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Application of Vertical Electrical Soundings to Characterize Aquifer Potentials and Subsurface Interpretation in Njikoka and Environs, Anambra State, Nigeria

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Abstract

Purpose: Geophysical exploration for water table characteristics were carried out in six (6) communities of Njikoka and environs through which water table depth, depth below the water table, thickness of the saturated zone, depth with reference to mean sea level (MSL) and types of aquifer were deduced. The proven geoelectric sections of the study area based on resisitivity from the subsurface and electrical log which confirmed that depth to water table of Njikoka and environs could range from 15 m – 100 m. Depth below the water table in the study area ranged 40 m (around Nimo, Enugu Agidi) to 200 m (Ifitedunu, Ukpo) while the thicknesses of the saturated zones (aquifers) varies from 25 m to 160 m within the respective communities. Depths to Mean Sea Level were delineated to range from – 20 m to – 198 m as obtained from the difference in the water table depths and the heights above sea level which is the elevations.

Methodology: Subsurface geophysical exploration was employed in the research of groundwater availability of Njikoka and environs. Schlumberger Vertical Electrical Sounding which is the subsurface geophysical method was carried out only on two locations in each of the communities. The geophysical investigation was made with Earth Resistivity equipment

Findings: From the revealed results the study area is dominated with low land topography and prominently composed of unconfined with less cases of confined aquifer as a result of the geological settings of the study area.

Keywords: *VES, Resistivity, IPI2WIN, Thickness, Water Table Depth, Depth Below The Water Table And Depth From Mean Sea Level*

INTRODUCTION

Groundwater is natural resource which plays a significant function in human and economic activities on this earth. Groundwater is an underground water that flow through space (rock) called aquifer. The formation of aquifer is solely engulfed in hydrologic cycle which is the inflow, outflow and storage of water in interrelationship of hydrosphere, biosphere, geosphere and atmosphere by way of processes like evaporation, transportation, condensation, precipitation, deposition, runoff, infiltration and groundwaterflow (Fig. 1). When there is sun radiation on rains, plant, water, stream, rivers or lake, moisture rise to the atmosphere to form vapour (Evaporation). There is cooling of vapour at that stage until it becomes liquid. Liquidification process of the moisture which is precipitation occur and transportation or deposition takes place, then two things are common at the stage of transportation which is Run off water and Infiltration. In the case of runoff water; some portion of water particles discharged on the surface and held temporarily while during infiltration; some of the water will be soaked or infiltrated into the ground to form groundwater as the move into the subsurface layers over time to form aquifer.

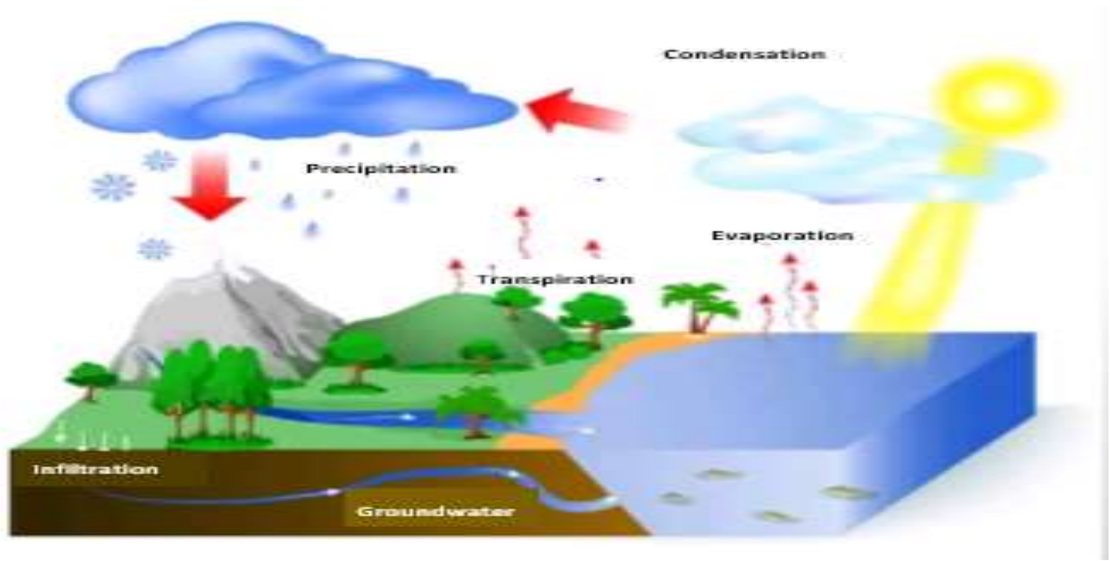

Figure 1: Water Cycle. (As Adapted From Http:// Water.Usgs.Gov/Ogw).

Accessibility and Topography of the Study Area

The study area includes six communities under Njikoka Local Government Area in Anambra State of Nigeria. The six major communities in the study area are Abba, Enugwuagidi, Nawfia, Abagana, Enugwuukwu and Nimo. Njikoka are generally characterized with broad ridges and fairly broad hills. It is also dominated with presence of relief lateritic crust hence said to be undulating topography (Ayadiuno et al. 2022). Njikoka and environs is mapped within the Latitudes 6^0 05'N and 6^0 13'N and Longitudes 7^0 01'E and 6^0 09'E that covers six (6) major towns with their specified range of elevation as 102 m – 228 m. The study area tends to be situated within two major landforms, namely the Eastern Lowland and Western Upland which is mostly covered with negative relief features by the occurrences of geohydrologic resources of the Eastern Lowland and groundwater discharge from the prolific Nanka Sand. The Fig. 2 below shows the map of Anambra State showing the study area and topographical overview of the study area under a scale of 1: 70,000 m in a contour interval of 20 m within the six communities with an indication of the major and minor roads.

