshi of Nasarawa State, North Central Nigeria., It lies within latitudes N08˚50'56"to N08˚49'34"and longitudes E7˚53'40" to E7˚55'00", covering about 25km^2 and underlain by the Basement Complex of North Central Nigeria (Figure 1).

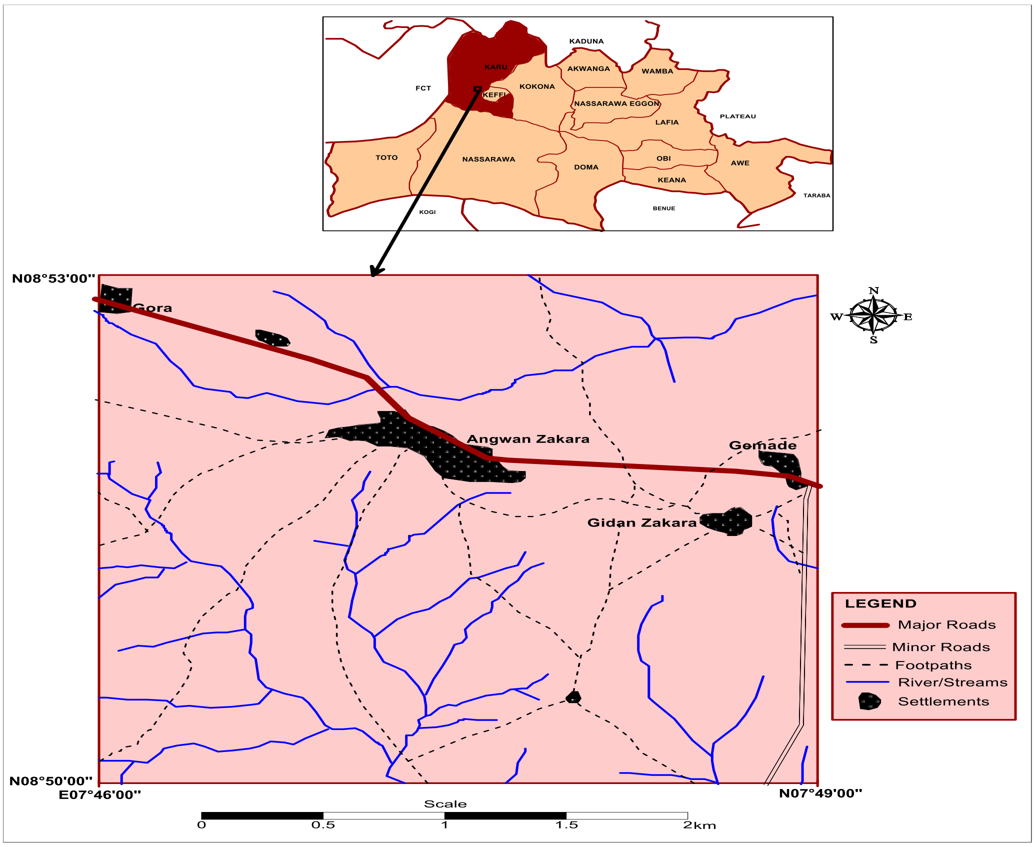

Figure 1: Map of Nasarawa state showing the location of the study area (After NGSA, 2016).
The study area has a tropical climate which is characterized by two seasons, namely; the rainy season and dry season. The rainy season lasts from April to October, while the dry season lasts

between November and March. The Hamattan (dry and dusty wind) is usually experienced from November to February. Mean annual rainfall varies from 850 mm to 1,800 mm, and the mean annual temperature ranges between 28 and 29.5 °C (Adefolalu, 2002). The vegetation falls within the Guinea savannah vegetation belt of Nigeria which is characterized by thick vegetation, tall grasses and trees but which has been greatly altered by human activities such as tree falling, land tilting, building structures and forest fires (Olorode, 2002). It generally becomes dense during the rainy season and sparse during the dry season due to fluctuation in the water table. This is more evident along the stream channels. The area is a flat plain surrounded by steep hills to the south. The highest elevation is about 382m above sea level and minor gullies make the low plain to offer minor rugged terrain to the west of settlement. The area is drained by a NE to SW flow and also has minor tributaries flowing NW-SE and SE to NW forming a dendritic flow pattern.

