HYDROGEOPHYSICAL EVALUATION OF AQUIFER UNITS AROUND THE LOWER ORASHI RIVER AREA, SOUTHEASTERN NIGERIA

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ABSTRACT

Hydrogeophysical characteristics of the aquifers of the Lower Orashi River Area, Southeastern Nigeria was done using VES to delineate the aquifers and evaluate their geometric characteristics. The study area is underlain by the Ameki, Ogwashi and Benin Formations. The unconsolidated nature of the Formations and their high susceptibility to contamination have made this study imperative, as it would assist water resource planners and developers in the area to understand the best way to plan and site boreholes in the area. Eighty eight (88) Schlumberger Vertical Electrical Soundings (VES) were carried out in various parts of the study area with a maximum electrode separation (AB/2) of 350 m. The VES data were processed using a combination of curve matching techniques and computer iterative modeling. The study revealed seven to ten geo-electric layers with varying lithologies majorly sand units and a multiple aquifer system ranging from confined to unconfined aquifers. The results indicate that aquifer thickness ranges from 20m to about 227m. A quantitative interpretation of the curves show that some of the aquifers are shallow at 20m while moderate and deep aquifers were also encountered at 64m to 156m. The results from the iso-resistivity curves reveal that there was a progressive increase in resistivity with depth suggesting a low resistive overburden to high resistive layer at the base which can be interpreted as the sands and sandstones of the Benin Formation; however the Northeastern part of the area shows a trend of low resistivity which could be indicating the clay of the Ameki Formation as well as Lignite series of the Ogwashi Formation. The concept of Dar-Zarrouk parameters (transverse unit resistance and longitudinal conductance in porous media) was used to determine aquifer hydraulic characteristics. Hydraulic conductivity for the study area varies between 0.42m/day to 179m/day. Transmissivity values vary from 14.89m^2/day to 3590m^2/day. Areas with high values of Hydraulic Conductivity and Transmissivity such as Ogboko, Otulu, Amiri, Umuma

Isiaku, Amike, Eziachi with values ranging from 3000 -5000 m^2/day and 60 -100m/day respectively have good prospects for groundwater development. On the other hand, those areas with low values which include Ugwu City, Umuhu Okabia, Orsu Ihiteukwa, Amaebu, Asaa Ubirielem, Amannachi, Mbosi, Ukpor, Abaja, Nwangele with values ranging 20-500m^2/day and 10- 25m/day respectively have minimal to low groundwater prospects.

Keywords: Hydrogeophysics, Transmissivity, Hydraulic Conductivity, Aquifer, Lower Orashi.

1.0 INTRODUCTION

The application of geophysical methods has generally proven very effective for water content estimation, water quality assessment, evaluation of aquifer properties, geo-electric parameters and mapping of the depth to water table (Hubbard and Rubin, 2005).

The integration of aquifer parameters gotten from existing borehole data as well as surface resistivity parameters derived from surface resistivity measurements has proven to be highly effective in hydrogeophysical studies (Ugada et al., 2013).

Some studies (Iduma and Abam, 2010; Ahiarakwem and Ejimadu, 2002; Ezeigbo, 1989; Uma, 1984; Etu-Efeotor, Odigi, 1983 and Onunkwo et al., 2018) have been carried out on some aspects of the hydrogeology of Southeastern Nigeria of which the study area is a part; the flow potential of the groundwater resources in the area is yet to be studied. Eluwole and Oladimeji (2013) did a hydrogeophysical evaluation of the groundwater potential of the Afe Babalola University, Ado Ekiti, Southwestern Nigeria using electrical resistivity method thereby arriving at the conclusion that the groundwater potential of the study area can be classified into good, moderate and poor groundwater zones. Teikeu et al (2012) characterized the aquifer in a hard rock environment using hydrogeophyscal parameters with a case study from Yaounde, Cameroun. He concluded that the use of geoelectrical sounding provides an inexpensive technique for calculating the hydraulic parameters and characterizing the aquifer system of the area. Aquifer characteristics of Ihiala and environs, Anambra state, Nigeria was estimated using vertical electrical sounding data by Obiajulu et al. (2016).

2.0 LOCATION OF THE STUDY AREA

The area lies within latitudes 5°39'N to 5°57'N and longitudes 6°45'E to 7°08'E. It is located within some parts of Imo and Anambra states of Nigeria. The main rivers that traverse the study area are Njaba, Orashi and Ogidi Rivers which are tributaries to the Niger River. The terrain of the study area is characterized by two types of landforms viz: high undulating ridge and flat topography. These undulating ridges and flat lands are somewhat related to the bedrock underlying the area. The ridges trend in the north-south direction and have an average elevation of about 122m above sea level (Iloeje 1991).

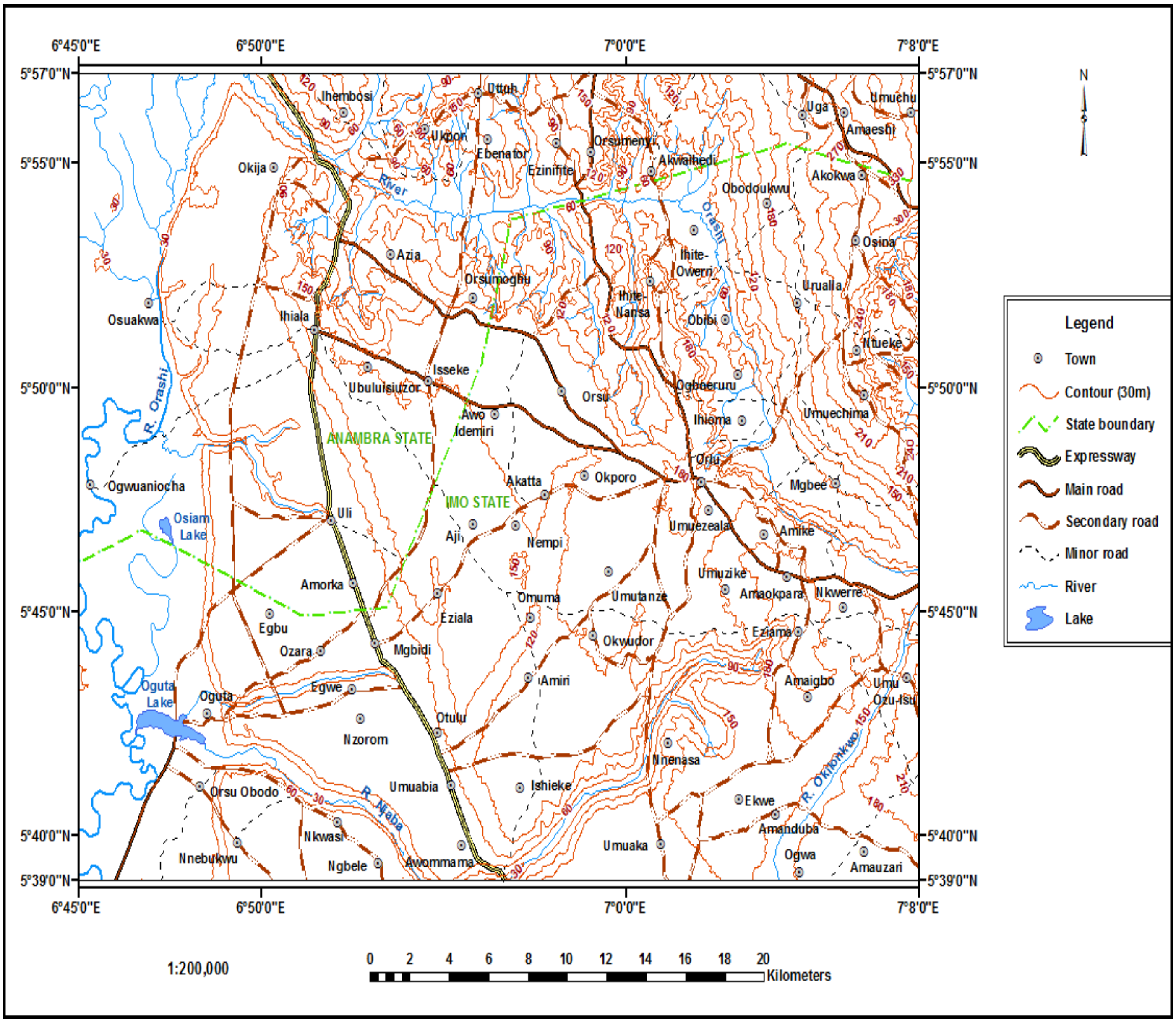


FIG 1: LOCATION MAP OF THE STUDY AREA.

3.0 GEOLOGY OF THE STUDY AREA

The area is part of the Benin Formation. The geology of the Benin Formation has been given by Short and Stauble (1967), Reyment (1965), Hospers (1965) among others. The Benin Formation is made up of friable sands and minor intercalation of clay. The sand units are mostly coarse grained, pebbly, poorly sorted and contain lenses of fine grained sands (Short and Stauble, 1967; Onyeagocha, 1980). Benin Formation is one of the three recognized subsurface stratigraphic units in the modern Niger Delta. It is fresh water bearing massive continental sand and gravel deposited in an upper deltaic environment. It was formerly designated as coastal plain sands (Reyment, 1965). As the study component in most areas form more than 90% of the sequence of the layers, permeability, transmissivity and storage coefficient are high. The Formation starts as a thin edge at its contact with Ogwashi Formation in the north of the area and thickens seawards. The Benin Formation conformably overlies the Ogwashi Formation. The Ogwashi Formation (Lignite series) is also predominantly sandy with minor clay units (Reyment 1965). The Formation is characterized by lignite seams at various levels. The lignite Formation has thickness of about 300m (Reyment 1965). This is underlain by the Ameki Formation with thickness of 1460m, as outcropped in the study area (Fig 2).