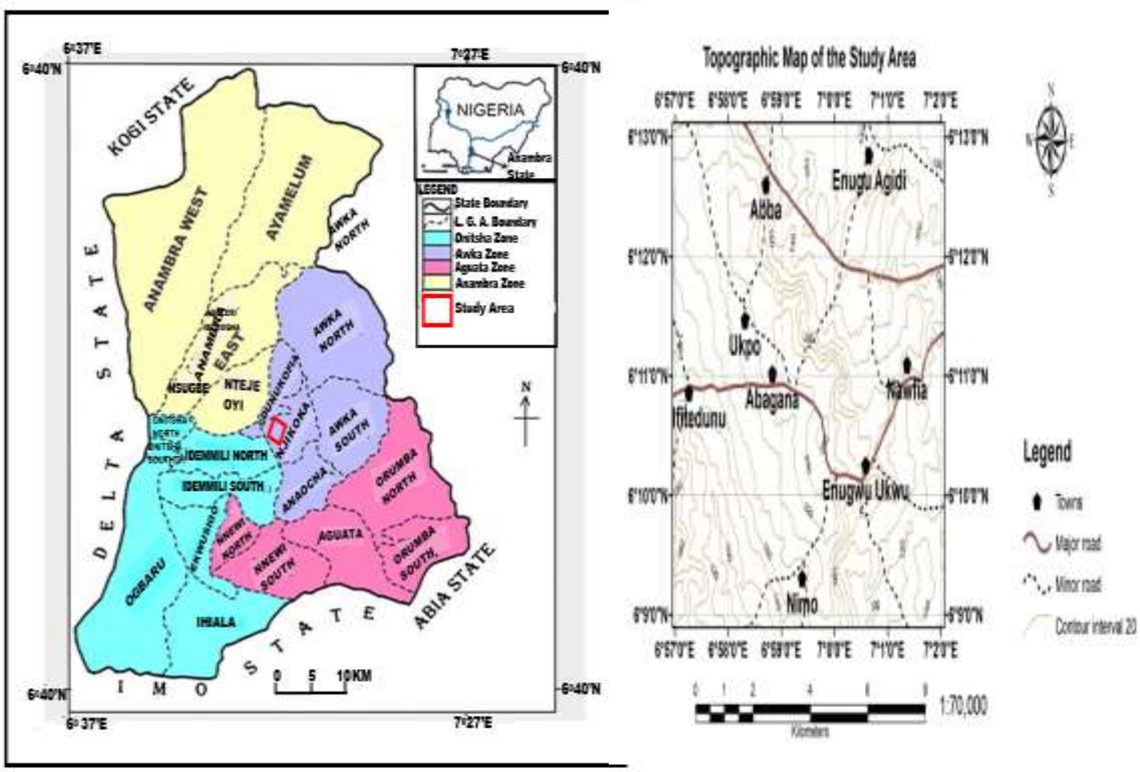

Fig. 2: Map of Anambra State showing the study area (Chinwuko et al, 2016) and Topographical setting of the Study Area modelled using Geographic Information System (GIS Software)

Geological Setting of the Study Area

Njikoka and environs is underlain by Ameki Group which consists of Ameki Formation, Nsugbe Formation and Nanka Sand (Fig. 3.). Ameki formation has general features thus, fossiliferous grayish- green sandy clay, calcareous concretions and white clayey sandstones. Nanka Formation composed of fine - coarse sandstone embedded with calcareous shale, thin shaly limestone intercalations, sandy clay and unconsolidated Cross-bedded white or yellow sandstone. Nanka Formation is basically seen outcropped at Agu-Awka and Umunya, around 18 km Onitsha-Enugu express way (Nwozor and Egboka, (2007); Nfor et al 2007) and has similar texture to Ajalli Sand with thickness of about 350 m at exposed locality in Nanka community, wide gullies in Oko and Agulu (Nwajide, 1979). Nanka Sand is characterized with biological, physical and chemical structures as cross-bedding, whitish color, friability that left it to a loose formation susceptible to erosion activities, forms hill-filling and concave shaped depression in Imo Shale.

As modified by Kogbe 1989, Nanka Sand forms the lateral equivalent of Ameki Formation believed occupying most part of the Anambra State. Based on lithology the Nanka Formation tends to form monotonous sand except occasional centimeter to meter scale glauconitic shale, mudstone, claystones and ferruginous sandstone horizons. Moreover, Nanka Sand is underlain by aquitard shale which helps sustain the major water reservoirs usually located within the formation (Nwajide, 1979).

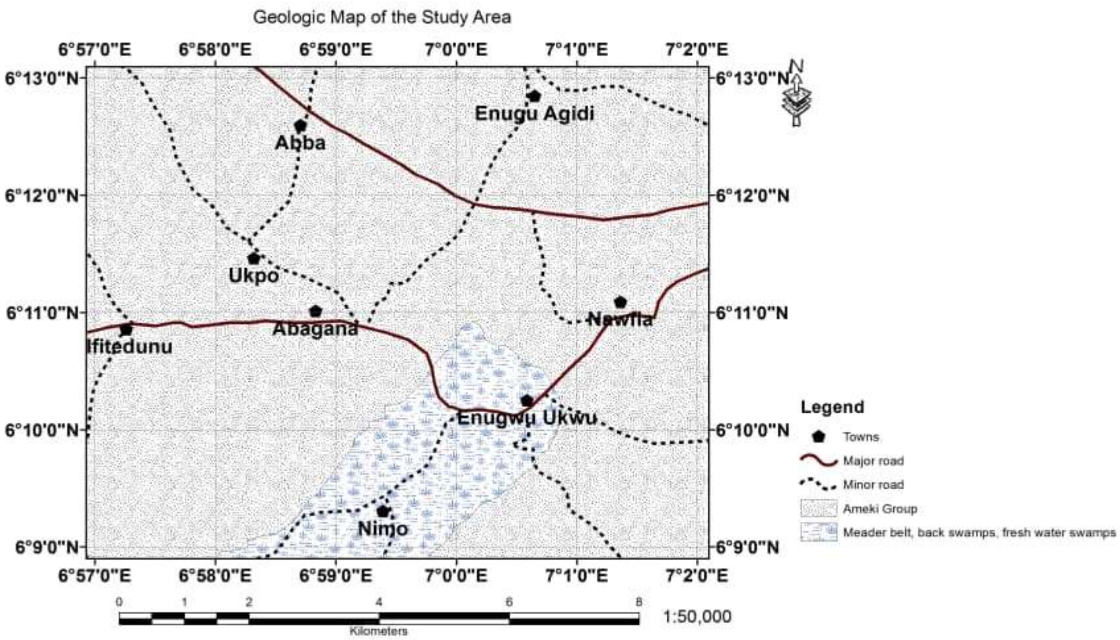

Figure 3: Geological Map of Njikoka and Environs Modelled Using Geographic Information System (GIS Software)

METHODOLOGY AND DATA COLLECTION

Subsurface geophysical exploration was employed in the research of groundwater availability of Njikoka and environs. Schlumberger Vertical Electrical Sounding which is the subsurface geophysical method was carried out only on two locations in each of the communities. The geophysical investigation was made with Earth Resistivity equipment, ABEM Terrameter SAS 300 which is highly sensitive with a digital readout. The instrument has the ability of giving out direct resistances of the earth layers which when multiplied with their individual geometric factor gives apparent resistivity of different layers. Fig. 4 shows how resistivity measurements are normally made by passing current into the ground through two current electrodes (AB/2), and measuring the resulting voltage difference at the two potential electrodes (MN/2).

Two VES traverses each were run in Abba, Enugwuagidi, Nawfia, Abagana, Enugwuukwu and Nimo. Njikoka towns in order to study the variations in each resistivity with depth (Fig. 3). The vertical electrical sounding (VES) data acquired from the field were converted to apparent resistivity values by multiplying the resistance with the appropriate Schlumberger geometric factor. The formula of the Schlumberger geometric factors (K) is stated below.

