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Regional Hydro-geophysical Study of the Groundwater potentials of the Imo River Basin Southeastern Nigeria using Surficial Resistivity Data

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Abstract

The Imo River Basin lies between Latitudes 4° 38'N and 6° 01'N and between Longitudes 6° 53'E and 7° 32'E and covers an area of about 9100 km².The litho-stratigraphic units within the study area include the Ajali, Nsukka, Imo Shale, Ameki, Ogwasi and Benin Formations. Regional hydro-geophysical evaluation of groundwater potentials in Imo River Basin has been carried out with the objective of delineating the aquifer units in the area of study. A total of five hundred and sixty-nine (569) Vertical Electrical soundings (VES) were carried out using the ABEM™ Terrameter (SAS) 4000.The VES data were acquired using the Schlumberger electrode configuration with a maximum current electrode spacing of 1000m. Out of the 569 VES data, twenty (20) parametric soundings were done at the vicinity of existing boreholes for correlative and quality control purposes. The acquired VES data were processed using the 1-D WINRESIST™ computer iterative software. Geo-electric curve types interpreted from the study area revealed a predominance of the AKH-type with about 3-10 geo-electric layers identified from the various formations. The mean values of aquifer resistivity and conductivity are 1963.2Ωm and 0.00186sm^{-1}respectively with the aquifer materials mainly made up silt, sand and coarse sandstones. Similarly, the mean depth to the aquifers across the study area is 115.5 m while the mean aquifer thickness is 39.8 m. The findings of this result revealed that the shale/clay across the entire area increased with depth. In addition, the aquifer potentials of the study area were revealed to be variable with the aquifer type, nature and characteristics generally controlled by the underlying geology. It was therefore concluded that the southern part of the study area has a high aquifer potential when compared to the northern part. In conclusion, the Benin Formation was delineated as the formation with the highest aquifer potentials in the study area. It is therefore recommended that a detailed groundwater exploration should be carried out before siting a borehole in the study area.

Keywords: Hydro-geophysical, Aquifer resistivity, Longitudinal Conductance, Transverse Resistance, Imo River Basin

INTRODUCTION

Availability of clean and good drinking water is one of the significant challenges before most developing countries of the world today in general and Nigeria in particular. Despite the achievements of the Millennium Development Goals (MDG) in Nigeria, most parts of the country are still without potable water (Emberga., 2019). The near-total collapse of rural water schemes in the area of study has made the majority of the populace to depend on other sources of water (rainwater, surface water, etc). However, groundwater is a major source of clean drinking water worldwide and it accounts for about 98% of the world's freshwater (Okoro et al. 2000).With the development of exploration and drilling technology, groundwater has become the choice of both domestic and industrial water supply in the world. Therefore, individuals who could afford the drilling of water boreholes have gone ahead to drill water wells for the purpose of harnessing groundwater. In most of the cases, these privately drilled boreholes were done without any form of geological/geophysical appraisal of the quantity and quality of the groundwater. In view of the afore-mentioned therefore; there is generally poor knowledge of the aquifer geometrical, hydraulic vulnerability

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characteristics of the study area. This has cumulatively led to a large number of abortive and unproductive wells in the study area (Ugada et al., 2014;Ejiogu et al.,2019).

The sedimentary sequences of Southeastern Nigeria including those of the Imo River basin are known to have several aquifer units (Uma,1989). The groundwater recharge in the area of study is good due to the high average annual rainfall of about 2275mm (Uma., 1989; Ejiogu et al., 2019). However, many boreholes in the area are not produced as a result of inadequate knowledge of the regional hydrogeology of the study area, lack of technical support (with respect to geophysical and geological exploration) and poor planning/execution of the drilling projects. This has led to a significant challenge in the area especially with respect to the near-complete dearth of hydrogeological data including information on the geometry and nature of the hydraulic boundaries of the aquifers been exploited(Uma., 1989;Eke et al.,2015;Ejiogu et al., 2019). Therefore, many boreholes have been drilled in the area without systematic and comprehensive studies to establish the types, nature, and lateral extent of the aquifers within the basin (Uma.,1989;Opara et al.,2012;Eke et al.,2015).

Direct current electrical resistivity method especially using the Vertical Electrical Sounding technique is one of the geophysical methods used in groundwater exploration. The subsurface information inferred from this technique give a better knowledge of the aquifer systems and a more realistic picture of the groundwater potential of any area (Okoro et al., 2006). The technique has been successfully used in investigating groundwater potentials in different geological settings around the study area (Eke et al., 2015; Ekwe and Opara.,2012). Similarly, the application of this technique to explore for groundwater in various sedimentary basins in Nigeria is well documented (Okoro, 2000). In the last few decades, there has been an increase in the application hydro-geophysical techniques in the location of potential water-bearing formations in many parts of the study area (Ejiogu et al.,2019). This study is an integrated geophysical and hydrogeological resource mapping of the study with the aim of establishing a hydro-geological database for Imo River Basin, Southeastern Nigeria. The main objectives, therefore, are to delineate the aquiferous zones in the area in addition to the estimation of the aquifer geometrical properties including the depth, thickness and lateral extent/continuity.