LITERATURE REVIEW

The Basement Complex is one of the three major litho-petrological components that make up the geology of Nigeria. The Nigerian Basement Complex forms part of the Pan-African mobile belts that lie between the West African and Congo Cratons and south of Tuareg Shield (Black, 1980). It was affected by Pan-African Orogeny 600 Ma and occupies the reactivated region which resulted from plate collision between passive Continental margin of West African Craton and active Pharusian Continental margin (Burke & Dewey, 1972; Dada, 2006). The Basement Complex rocks are believed to result from at least four (4) major orogenic cycles of several deformation, metamorphism and remobilization, which corresponds to the Liberian (2,700 Ma), the Eburnean (2, 000 Ma), the Kibaran (1,100 Ma) and the Pan-African (600 Ma) orogenies. The Pan-African orogeny was accompanied by regional metamorphism, migmatization and great granitization and gneissification which produced syn-tectonic granites and homogeneous gneisses (Abaa, 1983), and ended with faulting, fracturing and emplacement of Older Granites (Olayinka, 1992; McCurry, 1976). Geochronological data shows the polycyclic nature of the Nigerian Basement Complex (Ajibade *et al.*, 1988). Furthermore, the Pan-African orogeny led to the deformation of the Younger meta-sedimentary cover, initiates the intrusive phases of the Older Granite rocks and the rejuvenation of the Precambrian rocks. These events reset the mineral ages in most rocks thereby made dating of Basement rocks to become difficult (Ogezi, 1977). The Basement Complex rocks of Nigeria are grouped into four (4) lithological units; Migmatite-Gneiss Complex, Schists, Older Granites and the Undeformed acid-basic dykes. Two major aquifer units or systems are said to exist in the Basement Complex terrains, which are the weathered aquifer also known as weathered bedrock (saprolite) aquifer and the fractured aquifer also known as fractured bedrock (saprock) aquifer. Highest groundwater yields are obtained where the overburden weathered rock columns overlies the fractured zones (Eduvie *et al.*, 1999; Jatau & Obaje, 2007 Anudu *et al.*,2014). Surface geophysical survey, using electrical method has been used extensively in the search for groundwater in the Basement Complex terrain and has recorded a high success rate (Olurunfemi & Fasuyi, 1993; Jatau & Bajeh, 2007; Jatau *et al.*, 2013; Jatau *et al.*, 2014; Jatau *et al.*,2020; Ariyo *et al.*, 2003) and to study subsurface layering (Pazdirek & Blaha, 1996; Loke, 1999). Geological, geophysical and hydrogeochemical methods are being relied upon to achieve meaningful success in groundwater development of an area (Jatau & Bajeh, 2007; Anudu *et al.*, 2014; Maxwell, 2013). Others geoelectrical surveys to delineate subsurface structures were carried out successfully (Olurunfemi *et al.,* 2004; Mbiimbe,2010; Jatau *et al.*,2013; Jatau *et al.*,2020; Salako *et al.*,2012; Ariyo *et al*.,2012 and Abubakar,2012), The electrical resistivity method employs an artificial source of current which is introduced into the ground through point electrodes or long line contacts (Telford *et al.*, 1990).

MATERIALS AND METHODS

The materials used for this study were Omega Resistivity Terrameter, GPS12 Gamin, Cables, Data sheet, Computer software IX1D for processing electrical resistivity data and Surfer 8 for producing Iso-resistivity maps. The methods on which this research was carried out include Desk study, which involved review of existing literatures; books and journals in terms of location (north central Nigeria and methods that are similar to the ones employed in the research) and obtaining a location map of Angwan Zakara Nasarawa State and field work comprises of geological, geophysical investigations. Geological investigation involved the use of the topographical map of Angwan Zakara which falls within Keffi sheet 208 NE, Global Positioning System (GPS), compass clinometer, geological hammer, sample bag, field notebook and writing materials; where traverses were taken along the gridded blocks in order to map out the various rock units effectively. Also, all the above parameters aided in producing the Geological map of Angwan Zakara and it environ, Geophysical investigation was carried out using Allied Ohmega Resistivity Meter (Ohmega Ω model) along with location map, Global Positioning System (GPS), current and potential electrode cables, crocodile clips, hammers, log-log data sheets. Vertical electrical sounding (VES) technique employing Schlumberger electrode configuration was used. A total of forty nine (49) soundings were taken with interval of 500m, the electrode spacing used was AB=100m and potential MN/2=5m using Allied Omega Resistivity Meter. The data obtained from the electrical resistivity survey were plotted on a log-log graph paper. The actual resistivity and thickness of the subsurface layers were obtained by matching the field curves on the log-log graph with the two layer master curves and the corresponding auxiliary curves. These parameters were then used for the computer iteration technique of the IX1D software to give the actual resistivity, depths and thicknesses of the layers, which were subjected to qualitative analysis using Surfer 8.0.

DATA PRESENTATION AND ANALYSIS

Geology of Angwan Zakara and Environs.

Geological mapping of Angwan Zakara on a scale of 1:12500 were undertaken with the aim of delineating boundary between the various rock units within the area. Topographic map of Keffi Sheet 208 N-E Central Nigeria was used to extract the base map for the study. Surface traversing method was adopted in gridding the area. The study area fall within the Pre-Cambrian Basement Complex of Nigeria, where most of the Pan-African "Older Granite rocks outcrop. Rocks found in the study area include Medium grained Biotite granite/Biotite gneiss, phyllite and schist. The phyllite occupied about 80%, Biotite gneiss occupied about 15% of the map and schist occupied 5% of the map with structural features such as joints, veins, foliation, faults, and xenoliths trending NW-SE direction (Figure 2).