$K = \pi (L^2 - b^2) R\alpha/2$ …………………………………………………………….. (1)

Whereas, $\rho a = K \times R\alpha$ ……………………………………………………...…. (2)

Where;

π = 3.14 (Pi, constant) L = current electrode spacing (AB/2), b = potential electrode spacing (MN/2), ρa = apparent resistivity (the product of geometric factor and resistance measured in ohm-m) and $R\alpha$ = resistance reading in ohm

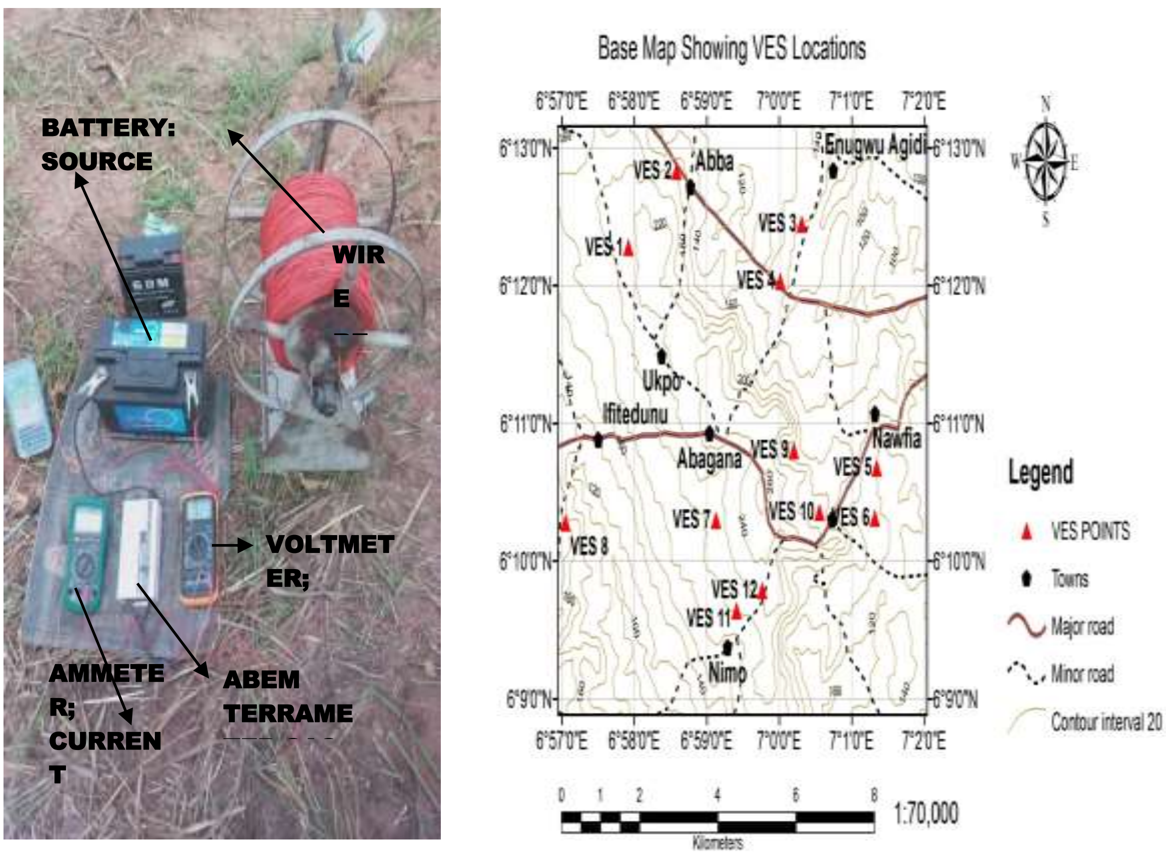

Figure 4: Geophysical Equipment and the VES Locations Surveyed in the Study Area

RESULTS AND DISCUSSION

The data obtained from surveyed VES locations in the study area characterized the groundwater sustainability. The features observed are resistivities, thickness and depths as regards to the saturated zone of the study area. Field data (current electrode AB/2, potential electrode MN/2 and apparent resistivities) of the entire sounding locations were plotted against the electrode spacing using IPI2WIN to obtain different curve types (Fig. 5 and Fig. 6).

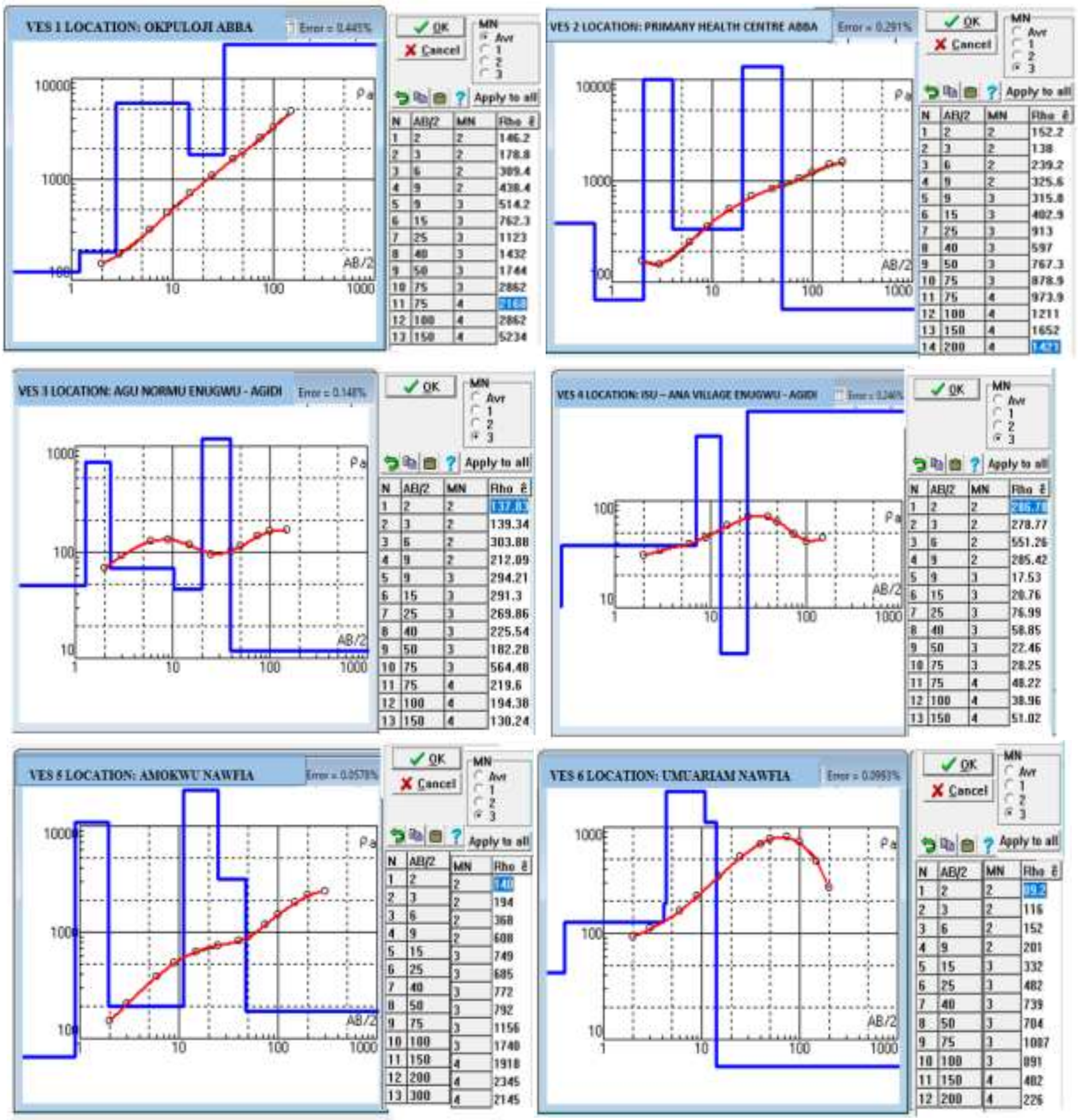

*Figure 5: Location 1 (Okpuloji Abba) showing VES Curve Type A and Location 2 (Primary health centre Abba) showing VES Curve Type A, Location 3 (Agu Normu Enugwuagidi) shows VES Curve Type H and Location 4 (Isu-ana village) VES Curve Type K. Location 5 (Amokwu Nawfia) revealed VES Curve Type A and Location 6 (Umuariam Nawfia) VES Curve Type AK***.**