1.2 Location, Physiography and Geology of the Study Area

The Imo River Basin lies between Latitudes 4° 38'N - 6° 01'N and between Longitudes 6° 53'E - 7° 32'E and covers an area of about 9100 km^2as shown in the Location/Topographic map of the study area (Figure 1). There are two main sub-basins within the basin: The Oramirukwa—Otamiri sub-basin and the Aba River sub-basin (Uma, 1989). The Imo River Basin is based on bedrock of a sequence of sedimentary rocks of about 5.5km thick and with ages ranging from Upper Cretaceous to Recent (Uma, 1989). The deposition of these sedimentary rocks is related to the opening of the South Atlantic Ocean and the formation of the rift-like Benue Trough of Nigeria in the Mesozoic (Emberga.,2019). Generally, there are two major classes of structures underlying the Imo River Basin (Uma, 1989). About 80% of the basin consists of Coastal Plain Sand, which is composed of non-indurated sediments represented by the Benin and Ogwashi-Asaba Formations, and alluvial deposits at the estuary at the Southern end of the Imo River Basin (Uma, 1989). The remaining 20% is underlain by a series of sedimentary rock units that get younger southwestward, a direction that is parallel to the regional dip of the formations(Uma, 1989).The geology of the study area is very complex and consists of six lithostratigraphic units which consist of the Ajali, Nsukka, Imo Shale, Ameki, Ogwasi and Benin Formations (Figure 2**)**. The stratigraphic sequence of the Imo River Basin is shown in table1.The Benin Formation otherwise known as the coastal plain sands unconsolidated sands/sandstones with high porosity and permeability (Ekwe and Opara.,2012).

Table 1: Regional stratigraphic sequence of the Imo River Basin (Uma, 1989)

Age	Formation	Maximum Appropriate Thickness	Characteristics
Miocene -Recent	Benin	2000	Unconsolidated, yellow and white sands, occasionally pebbly with lenses of grey sandy clay.
Oligocene – Miocene	Ogwashi/ Asaba	500	Unconsolidated sandstones with carbonaceous mudstones, sandy clays and lignite seams
Eocene	Ameki	1460	Sandstones grey to green argillaceous sandstones, shales and thin limestone
Paleocene	Imo	1200	Blue to dark grey shales and subordinate Sandstones. It includes two sandstone members: the Umuna and Ebenebe sandstones.
Upper Maestrichtian	Nsukka Formation	350	White to grey coarse-to-medium-grained sandstone; carbonaceous shales; sandy shales; subordinate coals; and thin limestones.
	Ajali Sandstone	350+	Medium-to-coarse-grained sandstones, poorly consolidated with subordinate white and pale grey shale bands.

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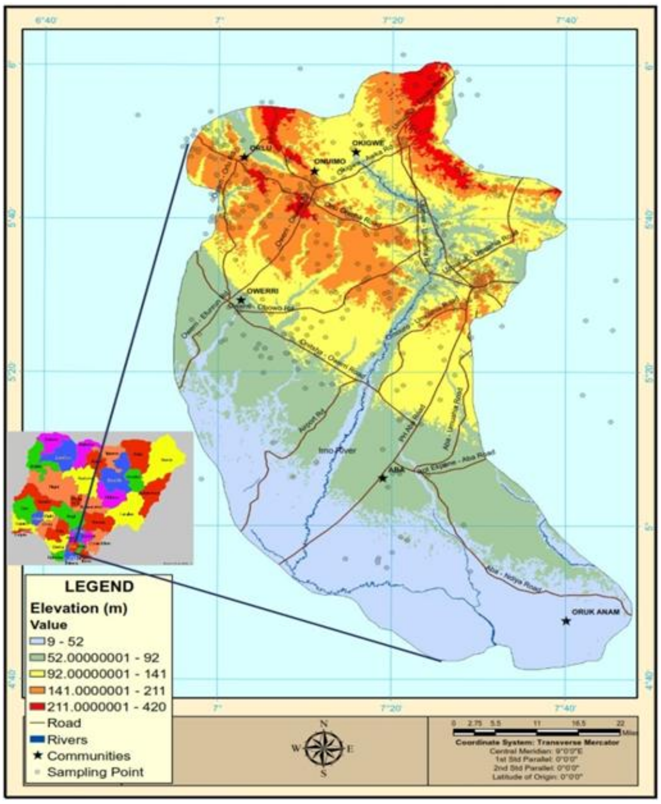

