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Research Article

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Application of Vertical Electrical Sounding Method to Delineate Subsurface Stratification and Groundwater Occurrence in Ideato Area of Imo State, Nigeria

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Abstract Twenty vertical electrical soundings (VES) were carried out in Ideato North and South areas of Imo State to delineate subsurface stratification and groundwater occurrence. Field data were acquired using Ohmega-500 resistivity meter. The Schlumberger electrode configuration and maximum electrode spread of 900m were used. The data were interpreted using the Advanced Geosciences Incorporation (AGI) ID software and the Schlumberger automatic analysis version. Interpretative geoelectric cross-sections constructed along three profile lines delineated the subsurface stratification. The sediments consist of sequence of shale, sandstone, siltstone and clay. Around Dikenafai in Ideato-South the geology tended towards the Benin Formation. Ideato-North is more shaly than Ideato-South. Groundwater was delineated within the zone interpreted to be fractured shale with aquifer materials composed of sand, sandstone and clay sandstone and resistivity ranging from 0.10Ωm recorded at Urualla to 1035Ωm observed at Obodoukwu. Depth to water table is quite high and varied from 71.90m to 138.32m. Aquifer thickness varied across the study area with high values at Obodoukwu, Ndiadumora and Dikenafai. These areas are good prospects for groundwater development. Analysis of pumping test and VES data led to estimation of aquifer parameters for the study area. Transmissivity values for the area are moderate and fairly uniform ranging from 516528m^2/day to 528m^2/day. Generally, correlating the Dar Zarouk parameters of longitudinal conductance and transverse resistance with geoelectric parameters reveal that Ideato-South has higher groundwater potential than Ideato-North. Hence, for groundwater development in the study area, standard water wells should be sited around Dikenafai and Isikenesi in Ideato-South.

Keywords Potable water, Groundwater potential, Aquifer horizon, Water table, Stratification

1. Introduction

1.1. Background of Study

Adequate water supply is essential to public health and well being as well as agricultural and industrial activities The electrical conductivity of any geological strata depends on the conductivity of the rock formation such as sand, clay and other available components, its porosity, the water contained in the pore spaces and the salinity of the water. The most important factor is the water content and so the determination of the resistivity structure of the subsurface reveals not only the geological structure but also the water bearing layers.

Ideato area is a difficult area for Groundwater exploitation due to the nature of the depositional environment. Geologically the area is underlain by the Imo Shale Formation which is not a good aquifer. As a result, the inhabitants of many communities in the area do not have access to potable water. Alternative source of water which is surface water is not readily available. The Orashi River which drains the neighbouring communities in Orlu is polluted. Only the eastern part of the study area is drained by few stream channels which are also not sources of potable water owing to pollution arising from domestic wastes, agricultural and industrial activities.

This study aims at delineating the subsurface stratification of the study area in order to map the aquifer horizon to enable sustainable groundwater development in the area.

1.2. Location and Description of the Study Area

Ideato area of Imo State lies in the Northern part along the border between the State and Anambra State. It occupies the area from lat $5^0 46^1$N to $5^0 57^1$N and long $7^0 02^1$E to long $7^0 4^1$E covering a total land area of about 2756 km^2 (Fig 1). The study area shares boundary in the eastern part with Okigwe and Omuma Local Government Area (L.G.A), in the western part with Orlu L.G.A and in the southern part with Nkwere and Nwangele L.G.A's. The area is quite accessible with a net work of tarred and untarred roads. There are topographic high and low areas observed across the study area. Vegetation is typically of rain forest environment.

Ideato area is not well drained. The Orashi river flows along the boundary between Orlu L.G.A and the study area. On the Eastern part there are few tributaries of the rivers that drain the adjacent Local Government areas of Okigwe and Omuma which flow into the Imo River.

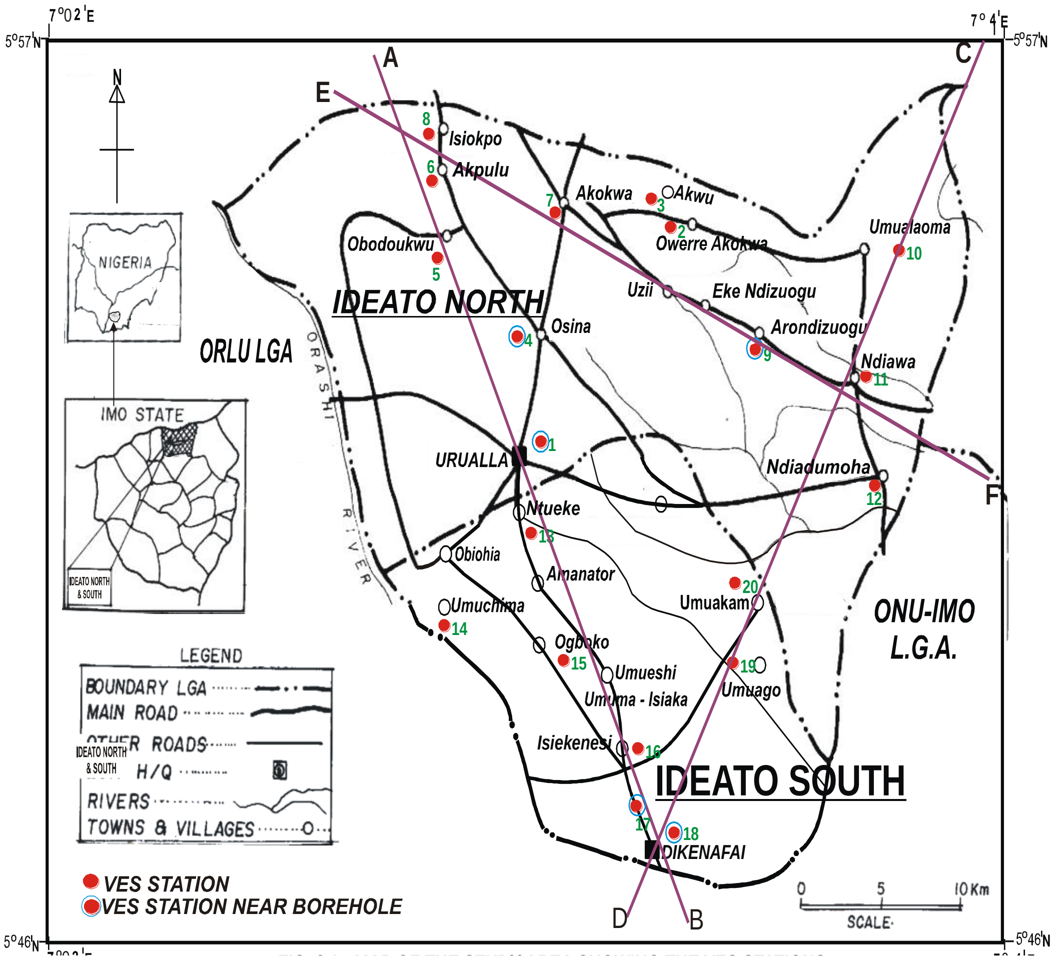

Figure 1: Map of the Study Area showing the VES stations and Interpretative Cross sections AB, CD and EF

1.3. Geology of the Study Area

The Geology of the area is explained by the map of Imo River basin in which Ideato area is situated (Fig .2). It shows the following major stratigraphic units: The Benin Formation, the Ogwashi- Asaba Formation, the Bende-Ameki Formation, the Imo Shale group, Nsukua Formation and Ajali Sandstone Formation. The study area is underlain by the Imo Shale group. The Benin Formation contains some isolated gravels conglomerates and very coarse sandstone in some places. Thickness of the Benin Formation is about 800m at its depocenter while the mean depth to water table is about 24m [1]. The Benin Formation is overlain by alluvium deposits and

underlain by Ogwashi-Asaba Formation which consists of lignite, sandstones, clays and shales. The Benin Formation provides the condition for Groundwater storage because of its high porosity and permeability [2].
The Ogwashi- Asaba Formation is made up of variable succession of clays, sands and grits with seems of lignite while the Ameki Formation consists of greenish – grey clayey sandstones, shales and mudstones with interbedded limestones. This Formation in turn overlies the impervious Imo Shale group characterized by lateral and vertical variations in lithology. It is underlain in succession by Nsukka Formation, Ajali Sandstones and Nkporo Shales [2].
Sediments of Imo Shale Formation consist of well laminated plain Shale with grey to light green colour. The shale contains occasional intercalations of thin bands of calcareous Sand Sandstones, marls and limestone. The Imo Shale Formation is of Paleocene age. Groundwater exploration is very difficult in this Formation [3].