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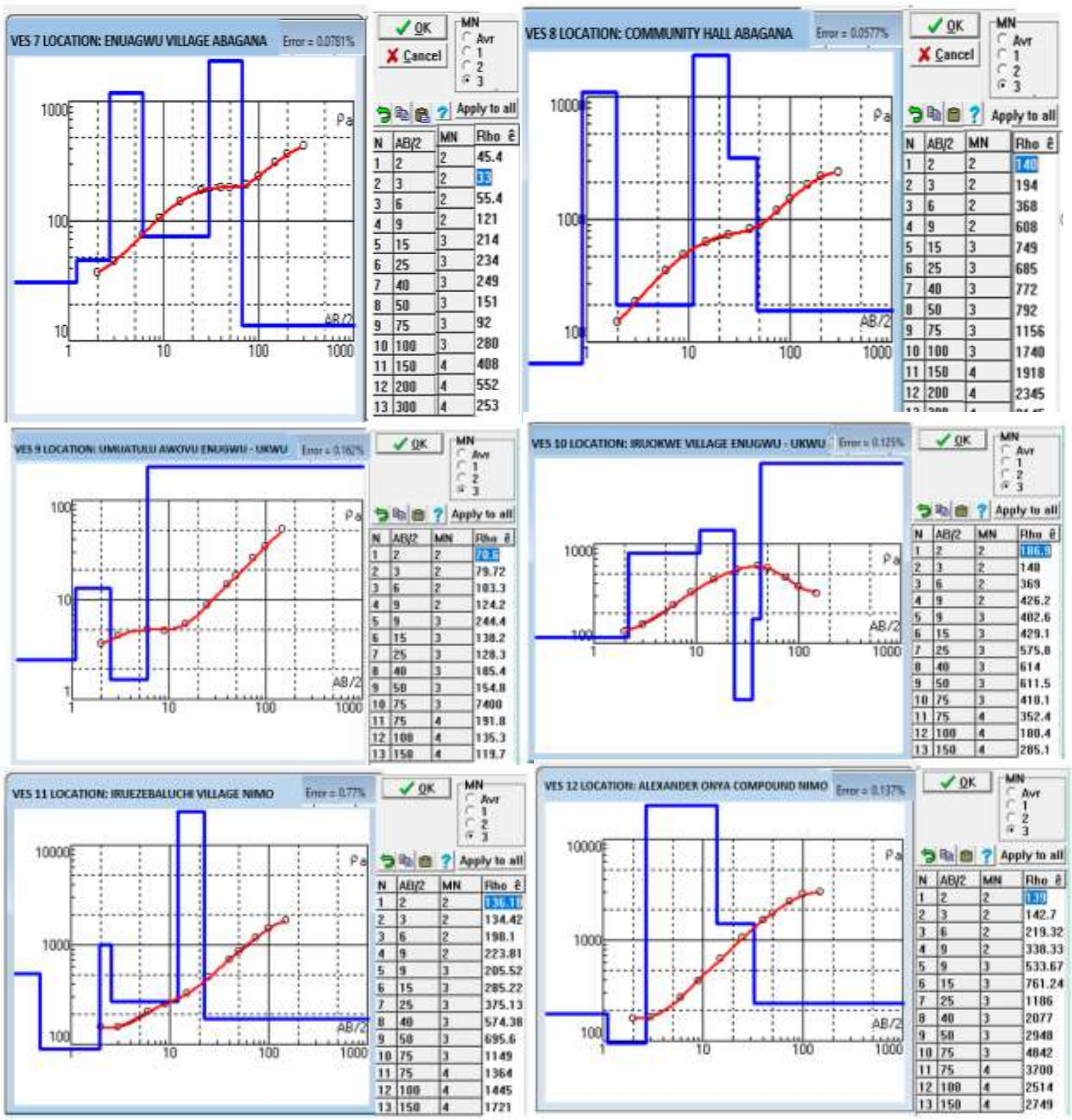

Fig. 6: Location 7 (Enuagwu Abagana) is VES Curve Type KH and Location 8 (Community Hall Abagana) VES Curve Type H. Location 9 (Umuatulu Awovu Enugwukwu) proved VES Curve Type H and Location 10 (Iruokwe Village) VES Curve Type K. Finally, Location 11 (Iruezebaluchi Nimo) shows VES Curve Type A and Location 12 (Alexander Onya Compd Nimo) showing VES Curve Type A.

Interpretation of VES Locations of the Study Area

The VES data obtained from the field were interpreted based on geological and geophysical knowledge (Table 1 and Table 2). In group A vertical electrical sounding Abba VES 1 and VES 2 has maximum of four geoelectric sections delineated Top soil, Dry sand, Water saturated sand, Top soil, Shale¸ Sandy shale and Water saturated sand respectively. Enugwuagidi VES 3 and 4 have five layers as Top soil, Dry sand, Shale, Water saturated sand and Shale and Top soil, Dry sand, Shale, Water saturated sand and Shale respectively. Nawfia VES 5 has Top soil, Dry sand, Water saturated and sand while VES 6 composed of Top soil, Dry sand, Water saturated sand and Shale. Abagana consist of Top soil, Dry sand, Shale, Water saturated sand and Shale in VES 7 location and Top soil, Dry sand, Shaly sand, Water saturated sand and dry sand in VES 8 location. Enugwukwu VES 9 is of Top soil, Dry sand, Shale, Water saturated sand and Shale while VES 10 location consist of Top soil, Dry sand, Water saturated sand and Shale. Nimo VES 11 locations composed of Top soil, Dry sand, Water saturated sand and VES 12 location; Top soil, Dry sand and Water saturated sand.