Figure 1: Location/Topographic map of the study area

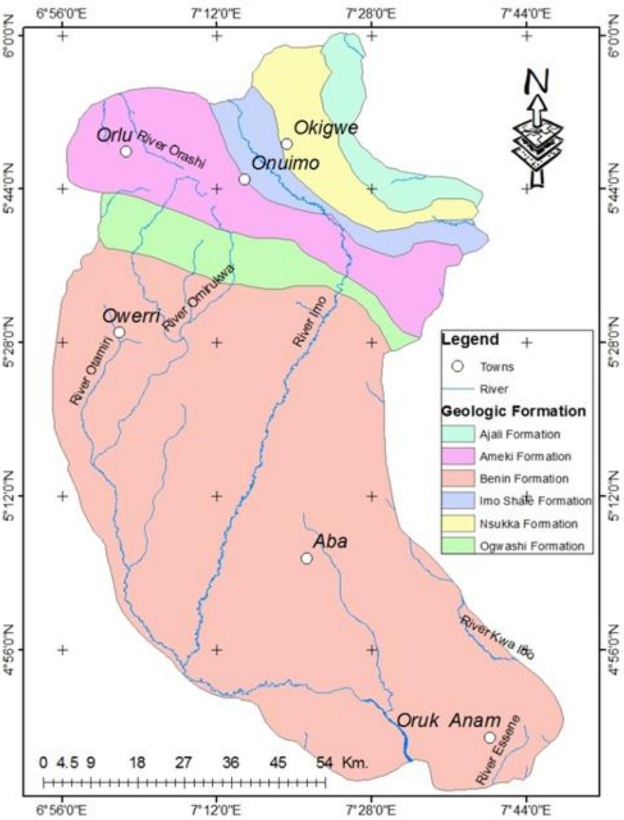

Figure 2: Geological map of Imo River Basin (Modified after Uma, 1989)

2.0 MATERIALS AND METHODS

A total of 569 Vertical Electrical Sounding (VES) data were acquired using the Schlumberger array with maximum current electrode separation of 500m. The Four (4) electrode array technique was deployed at the surface, one pair for injecting current into the ground while the other pair of electrodes are used for potential measurement. The data obtained is generally plotted as a graph of apparent resistivity against half current electrode spacing on a log-log paper. The electrode spacing at which inflexion occurs on the graph provides an idea of the depth to the interface. A useful approximation is that the depth of the interface is equal to two-thirds (2/3) of the electrode spacing at which the point of inflexion occurs (Koefoed., 1977). This approximation has found useful applications in computer iterative modelling. The apparent resistivity was plotted on the ordinate against the half current electrode spacing to obtain the sounding curve, on a bi-logarithmic paper. Geo-electric layer parameters (i.e., apparent resistivity and thickness values) are usually obtained from the method of asymptotes as input data for computer iterative modelling (Osemeikhian et al, 1982; Igbokwe et al., 2006). Hence, the computer program makes use of the reading obtained from the field which is then converted to apparent resistivity values using computer iterative modelling.

Five hundred and sixty-nine (569) vertical electrical soundings (VES) were carried out within the study area. The data was acquired using the ABEM™ Terrameter SAS 4000 with a maximum current electrode separation of 1000 m. For correlative and parametric purposes, twenty (20) parametric soundings were carried out at the sites of existing monitoring wells. This was done in addition to the correlation of the resistivity data with the litho-log, electric log and available pump test data from the monitoring wells across the study area. A total of five hundred and sixty-nine (569) Vertical Electrical soundings (VES) were carried out using the ABEM™ Terrameter (SAS) 4000. The VES data were acquired using the Schlumberger electrode configuration with maximum current electrode spacing of 1000m. Out of the 569 VES data, twenty (20) parametric soundings were carried out at the vicinity of existing boreholes for correlative and quality control purposes. The acquired VES data were later processed using the 1-D WINRESIST™ computer iterative modelling software to determine the layer parameters.

2.1 Transverse Resistance and Longitudinal Conductance

The transverse resistance and longitudinal conductance are two major important direct current electrical parameters that have found a considerable application in hydro-geophysical and environmental studies especially in estimating aquifer hydraulic parameters and estimation of aquifer protective capacity from surficial resistivity data. Consider a column of earth material consisting of horizontal beds, each with its own characteristic resistivity ρ_i and thickness h_i as shown in figure 3 below:

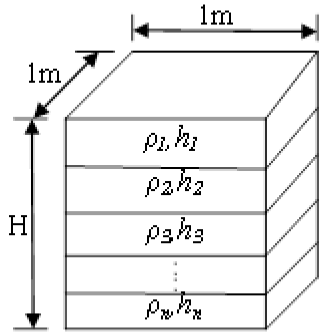

Figure 3: A 3-D Column of Rock Consisting of Horizontal Layers (Ward, 1990)

The total thickness $H = \sum_i^n h_{i\,;} \quad i = 1,2,3, \ldots \ldots \ldots \ldots, n$ (1)