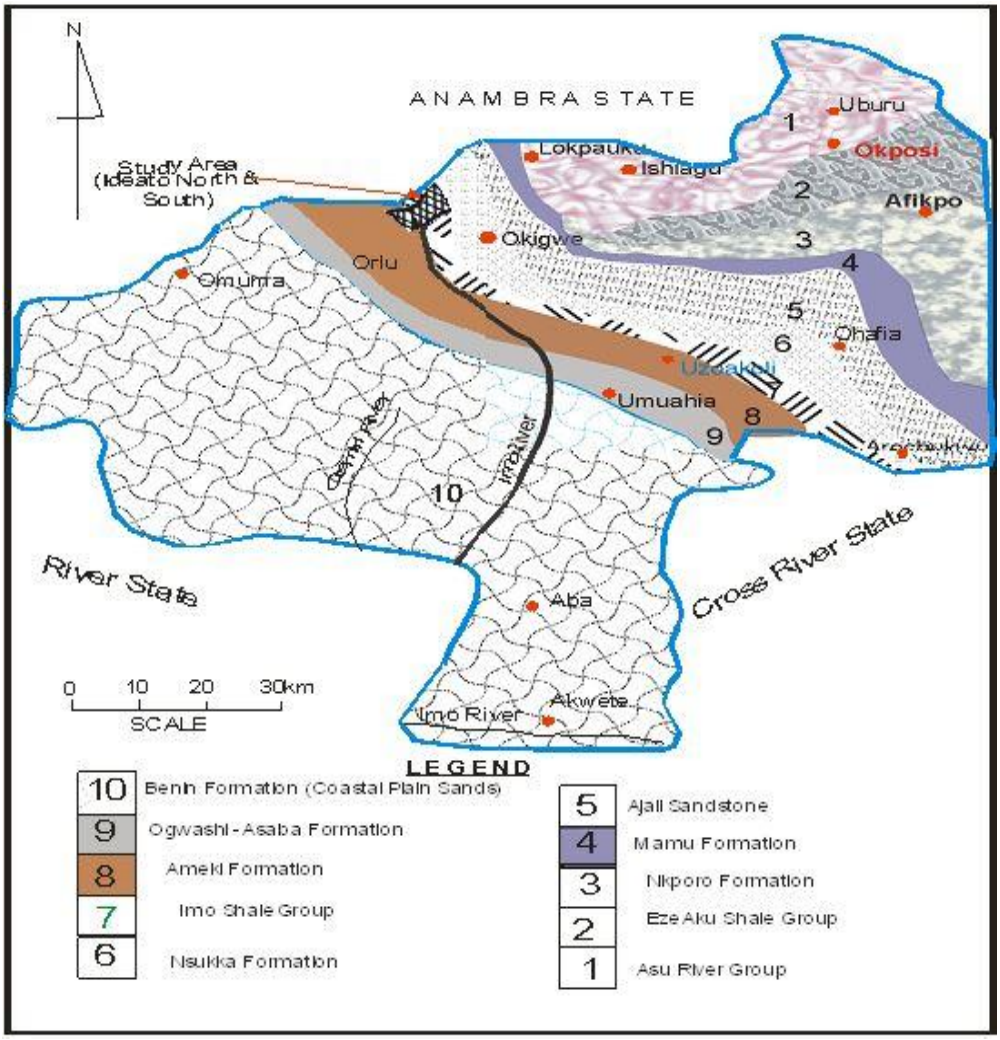

Figure 2: Geological map of Imo and Abia state showing the study area (adapted from [4])

2. Literature Review

Vertical Electrical Sounding (VES) has been a very effective means of probing the variation of electrical properties of rocks with depth. It is possible to infer from VES results the subsurface stratification as well as identify possible aquifer [5]. A Geo-electrical and hydro-geological investigation techniques with ten Schlumberger VES profiling conducted across Gombi, Hong and Mubi parts of Adamawa State, have been interpreted by [6] both qualitatively and quantitatively, to reveal three electro stratigraphic earth model. In this study, the weathered/fractured basement rocks of the areas having the least resistivity formed the aquifer.
Due to the geology of the study area, groundwater prospecting is very difficult. Aquifer occurs only in fractured shale. Several studies have shown that aquifer can be delineated in fractured rocks. For example a study of the

Benin Formation of Gombe sub- catchments, Benue valley, Nigeria delineated a good aquifer because of the presence of fracturing which makes the formation porous and permeable [7]. Similarly, the quest for local tectonics and ground water accumulation in basement terrain in the North-Eastern part of Guoza area of Borno State, Nigeria, showed that dyke intrusions and fracturing in the basement rocks induce groundwater accumulation [8]. Also studies on Nigerian Basement Complex rocks have shown that though the crystalline basement rocks are thought to be impermeable and non-water bearing, their groundwater potential appears to improve with induced secondary permeability derived from fractures, joints and solution channels [9].

Research findings of [10] and [11] equally support the fact that groundwater can be tapped from weathered and fractured rock.

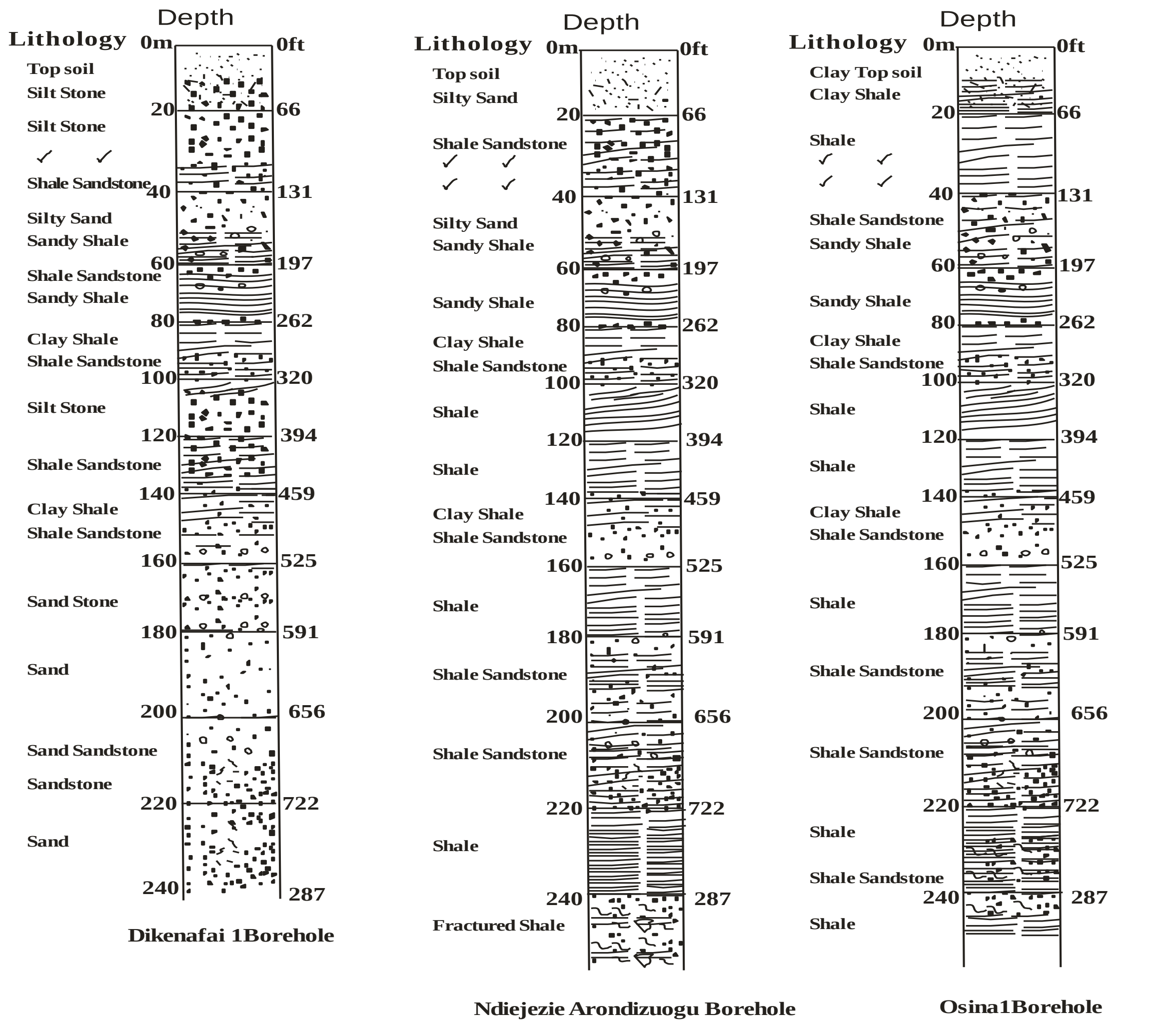

Figure 3: Bore hole Lithology obtained for Ideato North and South. Source: Imo Water Development Agency (IWDA) Owerri [12]

3. Materials and Methods

3.1. Instrumentation

The instruments used to acquire field data include Ohmega–500 Electrical Resistivity meter, Four stainless steel electrode (two potential and two current electrodes), a 12 volts DC power supply, Four reels of cables, Hammers, Measuring tapes, Clips and the Global positioning System (GPS).