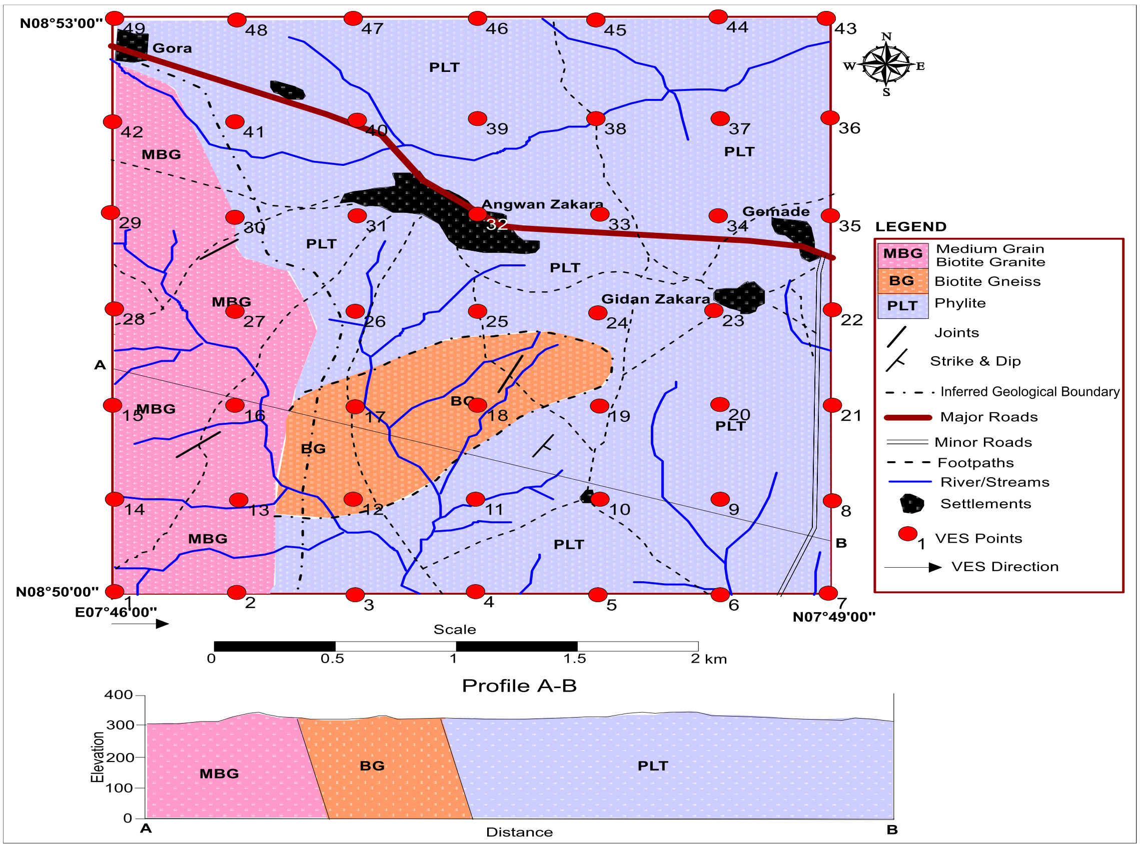

Figure 2: Geological map of Angwan Zakara and environ showing the Forty Nine (49) Vertical Electrical Sounding (VES) points probes.

Table2: Interpreted model Geoelectric parameters and curve types of Angwan Zakara and environ

S/N	VES POINTS	P1	P2	P3	P4	P5	P6	P7	H1	H2	H3	H4	H5	CURVE TYPE
1	VES 1	748	4262	40	178	797	6043		0.45	0.71	3.50	2.42	4.24	KHA
2	VES 2	572	3520	44	272	294	2629		0.40	0.82	5.26	3.14	6.24	KHA
3	VES 3	218	160	312	85	342	1436		1.07	3.27	5.62	7.80	8.57	HKH
4	VES 4	243	127	351	101	1270	4798		1.55	2.08	5.51	9.09	11.59	HKH
5	VES 5	1105	2951	116	148	193	4530		0.85	0.92	2.74	15.98	10.16	KHA
6	VES 6	745	5607	168	58	110	2873		0.30	0.52	4.85	4.66	5.60	KQH
7	VES 7	569	245	351	101	254	3206		1.49	1.87	0.62	60.4	11.7	HKH
8	VES 8	305	1109	150	35	142	4321		0.42	0.62	7.40	6.96	4.92	KQH
9	VES 9	263	2113	307	140	978			0.69	2.08	4.07	17.76		KQH
10	VES 10	98	720	147	100	6055			0.26	0.46	10.48	11.8		KQH

11	VES 11	581	2385	231	133	162	2388		0.62	1.01	6.57	15.1	17.52		KQH
12	VES 12	353	1507	210	92	8709			0.52	0.71	6.42	8.68			KQH
13	VES 13	760	161	79	113	7650			0.43	1.76	5.48	10.45			QHA
14	VES 14	544	205	55	448	1844	6523		0.42	3.32	2.82	1.99	3.12		QHA
15	VES 15	573	148	109	47	529	4520		1.58	3.56	3.52	5.49	6.28		QQH
16	VES 16	984	440	51	81	238	5607		0.89	1.25	4.46	10.3	8.1		QHA
17	VES 17	2687	1076	398	112	2066			0.38	3.17	7.65	13.28			QHA
18	VES 18	633	325	144	671	3060			1.79	1.12	4.46	10.8			QQH
19	VES 19	263	1136	509	537	6761			0.26	0.6	4.2	41.3			KHA
20	VES 20	1019	4676	493	168	71	7821		0.42	4.19	5.96	12.7			KQQ
21	VES 21	1121	5537	414	104	51	377	8185	0.56	1.0	5.4	5.5	9.6	8.7	KQQ
22	VES 22	1017	6269	256	83	60	4547		0.5	1.12	5.1	5.8	9.8		KQQ
23	VES 23	603	1089	218	186	1239			1.0	0.9	7.5	15.2			KQH
24	VES 24	248	1980	81	226	1930			0.5	1.18	4.7	12.7			KHA
25	VES 25	886	1637	63	67	146	4078		0.81	1.46	9.10	6.59	7.20		KHA
26	VES 26	737	92	29	106	272	6817		1.50	0.63	3.64	9.20	9.53		QHA
27	VES 27	549	265	68	162	282	3060		1.75	0.83	3.79	8.58	9.90		QHA
28	VES 28	142	1381	17	38	259	1300	6789	0.36	0.81	2.27	2.16	2.75	5.70	KHA
29	VES 29	1725	3206	110	212	456	2914		0.99	0.98	3.85	9.06	9.56		KHA
30	VES 30	276	526	13	206	1788			1.10	0.73	1.86	33.6			KHA
31	VES 31	487	109	20	122	1822	4320		0.80	2.11	2.75	1.90	3.22		QHA
32	VES 32	310	2238	266	281	400	1708		0.36	1.08	5.43	9.68	13.47		KHA
33	VES 33	940	3144	228	128	2980			0.72	0.65	5.50	6.96			KQH
34	VES 34	402	1146	344	289	2809			1.11	2.68	7.96	19.48			KQH
35	VES 35	509	1567	410	180	2310			1.89	3.18	7.34	12.89			KQH
36	VES 36	369	2265	100	186	127	2430		0.36	0.67	3.85	3.88	6.61		KHK
37	VES 37	274	4036	173	64	472	4786		0.32	0.67	5.25	6.15	4.38		KQH
38	VES 38	647	1945	72	268	239	4329		0.85	0.79	3.10	11.02	12.70		KHA
39	VES 39	207	3105	23	91	668	3450		0.22	0.50	1.10	4.85	11.32		KHA
40	VES 40	311	3943	365	170	146	4469		0.29	0.57	6.93	12.72	16.6		KQQ
41	VES 41	1628	1040	182	399	3540			0.28	2.05	11.4	4.96			QHA
42	VES 42	150	3908	40	78	339	2100		0.21	0.48	1.53	4.53	7.78		KHA
43	VES 43	180	1200	200	150	298	1205		1.09	1.98	4.78	4.98	8.08		KQH
44	VES 44	725	320	122	162	709	3015		2.10	1.38	5.79	4.52	4.87		QHA
45	VES 45	375	3107	83	114	182	2972		0.51	0.82	5.53	12.34	13.23		KHA
46	VES 46	706	58	95	228		6660		1.35	3.07	8.71	7.73			HA
47	VES 47	244	2258	98	136	4885			0.37	0.95	8.01	5.86			KHA
48	VES 48	135	2133	158	175	3387			0.42	1.07	8.19	17.40			KHA
49	VES 49	115	2294	156	131	240	1528		0.37	0.84	6.35	11.02	9.21		KHA