The total resistance due to the current flowing vertically through the column is usually derived by simply adding the resistances contributed by individual layer in the column. The resistance of i[th] layer is given by

$$R_i = \frac{\rho_i h_i}{A_i} = \rho_i h_i; \;\; A_i = 1m^2 \quad (2)$$

Therefore, sum of the resistances of the individual layers known as the transverse resistance (T) is given as:

$$T = \sum \rho_i \, h_{i;} \; i = 1,2,3, \ldots \ldots n \quad (3)$$

Combining equations 1-3, the average transverse resistivity (ρ_t) which is the transverse resistance per unit thickness is given by the relationship:

$$\rho_t = \frac{T}{H} = \frac{\sum \rho_i h_i}{\sum h_i}; \;\; i = 1,2,3 \ldots \ldots n \quad (4)$$

The total conductance due to the current flowing horizontally through the column is obtained by adding the conductances contributed by the individual layers in the column. However, the conductance of the i^{th}layer is as:

$$S_i = \frac{1}{R_i} = \frac{h_i}{\rho_i} \quad (5a)$$

Therefore, the sum of the conductance known as the longitudinal conductance (S) is given by

$$S = \sum \frac{h_i}{\rho_i}; \;\; i = 1,2,3, \ldots \ldots n \quad (5b)$$

The quantities transverse resistance and longitudinal conductance (S) are generally referred to as Dar-Zarrock parameters.

3. RESULT AND INTERPRETATION

3.1 Interpretation of the Layer Parameters

The acquired field resistivity data were used to generate geo-electric curves representative of the underlying geology of the study area. The configuration of the curves for each sounding location usually gives an understanding of the physical characteristics of the layers within such site. Several geoelectric sounding curve types were therefore interpreted from the study

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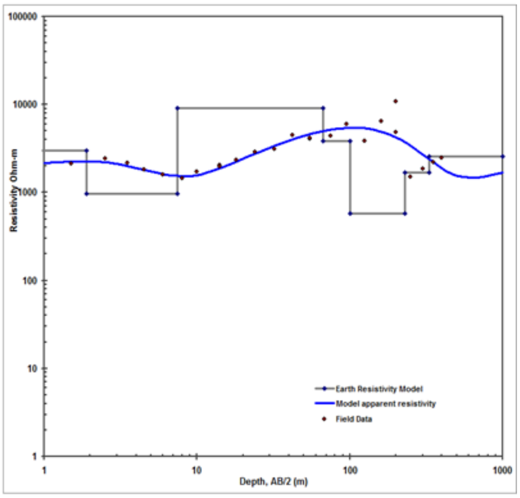
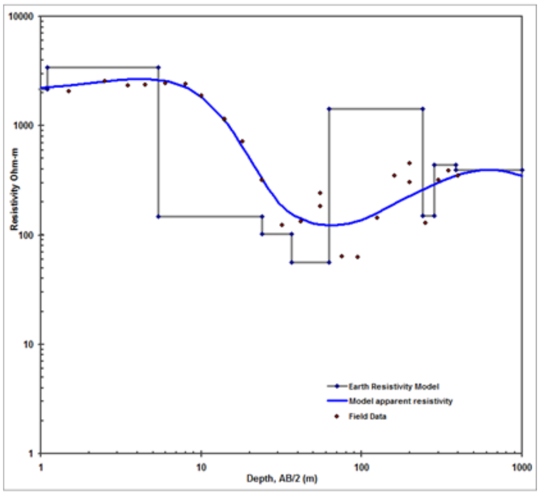
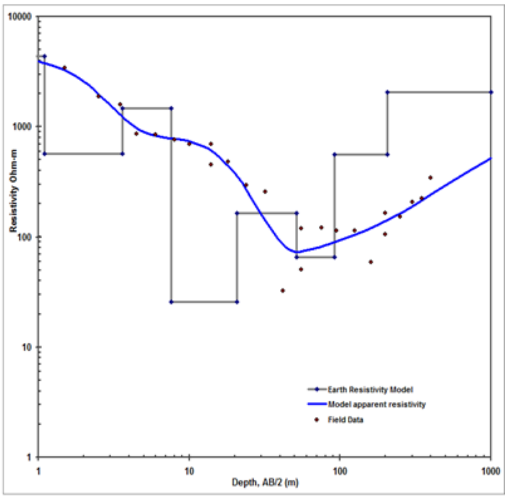
area reflecting the complex geology of the study area. This is because the configuration of a VES curve is a function of the number of layers in the subsurface, the thickness of each layer, and the ratio of the resistivity of the layers (Inyang et al., 2017). Typical geo-electric curves interpreted from the study area are shown in figure 4. Curve types interpreted from the study area include the A, AH, AHA, AK, AKH, HKA,KHA etc with the dominant curve type being the AKH type as summarized in Table 2 and figure 5.