3.2. Field Procedure

A total of twenty Vertical Electrical Soundings (VES) were carried out using the Schlumberger electrode array with a maximum current electrode spread of 900m. Some of the stations were sited near existing borehole for

correlation. The Ohmega -500 Electrical Resistivity meter was placed at the station point in-between the potential electrodes M and N and its terminals P1 and P2 connected to the terminals M and N respectively using the ABEM Sounding set. The current electrodes A and B were connected to the terminals C1 and C2 respectively using the ABEM sounding current cables wound on two separate metal reels mounted on the stand. Before connections were completed, the electrodes which were about 0.7m long were driven to a reasonable depth into the ground using a hammer and ensuring accurate spacing.
Current was introduced into the ground and the field resistance displayed on the Resistivity meter was read and then recorded against the corresponding current and potential electrode spacing. At each VFS station, elevation and coordinates were measured using the GPS.

3.3. Ves Data Interpretation

After initial manual computation, the field data were subjected to computer interpretation using the Advanced Geosciences Incorporation (AGI) ID software and the Schlumberger automatic analysis version. The result is a display of 12 geoelectric layers which were constrained to between seven to ten layers depending on the significant value of the thicknesses. The lithologic units were inferred using the borehole information obtained from the bore holes located in the study area [3].

3.4. Estimation of Aquifer Parameters from Pumping Test Data

Pumping test data obtained for the area [Table 1] were used to calculate the aquifer parameters to enable evaluation of the groundwater potential of the study area. Using equations 1, 2 and 3 the aquifer hydraulic conductivity, K and Transmissivity, T were computed.
Based on the pumping test data with drawdown values in Table 1, the aquifer parameters were determined as follows:
The aquifer hydraulic conductivity K is obtained using equation 1

$$K = \frac{1.18Q}{hs_{mw}} \qquad 1$$

The Transmissivity, T was obtained using equation 2

$$T = kh \qquad 2$$

where
Q Is groundwater yield in m^3/day
S_{mw} is the drawdown in meters
h is the screen depth in meters
For VES data, the hydraulic conductivity K is given by

$$K = \frac{T}{h} \qquad 3$$

where
T Is the average transmissivity determined from pumping test data in m^2/day,
h is the aquifer thickness in meters.

Table 1: Existing Borehole Data in Ideato North and South

S/No	Location	Drill Depth (m)	Casing Diameter (m)	Screen Diameter (m)	Casing Depth (m)	Screen Length (m)	Static Water Level (m)	Yield (m^3/day)	Draw Down (m)
1	Osina 1	189.0	0.300	0.2000	174.0	15.0	159.0	5145.74	2.20
2	Osina 2	180.0	0.200	0.1500	168.0	15.0	150.0	5145.74	-
3	Arondizuogu	90.3	0.125	0.1125	74.7	9.0	22.8	1878.28	36.00
4	Urualla 1	171.0	0.300	0.2000	150.0	21.0	119.7	2271.25	4.50
5	Urualla 2	165.0	0.300	0.2000	174.0	21.0	119.4	2634.65	4.41
6	Dikenafai 1	114.0	0.300	0.2000	96.0	15.0	61.71	3270.60	3.42
7	Dikenafai 2	144.0	0.300	0.2000	126.0	15.0	64.53	3270.60	-

3.5. Subsurface Stratification

In order to delineate the subsurface stratification of Ideato area, three profile lines AB, CD and EF (Fig.1) were drawn giving rise to three interpretative geoelectric cross sections (Figs. 13, 14 and 15). The line AB lies in the Northwest, Southwest parts of the study area traversing Isiokpo (VES 8) in Ideato North down to Dikenafai (VES 17 and 18) in Ideato South, covering a distance of about 40 km. Profile line CD lies in the Northeast, Southeast area covering a distance of about 40km also but traversing Umualaoma (VES 10) in the Northeastern area down to Dikenafai (VES 18) in ideato South The profile line EF lies entirely in Ideato North within the vicinity of Isiokpo (VES 8) and Akpulu (VES 6) to Ndiawa (VES 11). It covers a distance of about 32.5km. The resistivity values of the geoelectric layers underlying each VES point along the profile lines were plotted against depth and this enhanced the delineation of the stratigraphic units using available borehole information (Fig.3) [12].

4. Results and Discussions

4.1. Results

Typical modelled VES results are shown in Fig.4 to Fig.7 with corresponding analytical results displayed in Tables 2 to 5. Table 6 gives the summary of the modelled VES results for the study area.

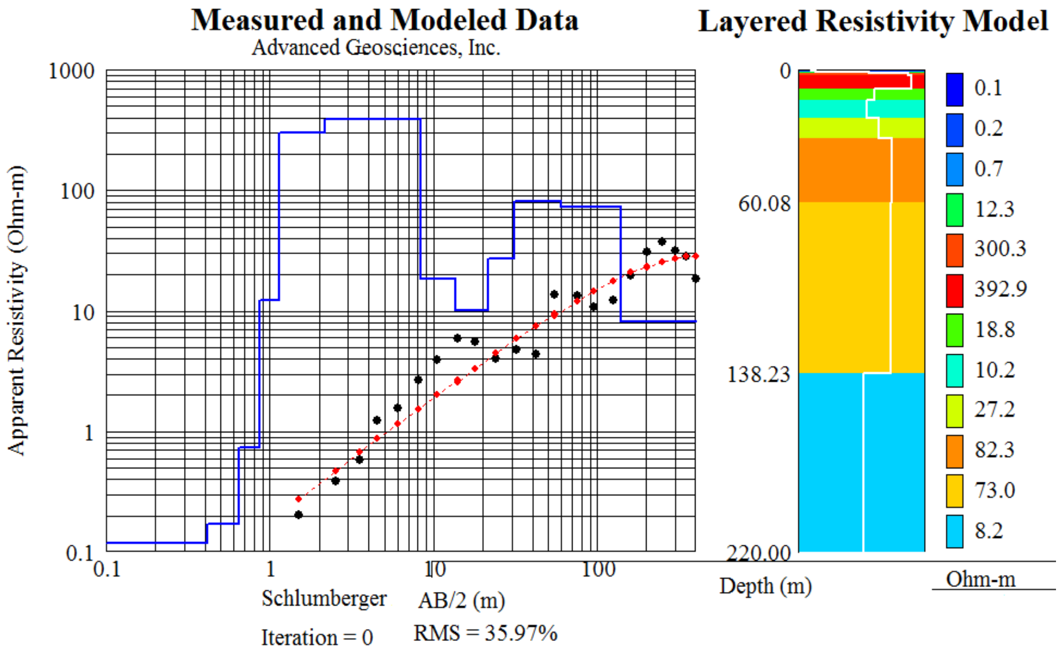

Figure 4: Modeled Result for VES Located at Akokwa Ideato North

Table 2: Akokwa Ideato North VES analytic result presented by the AGI 1D Software and the Schlumberger Automatic analysis package revealing nine sub-layers

Layer	Depth (m)	Resistivity (Ohm-m)	Lithology	Colour
1	0.6	0.17	Topsoil	Mixed Blue
2	2.1	300.0	Sandstone	Red
3	8.3	392.0	Sandstone	Red
4	13.6	18.8	Clay-sand	Green
5	21.5	10.2	Clay-sand	Light blue
6	31.0	27.2	Clay-sand	Orange
7	60.0	82.2	Clay-sand	Red
8	138.2	73.0	Clay-sand	Yellow
9	220	8.2	Sand (Prospect unit)	Blue