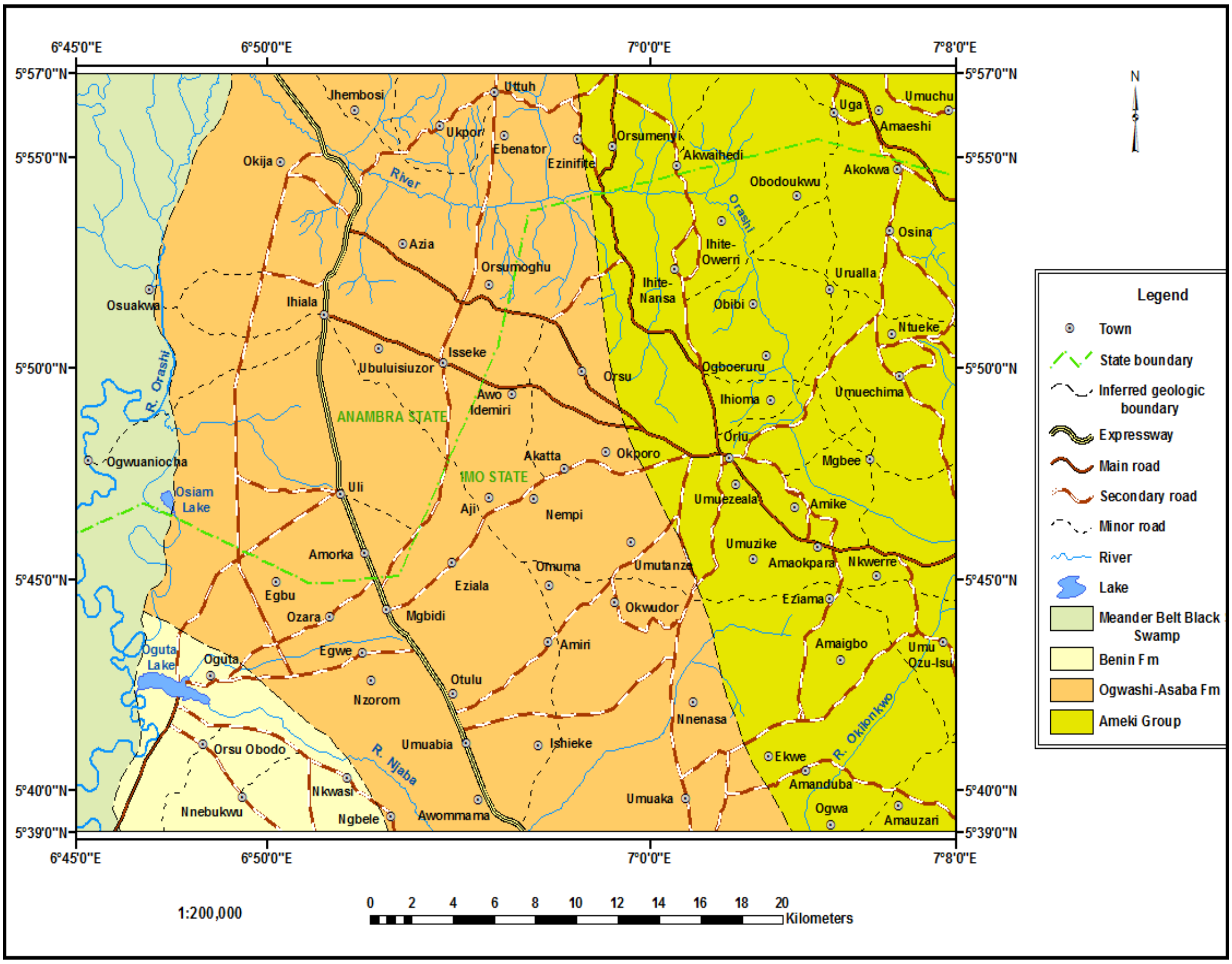


FIG 2: GEOLOGY MAP OF THE STUDY AREA

4.0 MATERIALS AND METHODS

The geophysical data helps to evaluate the structures within the subsurface in this environment. A total of eighty eight (88) Vertical Electrical Sounding (VES) stations were established using the schlumberger configuration with ABEM SAS 4000 Terrameter. Standard VES procedure for data acquisition which has been utilized by the likes of Onu (1995), Olayinka and Olayiwola (2001), Ibeneme et al. (2013), Ibeneme et al. (2014) and Opara et al. (2018) was adopted in this research using Schlumberger Electrode Configuration with field layout shown in fig 3 below. The electrode spacing (AB/2) distances of 1.5m, 2.0m, 3.4m, 4.5m, 6.0m, 8.0m, 14.0m, 18.0m, 24.0m, 34.0m, 42.0m, 55.0m, 72.5m, 95.0m etc with cross over points or looping observed at 14.0m and 55.0m to reduce the effect of attenuation of the current and voltage supply in order to have a consistent and reliable signals as readings in Ohm.

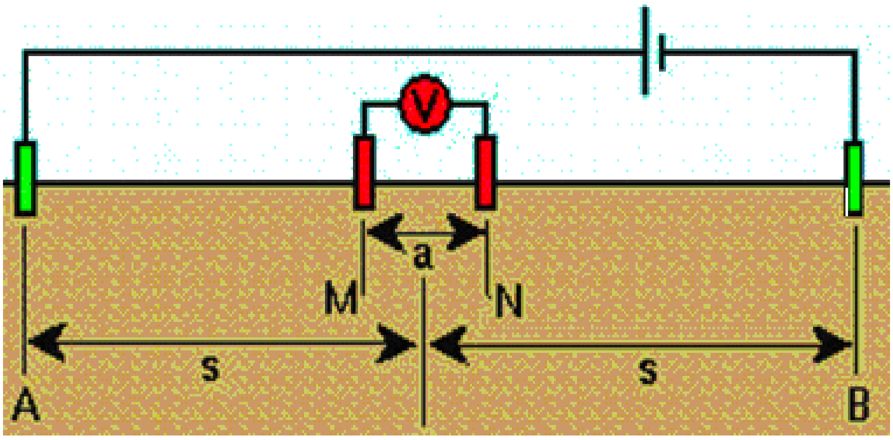


Figure 3: Typical Schlumberger Array. M and N; potential electrodes, A and B; current electrodes.

The data obtained is usually plotted as a graph of apparent resistivity against half electrode spacing. The raw data (as below) acquired from vertical electrical sounding using the Schlumberger array were further processed and interpreted using a combination of curve matching and computer iterative modeling. Detailed quantitative interpretation was done using IP 2win 1D Computer Program. The VES data were finally presented as sounding curve and the results used to prepare geoelectric sections with the appropriate geo-software (surfer 12).

5.0 RESULTS PRESENTATION.

TABLE 1: VES LOCATIONS, COORDINATES AND ELEVATION

VES NO.	VES LOCATION	LAT. (N)	LONG. (E)	HEIGHT (ft)
1	Ogboko, Ideato North, Imo State	5°49.653'	7°04.974'	633
2	Akokwa, Ideato North, Imo State	5°54.007	7°06.587'	921
3	Obiohia, Ideato North, Imo State	5°50.232'	7°04.701'	568
4	Osina, Ideato, North, Imo State	5°53.423'	7°05.128'	772
5	Obodoukwu, Ideato North, Imo State	5°54.499'	7°03.768'	568
6	Urualla, Ideato North, Imo State	5°51.870'	7°04.927'	637
7	Ntueke, Ideato North, Imo State	5°50.752'	7°06.380'	791

8	Akpulu, Ideato North, Imo State	5^{o}55.070'	7^{o}04.092'	701
9	Isiekenesi, Ideato South , Imo State	5^{o}53.579'	7^{o}07.809'	656
10	Dikenafai, Ideato South, Imo State	5^{o}45.812'	7^{o}09.288'	504
11	Ogboza, Ideato South, Imo State	5^{o}48.447'	7^{o}06.841'	758
12	Ogboo Akwu, Ideato North, Imo State	5^{o}54.419'	7^{o}07.637'	1056
13	Umuojishi, Ideato South, Imo State	5^{o}46.913'	7^{o}07.697'	505
14	Ogwume, Ideato South, Imo State	5^{o}50.435'	7^{o}05.045'	633
15	Amanator, Ideato South, Imo State	5^{o}49.364'	7^{o}06.832'	892
16	Umunaga, Umueshi Ideato South, Imo State	5^{o}49.805'	7^{o}07.637'	874
17	Uga, Aguata, Anambra State	5^{o}56.726'	7^{o}06.087'	891
18	Umuma Isiaku, Imo State	5^{o}47.940'	7^{o}05.727'	322
19	Amike, Orlu , Imo State	5^{o}46.732'	7^{o}04.115'	641
20	Eziachi, Orlu , Imo State	5^{o}45.497'	7^{o}03.898'	771
21	Umuzike, Orlu Imo State	5^{o}45.195'	7^{o}02.300'	689
22	Mgbee, Orlu, Imo State	5^{o}48.577'	7^{o}03.106'	308
23	Umuowa, Orlu, Imo State	5^{o}45.568'	7^{o}01.779'	570
24	Orlu, Imo State	5^{o}47.280'	7^{o}03.756'	633
25	Eziama Obaire, Nkwerre, Imo State	5^{o4}4.866'	7^{o}05.028'	755
26	Owerre Nkworji, Nkwerre, Imo State	5^{o}45.326'	7^{o}07.154'	636
27	Ihitte Isu, Isu, Imo State	5^{o}43.946'	7^{o}04.133'	607
28	Amuzi Isu, Nwangele, Imo State	5^{o}42.476'	7^{o}09.365'	755
29	Umuozu Nwangele, Imo State	5^{o}43.367'	7^{o}07.789'	641
30	Amaigbo, Nwangele, Imo State	5^{o}43.002'	7^{o}05.367'	649
31	Amaokpara, Nwangele, Imo State	5^{o}46.391'	7^{o}04.800'	744
32	Abaja, Nwangele, Imo State	5^{o}40.376'	7^{o}07.672'	615
33	Amurie Omanze, Isu, Imo State	5^{o}40.379'	7^{o}02.247'	541
34	Umundugba, Isu , Imo State	5^{o}41.396'	7^{o}04.282'	587
35	Ekwe, Isu , Imo State	5^{o}42.630'	7^{o}03.093'	593
36	Amauju, Isu , Imo Stae	5^{o}43.780'	7^{o}05.093'	768
37	Dim Na Nume, Isu, Imo State	5^{o}42.568'	7^{o}09.252'	830