(a)



(b)



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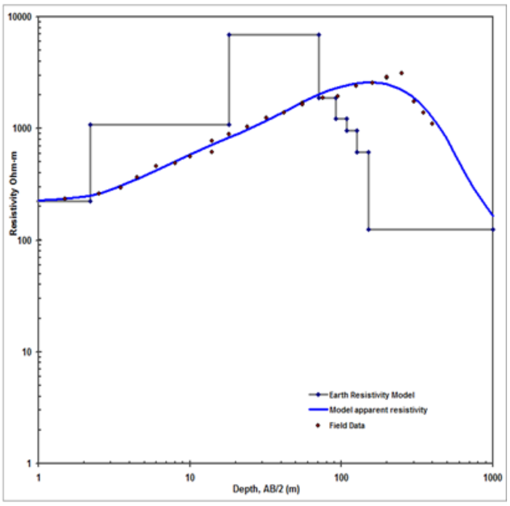

(d)

Figure 4: Typical representative geo-electric curves generated from the resistivity data of the study area: (a)Umulolo, Okigwe (b) Ovim, Isikwuato (c) Ubaha Nneato (4) Anara Mbano

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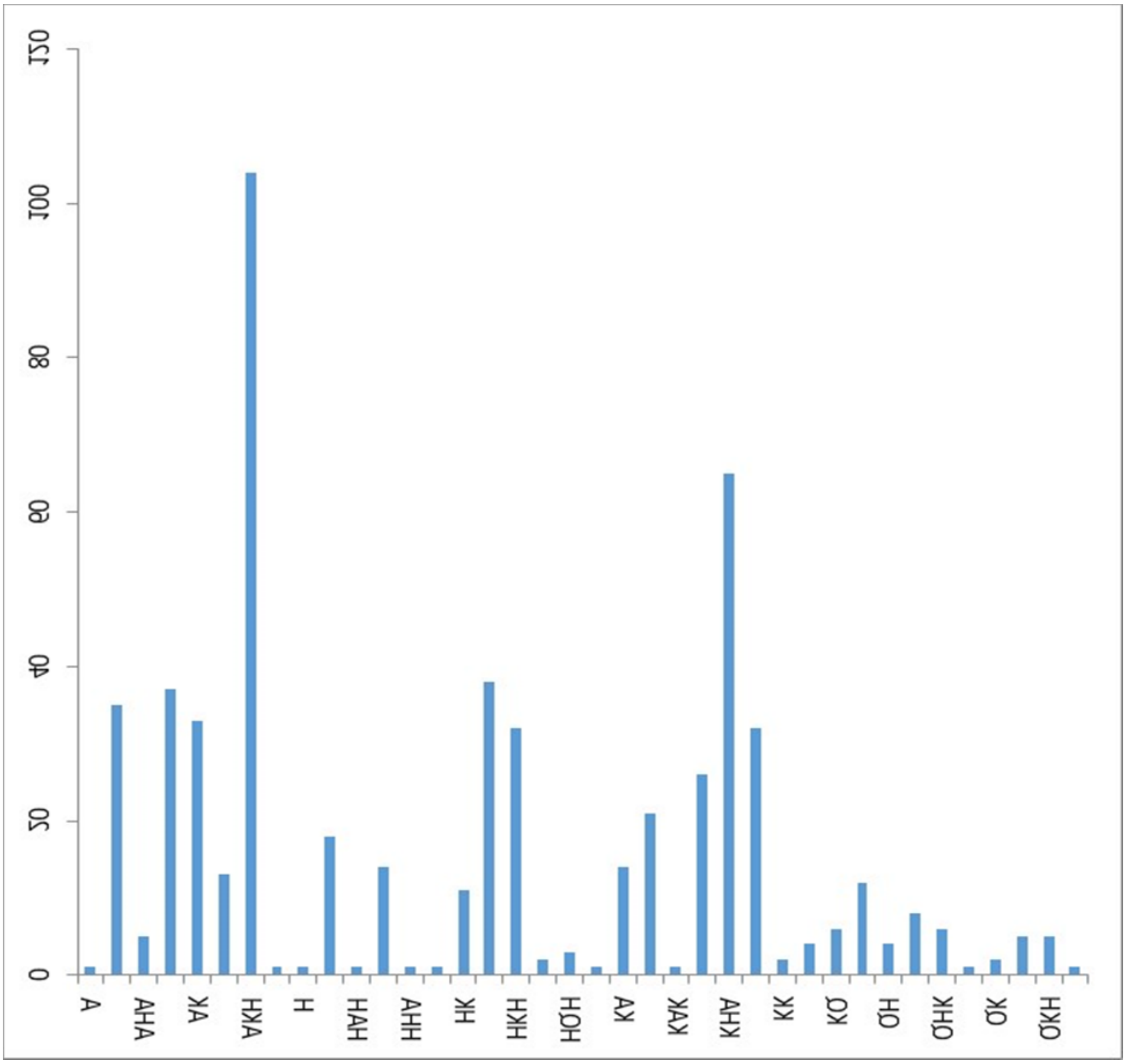