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Analysis of hydrogeophysical survey Results

The field curves are dominantly KHAA, KQH, QHA types (Keller & Frischknecht, 1966). Geoelectric interpreted parameters of the study area is summarized in Table 2. The various vertical electrical sounding points were modelled with IX1D software where their layers resistivity and thickness were obtained. The study area revealed seven, six and five layer cases. The types of lithology revealed are Top soil, sandy clayey and laterite, partially fractured/weathered basement, weathered and fractured basement and fresh basement. The inferred lithologies to each layer were based on geological and inference of previous work carried out (Jatau *et al.*, 2013; Dan Hassan & Olorunfemi, 1999). A typical geoeletric section reveals the presence of different geoelectric layers of different thickness obtained and different types of lithology was discovered which ranges from top soil to fresh basement (Figure 3).

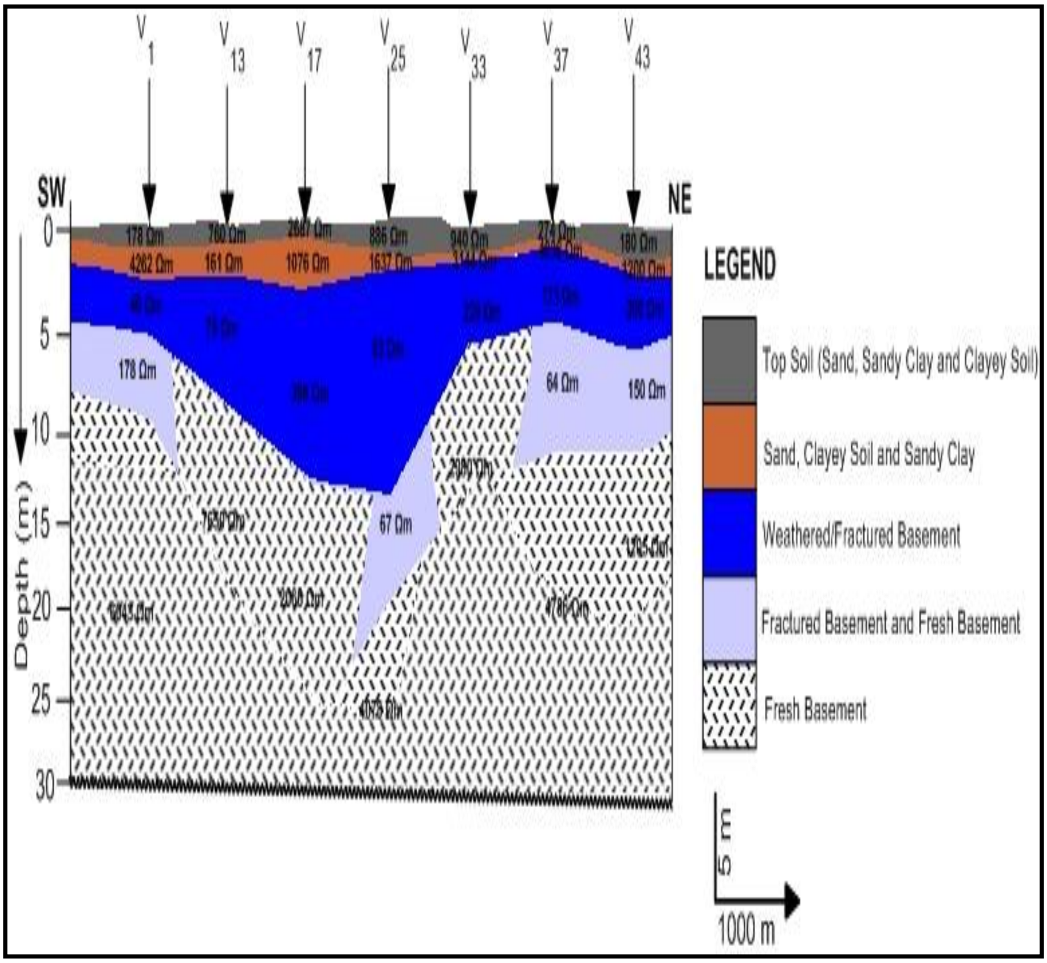

Figure 3: NE-SW Geoelectric cross-section of Angwan Zakara and environs.