38	Okwudor, Njaba, Imo State	5°42.637'	7°00.313'	545
39	Umuaka, Njaba, Imo State	5°40.617'	7°00.403'	535
40	Nkume, Njaba,Imo State	5°44.733'	7°00.998'	584
41	Nnennasaa, Njaba,Imo Stae	5°41.980'	7°01.098'	416
42	Amaiyi Aka, Njaba, Imo State	5°39.039'	7°00.105'	499
43	Ugwu City, Umuhu Okabia, Orsu, Imo State	5°49.662'	7°59.806'	413
44	Ofeahia, Umuhu Okabia, Orsu, Imo State	5°49.096'	6°59.103'	623
45	Orsu Ihiteukwa, Orsu, Imo State	5°51.256'	6°59.718'	628
46	Amaebu, Orsu, Imo State	5°48.879'	6°57.732'	569
47	Asaa Ubirielem, Orsu, Imo State	5°51.387'	6°59.824'	509
48	Amannachi, Orsu, Imo State	5°48.295'	6°58.600'	545
49	Amaruru, Orsu, Imo State	5°53.856'	6°59.038'	361
50	Ihittenansa, Orsu, Imo State	5°52.558'	6°59.248'	320
51	Awo Idemili, Orsu, Imo State	5°50.720'	6°56.988'	361
52	Amazu, Orsu, Imo State	5°46.277'	6°58.220'	478
53	Awo Omamma, Oru East, Imo State	5°40.521'	6°56.334'	425
54	Ohakpu, Oru West, Imo State	5°45.027'	6°60.6584'	227
55	Omuma, Oru East, Imo State	5°45.538'	6°56.577'	447
56	Okporo, Orlu, Imo State	5°47.572;	7°00.847'	616
57	Akatta, Oru East, Imo State	5°46.892'	6°57.632'	493
58	Akuma, Oru East, Imo State	5°48.974'	6°57.139'	584
59	Ihitte Owerri, Orlu, Imo State	5°53.054'	7°00.697'	137
60	Obibi Ochasi, Orlu, Imo State	5°50.660'	7°01.225'	630
61	Ogberuru, Orlu, Imo State	5°50.283'	7°01.538'	539
62	Aji, Oru West, Imo State	5°44.723'	6°54.113'	319
63	Mgbidi, Oru West, Imo State	5°44.028'	6°53.510'	341
64	Otulu, Oru West, Imo State	5°42.450'	6°54.557'	265
65	Amiri, Oru East, Imo State	5°43.865'	6°57.544'	515
66	Ubulu Ihejiofor, Oru West, Imo State	5°48.879'	6°54.951'	560

67	Ibiasoegbe, Oru West, Imo Sate	5°54.260'	6°53.915'	418
68	Uli, Ihiala, Anambra State	5°48.865'	6°52.586'	436
69	Amorka, Ihiala Anambra State	5°43.988'	6°52.342'	251
70	Ubulu Isiuzor, Ihiala, Anambra State	5°50.652'	6°52.852'	551
71	Issekke, Ihiala, Anambra State	5°50.970'	6°54.792'	584
72	Azia, Ihiala, Anambra State	5°52.293'	6°54.001'	420
73	Orsumoghu, Ihiala , Anambra State	5°51.983'	6°55.899'	465
74	Mbosi, Ihiala, Anambra State	5°51.317'	6°53.617'	505
75	Ukpor, Nnewi South, Anambra State	5°56.085'	6°54.160'	270
76	Osumenyi, Nnewi South, Anambra State	5°56.085'	6°54.160'	270
77	Ezinifitte, Nnewi South, Anambra State	5°55.395'	6°58.180'	320
78	Lilu. Ihiala, Anambra State	5°53.126'	6°57.160'	256
79	Unubi, Nnewi South, Anambra State	5°56.324'	7°01.472'	481
80	Umuchu, Aguata, Anambra State	5°57.092'	7°07.681'	1066
81	Oguta, Oguta , Imo State	5°43.382'	6°48.530'	72
82	Ogwa, Mbaitoli , Imo state	5°39.459'	7°04.358'	591
83	Ngbele, Oguta, Imo State	5°40.853'	6°50.870'	217
84	Orsu Obodo, Oguta, Imo State	5°38.251'	6°48.551'	53
85	Egbuoma,Oguta, Imo State	5°42.462'	6°47.885'	50
86	Egwe, Oguta, Imo State	5°42.556'	6°48.777'	114
87	Osuakwa, Ihiala, Anambra State	5°52.000'	6°47.000'	551
88	Ezinifitte, Aguata, Anambra State	5°59.472'	7°04.535'	837

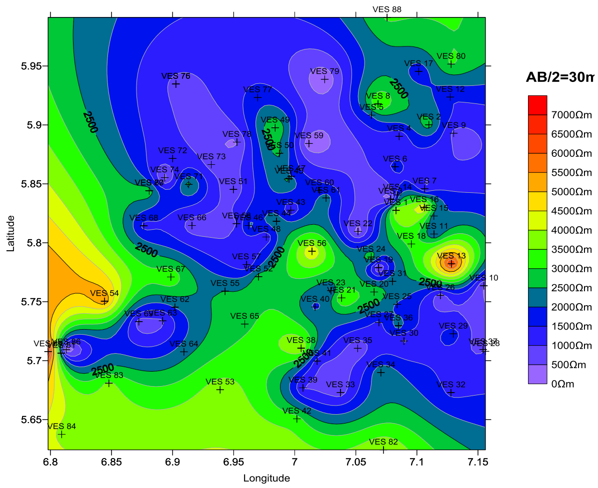
TABLE 2: AQUIFER PARAMETERS

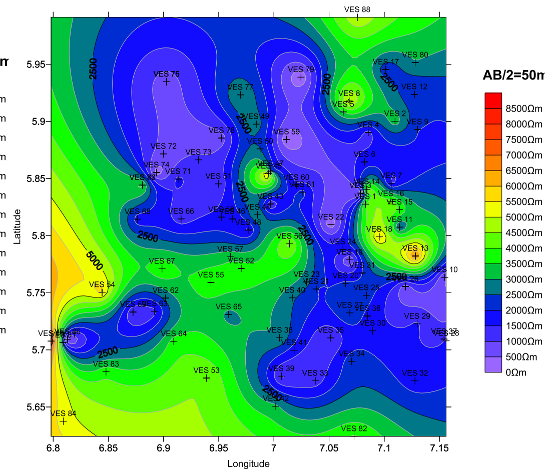
VES NO	HEIGHT (ft)	TOP OF AQUIFER (m)	BOTTOM OF AQUIFER (m)	AQUIFER THICKNESS (m)	AQUIFER RESISTIVITY, ℓ(Ωm)	AQUIFER CONDUCTIVITY 1/ℓ (Ωm)-1	TRANSVERSE RESISTANCE	LONGITUDINAL CONDUCTANCE	STORATIVITY	K FROM PUMP TEST	Kδ	TRANSMISSIVITY	HYDRAULIIC CONDUCTIVITY
VES 1	633	79.4	208	128.6	79180	1.26295E-05	10182548	0.001624148	0.0003858		0.000794	8084.943	62.87
VES 2	921	131	321	190	5112	0.000195618	971280	0.037167449	0.00057	4.06	0.000794	771.1963	4.06
VES 3	568	93.8	312	218.2	13630	7.33676E-05	2974066	0.016008804	0.0006546		0.000794	2361.408	10.82
VES 4	772	119	222	103	23500	4.25532E-05	2420500	0.004382979	0.000309		0.000794	1921.877	18.66
VES 5	568	77.6	232	154.4	2200	0.000454545	339680	0.070181818	0.0004632		0.000794	269.7059	1.75
VES 6	637	118	278	160	6877.5	0.000145402	1100400	0.023264268	0.00048	5.19	0.000755	830.802	5.19
VES 7	791	16.7	52.3	35.6	554.3	0.001804077	19733.08	0.064225149	0.0001068		0.000755	14.89848	0.42
VES 8	701	126	312	186	7990	0.000125156	1486140	0.023279099	0.000558		0.000755	1122.036	6.03
VES 9	656	113	245	132	3840	0.000260417	506880	0.034375	0.000396		0.000755	382.6944	2.90
VES 10	504	95	248	153	749.7	0.001333867	114704.1	0.204081633	0.000459		0.000755	86.6016	0.57
VES 11	758	98.5	239	140.5	5160	0.000193798	724980	0.027228682	0.0004215		0.000755	547.3599	3.90
VES 12	1056	111	273	162	7175	0.000139373	1162350	0.022578397	0.000486		0.000755	877.5743	5.42
VES 13	505	130	220	90	6136.7	0.000162954	552303	0.014665863	0.00027		0.000755	416.9888	4.63
VES 14	633	98.2	189	90.8	5116.7	0.000195438	464596.36	0.017745813	0.0002724		0.000755	350.7703	3.86
VES 15	892	125	219	94	3153.3	0.000317128	296410.2	0.02981004	0.000282		0.000755	223.7897	2.38
VES 16	874	120	290	170	8292.5	0.000120591	1409725	0.020500452	0.00051		0.00076	1071.391	6.30
VES 17	891	119	230	111	35787	2.79431E-05	3972357	0.003101685	0.000333		0.000755	2999.13	27.02
VES 18	322	91.4	191	99.6	3650	0.000273973	363540	0.027287671	0.0002988		0.000755	274.4727	2.76
VES 19	641	41.9	110	68.1	494.8	0.002021019	33695.88	0.137631366	0.0002043	4.02	0.008124	273.7453	4.02