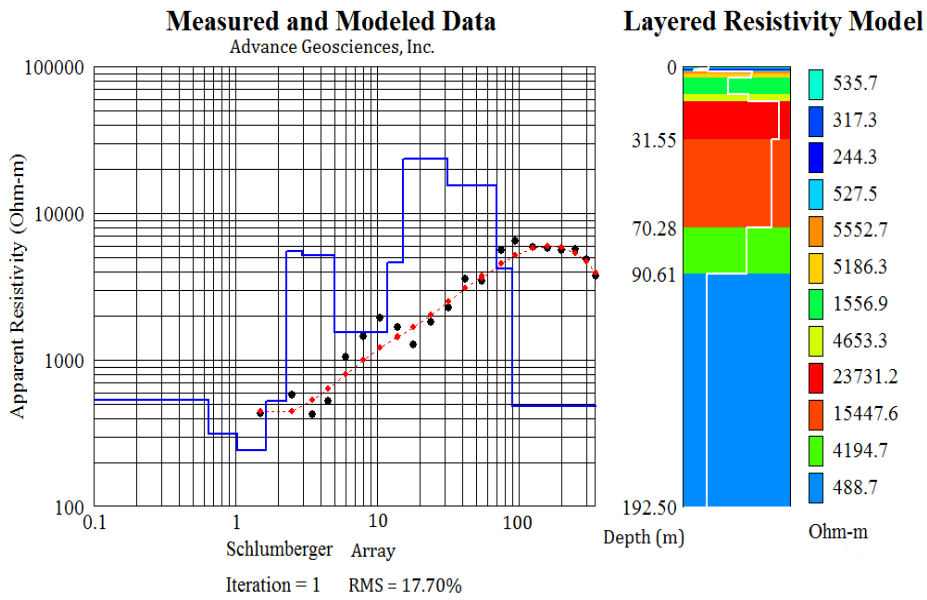

Figure 5: Modeled result for VES Located at Dikenafai 1, Ideato South

Table 3: Dikenafai 1, Ideato south VES analytic result presented by the AGI 1D Software and the Schlumberger Automatic analysis package revealing eight sub-layers

Layer	Depth (m)	Resistivity (Ohm-m)	Lithology	Colour
1	0.64	535.7	Topsoil	Mixed Blue
2	4.97	5186.4	Siltstone	Yellow
3	11.74	1556.9	Mixed Sand	Green
4	15.23	4653.3	Siltstone	Orange
5	31.55	23731	Shale-sandstone	Red
6	70.28	15447.6	Shale-sandstone	Red
7	90.61	4149.7	Siltstone	Green
8	192.5	488.7	Sand (Prospect unit)	Blue

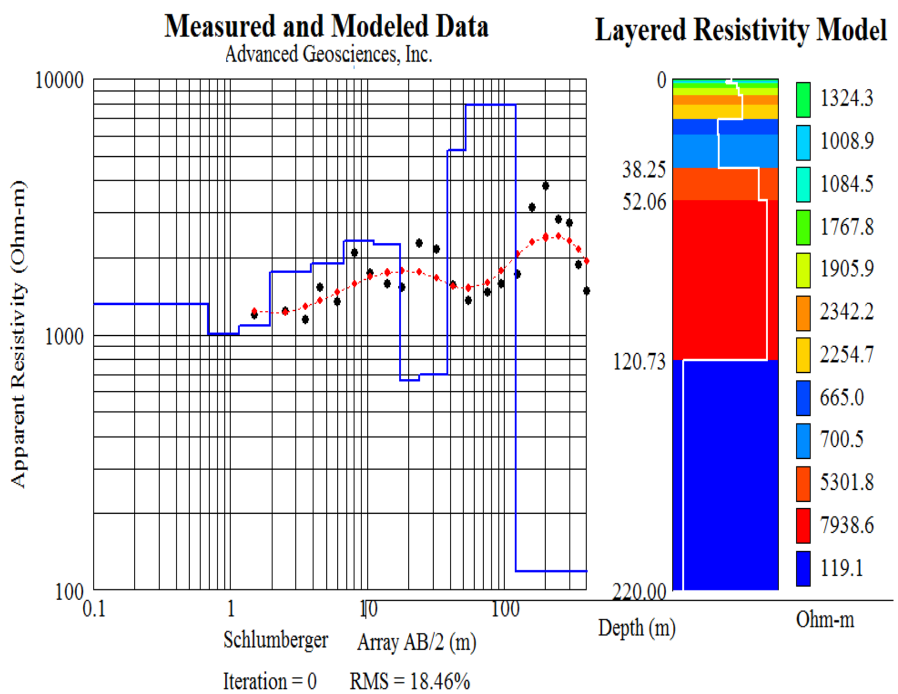

Figure 6: Modelled Result for VES Located at Osina Ideato North

Table 4: Osina Ideato North VES analytical result presented by the AGI 1D Software and the Schlumberger Automatic Analysis Package revealing nine Sub-Layers

Layer	Depth (m)	Resistivity (Ohm-m)	Lithology	Color
1	0.36	137	Topsoil	Mixed Blue
2	3.8	1767	Silty sand	Green
3	6.7	1905	Sand-silty	Green
4	11	2342	Sand stone-shale	Off-Red
5	17	2254	Sandy-shale	Yellow
6	38	5848	Shale	Blue
7	52	5301	Shale	Red
8	120	7938	Shale	Red
9	220	119	Lower prospect, fractured shale	Blue

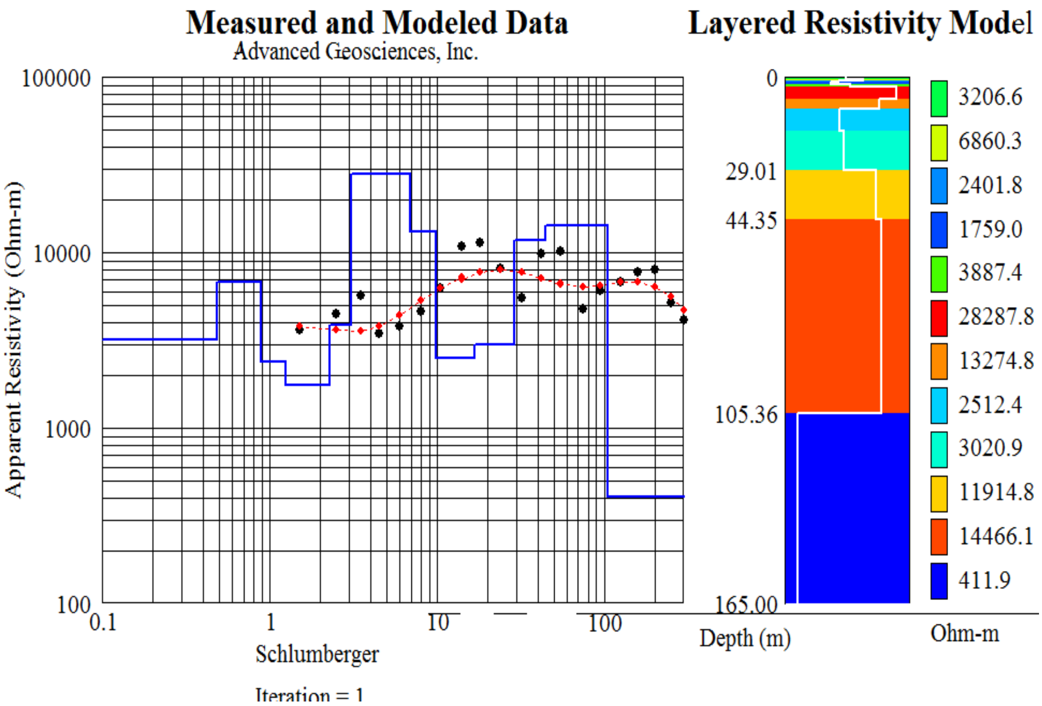

Figure 7: Modeled result for VES Located at Ndiejezie arondizuogu

Table 5: Ndiejezie VES Analytical result presented by the AGI 1D Software and the Schlumberger Automatic analysis package revealing ten sub-layers

Layer	Depth (m)	Resistivity (Ohm-m)	Lithology	Color
1	0.9	6860	Topsoil	Orange
2	2.3	1759	Silty sand	Blue
3	6.9	28287	Shale-Sandstone	Red
4	9.9	13274.8	Sand-silty	Off-Red
5	16.7	2512	Sand-shale	Blue
6	29.0	3020	Clay-Shale	Light blue
7	44	11914.8	Shale-sandstone	Yellow