The Basement Resistivity of Angwan Zakara and Environs

The basement resistivity for each sounding point was obtained from the interpreted geoelectrical data (Table 2). The basement resistivity of the sounding point defines the type, nature and character of the layer. In the study area, the contour map shows a NW-SE and E-W trend which are controlled by structures (fractures and weathered). Resistivities values >1000 revealed a fresh basement granitic rock and values<1000 revealed the weathered/fractured

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quartzite and granite. The basement resistivity in the southern areas in purple colour revealed a low potential area due to the rocks nature (Figure4). The fresh basement has resistivity of 974 Ωm to 7821 Ωm and the thickness tends to infinity. This result shows that aquifer units are present with significant ground water potential, which may be safe from contamination.

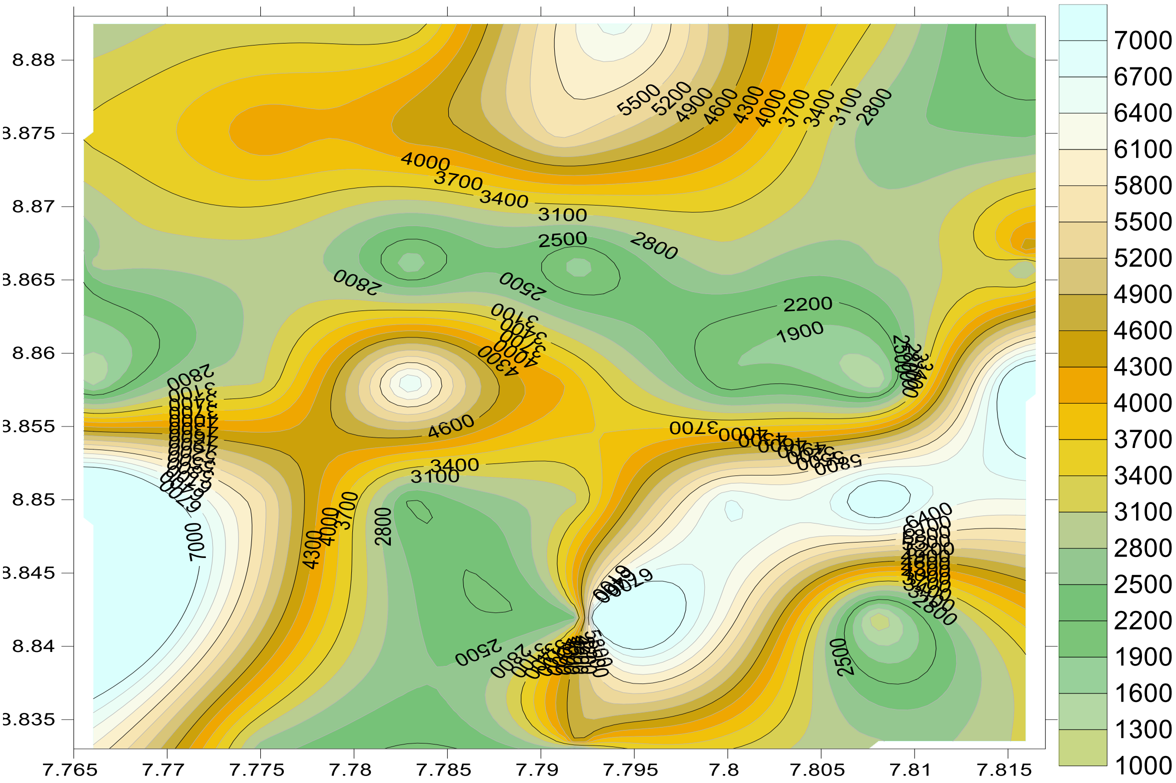

Figure 4: Basement Resistivity Map of Angwan Zakara and Environ

Depth to Basement Map of Angwan Zakara and Environs

This is the depth to the basement rock beneath the surface. The depth to fresh basement rocks beneath the sounding point was rounded up to the nearest whole number as obtained from the quantitative interpretations (Table 2). The depth to basement rocks ranges from 10m -70m. The basement is deeper at the southern portion of the study area with 50-70m. Generally, the depth to the basement decreases from Gora, Angwan Zakara, eastward, and westward. This makes the southern portion and southern of Angwan Zakara a groundwater receptacle zone, since groundwater will flow down topography to it. The result is in close range with the other research work carried out in the North-central, Nigeria like Dan Hassan and Olorunfemi (1999) that predicted 4.3m – 64m and Jatau *et al.* (2013) 15m- 49m. The study area map reveals shallow overburden areas where the depth to basement is shallow. Two depressions were revealed in Gora Angwan Zakara, and also two ridges were also revealed in southern portion, south of Angwan Zakara axis (Figure 4). Areas of thick overburden, less percentage of clay and good degree of porosity and permeability may have relatively good groundwater yield.

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True Aquifer Resistivity Map of Angwan Zakara and Environs

The individual true aquifer resistivity of the study area obtained from the processed data (Table2) were plotted and contoured as shown in (Figure 5). Area with good aquiferious zone for water potential in the map are Angwan Zakara, Angwan Sallow, part of Gora and S-W of Angwan Zakara with apparent resistivity value of 100 – 240 (weathered and fractured basement) and Gora, south of Angwan Zakara have moderate water potential with resistivity value of 280 –500 partially fractured basement and weathered laterite. The lithology of the area has less percentage clay in weathered basement layer. Its thickness ranges from 0.36-0.56m and 2.16-5.8m.