VES 20	771	79.6	271	191.4	3084	0.000324254	590277.6	0.062062257	0.0005742		0.008124	4795.415	25.05
VES 21	689	87	194	107	4230	0.000236407	452610	0.025295508	0.000321		0.008124	3677.004	34.36
VES 22	308	134	182	48	1036	0.000965251	49728	0.046332046	0.000144		0.008124	403.9903	8.42
VES 23	570	104	124	20	22100	4.52489E-05	442000	0.000904977	0.00006		0.008124	3590.808	179.54
VES 24	633	74.9	164	89.1	7960	0.000125628	709236	0.011193467	0.0002673		0.008124	5761.833	64.67
VES 25	755	90	300	210	6694	0.000149388	1405740	0.031371377	0.00063	5.81	0.000868	1220.182	5.81
VES 26	636	22.7	63.2	40.5	593.5	0.00168492	24036.75	0.068239259	0.0001215		0.000868	20.8639	0.52
VES 27	607	90	193	103	12500	0.00008	1287500	0.00824	0.000309		0.000868	1117.55	10.85
VES 28	755	55.6	144	88.4	1250	0.0008	110500	0.07072	0.0002652		0.000868	95.914	1.09
VES 29	641	72.2	165	92.8	992.3	0.00100776	92085.44	0.093520105	0.0002784		0.000868	79.93016	0.86
VES 30	649	59.7	250	190.3	7396.7	0.000135195	1407592	0.025727689	0.0005709		0.000868	1221.79	6.42
VES 31	744	79.1	288	208.9	4887.5	0.000204604	1020998.8	0.042741688	0.0006267		0.000868	886.2269	4.24
VES 32	615	90.3	158	67.7	4126.7	0.000242324	279377.59	0.01640536	0.0002031		0.000868	242.4997	3.58
VES 33	541	110	311	201	3214	0.000311139	646014	0.062538892	0.000603		0.000868	560.7402	2.79
VES 34	587	85.5	297	211.5	4045	0.000247219	855517.5	0.052286774	0.0006345		0.000868	742.5892	3.51
VES 35	593	117	331	214	4265	0.000234467	912710	0.05017585	0.000642	2.53	0.000593	541.237	2.53
VES 36	768	84.8	288	203.2	3770	0.000265252	766064	0.053899204	0.0006096		0.000593	454.276	2.24
VES 37	830	96.7	234	137.3	1890	0.000529101	259497	0.072645503	0.0004119		0.000593	153.8817	1.12
VES 38	545	100	161	61	960	0.001041667	58560	0.063541667	0.000183		0.000593	34.72608	0.57
VES 39	535	85.5	221	135.5	2405	0.0004158	325877.5	0.056340956	0.0004065	4.9	0.002037	663.8125	4.90
VES 40	584	86	171	85	2997	0.000333667	254745	0.028361695	0.000255		0.002037	518.9156	6.10
VES 41	416	95	269	174	9210	0.000108578	1602540	0.018892508	0.000522		0.002037	3264.374	18.76
VES 42	499	91.6	319	227.4	5516	0.000181291	1254338.4	0.041225526	0.0006822		0.002037	2555.087	11.24
VES 43	413	110.5	191	80.5	5245	0.000190658	422222.5	0.01534795	0.0002415		0.002037	860.0672	10.68
VES 44	623	91	235	144	7198	0.000138927	1036512	0.020005557	0.000432	4.72	0.000656	679.9519	4.72
VES 45	628	142	252	110	2370	0.000421941	260700	0.046413502	0.00033		0.000656	171.0192	1.55
VES 46	569	99.2	251	151.8	7028	0.000142288	1066850.4	0.021599317	0.0004554		0.000656	699.8539	4.61

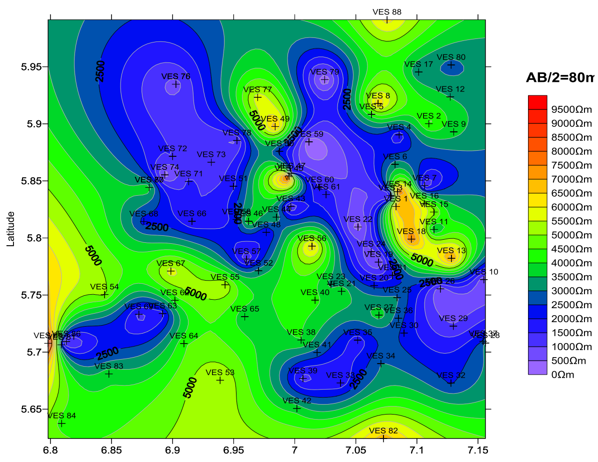
VES 47	509	111	268	157	3303	0.000302755	518571	0.047532546	0.000471		0.000656	340.1826	2.17
VES 48	545	110.5	304	193.5	3406	0.0002936	659061	0.056811509	0.0005805		0.000656	432.344	2.23
VES 49	361	37	75	38	1987	0.000503271	75506	0.019124308	0.000114		0.000656	49.53194	1.30
VES 50	320	97.1	217	119.9	3525	0.000283688	422647.5	0.034014184	0.0003597		0.000656	277.2568	2.31
VES 51	361	156	282	126	6505	0.000153728	819630	0.019369716	0.000378		0.000656	537.6773	4.27
VES 52	478	93.3	249	155.7	3920	0.000255102	610344	0.039719388	0.0004671		0.000656	400.3857	2.57
VES 53	425	97.8	278	180.2	4350	0.000229885	783870	0.041425287	0.0005406	1.9	0.000437	342.5512	1.90
VES 54	227	72.5	232	159.5	3404	0.000293772	542938	0.046856639	0.0004785		0.000437	237.2639	1.49
VES 55	447	72	172	100	11845	8.44238E-05	1184500	0.008442381	0.0003		0.000437	517.6265	5.18
VES 56	616	80.7	155	74.3	9125	0.000109589	677987.5	0.008142466	0.0002229		0.000437	296.2805	3.99
VES 57	493	107	230	123	1983	0.000504286	243909	0.062027231	0.000369		0.000437	106.5882	0.87
VES 58	584	80	210	130	42027	2.37942E-05	5463510	0.00309325	0.00039		0.000437	2387.554	18.37
VES 59	137	101	183	82	3400	0.000294118	278800	0.024117647	0.000246		0.000437	121.8356	1.49
VES 60	630	64	202	138	2667	0.000374953	368046	0.051743532	0.000414		0.000437	160.8361	1.17
VES 61	539	66.4	133	66.6	5330	0.000187617	354978	0.01249531	0.0001998		0.000437	155.1254	2.33
VES 62	319	44.9	138	93.1	526	0.001901141	48970.6	0.176996198	0.0002793	3.59	0.006825	334.2243	3.59
VES 63	341	71.5	164	92.5	4745	0.000210748	438912.5	0.019494204	0.0002775		0.006825	2995.578	32.38
VES 64	265	86.7	278	191.3	4130	0.000242131	790069	0.046319613	0.0005739		0.006825	5392.221	28.19
VES 65	515	83	289	206	3155	0.000316957	649930	0.065293185	0.000618		0.006825	4435.772	21.53
VES 66	560	72.9	192	119.1	4160	0.000240385	495456	0.028629808	0.0003573		0.006825	3381.487	28.39
VES 67	418	93.2	233	139.8	1513	0.000660939	211517.4	0.092399207	0.0004194		0.006825	1443.606	10.33
VES 68	436	72.1	377	304.9	1010	0.000990099	307949	0.301881188	0.0009147	3.37	0.003337	1027.626	3.37
VES 69	251	55.5	171	115.5	1203	0.000831255	138946.5	0.096009975	0.0003465		0.003337	463.6645	4.01
VES 70	551	62.2	149	86.8	8418.5	0.000118786	730725.8	0.010310625	0.0002604	3.05	0.000362	264.5227	3.05
VES 71	584	68.4	175	106.6	4155	0.000240674	442923	0.025655836	0.0003198		0.000362	160.3381	1.50
VES 72	420	96.8	249	152.2	1427.5	0.000700525	217265.5	0.106619965	0.0004566		0.000362	78.65011	0.52
VES 73	465	67	274	207	7404.7	0.000135049	1532772.9	0.027955218	0.000621		0.000362	554.8638	2.68

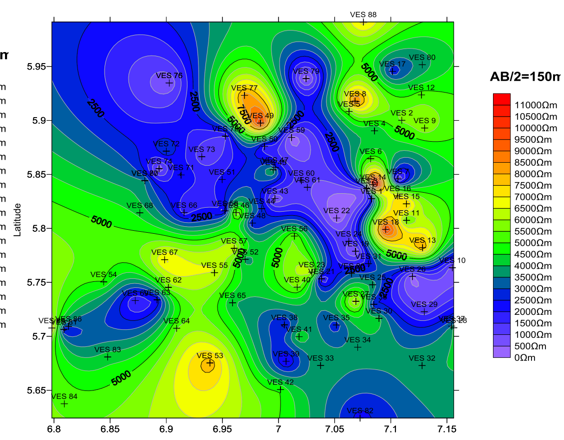
VES 74	505	135	248	113	893	0.001119821	100909	0.126539754	0.000339	3.73	0.004177	421.4969	3.73
VES 75	270	-	-	-	-	-	-	-	-				
VES 76	270	81.1	145	63.9	2044	0.000489237	130611.6	0.031262231	0.0001917		0.004177	545.5647	8.54
VES 77	320	118	186	68	1017.5	0.000982801	69190	0.066830467	0.000204	5.81	0.00571	395.0749	5.81
VES 78	256	81.8	219	137.2	2610	0.000383142	358092	0.05256705	0.0004116		0.00571	2044.705	14.90
VES 79	481	93.8	212	118.2	3716.7	0.000269056	439313.94	0.031802405	0.0003546		0.00571	2508.483	21.22
VES 80	1066	32.2	158	125.8	1932	0.000517598	243045.6	0.065113872	0.0003774		0.00571	1387.79	11.03
VES 81	72	68.3	208	139.7	12395	8.06777E-05	1731581.5	0.011270674	0.0004191	10.02	0.000808	1399.118	10.02
VES 82	591	39.5	239	199.5	3694.7	0.000270658	737092.65	0.053996265	0.0005985		0.000808	595.5709	2.99
VES 83	217	52.4	269	216.6	21258	4.70411E-05	4604482.8	0.010189105	0.0006498		0.000808	3720.422	17.18
VES 84	53	53.6	140	86.4	1996.7	0.000500826	172514.88	0.043271398	0.0002592		0.000808	139.392	1.61
VES 85	50	45.8	250	204.2	1331.7	0.00075092	271933.14	0.153337839	0.0006126		0.000808	219.722	1.08
VES 86	114	99.1	277	177.9	15567	6.42385E-05	2769369.3	0.011428021	0.0005337		0.000808	2237.65	12.58
VES 87	551	113.7	275	161.3	3892.5	0.000256904	627860.25	0.041438664	0.0004839		0.000808	507.3111	3.15
VES 88	837	104	273	169	8202.5	0.000121914	1386222.5	0.020603475	0.000507		0.000808	1120.068	6.63