Figure 5: Bar Chart showing various curve types in the study area

Table 2: Statistical representation of curve type in the study area

S/N	Curve Type	Frequency	Percentage (%)
	A	1	0.17574692
	AH	35	6.15114236
	AHA	5	0.87873462
	AHK	37	6.5026362
	AK	33	5.79964851
	AKA	13	2.28471002
	AKH	104	18.2776801
	AQ	1	0.17574692
	H	1	0.17574692
	HA	18	3.16344464
	HAH	1	0.17574692
	HAK	14	2.46045694
	HHA	1	0.17574692
	HHQ	1	0.17574692
	HK	11	1.93321617
	HKA	38	6.67838313
	HKH	32	5.62390158
	HQ	2	0.35149385
	HQH	3	0.52724077

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	K	1	0.17574692
	KA	14	2.46045694
	KAH	21	3.69068541
	KAK	1	0.17574692
	KH	26	4.56942004
	KHA	65	11.4235501
	KHK	32	5.62390158
	KK	2	0.35149385
	KKH	4	0.7029877
	KQ	6	1.05448155
	KQK	12	2.10896309
	QH	4	0.7029877
	QHA	8	1.4059754
	QHK	6	1.05448155
	QJK	1	0.17574692
	QK	2	0.35149385
	QKA	5	0.87873462
	QKH	5	0.87873462
	QKK	1	0.17574692

The AKH-type curves are the most prevailing in the study area representing about 18.28% of the total number of curve types. This is followed by the KH-type (11.42%). The overall signature of the curves represents alternating sequences of resistive-conductive layers. Table 3 is the summary of the layer parameters interpreted from the VES data. Geo-electric layers interpreted ranges from 5 to 10 layers as shown in table 3.

Table 3**.** Representative Results of Interpreted Layer Parameters from the Study Area

VES No.		**No. of Layers**	**Layer Resistivity ρ (Ωm)**										**Layer depth d (m)**									**Layer Thickness h (m)**									**Curve Type**
	LOCATION		**ρ_1**	**ρ_2**	**ρ_3**	**ρ4**	**ρ5**	**ρ6**	**ρ7**	**ρ8**	**ρ9**	**ρ10**	**d1**	**d2**	**d3**	**d4**	**d5**	**d6**	**d7**	**d8**	**d9**	**h1**	**h2**	**h3**	**h4**	**h5**	**h6**	**h7**	**h8**	**h9**	
AJ01	OBILOZU IHITE-LOKPA,UMUNNEOCHI	10	133	422	82	9.2	84	388	2780	2390	2140	3540	1.3	6.4	9.4	20	28.5	41.1	89	136	198	1.3	5.1	3	11	8.1	12.6	48.2	48	62	KHK
AJ02	EZIAMA LOPKAUKWU UMUCHIEZE,UMUNNEOCH	10	64.7	263	34.1	4.6	230	81	28.6	38.6	51.1	48.2	0.9	3	4.4	7	19	35.4	71	115	167	0.9	2.1	1.4	3	11.6	16.4	35.4	44	52	KHK
AJ03	UBAHU NNEATO,UMUNNEOCHI	10	260	1030	451	8100	4790	667	667	1330	2220	3240	0.7	8.2	19	37	59.1	81.7	106	142	172	0.7	7.5	11	18	22.4	22.6	24.3	36	30	AHK
AJ04	NKWOAGU -AMUDA,ISUOCHI,UMUNNEOCHI	10	184	284	12.4	70	20600	13100	11900	8700	6740	5810	0.9	2	7.3	17	77.6	118	114	174	235	0.9	1.1	5.3	9.6	60.7	40.4	-	60	61	HKA
AJ05	ELUAMA LOKPOUKWU UMUCHIEZE,UMUNNEOCHI	10	45.7	463	4	4.1	43.4	208	303	227	174	211	0.6	2.4	6.3	13	21.9	46.5	89	138	186	0.6	1.8	3.9	6.8	8.8	24.6	42.7	49	48	KHK
AM40	UMUDIMOHA -AMIKE	5	698	450	682	6988	1345	-	-	-	-	-	0.7	3	6.5		-	-	-	-	-	0.7	2.7	3.5	139	-	-	-	-	-	AH
AM41	UMUZIKE,UMUOBA 1	9	880	2620	###	1620	2450	4110	6590	3690	1360	-	0.4	8.8	17	39	60.5	88.4	138	184	-	0.4	8.4	8.2	22	21.5	27.9	49.6	46	-	AKH
AM42	OGBERURU	6	3510	8300	1180	840	3560	8000	-	-	-	-	11	20	34	58	83.5	-	-	-	-	11	8.7	14	24	25.5	-	-	-	-	HA
AM43	ONUNKWO UMUELE	6	598	7360	598	3060	1400	1070	-	-	-	-	8.7	38	103			-	-	-	-	8.7	29	65	28	56	-	-	-	-	AKH
AM44	UMUDIM UMUELE AMAZANO	10	3860	2330	406	3020	12100	11800	1700	9200	6430	5000	0.5	2.9	9.9	27	66.3	102	154	204	256	0.5	2.4	7	17	36.4	38.7	52	50	52	AHK