Table 1: Summary result of interpreted geoelectric sections of group A of the study area

Location	VES No.	Total layer	Litho layer	No. of ρa (Ωm)	Calculated Average	Calculated Thickness	Calculated depth (m)	Inferred lithology	Longitude	Latitude	Elevation (m)
Abba	VES 1	324.96	Layer 1	2	162.48	3	3	Top soil	E006^0 58.046'	N06^0 12.367'	221
		6323.72	Layer 2	7	903.38	47	50	Dry sand			
		13126.32	Layer 3	3	3281.58	100	150	Water saturated sand			
	VES 2	290.16	Layer 1	2	145.08	3	3	Top soil	E006^0 57.918'	N06^0 12.257'	205
		2196.55	Layer 2	5	439.31	22	25	Shale			
		597.055	Layer 3	1	597.05	15	40	Sandy shale			
		6904.56	Layer 4	6	1150.76	140	200	Water saturated sand			
Enugwuagidi	VES 3	581.04	Layer 1	3	193.58	6	6	Top soil	E007^0 00.23'	N06^0 12.460'	127
		797.58	Layer 2	3	265.868	9	15	Dry sand			
		677.67	Layer 3	3	225.895	35	50	Shale			
		784.08	Layer 4	2	392.042	25	75	Water saturated sand			
		324.60	Layer 5	2	162.308	75	150	Shale			
	VES 4	565.54	Layer 1	2	282.775	3	3	Top soil	E007^0 00.013'	N06^0 12.014'	102
		836.68	Layer 2	2	418.34	6	9	Dry sand			
		38.29	Layer 3	2	19.145	6	15	Shale			
		135.84	Layer 4	2	67.92	25	40	Water saturated sand			
		185.00	Layer 5	5	37.782	110	150	Shale			

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Table 2: Summary Result of Interpreted Geoelectric Sections of Group B of the Study Area

Location	VES No.	Total layer	Litho layer	No. of ρa (Ωm)	Calculated Average	Calculated Thickness	Calculated depth (m)	Inferred lithology	Longitude	Latitude	Elevation (m)
Nawfia	VES 5	333.78	Layer 1	2	166.89	3	3	Top soil	E007^0 01.364'	N06^0 10.936'	170
		3973.62	Layer 2	6	662.27	47	50	Dry sand			
		2896.18	Layer 3	2	1448.09	50	100	Water saturated sand			
		6408.18	Layer 4	3	2136.06	200	300	Dry sand			
	VES 6	89.18	Layer 1	1	89.18	2	2	Top soil	E007^0 01.318'	N06^0 10.325'	193
		2021.76	Layer 2	6	336.96	38	40	Dry sand			
		2601.54	Layer 3	3	867.18	60	100	Water saturated sand			
		707.96	Layer 4	2	353.98	100	200	Shale			
Abagana	VES 7	133.77	Layer 1	3	44.593	6	6	Top soil	E006^0 59.126'	N06^0 10.324'	120
		968.95	Layer 2	5	193.792	44	50	Dry sand			
		371.90	Layer 3	2	185.955	50	100	Shale			
		960.08	Layer 4	2	480.043	100	200	Water saturated sand			
		253.44	Layer 5	1	253.44	100	300	Shale			
	VES 8	333.78	Layer 1	2	166.89	3	3	Top soil	E006^0 57.020'	N06^0 10.291'	190
		1724.79	Layer 2	3	574.93	12	15	Dry sand			
		2248.83	Layer 3	3	749.613	35	50	Shaly sand			
		4814.16	Layer 4	3	1604.72	100	150	Water saturated sand			
		4489.78	Layer 5	2	2244.89	150	300	Dry sand			
Enugwukwu	VES 9	150.32	Layer 1	2	75.16	3	3	Top soil	E007^0 00.219'	N06^0 10.786'	193
		471.87	Layer 2	3	157.294	6	9	Dry sand			
		266.52	Layer 3	2	133.265	16	25	Shale			
		7932.08	Layer 4	4	1983.0	50	75	Water saturated sand			
		254.96	Layer 5	2	127.483	75	150	Shale			
	VES 10	334.96	Layer 1	2	167.48	3	3	Top soil	E007^0 00.541'	N06^0 10.382'	213
		1626.92	Layer 2	4	406.735	12	15	Dry sand			
		1801.32	Layer 3	3	600.443	35	50	Water saturated sand			
		1228.04	Layer 4	4	307.01	100	150	Shale			
Nimo	VES 11	270.58	Layer 1	2	135.298	3	3	Top soil	E006^0 59.379'	N06^0 09.651'	193
		1869.12	Layer 2	6	311.525	37	40	Dry sand			
		6374.50	Layer 3	5	1274.90	110	150	Water saturated sand			
	VES 12	281.70	Layer 1	2	140.851	3	3	Top soil	E006^0 59.734'	N06^0 09.783'	228
		1852.52	Layer 2	4	463.139	12	15	Shaly sand			
		4658.73	Layer 3	3	1552.91	35	50	Dry sand			
		13806.00	Layer 4	4	3451.50	100	150	Water saturated sand			

The permeable layer that yield groundwater below the zone of saturation is called aquifer whereas the water table is the upper surface of the zone of saturation (aquifer). From the distribution of geoelectric sections in group A and B of the VES locations in the study area the prominent aquifers are revealed to be confined and unconfined aquifers with their respective resistivity values. The types of aquifer seen in the study area are relevant to the undulated topographic, poor drainage and recharge systems human and economic activities over the years. VES 3, VES 4, VES 7 and VES 9 are dominated with confined aquifer which enclose between impermeable layers while unconfined aquifer has permeable layer above and impermeable layer only below the saturated rock formation as shown in VES 1, VES 2, VES 5, VES 6, VES 8, VES 10, VES 11 and VES 12 locations (Fig. 7 and Fig. 8).