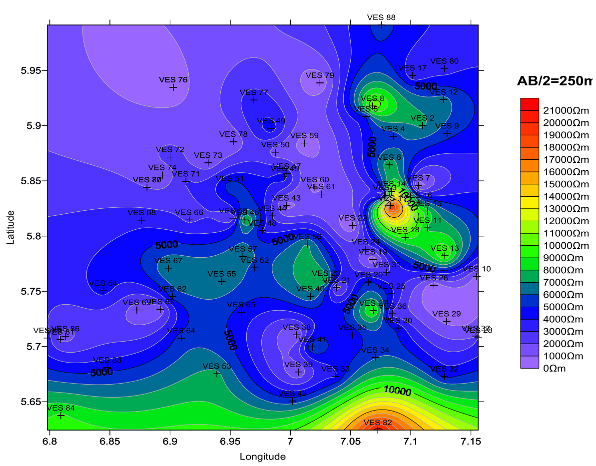


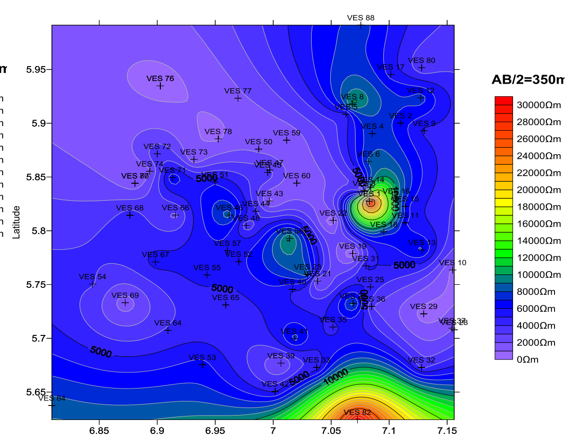
a (d=30m) **b (d=50m)**





c (d=80m) **d (d=150m)**





e (d=250m) **f (d=350m)**

FIG. 4 (a-f) Iso-resistivity maps at depths 30m 50m,80m,150m, 250m and 350m

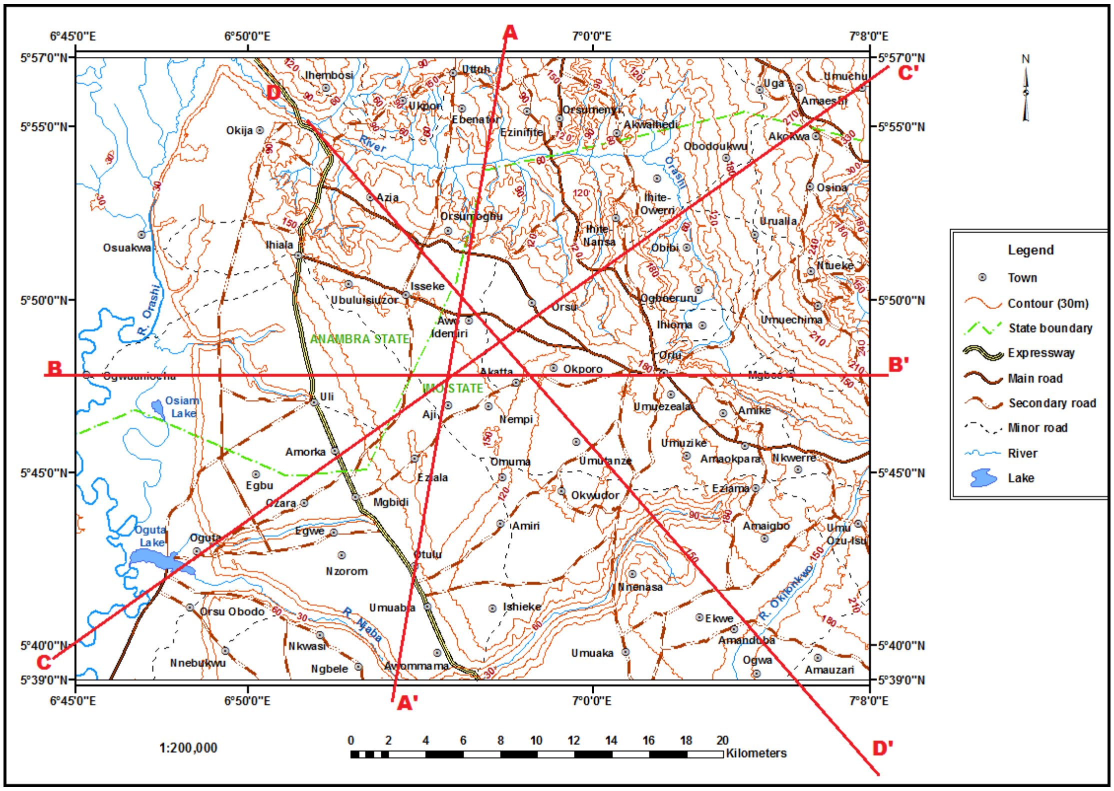


Fig 5: LOCATION MAP OF THE STUDY AREA SHOWING PROFILE DIRECTIONS

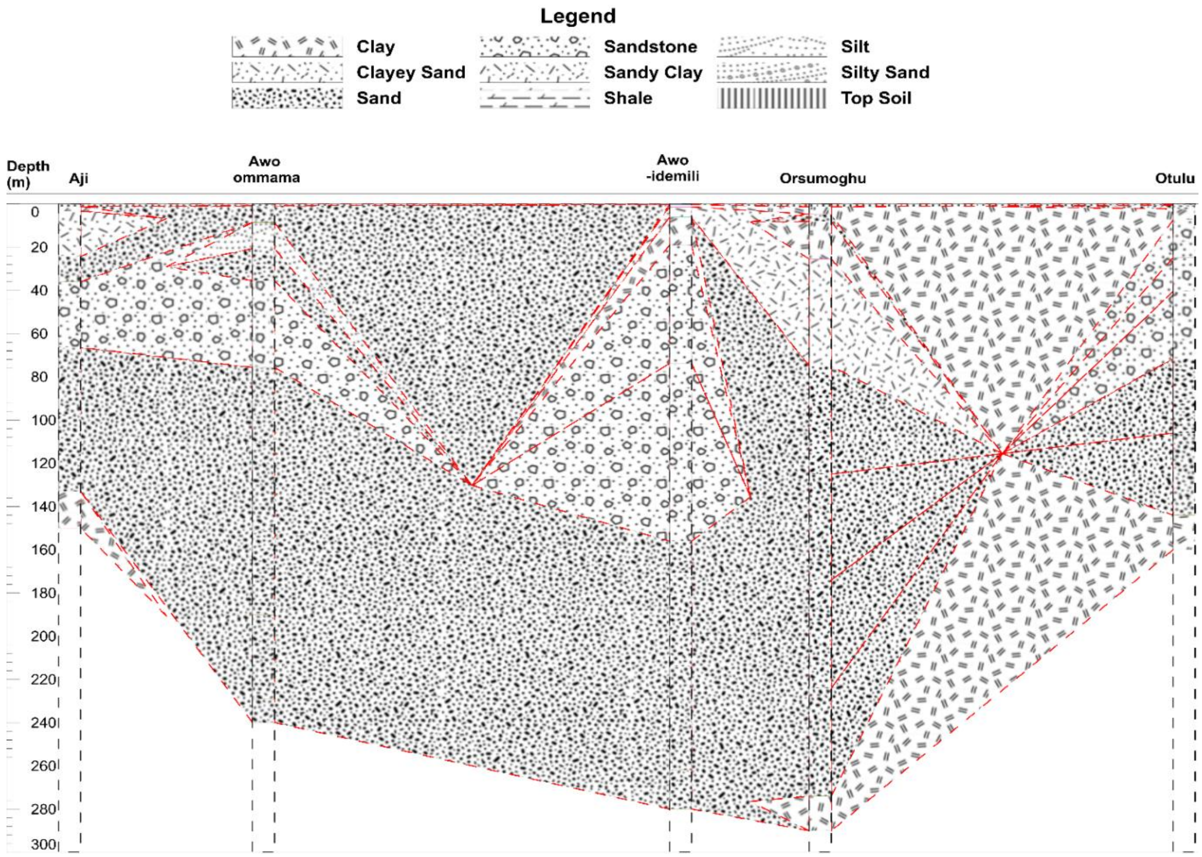


FIG 6: PROFILE A – A[1]

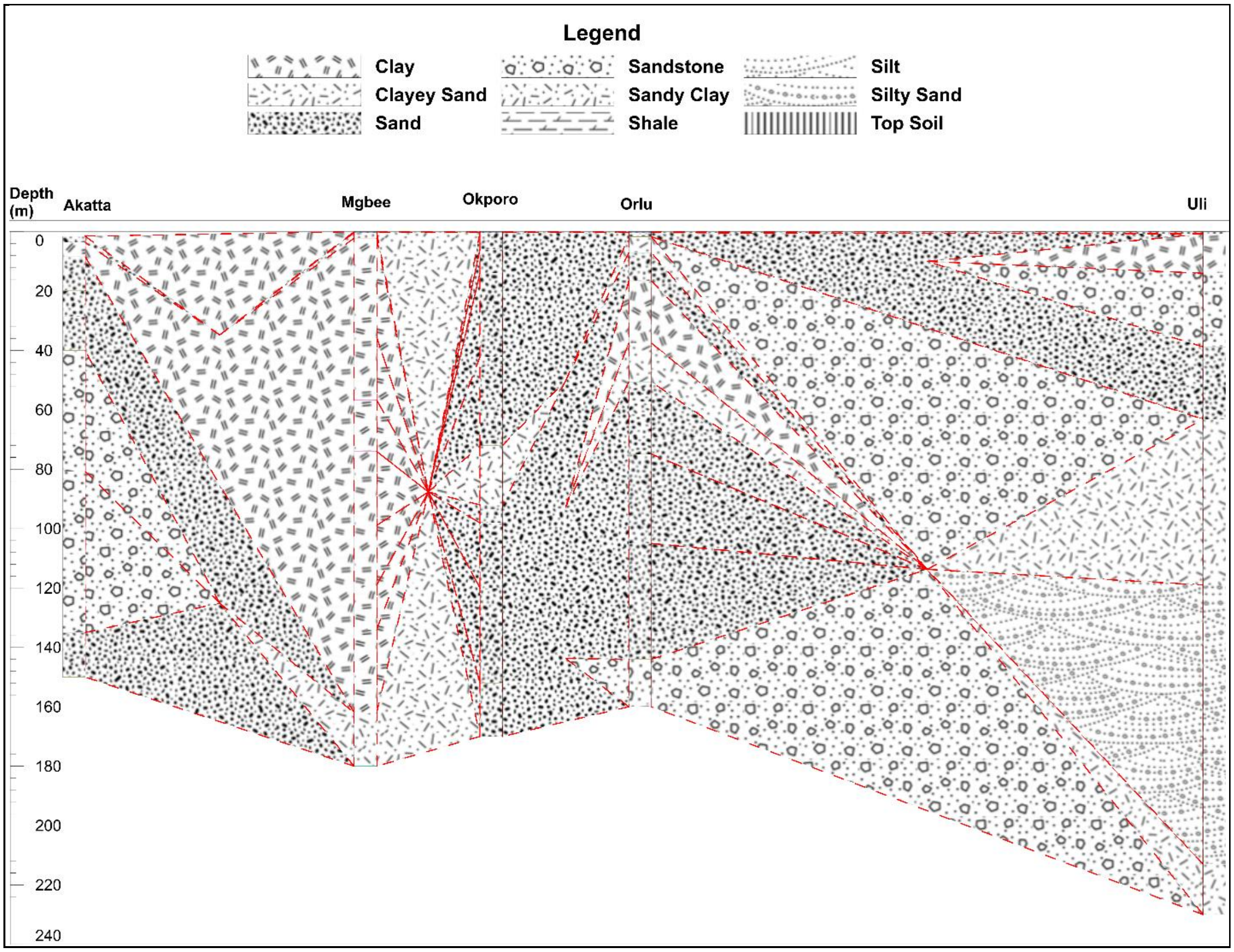


FIG 7: PROFILE B – B[1]