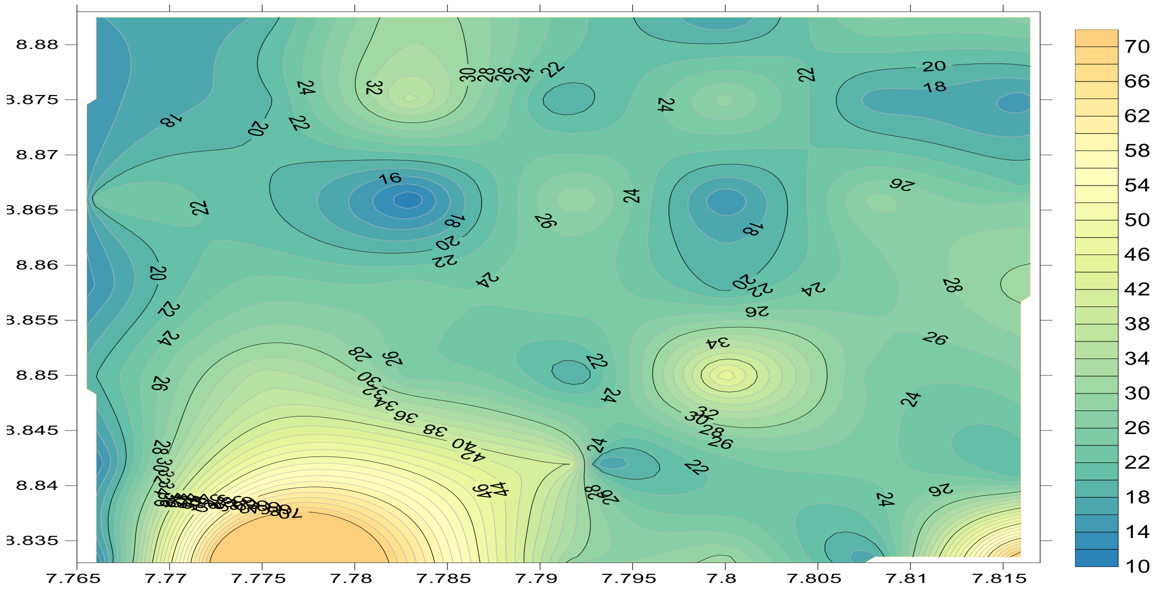

Figure.5: Depth to Basement Map of Angwan Zakara

Piezometric Map of Angwan Zakara and Environs

The piezometric map was obtained by subtracting the field spot elevation by the depth of the overburden thickness of each location this help in determining the direction of flow of aquifer water in the study area. The direction of the groundwater movement can be understood in the fact that groundwater always flows in the direction of decreasing head. The piezometric map of Angwan Zakara revealed that Gora which is the N-E of the map show high piezometric spot of 380m and around Angwan Zakara record a piezometric spot of 350m and Angwan Sallu and area with green colour recording lowest piezometric spot which implies that the flow of the stream in the study area lies within the basement depression.

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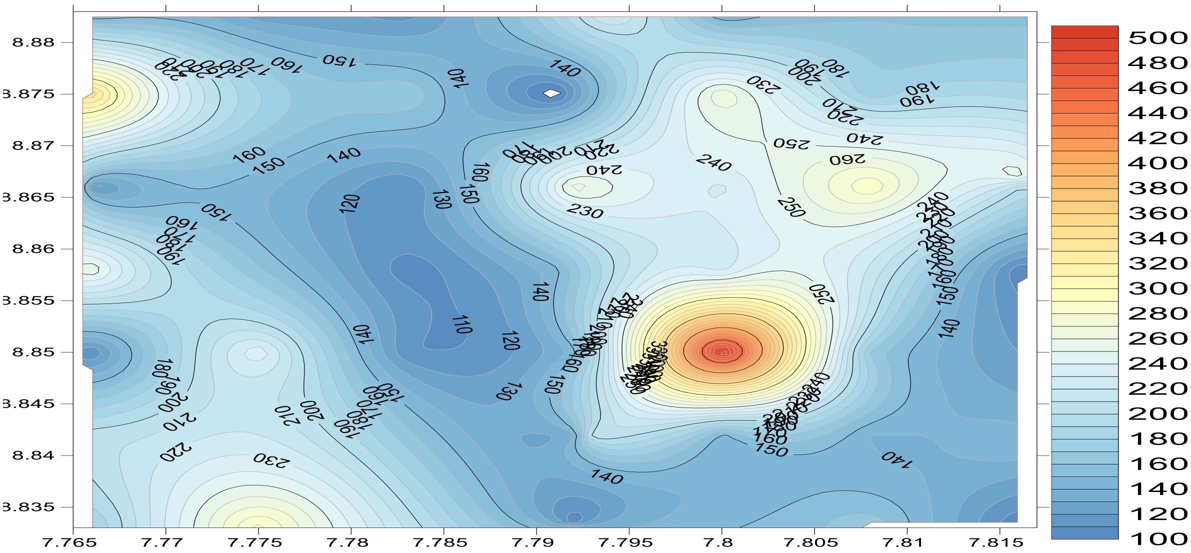