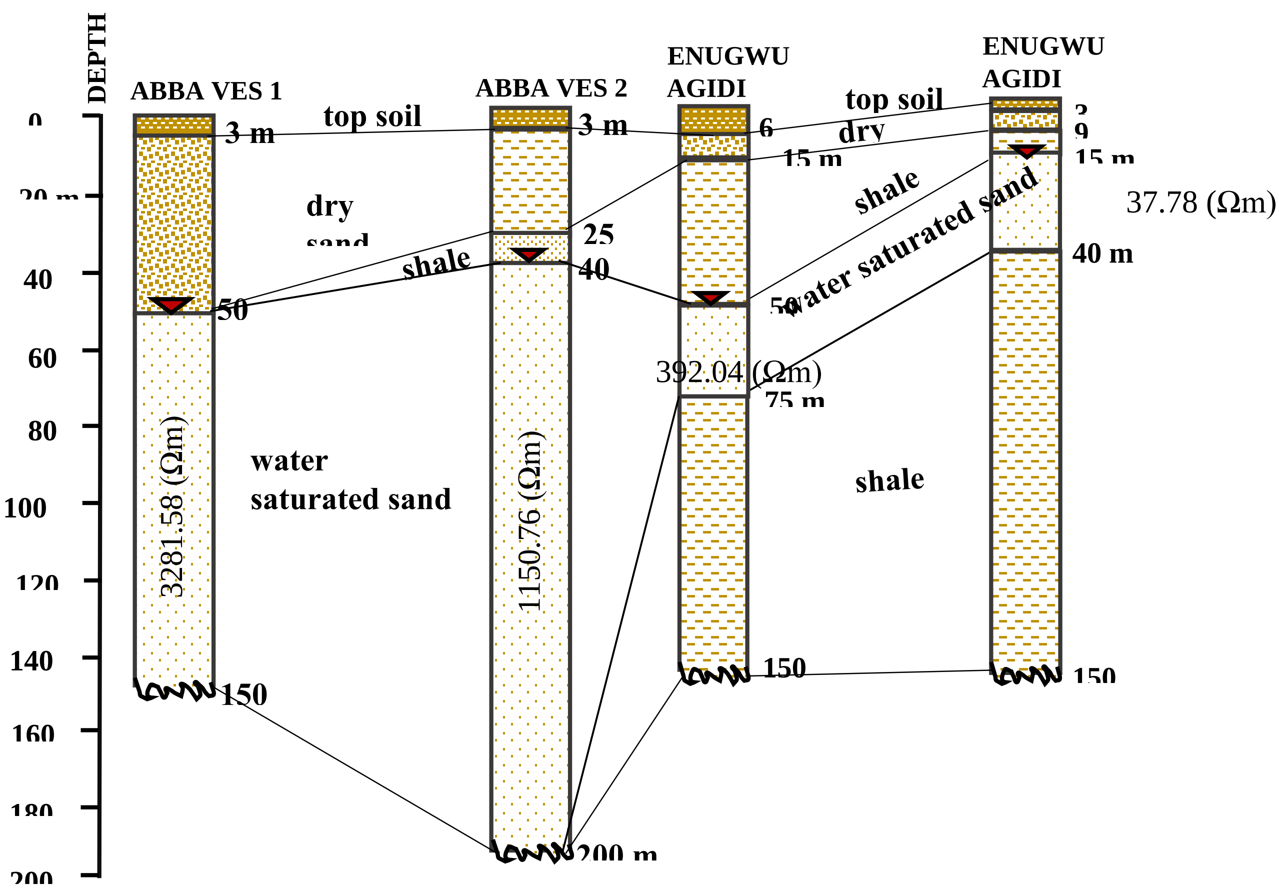

Figure 7: Geoelectric Sections of VES 1, VES 2, VES 3 and VES 4 in group A

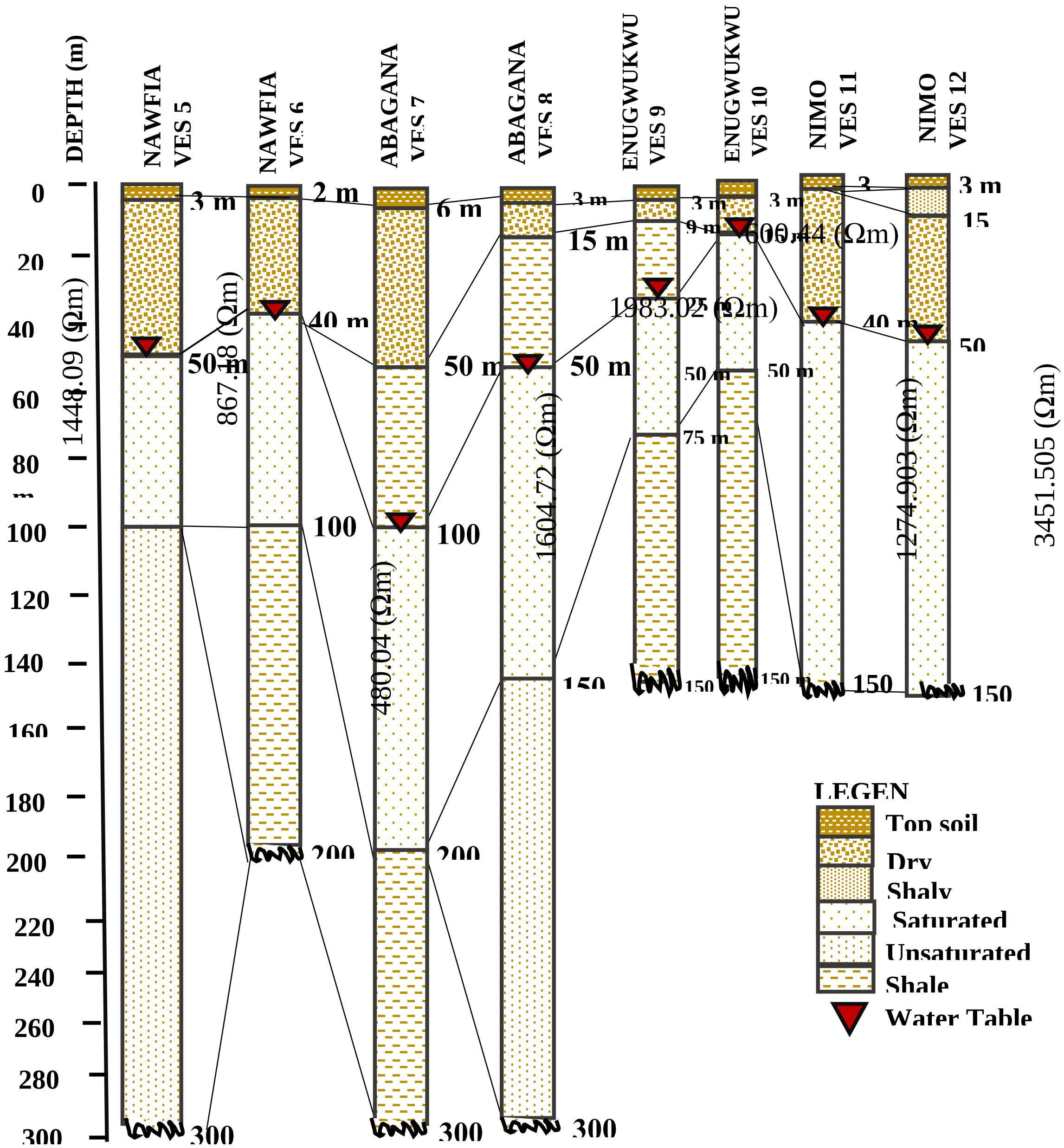

Figure 8: Geoelectric Sections of VES 5, VES 6, VES 7, VES 8, VES 9, VES 10, VES 11 and VES 12 in group B

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Summary of Aquifer Information of the Study Area

Application of subsurface geophysical methods as employed in this study proved to be better in delineating water table information and better interpretation of geoelectric sections which revealed aquifer parameters as thus; depth below the water table from surface level (SL), depth to water table from SL, thickness and depth of aquifer with reference to mean sea level (MSL) of the study area shown in (Table 3).