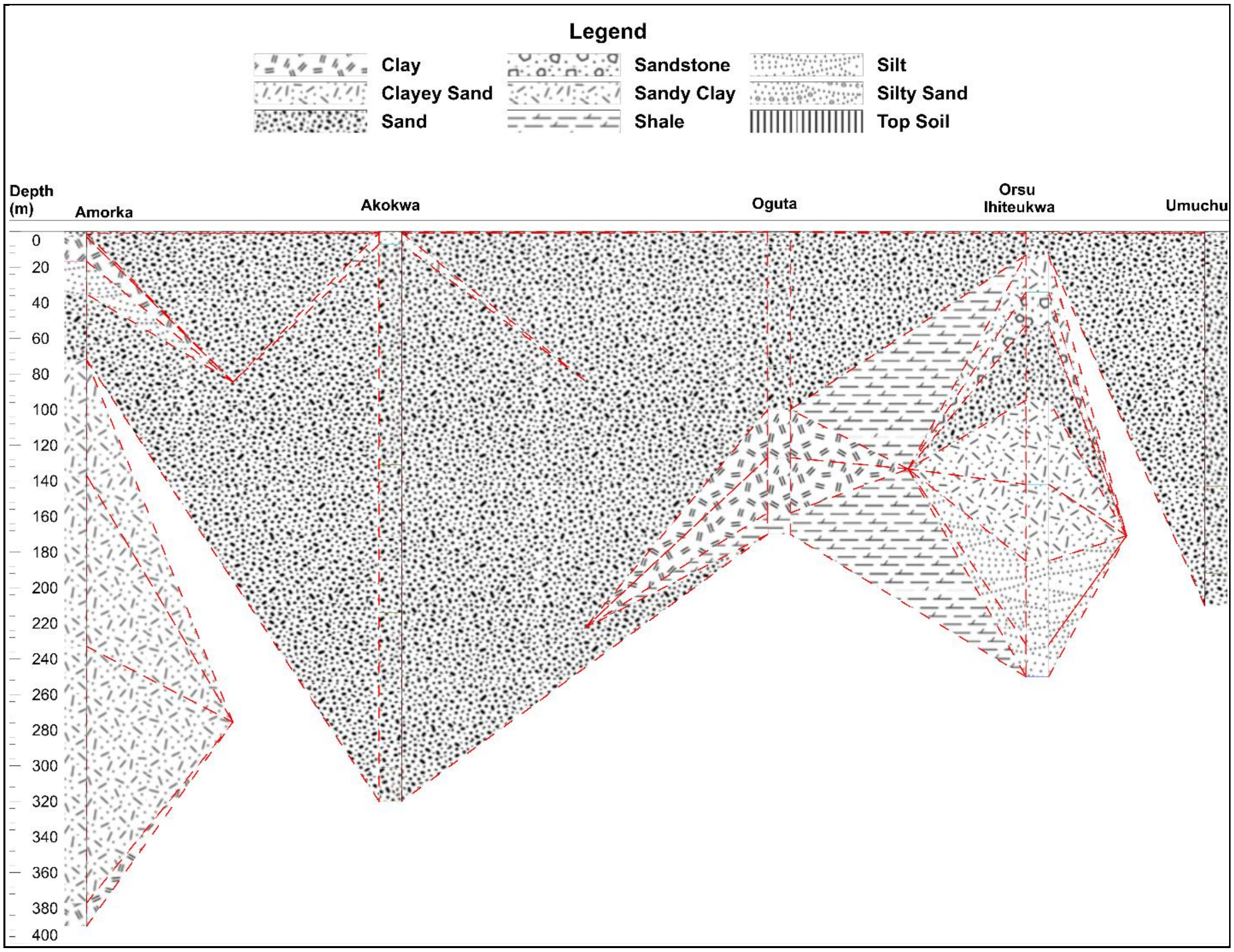


FIG. 8: PROFILE C-C^{I}

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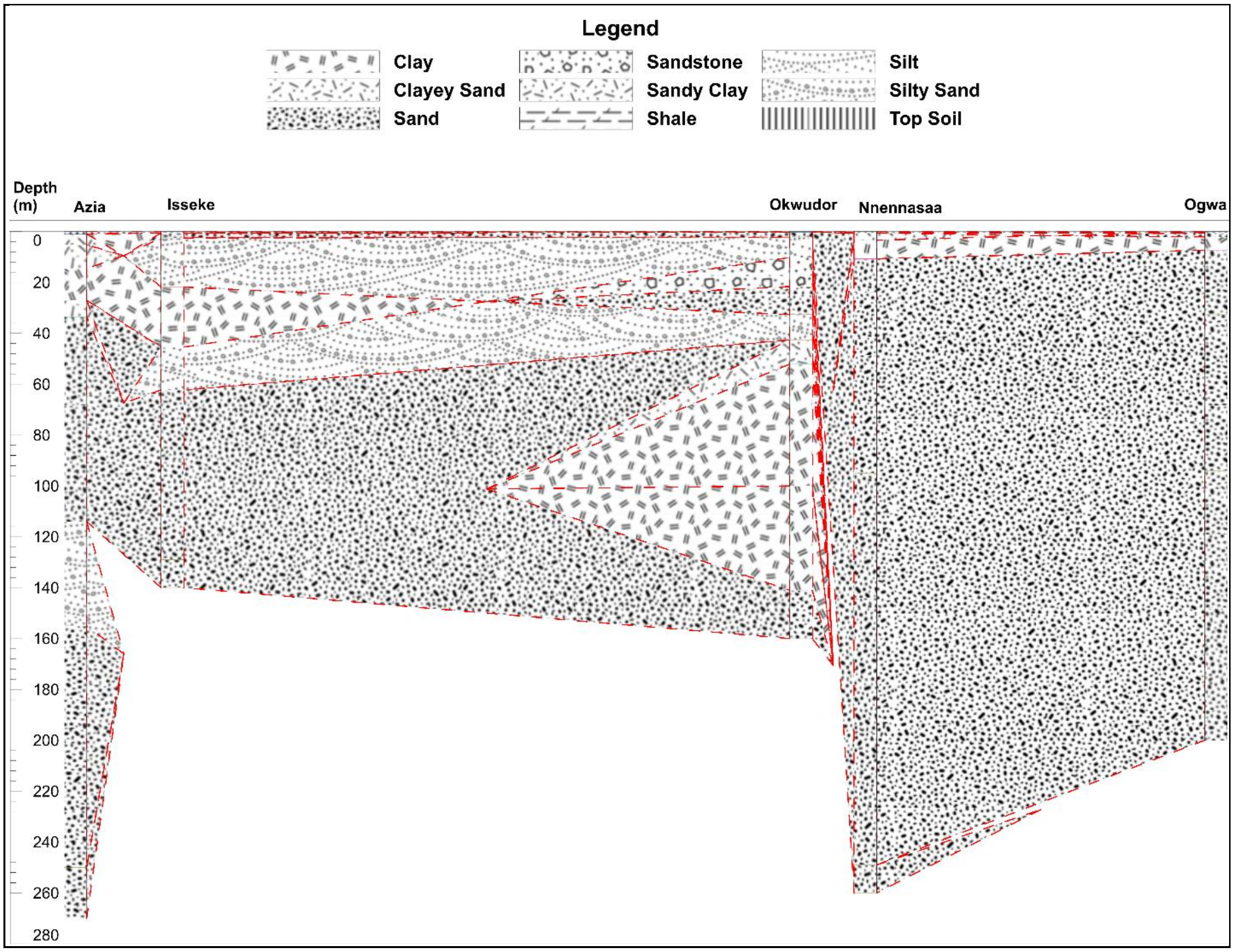
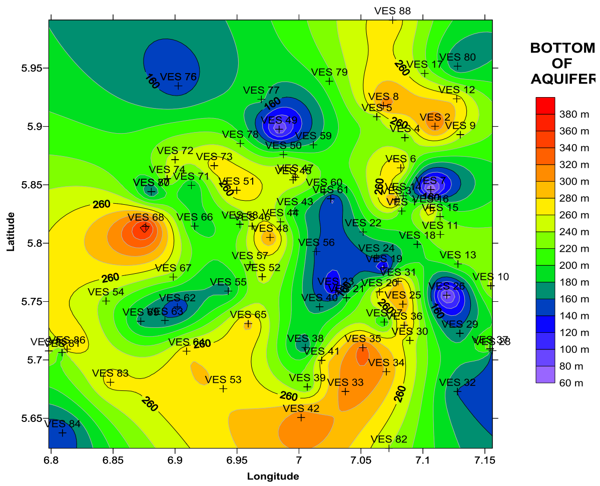


FIG 9: PROFILE D-D^{I}



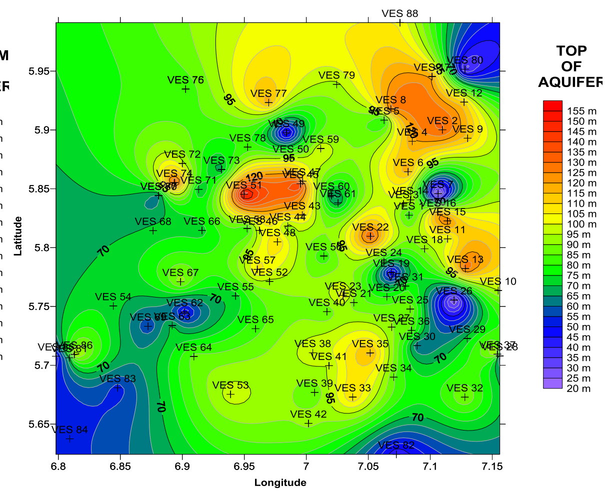
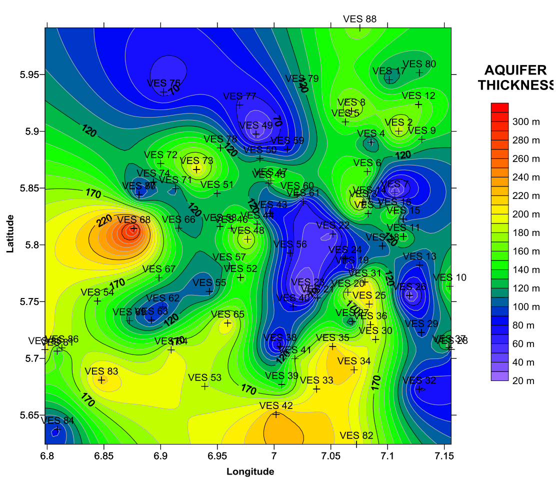