Table 6: Summary of the Modeled VES Results for Ideato

S/N	VES Location	N (Degree) Latitude	E (Degree) Longitude	Elevation (ft)	Depth to Water Table (m)	Aquifer Resistivity (Ωm)	Aquifer Thickness (m)
1	Urualla	05°51.905	07°04.328	520	131.60	0.10	87.00
2	Akokwa	05°55.182	07°06.882	974	124.81	1035.20	67.69
3	Osina 1	05°55.151	07°05.960	911	97.62	847.10	94.88
4	Osina 2	05°22.100	07°03.452	878	74.33	0.50	63.17
5	Obodonkwu	05°53.864	07°04.491	701	103.17	888.00	117.00
6	Akpulu	05°54.846	07°03.197	357	94.19	645.90	98.31
7	Akokwa	05°54.411	07°07.504	1007	138.23	8.20	81.77
8	Isiokpo	05°50.712	07°00.529	459	101.00	30.70	119.00
9	NdiejezieArondizuogu	05°53.182	07°11.806	469	105.36	411.90	60.00
10	Umualoma	05°52.922	07°10.352	512	120.73	119.10	100.00
11	Nidawa	05°47.589	07°18.954	414	79.96	0.10	140.04
12	Ndiadumora	05°50.994	07°12.032	391	71.90	0.50	175.60
13	Ntueke	05°06.3	07°07.6	820	54.25	0.30	100.75
14	Umuchima	05°54.470	07°09.604	667	110.64	397.20	81.86
15	Ogboko	05°52.425	07°10.996	472	105.36	411.90	57.68
16	Isiekenesi	05°47.835	07°07.700	677	94.19	645.90	98.31
17	Dikenafai 1	05°46.927	07°09.317	677	90.61	488.70	100.89
18	Dikenafai 2	05°46.927	07°09.317	677	90.33	442.50	102.19
19	Umuago	05°46.422	07°08.514	420	129.00	254.00	63.50
20	Umuakam	05°49.337	07°05.661	407	97.64	667.30	94.86