Table 4.10: Summary of Information on the aquifer of the Study Area

Group	*Longitude*	*Latitude*	*Elevation (m)*	*VES Location*	*Aquifer Average Resistivity (Ωm)*	*Depth to Aquifer (m)*	*Depth to Aquifer reference to G.S (m)*	*Depth to Aquifer reference to MSL (m)*	*Aquifer thickness (m)*
	E006^{0} 58.046'	N06^{0} 12.367'	221	VES 1 Abba	3281.58	50	150	-171	100
	E006^{0} 57.918'	N06^{0} 12.257'	205	VES 2 Abba	1150.76	40	200	-165	160
	E007^{0} 00.233'	N06^{0} 12.460'	127	VES 3 Enugwuagidi	392.04	50	75	-77	25
Group A	E007^{0} 00.013'	N06^{0} 12.013'	102	VES 4 Enugwuagidi	37.78	15	40	-87	25
	E007^{0} 01.364'	N06^{0} 10.936'	170	VES 5 Nawfia	1448.09	50	100	-120	50
	E007^{0} 01.318'	N06^{0} 10.325'	193	VES 6 Nawfia	867.18	40	100	-153	60
	E006^{0} 59.126'	N06^{0} 10.324'	120	VES 7 Abagana	480.04	100	200	-20	100
	E006^{0} 57.020'	N06^{0} 10.291'	190	VES 8 Abagana	1604.72	50	150	-140	100
	E007^{0} 00.219'	N06^{0} 10.786'	193	VES 9 Enugwukwu	1983.02	25	75	-168	50
	E007^{0} 00.541'	N06^{0} 10.382'	213	VES 10 Enugwukwu	600.44	15	50	-198	35
Group B	E006^{0} 59.379'	N06^{0} 09.651'	193	VES 11 Nimo	1274.903	40	150	-153	110
	E006^{0} 59.734'	N06^{0} 09.73'	228	VES 12 Nimo	3451.505	50	150	-178	100

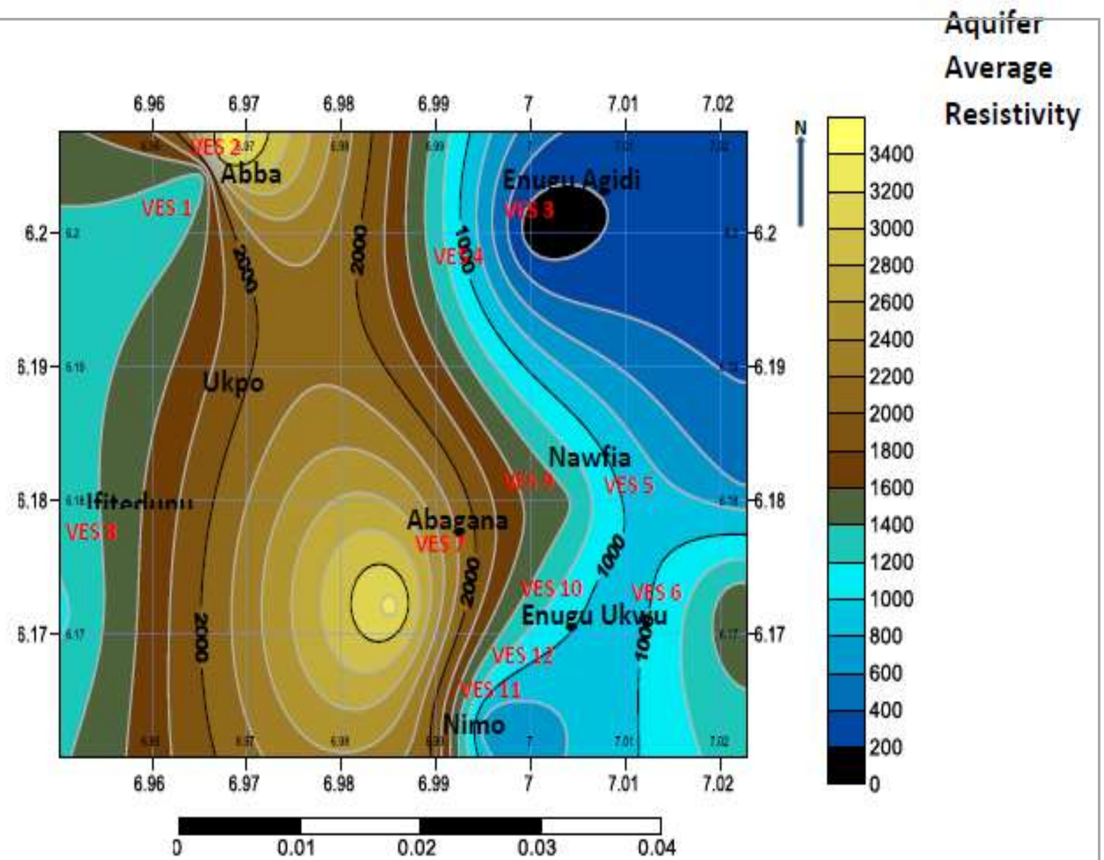

Fig. 9: Map of Average Aquifer Resistivity of the Study Area Modelled Using Surfer 16 Software

The resistivity of the area according to the map shows a vertical trend from the left part of North to the South cutting across parts Abba, Abagana, Nawfia and Nimo with values higher than the rest of other communities. The value range of the resistivity of the study area is 37.7 Ωm to 3451 Ωm (Fig. 9). The resistivity values were deduced from the average apparent resistivity of the individual water saturated units for all the VES location. The parameter forms major part of the determination of groundwater existence and hydrologic characteristics of an aquiferous layer in the study area.

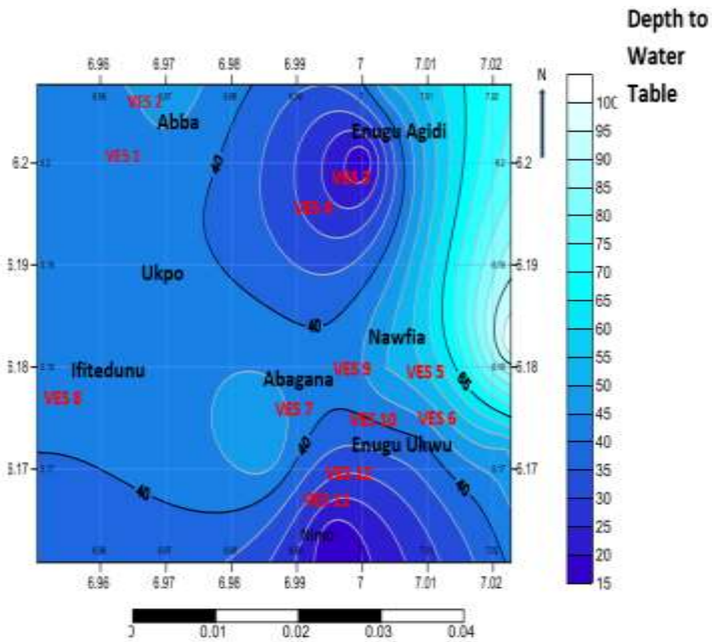

Fig. 10: Contour Maps showing Depth to Aquifer with reference to Ground Surface (G.S) of the Study Area modelled u

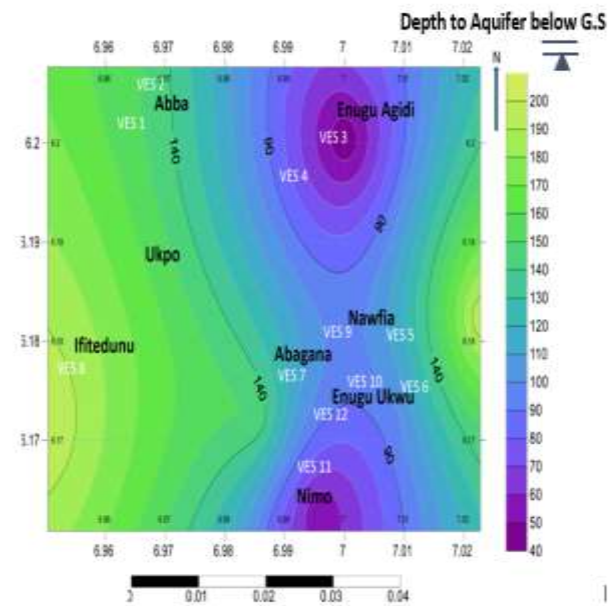

Figure 11: Contour Map Showing the Depth Aquifer below the Ground Surface (G.S) of the Study Area Modelled Using Surfer 16 Software.