FIG 10 (a): BOTTOM OF AQUIFER

FIG 10(b): TOP OF AQUIFER



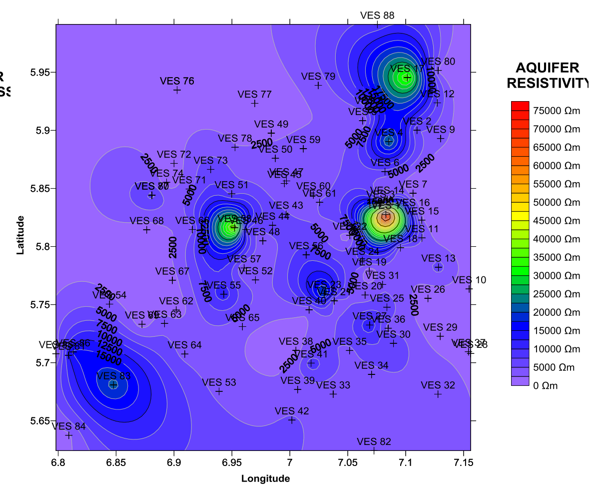
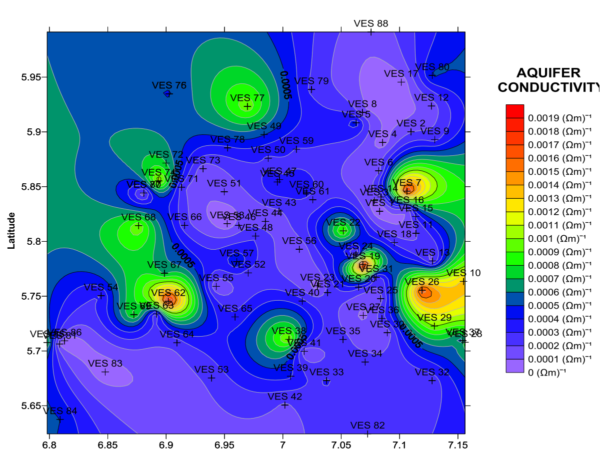


FIG. 10(c) AQUIFER THICKNESS

FIG 10(d) AQUIFER RESISTIVITY



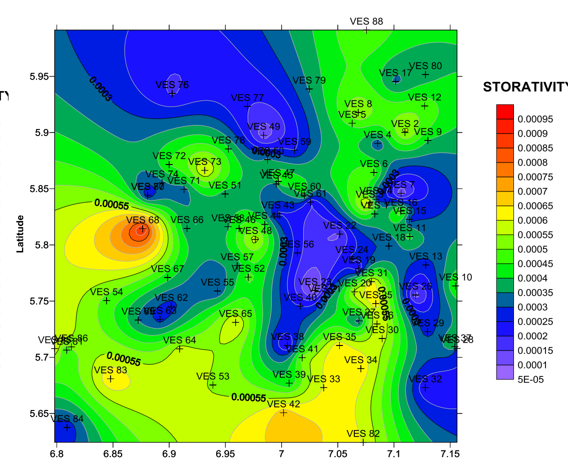
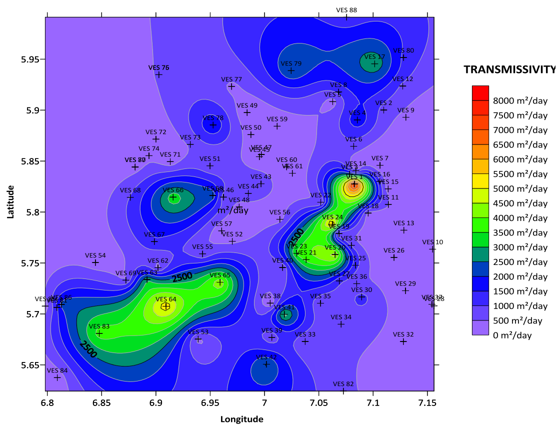


FIG. 10(e) :AQUIFER CONDUCTIVITY **FIG. 10(f):STORATIVITY**



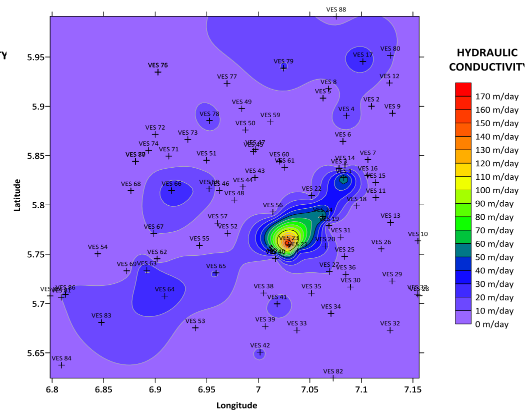


FIG. 10(g) TRANSMISSIVITY **FIG. 10(h) HYDRAULIC CONDUCTIVITY**

Figures 10 (a-h) Different aquifer characteristics within the study area.

6.0 DISCUSSION OF RESULTS

6.1 PROFILES

Four profiles were taken and the directions of the profiles are shown in fig 5.

ProfileA-A[1] as shown in fig. 6 cuts across VES 53, 51, 43, 62, 64 and 73. They all comprise of ten geoelectric layers except VES 62 which has eight layers. Aquifer depths are 260m, 240m, 130m, 120m and 260m respectively with thickness of 25m, 39m, 35.7m, 31m and 50m respectively. The aquifer is mostly a sandy body of a reasonable thickness and is overlain by an upper layer of sandstone, sand and silt sand. This could be said to be in line with the geology of the area which is the Benin and Ameki Formation.

Profile B-B[I] as illustrated in fig. 7 traverses the east- west direction through VES 22, 24, 56, 57 and 68, and comprises of ten geoelectric layers except for VES 57 and 68 which has nine and seven geoelectric layers respectively. The depths to aquifer are 145m, 150m, 165m and contain smaller units of sand and sandstone but a large amount of clays within the Formation. This is typical of the Ameki formation which the profile cuts across.

Profile C-C^{I} as shown in fig. 8 traverses in the northeast and southwest directions cutting through VES 2, 45, 69, 80 and 81. This comprises of ten geo electric layers except for VES 69 and 81 which has nine layers. Aquifer depths are 320m, 100m, 70m, 180m and 100m with thickness of 44m, 32m, 36.9m, 49.2m and 23.9m respectively.

Profile D-D^{I} runs along the northwest and southeast directions through VES 38, 41, 71, 72, and 82 as illustrated in fig. 9. They all comprise of ten geoelectric layers except VES 71 which has seven layers. Aquifer depths are 30m, 280m, 140m, 290m and 200m respectively with thickness of 11m, 52m, 66.9m, 95m and 40m respectively.

6.2 ISORESISTIVITY

In the iso-resistivity map above for AB/2=30.00m (fig 4a), it shows that most of the areas within the study area is underlain by low iso- resistivity, these areas include: Obiohia, Osina, Urualla, Ntueke, Isiekenesi, Dikenafai, Ogbooakwu, Ogwume, Eziama, Owerre nkwoji, , Abaja, Amurie omanze, Mgbidi, Uli ihiala, Amorka, Azia, Orsumoghu, Mgbosi, Osunmenyi, Ezinfite, Lilu, Unubi, Egwe, with iso resistivity values ranging from 0Ωm to 2000Ωm, with colour indications (lilac, sky blue, blue and royal blue). While areas with moderate iso resistivity values include: Ogboko, Akokwa, Obodoukwu, Akpulu, Ogboza, Umuowa, Umudugba, Amauju, Amaiyi akah, Amaruru, Ihittenansa, Amazu, Awo- omamma, Okporo orlu, Ogberuru, Amiri, Ibiasoegbe, Isseke, Umuchu, Ogwa, Ngbele, Orsu obodo with iso resistivity values ranging from 2500Ωm to 5500Ωm, with colour indications (lemon green, green and yellow). Areas with high iso-resistivity values include: Umuojishi, Ohakpu with iso resistivity values ranging from 6000Ωm to 9000Ωm, with color indications (orange and red).

In the iso-resistivity map above for AB/2=50.00m (fig 4b), it shows that most of the areas within the study area is underlain by low iso- resistivity, some of these areas include: Obiohia, Osina, Urualla, Ntueke, Isiekenesi, Dikenafai, Amike, Eziachi, Umuzike, Mgbee, Orlu, Eziama obire, Owerre nkoji, Umuozu, Amaigbo, Amurie, Umudugba, Ekwe, Mbosi, Lilu, with iso resistivity values ranging from 0Ωm to 2000Ωm, with colour indications (lilac, sky blue, blue and royal blue). While areas with moderate iso resistivity values include: Ogboko, Akokwa, Obodoukwu, Akpulu, Ogwume, Amanator, Amazu, Awo- omamma, Omuma, Okporo orlu, Akatta, Aji, Otulu, Ibiasoegbe, Ezinfite, Ogwa, Ngbele, Orsu obodo, with iso resistivity values ranging from 2500Ωm to 5500Ωm, with colour indications (lemon green, green and yellow). Areas with high iso- resistivity values include: Ohakpu, Umuojishi, with iso resistivity values ranging from 6000Ωm to 9000Ωm, with color indications (orange and red).

In the iso-resistivity map above for AB/2=80.00m (fig 4c), it shows that most of the areas within the study area is underlain by low iso- resistivity which include: Osina, Ntueke, Dikenafai, Amike, Eziachi, Mgbee, Orlu, Owerre nkwoji, Umuozu, Amaigbo, Uli ihiala, Isseke, Azia, Orsumoghu, Mboisi, Osunmenyi, Lilu, Unubi, Umuchu, with iso resistivity values ranging from 0Ωm to 2000Ωm, with colour indications (lilac, sky blue, blue and royal blue). While areas with moderate iso resistivity values include: Akokwa, Obodoukwu, Isiekenesi, Ogbooakwu, Uga aguata, Umuzike, Ezinfite, Ngbele, Orsu obodo, with iso resistivity values ranging from 2500Ωm to 5500Ωm, with colour indications (lemon green, green and yellow). Areas with high iso- resistivity values include: Ogboko, Obiohia, Akpulu, Umuojishi, Umuma isiaku, Orsu- Ihitte ukwa, Amaruru, Okporo orlu, Ogwa, Eziniftte aguata, with iso resistivity values ranging from 6000Ωm to 9000Ωm, with color indications (orange and red).