Figure 6: True Aquifer Resistivity Map of Angwan Zakara

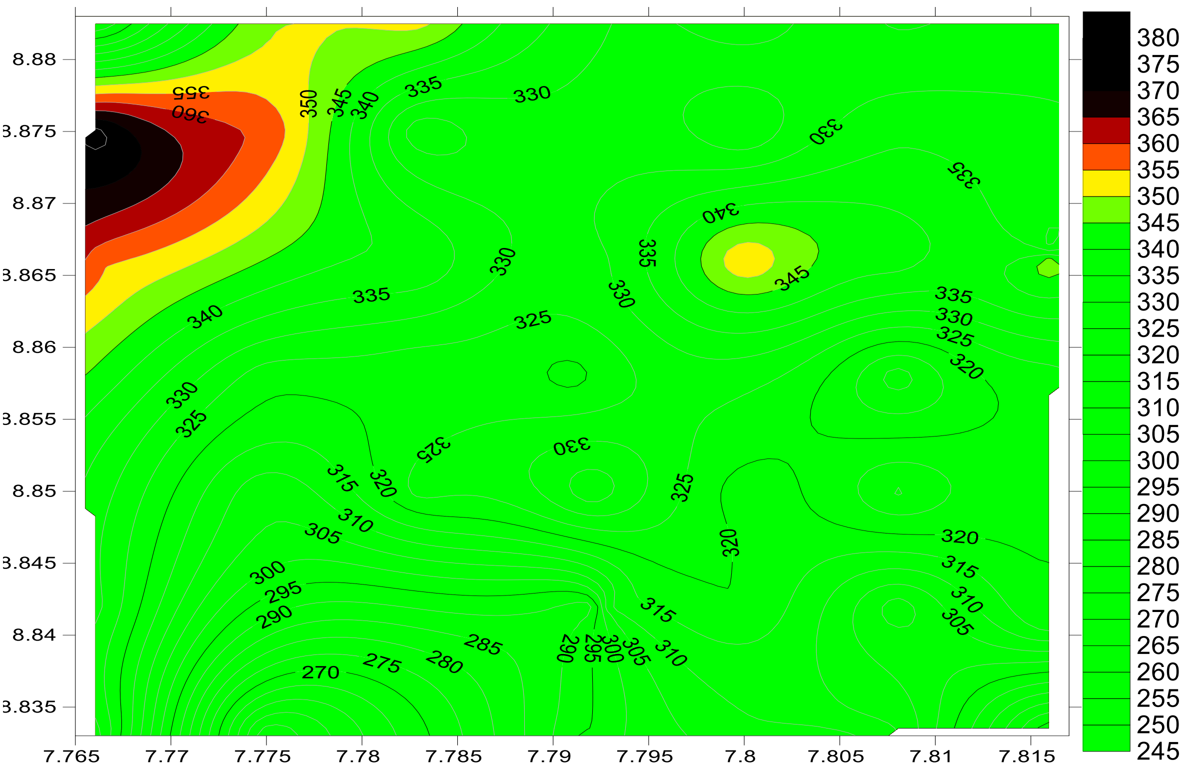

Figure 7: Piezometric Map of Angwan Zakara and environ.

The bedrock relief map of the study area ranges in relief or elevation from 245-380 m is illustrated in Figure7. It reveals the uneven nature of the bedrock comprising of ridges (areas of high relief) and depressions (areas of low relief). Low relief areas are represented by green colour, medium relief represented by lemon green-yellow colour; and high relief are represented by black colour. The relief zone acts as convergence zones for good groundwater flow/accumulation; while areas of high reliefs in of the study area acts as divergence zones for groundwater flow/accumulation due to the presence of the ridges and also serves as structural control to the streams, which correlates with the findings of (Jatau *et al.*, 2014), (Figure7) while the 3-D view is shown in Figure 8.

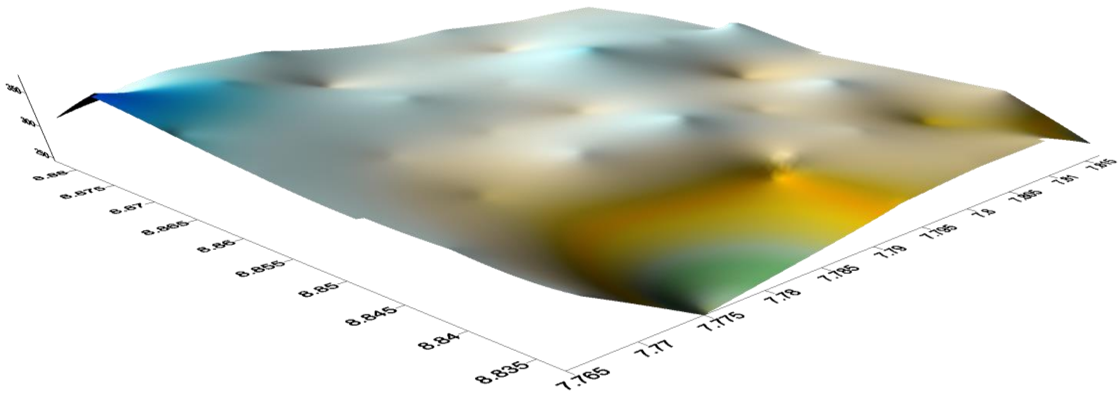

Figure 8.The 3-D view Map of Angwan Zakara and environ.

DISCUSSION OF RESULTS

The study area fall within the Pre-Cambrian Basement Complex of Nigeria, where most of the Pan-African “Older Granite rocks outcrop. Rocks found in the study area include migmatite gneiss, phyllite and schist. The phyllite occupied about 80%, migmatite gneiss occupied about 15% of the map and schist occupied 5% of the map with structural features such as joints, veins, foliation, faults, and xenoliths trending NW-SE direction.

The types of lithology revealed are Top soil, sandy clayey and laterite, partially fractured/weathered basement, weathered and fractured basement and fresh basement. The summary of the layers interpretation based on the lithology is shown in (Table 2). The inferred lithologies to each layer were based on geological and inference of previous work carried out (Jatau *et al.,* 2013; Dan Hassan & Olorunfemi, 1999). While, the basement resistivity was recorded as the last layer resistivity and the sounding point defines the type, nature and character of the layer. The result is in close range with the other research work carried out in the North-central, Nigeria such as Dan Hassan and Olorunfemi (1999) that predicted 4.3m – 64m and Jatau *et al.* (2013) 15m- 49m. The study area map reveals shallow overburden areas where the depth to basement is shallow. Two depressions were revealed in Gora Angwan Zakara, and also two ridges were also revealed in southern portion, south of Angwan Zakara axis (Figure 4). Areas of thick overburden, less percentage of clay and good degree of porosity and permeability may have relatively good groundwater yield.