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BN195	UMUEZEA -ITU	10	574	2660	1520	7200	11300	2590	2100	1970	820	696	0.6	5.7	15	---	63.1	104	137	171	209	0.6	5.1	9.1	12	36.4	40.9	33	34	38	AKH
BN196	UMUAKAM EZIUDO	6	1030	637	2590	7320	8100	5060	-	-	-	-	9.6	19	35	61	96.4	-	-	-	-	9.6	9.2	16	26	36.3	-	-	-	-	HA
BN197	AMUDI OBIZI	5	3470	2120	3920	5820	311	-	-	-	-	-	13	51	60		-	-	-	-	-	13	39	38	32	-	-	-	-	-	QH
BN198	OKWELLE 1	8	193	4210	1040	1950	2900	1810	645	300	-	-	0.6	3.5	10	23	44.4	60.7	79	-	-	0.6	2.9	6.9	13	21.5	16.3	17.9	-	-	AKH
BN199	OKWELE 2	9	193	5260	550	732	9000	3480	1890	1400	222	-	0.6	2.5	5	13	38.4	59.9	80	102	-	0.6	1.9	2.5	8	25.4	21.5	20.4	22	-	AKH
IS501	COPMP. HEALTH CENTER,OSU	10	604	502	29.8	4.9	71	236	260	1250	1650	2100	0.9	1.9	4.9	10	18.9	32	54	91	125	0.9	1	3	4.9	9.1	13.1	21.5	38	34	HKA
IS502	UMUZOHO -EZIHE	8	61	186	1570	8300	2130	382	298	87	-	-	0.4	7.2	13	30	44.5	64	91	-	-	0.4	6.8	5.3	18	14.2	19.5	26.9	-	-	AKH
IS503	UMUDURUOBI UMUOHIRI OSUACHARA	10	146	3080	102	171	53.2	49.8	111	249	232	5140	0.4	1.9	14	36	53.9	70.6	91	114	129	0.4	1.5	12	22	17.9	16.7	20.6	23	15	KHK
IS504	ISIEBU UMUDURU	10	101	2640	23.5	7.4	291	69.2	29.2	23	30.2	9	0.4	1.1	2.6	11	42.7	66.6	96	128	163	0.4	0.7	1.5	8	32.1	23.9	29.1	32	35	KHK
IS505	EWURU - UMUNACHI	10	445	423	5	124	364	511	478	437	520	3190	0.9	7.1	21	35	55.5	80.6	105	128	156	0.9	6.2	14	14	20.8	25.1	24.4	23	28	HKH
NS517	OBICHIE OVIM,ISUKWUATO	7	582	31400	1860	1380	686	207	13.5	-	-	-	0.7	4.1	8.2	78	93.4	113	-	-	-	0.7	3.4	4.1	69	15.9	19.6	-	-	-	KQ
NS518	UMUORA AGBOR UMUNNEUKWU,ISIKWUATO	10	165	513	1000	1190	49.1	1.8	13.4	40.1	47.8	190	0.6	4.1	6	10	15.3	37	54	77	102	0.6	3.5	1.9	4.2	5.1	21.7	17.1	23	25	KHK
NS519	UMUSUH VILLAGE,ELUAMA,ISIKWUATO	9	223	3460	471	7850	1600	3540	2070	1390	860	53	0.5	2.9	10	23	51,1	71.1	93	118	-	0.5	2.4	7.1	13	28.4	20.6	21.1	25		KHK
NS520	UMUOVO - ELUELU,UMUAHIA SOUTH	10	1550	9500	1010	4010	1820	860	1650	2460	2680	7620	0.5	1.9	7	52	79.5	125	164	204	244	0.5	1.4	5.1	45	27.9	45.5	39	40	40	KHK
NS521	OGUDUASA EROSION SITE,ISIKWUATO	10	2320	688	4880	267	714	8600	34600	13700	6520	4930	0.6	1.7	4.2	12	21.9	41.6	117	186	291	0.6	1.1	2.5	8.1	9.6	19.7	75.4	69	##	HKH
OG544	UMUALI 1 MBEKE (LT.COL OKEJIEGBE'S COMPOUND)	10	1650	714	5760	340	71.2	24.1	71.8	147	220	1880	1	2.9	8.7	42	60.1	92	117	143	173	1	1.9	5.8	33	18.2	31.9	25	26	30	HKH
OG545	ANARA	10	271	52.1	435	1180	5410	1700	679	421	305	49.3	0.8	4.5	6.8	10	29.3	44.8	61	79	99.6	0.8	3.7	2.3	3.5	19	15.5	16.5	18	21	HKH
OG546	UMUOZO EZUMOHA	10	295	27100	4840	632	2640	3190	4130	10900	4280	7390	0.4	3.1	8	33	60.1	86.4	121	179	226	0.4	2.7	4.9	25	26.7	26.3	34.6	58	47	KHK