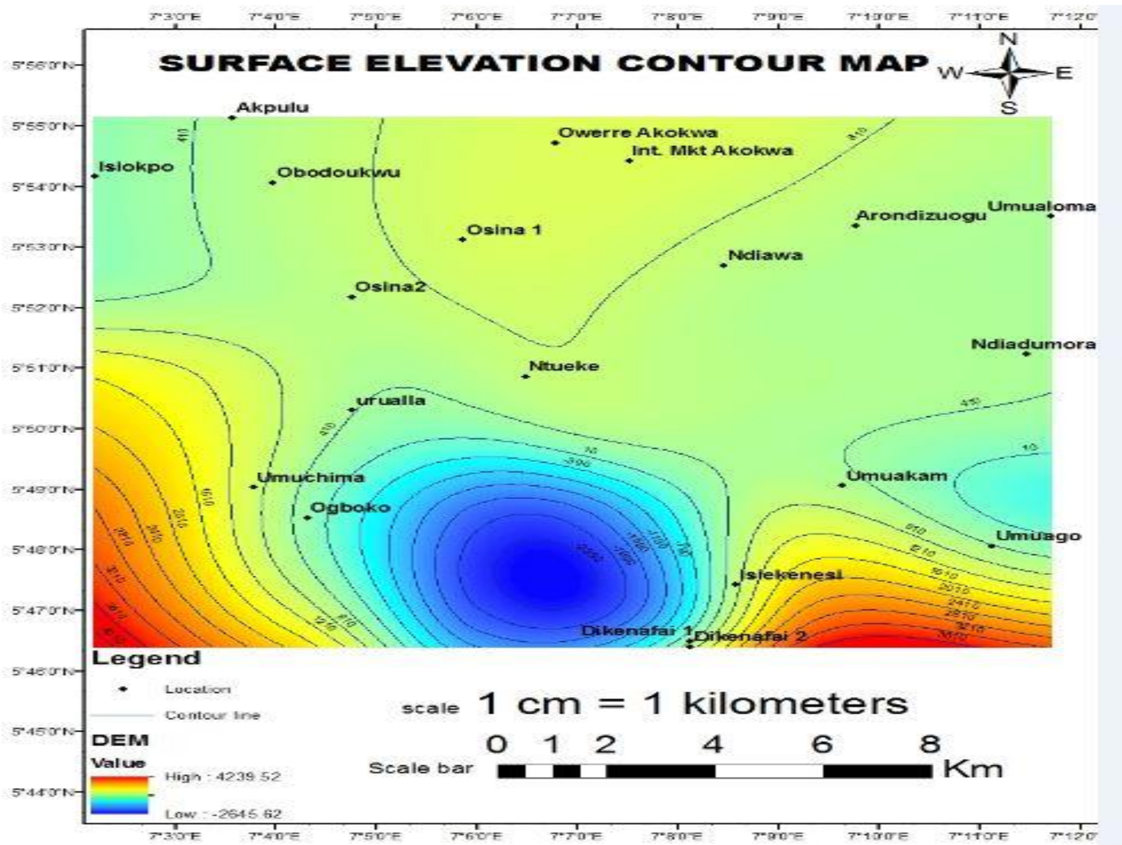

Figure 8: Surface Elevation Map of the Study Area

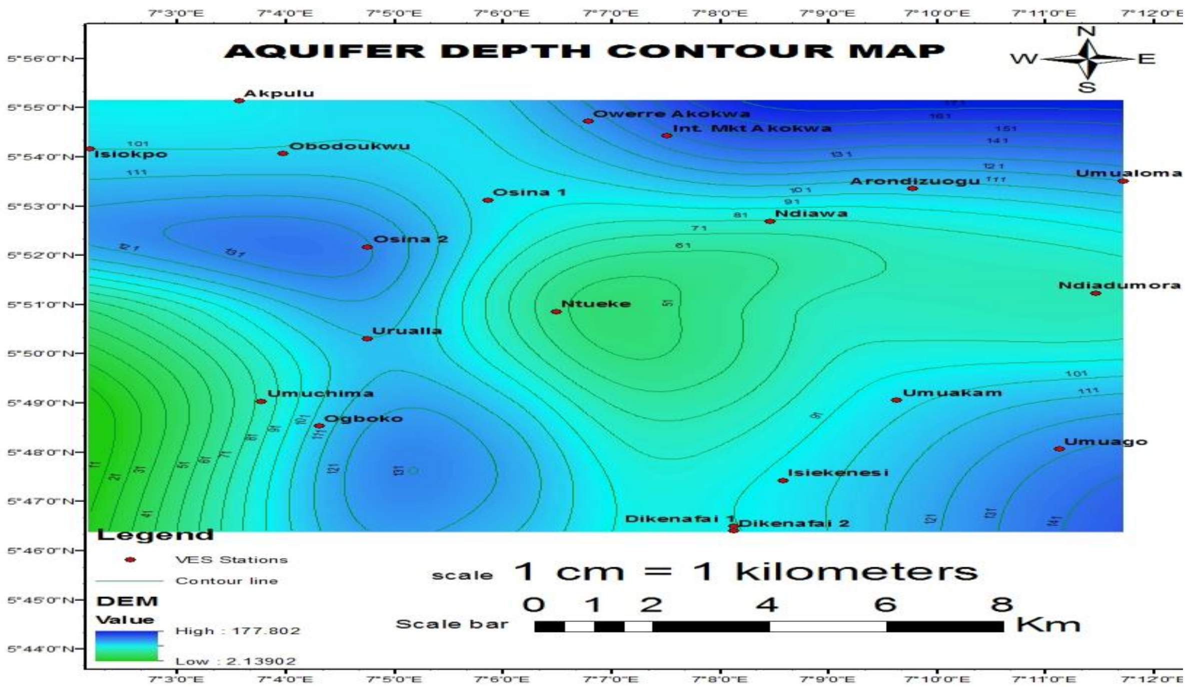

Figure 9: Aquifer Depth Contour Map of the Area

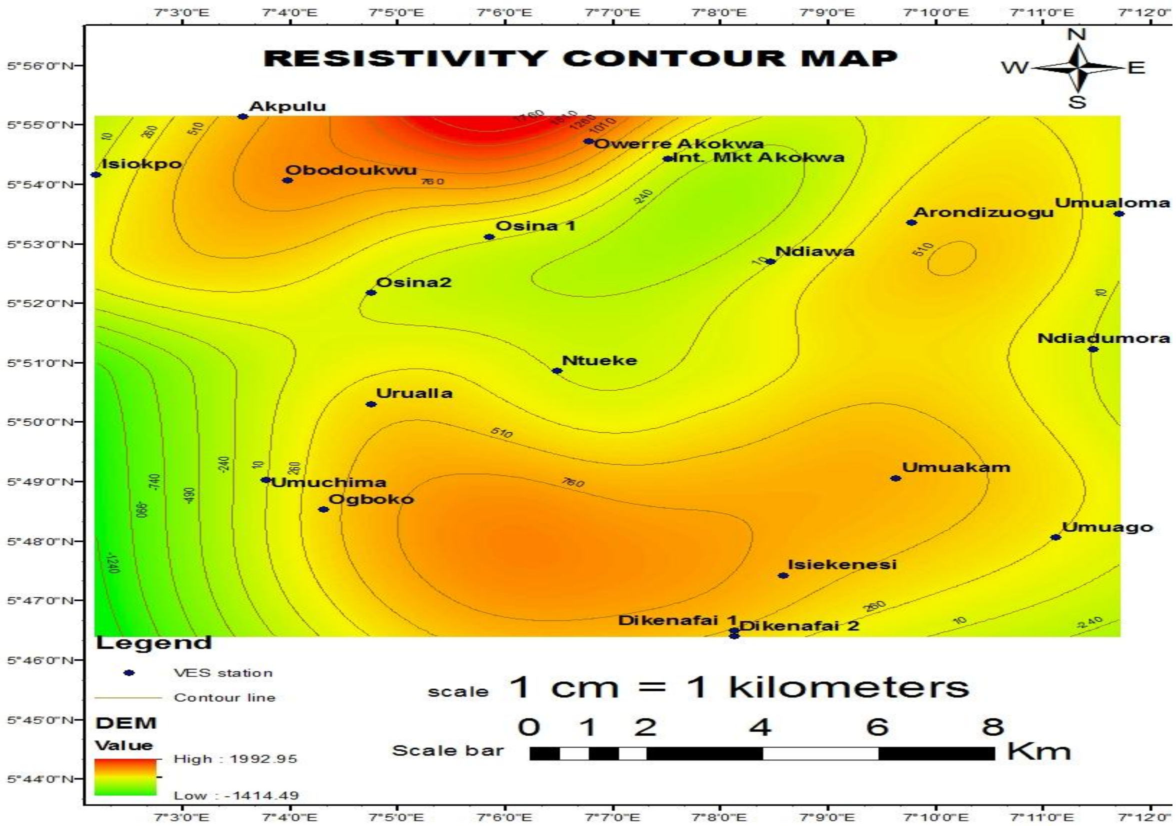

Figure 10: Resistivity Contour Map of the Study Area

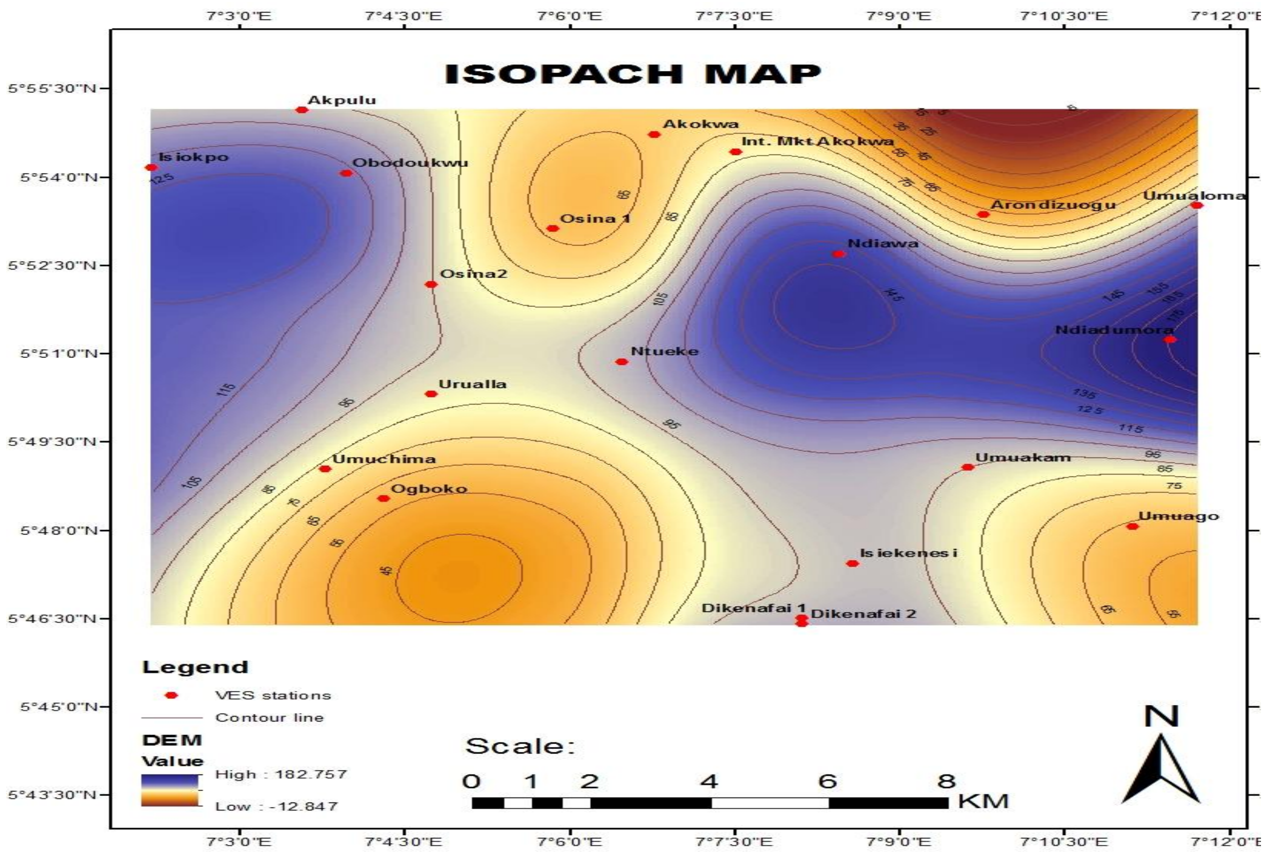

Figure 11: Isopach Map of the Study Area

Table 7: Summary of aquifer characteristics for all the sounding stations in the study area

VES NO.	VES Location	Aquifer Resistivity (Ωm)	Water table (m)	Acquifer thickness (m)	Conductivity σ ($\Omega^{-1}m^{-1}$)	Transverse Resistance R (Ω)	Longitudinal Conductance S (m Ω^{-1})	Hydraulic conductivity K (m/day)	Transmissivity (m^2/day)	K σ
1	Urualla	0.10	131.60	89.00	10.00000	8.9000	890.00	5.808	516.912	58.080
2.	Akokwa	1035.20	124.81	67.69	0.00097	70072.69	0.06538	7.636	518.538	0.0074
3.	Osina 1	847.10	97.62	94.88	0.00180	80372.85	0.11196	5.448	514.386	0.0064
4.	Osina 2	0.50	74.33	63.17	2.00000	31.5800	126.34	8.183	516.838	16.3660
5.	Obodoukwu	888.00	103.17	117.00	0.00113	103896.00	0.1317	4.418	514.363	0.00497
6.	Akpulu	645.90	94.19	98.31	0.00155	63498.43	0.1522	5.258	516.877	0.00814
7.	Akokwa	8.20	138.23	81.77	0.12200	670.51	9.9759	6.322	517.64	0.7713
8.	Isiokpo	30.70	101.00	119.00	0.03260	3653.30	3.8794	4.344	517.307	0.1416
9.	Ndiejezie Arondizuogu	411.90	105.36	60.00	0.00243	24714.00	0.1488	8.615	528.880	0.0214
10.	Umualoma	119.10	120.73	100.00	0.00840	11910.00	0.8400	5.169	516.894	0.0234
11.	Ndiawa	0.10	79.96	140.04	10.0000	14.0000	1400.4	3.691	516.740	36.910
12.	Ndiadumora	9.50	71.90	173.60	0.10500	1649.20	18.228	2.978	515.705	0.3127
13.	Ntueke	0.30	54.25	100.75	3.33333	30.2200	335.830	5.131	516.855	17.1031
14.	Umuchima	397.20	110.64	81.86	0.00252	32514.79	0.2063	6.315	516.985	0.0159
15.	Ogboko	411.90	105.36	57.68	0.00243	23758.39	0.1409	8.962	5`7.458	0.02178
16.	Isiekenesi	465.90	94.19	98.31	0.00215	45802.63	0.2110	5.258	516.654	0.01128
17.	Dikenafai 1	488.70	90.61	100.89	0.00205	49304.94	2.064	5.123	516.716	0.01048
18.	Dikenafai 2	442.50	90.33	102.07	0.00226	45165.97	0.2307	5.064	516.699	0.01144
19.	Umuago	254.00	129.00	63.50	0.00394	16129.00	0.2499	8.140	516.934	0.03205
20.	Umuakam	667.30	97.64	74.86	0.00150	49954.00	0.1122	6.905	517.025	0.01035