Area with good aquiferious zone for water potential in the map are Angwan Zakara, Angwan Sallow, part of Gora and S-W of Angwan Zakara with apparent resistivity value of 100 – 240 (weathered and fractured basement) and Gora, south of Angwan Zakara have moderate water potential with resistivity value of 280 –500 partially fractured basement and weathered laterite. The lithology of the area has less percentage clay in weathered basement layer. Its thickness ranges from 0.36-0.56m and 2.16-5.8m.The thickness implies that the aquifer is confined below lateritic bed and can be classified as upper confined.

The direction of the groundwater movement can be understood in the fact that groundwater always flows in the direction of decreasing head. The piezometric map of Angwan Zakara reveals that Gora which is the N-E of the map show high piezometric spot of 380m and around Angwan Zakara record a piezometric spot of 350m and Angwan Sallu and area with green colour recording lowest piezometric which implies that the flow of the stream in the study area lies within the basement depression. The relief zone acts as convergence zones for good groundwater flow/accumulation; while areas of high reliefs in of the study area acts as divergence zones for groundwater flow/accumulation due to the presence of the ridges and also serves as structural control to the streams, which correlates with the findings of (Jatau *et al.*, 2014). Geological structures found were veins (quartz and quartzo-feldspathic), joints and foliations with NW-SE and NE-SW dominant structural trend respectively, which correlates with other workers (Anudu *et al.*, 2014; Jatau *et al.*, 2014).

CONCLUSION

Geologically, the study area has three (3) major rock units namely the medium grained Biotite Gneiss, Biotite Gneiss and Schist as shown on the geological map of the study area. Geological structures found were veins (quartz and quartzo-feldspathic), joints and foliations with NW-SE and NE-SW dominant structural trend respectively, which correlates with other workers (Anudu *et al.*, 2014; Jatau *et al.*, 2014). Groundwater potential (weathered and/or fractured basement layer) with respect to their thickness values, were zoned into low, medium and high potentials for groundwater development. Geophysical survey revealed 5-7 geoelectic layers comprising of top soil, laterite, weathered basement, partially weathered/fractured basement, fractured basement and fresh basement; which gave rise to the weathered and fractured aquifer that are peculiar to the Basement Complex terrain. The depth to fresh basement or overburden thickness ranged from 29-79.5 m, which implies that the area is generally good for groundwater development, especially places with distinctive weathered and/or fractured layers thicknesses. Boreholes drilled through these stations, may provide sufficient water for sustainable supply. Also there are three major rock types, which consist of Biotite Gneiss, Granite Gneiss and Muscovite Schist, containing veins, joint and foliation, with NW-SE and NE-SW dominant structural trend. Based on the vertical electrical sounding carried out it is recommended that in some very complex terrain other geophysical methods such as VLF and Electrical profiling using dipole-dipole array would be useful before sounding. The need to harness the water system in the area as the potential is enormous will go a long way in easing water problems in the study area. This study can be a useful guide to individuals, researchers, agencies and managers in water resources planning and development in the area.

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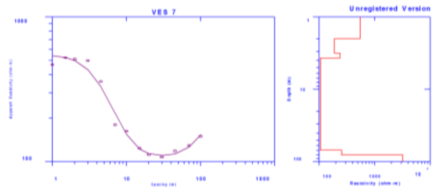
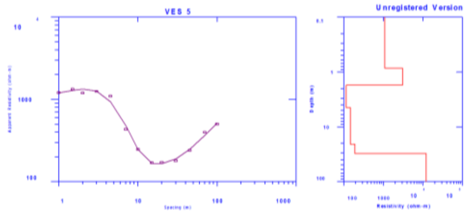
APPENDIX TYPICAL CURVES TYPES IN THE STUDY AREA

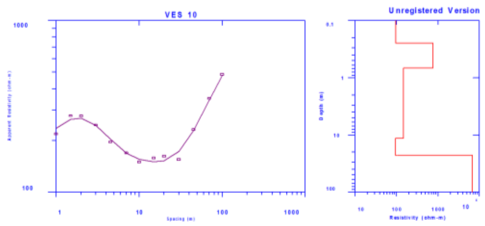
Appendix 1: HK curve type



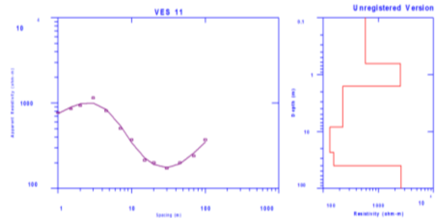
Appendix 2: HA curve TYPE



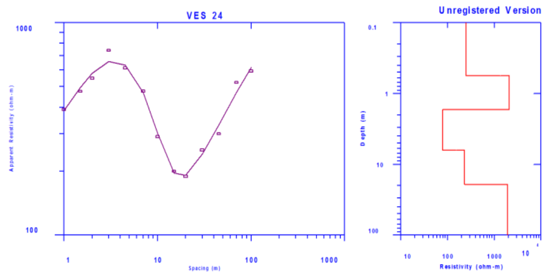
Appendix 3: QHA curve type



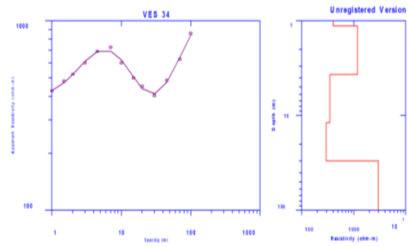
Appendix 4: AH curve type



Appendix 5: H curve type



Appendix 6: QAH curve type



Appendix 7: QAH curve type