In the iso-resistivity maps above for AB/2=150.00m (fig 4d), it shows that most of the areas within the study area is underlain by low iso- resistivity which include: Ntueke, Dikenanefai, Uga aguata, Amike, Eziachi, Umuzike, Mgbee, Orlu, Owerre nkwoji, Umuozu, Ekwe, Okwudor Njaba, Umuakah, Asaa ubirielem, Amannachi, Ihittenansa with iso resistivity values ranging from 0Ωm to 2000Ωm, with colour indications (lilac, sky blue, blue and royal blue). While areas with moderate iso resistivity values include: Akokwa, Osina, Obodoukwu, Urualla, Isiekenesi, Ogboza, Ogbooakwu, Umuchu, Ngbele, Orsu obodo, with iso resistivity values ranging from 2500Ωm to 5500Ωm, with colour indications (lemon green, green and yellow). Areas with high iso- resistivity values include: Akpulu, Umuojishi, Ogwume, Amanator, Umuma isiaku, Amaruru, Awo- omamma, Ezinfite, Ezinfite aguata, with iso resistivity values ranging from 6000Ωm to 9000Ωm, with color indications (orange and red)

In the iso-resistivity map above for AB/2=250.00m (fig 4e), it shows that most of the areas within the study area is underlain by low iso- resistivity, these areas include: Osina, Isiekenesi, Ogbooakwu, Eziachi, Mgbee, Orlu, Eziama obire, Umuozu, Amaopkara, Amurie omanze, Umudugba, Ekwe, Okwudor njaba, Nnenassa, Amaruru, Orsu- Ihitte, Asaa ubirielem, Ihittenansa, Ihitte owerre, Obibi ochasi with iso resistivity values ranging from 0Ωm to 2000Ωm, with colour indications (lilac, sky blue, blue and royal blue). While areas with moderate iso resistivity values include: Akokwa, Akpulu, Ogboza, Umoojishi, Ogwume, Umuma isiaku, Umuowa, Ihitte isu, Nkumeh, Orsu- Ihitte, Omuma, Akatta, Ibiasoegbe, Orsu obodo, with iso resistivity values ranging from 2500Ωm to 5500Ωm, with colour indications(lemon green, green and yellow). Areas with high iso- resistivity values include: Ogboko, Ogwa, with iso resistivity values ranging from 6000Ωm to 9000Ωm, with color indications (orange and red).

In the iso-resistivity map above for AB/2=350.00m (fig 4f), it shows that most of the areas within the study area are underlain by low iso- resistivity, these areas include: Akokwa, Osina, Isiekenesi, Ogboza, Ogbooukwu, Amanator, Umuzike, Mgbee, Ama okpara, Ekwe, Amauju, Ugwucity umuhuokabia, Ofeahia, Orsu- Ihitte, Ihittenansa, Awo idemilli, Ihitte owerre, Otulu, Ibiasoegbe, Isseke, Azia, Orsumoghu, Mbosi, Umuchu, with iso resistivity values ranging from 0Ωm to 2000Ωm, with colour indications (lilac, sky blue, blue and royal blue). While areas with moderate iso resistivity values include: Akpulu, Umunaga umueshi, Okporo orlu, with iso resistivity values ranging from 2500Ωm to 5500Ωm, with colour indications (lemon green, green and yellow). Areas with high iso- resistivity values include: Ogboko, Ogwa, with iso resistivity values ranging from 6000Ωm to 9000Ωm, with color indications (orange and red).

6.3 AQUIFER DEPTH AND THICKNESS

The depth to the aquifer or water table is the distance from the ground to the water table. This was deduced across the area from the sounding results by a quantitative interpretation of the sounding curves and shown in Table 2 and fig10 a - c above. The deductions show that the aquifers range from shallow to moderate and deep aquifers.

Communities with shallow aquifers include: Ntueke, Amike, Owerre nkwoji, Amaruru, Aji, Umuchu, Ogwa, Orsu obodo, with top of aquifer values ranging from 20m to 50m, with colour indications (lilac, sky blue, blue and royal blue).

Communities with moderate values include: Ogboko, Umuozu, Abaja, Amaiyi akah, ihitte owerre, Obibi ochasi, Ogberuru, Isseke, Azia, Osunmenyi, Lilu, with top of aquifer values ranging from 60m to 100m, with colour indications (lemon green, green and yellow).

Communities with high values include: Akokwa, Osina, Urualla, Akpulu, Umujoshi, Amanator, Mgbee, Ekwe, Orsu- Ihitte, Assa ubirielem, with top of aquifer values ranging from 105m to 155m, with color indications (orange and red).

From the isopach map in fig 10c, it shows how the various aquifers in the study area vary in thickness. Areas such as Ntueke, Umuojishi, Ogwume, Amanator, Amike, Eziachi, Umuzike, Mgbee, Orlu, Owerre nkwoji, having thinner aquifer ranging from 20m to 100m with color indications (lilac, sky blue, blue and royal blue) and this is trending the NW-SE direction. Areas like Amazu, Awo- omamma, Ohakpu, Akatta, Obibi ochasi, Amiri, Ibiasoegbe, Azia, have moderate aquifer thickness ranging from 120m to 220m with color indications (lemon green, green and yellow). The areas with the thickest aquifers include Amaiyi akah, Uli ihiala, having the highest aquifer thickness ranging from 240m to 300m with color indications (orange and red).

6.4 AQUIFER RESISTIVITY AND CONDUCTIVITY

The resistivity of an aquifer serves as a yardstick for determining the aquiferous or the water bearing unit of any place. This implies that areas with high resistivity values bear good and prolific aquifers. In contrast, Aquifer conductivity is the inverse of aquifer resistivity. This implies that the locations of high conductivity are direct opposite of resistivity of the area.

Based on this, in my study area (fig. 10d and e), areas like Ntueke, Dikenafai, Ogboza, Umuojishi, Amike, Owerre nkwoji, Umuozu, Abaja, Amurie omanze, Umudugba, Ekwe, Okwudor Njaba, Umuakah, Amaiyi akah, Ihittenansa, Ihitte owerre, Obibi ochasi, Ogberuru, Otulu, Ibiasoegbe, Isseke, Azia, Orsumoghu, Mbosi, Osunmenyi, Ezinfite, Lilu, Unubi, Umuchu, Ogwa, are having somewhat low resistivity ranging from 5,000Ωm to 20,000Ωm with colour indications (lilac, sky blue, blue and royal blue) while having high conductivity values ranging from 0.0012($Ωm^{-1)}$ to 0.0019($Ωm^{-1)}$, with color indications (orange and red). On the contrary, areas like Osina, Amaebu, Akuma, Ngbele, are having moderate resistivity ranging from 25,000Ωm to 45,000Ωm with color indications (lemon green, green and yellow) whilst having low aquifer conductivity values ranging from 0.0001($Ωm^{-1)}$ to 0.0005($Ωm^{-1)}$, with color indications (lilac, sky blue, blue and royal blue). The only area within the study area with very high resistivity value ranging from 50,000Ωm to 75,000Ωm is Ogboko with color indication (red).

Though almost all the parts have high aquifer resistivity, but there are some areas that have higher aquifer resistivity than others. By implication, what that means is that those places like Ntueke, Dikenafai, Amike, and Owerre nkwoji which have higher aquifer conductivity values, on the contrary have low aquifer resistivity values, indicating that those places could be overlain by clay, mud, shale, somewhat silt and siltyclay in which these lithologies cannot serve as the aquiferous units (zones) within my study area, therefore borehole drilling might not yeild much in sites like these except if the driller goes deeper in order to reach the aquiferous zone/unit. Whereas place like Ogboko with low aquifer conductivity value and on the contrary a higher aquifer resistivity value might contain thick/thicker volume of sand and sandstones lithologies and these places should be the aquiferous zones within the study area. Such places should be recommended for siting a borehole.

6.5 STORATIVITY

The distribution of the aquifer storativity within the study area indicates that the area is characterized with various storativity values from very high, moderate and low storativity values. Communities such as Osina, Ntueke, Umuojishi, Uga aguata, Mgbee, Umuowa, Orlu, Owerre Nkwoji, Umuozu, Abaja, Okwudor Njaba are areas within the study area with low storativity values ranging from 0.00005 to 0.0003 with color indications (lilac, sky blue, blue and royal blue). Then communities like: Akokwa, Obodoukwu, Urualla, Akpulu, Isiekenesi, Dikenafai, Ogboza, Ogbooakwu, Amurie omanaze, Otulu, Ubulu- ihejiofor, Ibiasoegbe, Isseke, Azia, Orsumoghu are areas with relatively moderate storativity values ranging from 0.00035 to 0.0006 with color indications (lemon green, green, and yellow). While communities such as Amaiyi akah, and uli ihiala are areas within the study area with high storativity values ranging from 0.00065 to 0.00095 with color indications (orange and red). fig. 10f shows image for Storativity.

6.6 HYDRAULIC CONDUCTIVITY AND TRANSMISSIVITY

Areas with high values of hydraulic conductivity and transmissivity are normally preferred to low areas in groundwater exploration and siting of boreholes as they have greater potentials of productive aquifers and it is easier to extract water from those areas.

From the maps (figs. 10g and h) it can be observed that areas with high values include communities such as Ogboko, Otulu, Amiri, Umuma Isiaku, Amike, Eziachi with values ranging from 3000 -5000 m^2/day and 60 -100m/day respectively. While those areas with low values include Ugwu City, Umuhu Okabia, Orsu Ihiteukwa, Amaebu, Asaa Ubirielem, Amannachi, Mbosi, Ukpor, Abaja, Nwangele with values ranging 20-500m^2/day and 10- 25m/day.

7.0 CONCLUSION

The research presented the hydrogeophysical properties of the study area in order to create an awareness on the productive aquifer of the area for sustainable development. The study has also helped to delineate the aquiferous horizons within the study area. Vertical electrical sounding data interpretation results obtained revealed seven to ten geoelectric layers which have been interpreted as top soil, sand, clay, clayey sand, dry sand saturated sandstone and shale. Data from the Isoresistivity models revealed a multi- aquifer system.

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