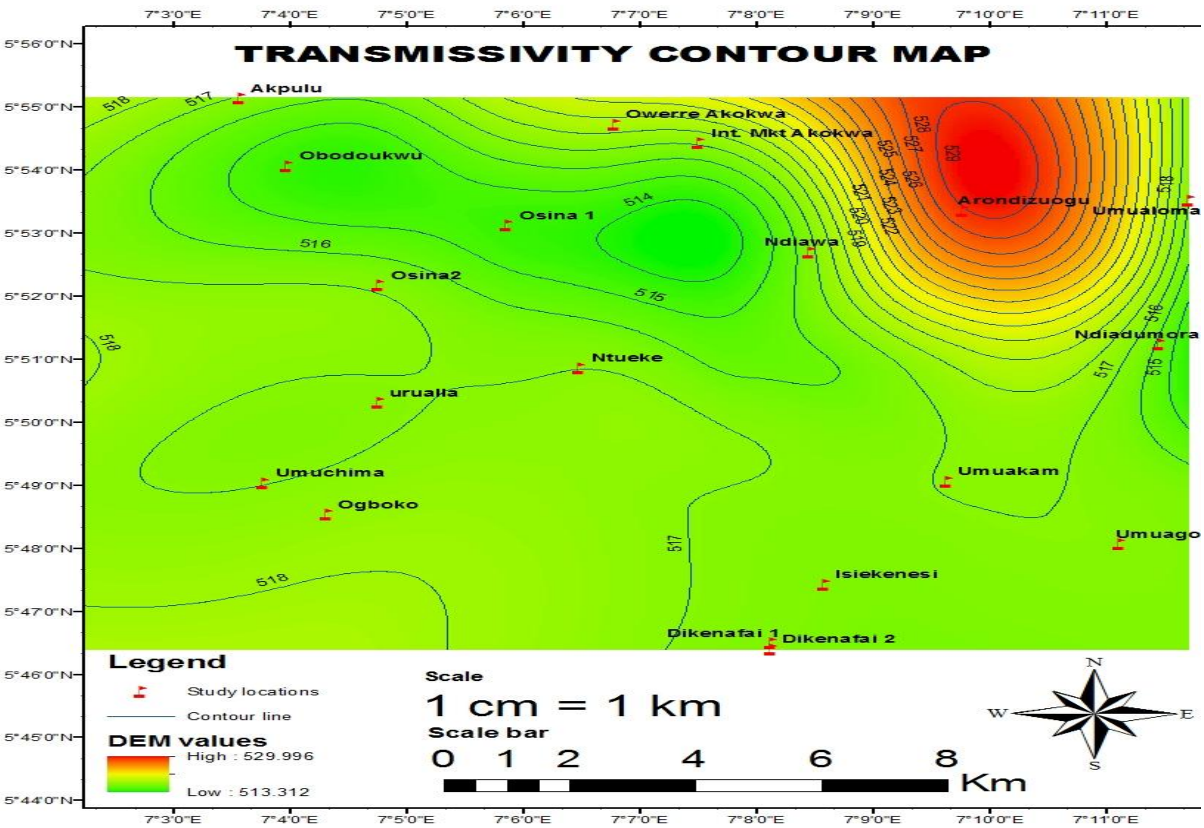

Figure 12: Transmissitivity Contour Map of the Study Area

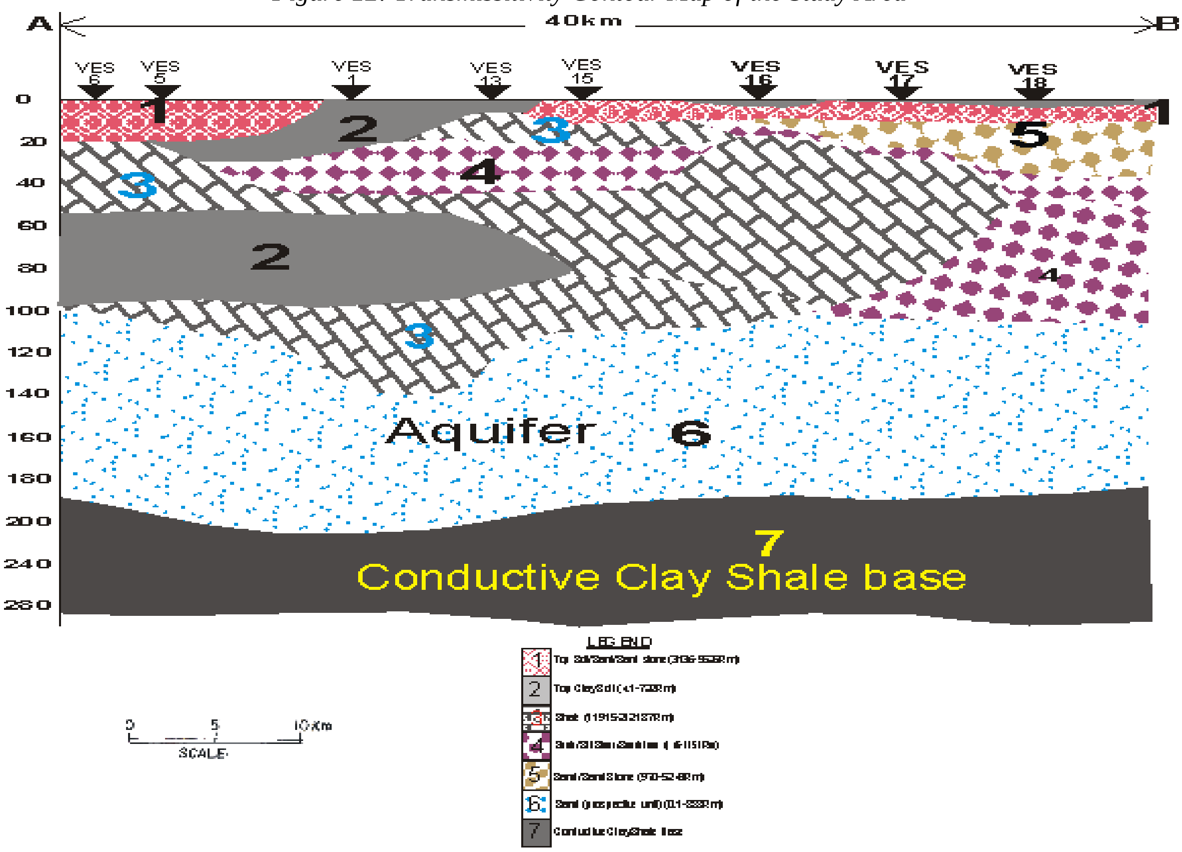

Figure 13: Interpretative Cross Section across Profile A-B (Subsurface stratification of the Study Area)

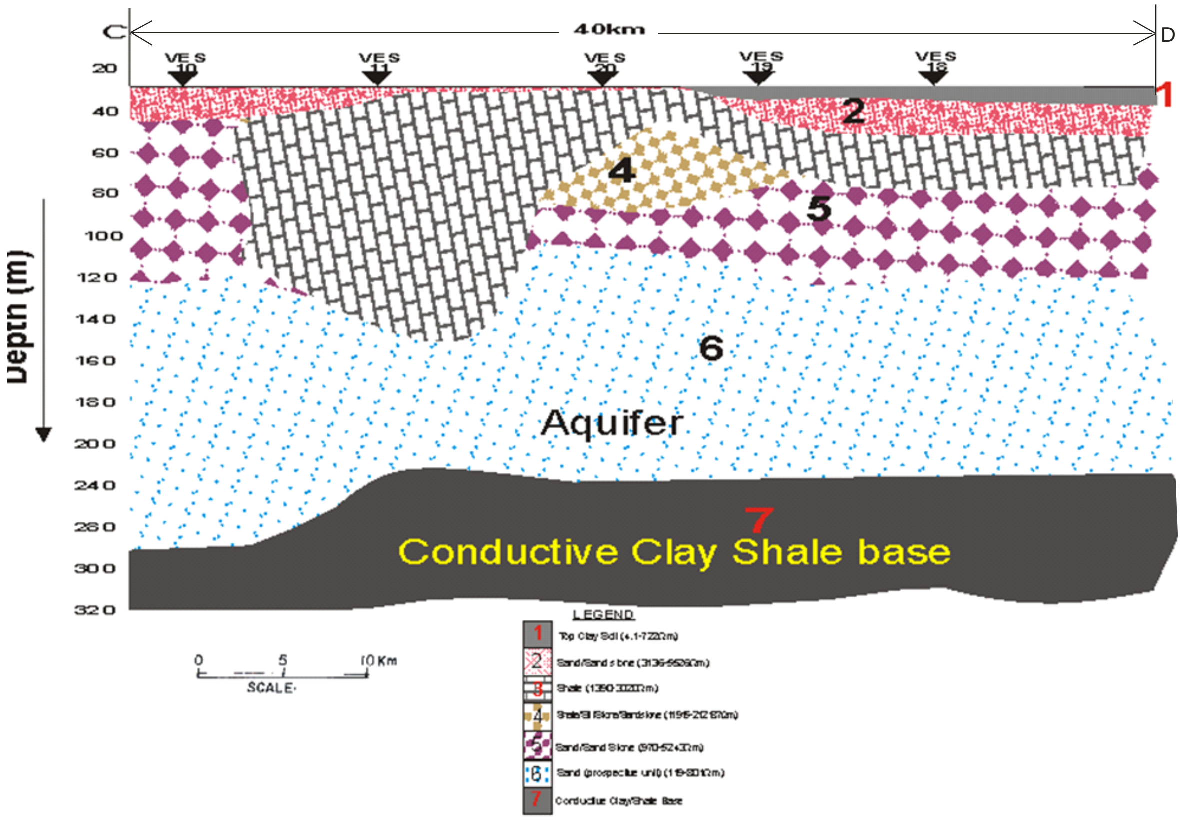

Figure 14: Interpretative Cross Section across Profile C-D (Subsurface stratification of the Study Area)