The contour map in Fig. 10 above show that the depths of water table in the study area tend geographically low towards the south – western part at the range of 15 m – 100 m. Abba VES location 1 and 2 has aquifer depth of 50 m – 40 m within the coordinates of E006^0 58.046' - N06^0 12.367' and E006^0 57.918' - N06^0 12.257' respectively, Enugwuagidi aquifer depths tend relatively shallower at some parts at range of 50 m – 15 m within a coordinate variation of E007^0 00.233' - N06^0 12.460' and E007^0 00.013' - N06^0 12.013'. Nawfia and Nimo proved the same aquifer depth with Abba VES locations. Among all the VES locations that have close depth of 50 m – 100 m, Enugwukwu has aquifer depth of 15 m – 25 m with reference to coordinates E007^0 00.541' - N06^0 10.382' which is predominantly shallow. The depth below the saturated zone increases towards the North – West direction. The Depth below the water table which is the phreatic zone or depth below which the ground is saturated with water is illustrated in Fig. 11. The map is a useful tool for measuring saturated areas beneath the water table and it is influenced by factors such as geology, topography, weather, ground cover, and land use. The map which was modelled using Surfer which is a terrain software shows the groundwater distribution across the study area. From the map the depth varies from 40 m (around Nimo, Enugu Agidi) to 200 m (Ifitedunu, Ukpo). Fluctuations in this values may occur by changes in precipitation or aquifer recharge between seasons and years.

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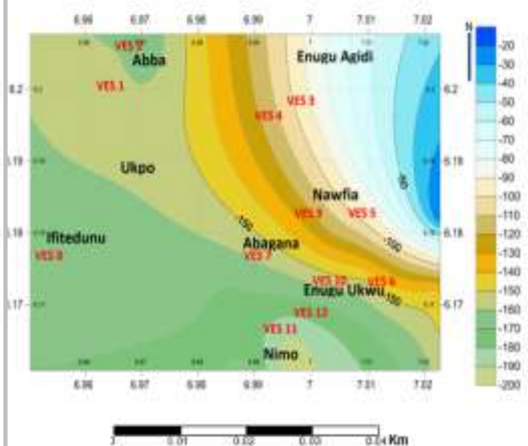

Figure. 12: Contour Map Showing the Depth Aquifer with Reference to Mean Sea Level of the Study Area modelled

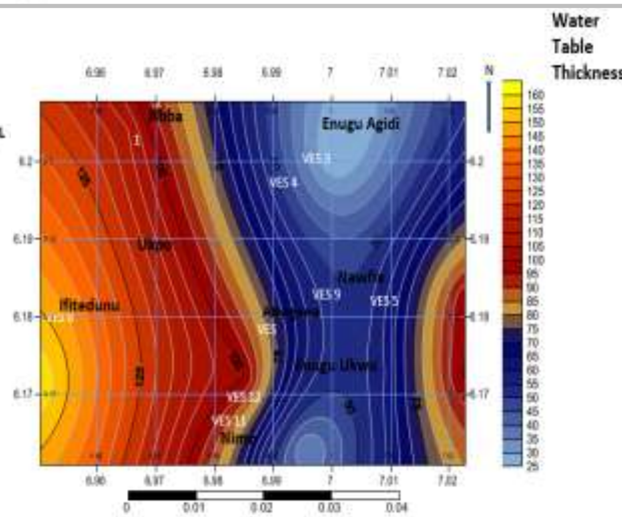

Figure 13: Contour Maps Showing the Aquifer Thickness of the Study Area Modelled Using Surfer 16 Software.

The above maps Fig. 12 show the depth of water table from mean sea level (MSL) of Njikoka and environs which the elevation of the communities support the flow tendency towards the North – South direction which depicts relatively low land area. The values of the depth to the water table which were gotten from the geoelectric sections were subtracted from the elevation values. The distribution of the depth to aquifer with reference to mean sea level (MSL) in the map above inferred that the study area is geographically situated on Eastern Lowland as the aquifers in the communities increases negatively towards the East-West direction, hence the negative values signify locations with low landform. The Fig. 13 above show that the aquifer thickness of the study area trends through SW – NE direction. The thickness of rock layers from the surface to the subsurface water table is called vadose zone and it is usually unsaturated or discontinuously saturated. The thickness varies from 25 m to 160 m within the respective communities. The hydrologic parameters of the Njikoka and environs increased from Enugwuagidi region to very low values in other communities. Increased aquifer productivity in Enugwuagidi could be attributed to better aquifer recharge system provided by the presence of many stream channels available in the area.

Conclusion and Contribution to Knowledge

The result of this research revealed that Vertical electrical sounding data from the study area identified four (3) to six (5) geoelectric layers. The layers characterized to be top soil, dry sand, water saturated sand, top soil, shale¸ sandy shale and water saturated sand respectively.

Enugwuagidi VES 3 and 4 have five layers as top soil, dry sand, shale, water saturated sand and shale and top soil, dry sand, shale, water saturated sand and Shale respectively. Nawfia VES 5 has top soil, dry sand, water saturated and sand while VES 6 composed of Top soil, Dry sand, water saturated sand and shale. Abagana consist of top soil, dry sand, shale, water saturated sand and shale in VES 7 location and top soil, dry sand, shaly sand, water saturated sand and dry sand in VES 8 location. Enugwukwu VES 9 is of top soil, dry sand, shale, water saturated sand and shale while VES 10 location consist of top soil, dry sand, water saturated sand and shale. Nimo VES 11 locations composed of top soil, dry sand, water saturated sand and VES 12 location; top soil, dry sand and water saturated sand. with respect to their depths. Aquifer resistivity values of the aquifers in the study area are stated as; VES 1 Abba 3281.58 Ωm, VES 2 Abba 1150.76 Ωm, VES 3 Enugwuagidi 392.04 Ωm, VES 4 Enugwuagidi 37.78 Ωm, VES 5 Nawfia 1448.09 Ωm, VES 6 Nawfia 867.18 Ωm, VES 7 Abagana 480.04 Ωm, VES 8 Abagana 1604.72 Ωm, VES 9 Enugwukwu 1983.02 Ωm, VES 10 Enugwukwu 600.44 Ωm, VES 11 Nimo 1274.903 Ωm and VES 12 Nimo 3451.505 Ωm.

The summary of VES curve types obtained from the study area are A, H, K, AK and KH which K curve type is the most occurred curve type in the study area. The aquifer thickness ranged from 25 m - 160 m and the depth to water table posed to range from 15 m – 100 m which composed of confined and predominantly unconfined aquifers. The difference in elevation and estimated depth of each location revealed the depth to water table from mean sea level which tend negatively towards the East-West direction, hence the negative values signify that the study area is dominated with low landform.

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