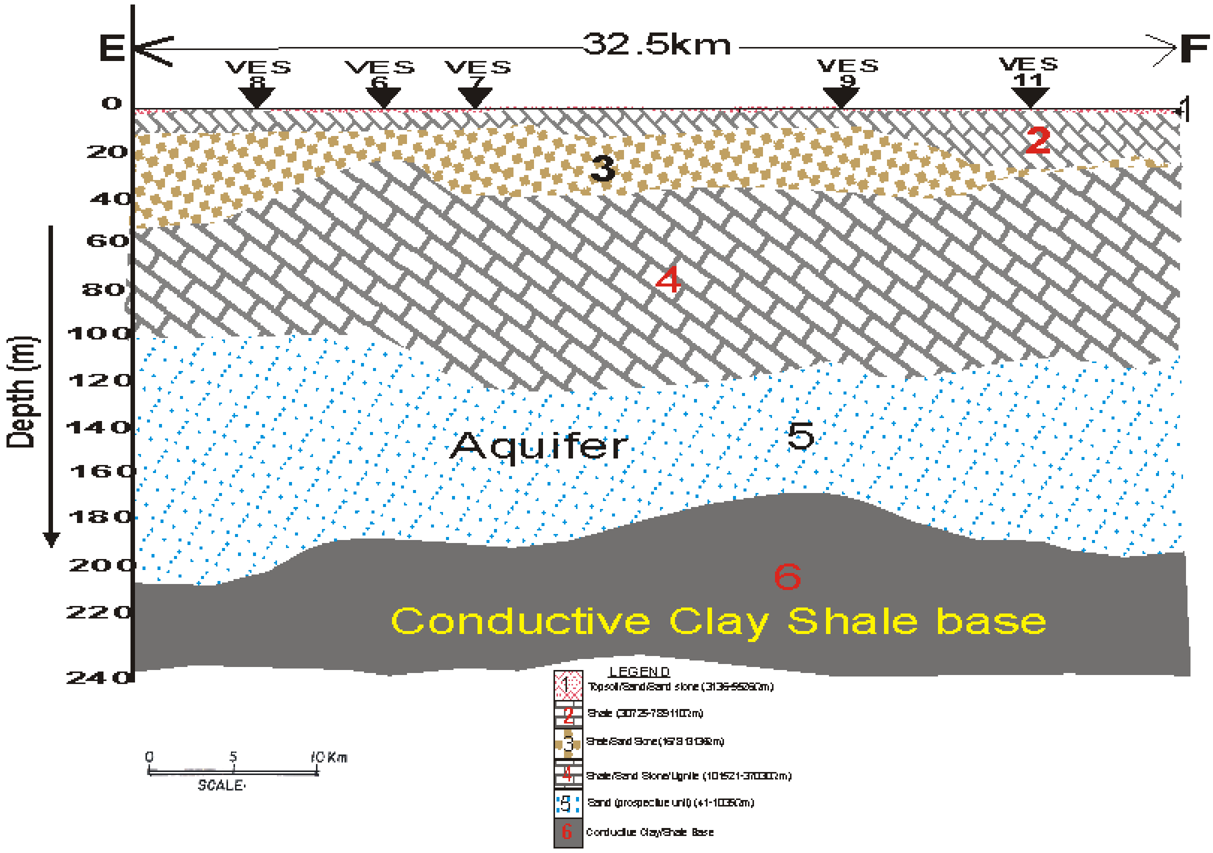

Figure 15: Interpretative Cross Section across Profile E-F (Subsurface stratification of the Study Area)

4.2. Discussion of Results

The modelled VES results show that the study area is underlain by alternating layers of shale, sandstone and clay. Table 7 is the summary of aquifer characteristics for all the sounding stations. The aquifer is delineated within the fractured shale. The aquifer materials are made up of shale, sandstone and clay. The resistivity of the aquifer varies across the study area and range from 0.1 Ωm observed around Urualla (VES 1) to 1035.20 Ωm recorded at Akokwa (Fig. 10). The low resistivity observed at Urualla could be due to the conductive materials or presence highly saturated aquifer [13].

The depth to water table also varied across the study area (Fig.9) with higher values observed in Ideato North than South. Areas with high depth to aquifer include Urualla with a depth of 131.60m, Akokwa with a value of 124.81m and Ndiejezie Arondizogu having a value of 105.36m. These results are expected as these areas correspond to topographic high places. Thus high drill depths are required for standard water well in such area [14]. In Ideato South area, relatively shallow aquifer is delineated around Isiekenesi and Dikenafai with water table at depths of 94.19m and 90.00m respectively. The depositional environment of this part of the study area tends towards the Benin Formation. Figure 11 shows the variation of aquifer thickness in the study area while Figure 12 reveals the variation of Transmissivity within the area.. Areas with high aquifer thickness have corresponding high Tsransmissivity values as Transmissivity is a function of aquifer thickness [15]. Such areas have good prospect for groundwater exploitation [16-17]. The Transmissivity values are moderately high and fairly uniform indicating similar geologic setting.

The transverse resistance and longitudinal conductance called the Dar Zarrouk parameters determined for the study area showed variation across the area (Table 7). These parameters have shown to be very powerful interpretational aid in groundwater survey [18-19]. The variation in Longitudinal conductance values show that parts of the study area such as Akokwa,Osina, Arondizuogu and Ogboko are underlain by relatively resistive (low longitudinal conductance) aquifer materials. These areas may not be good prospects for drilling of boreholes with high yield expectations [20].

The distribution of hydraulic conductivity and electrical conductivity product (K σ) values also displayed in Table 7 indicates that in some of the VES stations, the values are fairly constant. These locations include VES 2, 3, 5 and 6 on one hand and VES 14 to 20 on the other hand. This could be interpreted as areas with similar geologic setting and water quality [19].

The results of subsurface stratification of the study area are shown by Figures 13, 14 and 15 corresponding to the geoelectric interpretative cross-section along profile lines AB, CD and EF (Fig. 1). These show that the subsurface stratification gradually changed from alternation of shale/clay in Ideato North to sandstone, siltstone and sand towards Ideato south with geology tending towards the Benin Formation.

For the cross section AB, the first stratigraphic unit observed below VES 6, VES 5 and close to VES 1 is top soil composed of sand / sandstone with resistivity ranging from 131.60Ωm to 888.00Ωm. Greater part of this unit is underlain by top clay which overlies this unit from VES 1 to VES 18 along the profile line. Outcrops of the consolidated sandstones were observed around VES 5 and VES 6 with alternation of shale/siltstone and sandstone. A band of thick unconsolidated shale with resistivity ranging from 131.60Ωm to 645.90Ωm was delineated within Ideato North area.

Towards Ideato South, the subsurface layers tend to change in composition from sand/sandstone to shale/sandstone to shale/siltstone/sandstone. This observation can be explained by the fact that this part of Ideato South especially Dikenafai has geology tending towards the Benin Formation. The acquiferous unit believed to be the fractured shale has varying thickness along the transverses. Generally, Ideato north is shaleier than Ideato south.

4.3. Conclusion

The subsurface stratification of the study has been delineated and the aquifer horizon mapped out. The depth to fractured zone of the Imo Shale Formation has been delineated for tapping groundwater.

Total drill depth for standard well required for groundwater development should not be less than 178m (583ft) around Akokwa in Ideato North, while in Ideato South, the total drill depth should not be less than 134m (439ft) at Isiekenesi and 130m (426ft) around Dikenafai area. Ideato South has higher groundwater potential than

Ideato North of the study area. It is therefore possible to site public water supply project in Ideato south to serve the entire study area.

The knowledge of the total drill depth for standard water well determined in this study will reduce the time, cost and materials wasted in drilling private water wells without pre-drilling geophysical survey, which might prove abortive. The results of this study will reduce the difficulty in groundwater development in the study area.

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