Citation: Terhemba Theophilus Emberga, *et al.*, Regional Hydro-geophysical Study of the Groundwater potentials of the Imo River Basin Southeastern Nigeria using Surficial Resistivity Data. Australian Journal of Basic and Applied Sciences, 13(8): 76-94.DOI: 10.22587/ajbas.2019.13.8.12

OG547	UMUEZEALA-UMUDURU	7	741	1660	2620	32200	7200	3040	733	-	-	-	0.6	3.2	6.1	20	39.7	74.3	-	-	-	0.6	2.6	2.9	14	19.5	34.6	-	-	-	AKH
OG548	UMULOLO-OBOH,OSUAMA	8	502	4410	1030	40.8	232	1720	170	101	-	-	0.5	2	19	42	62.1	152	243	-	-	0.5	1.5	17	24	19.8	89.9	91	-	-	KHK

3.2 Aquifer Resistivity

Aquifer resistivity across the study area was estimated from the geo-electric curves generated from the Vertical Electrical Sounding data. The aquifer resistivity varied spatially across the study area in line with the geological complexity of the study area. Aquifer resistivity values across the study area varied from as low as 16.38Ωmto as high as 10,000Ωmas shown in figure 5 below. These areas with low resistivity are generally believed to be made up of conductive earth materials like clay or shale which may not be good for citing boreholes.

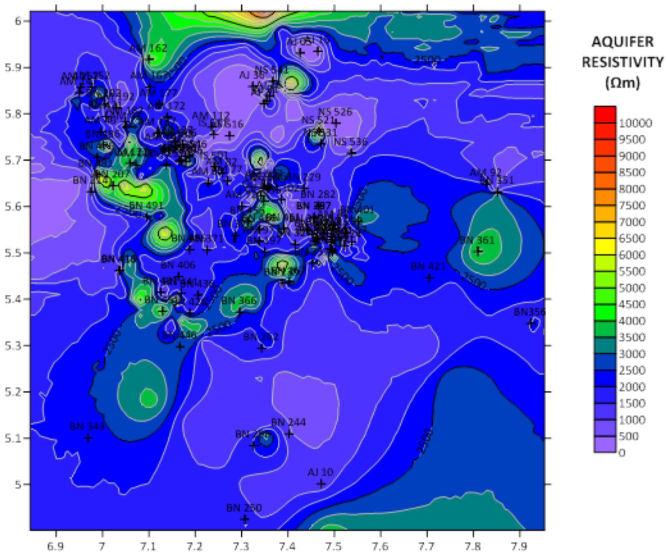
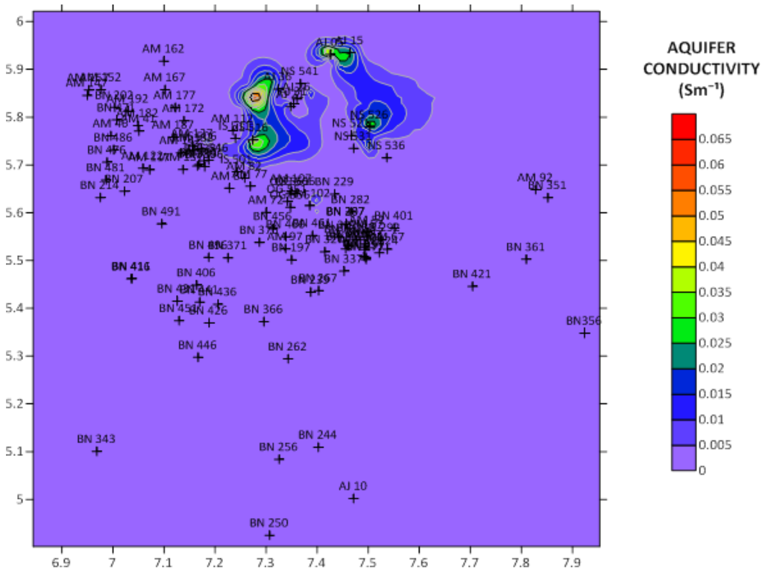


Figure 5: Spatial Variation of Aquifer Resistivity across the study area

3.3. Aquifer Conductivity

Aquifer conductivity across the study area was derived by taking the inverse of the aquifer apparent resistivity values. The calculated aquifer conductivity values for all the sounding locations were therefore contoured to generate a spatial map of aquifer conductivity in the study area (Figure 6).The study area revealed a near homogenous conductive region with very low conductivity values with values between 0-0.005Sm^{-1} to 0.065Sm^{-1}(Figure 6). The areas slightly below the northern part of the study area appears to have fairly high aquifer conductivity with Eluama Lokpoukwu areas having the highest value of 0.0629 Sm^{-1} These low conductivity areas may not be good for groundwater exploration and exploitation.



Citation: Terhemba Theophilus Emberga, *et al.*, Regional Hydro-geophysical Study of the Groundwater potentials of the Imo River Basin Southeastern Nigeria using Surficial Resistivity Data. Australian Journal of Basic and Applied Sciences, 13(8): 76-94.DOI: 10.22587/ajbas.2019.13.8.12

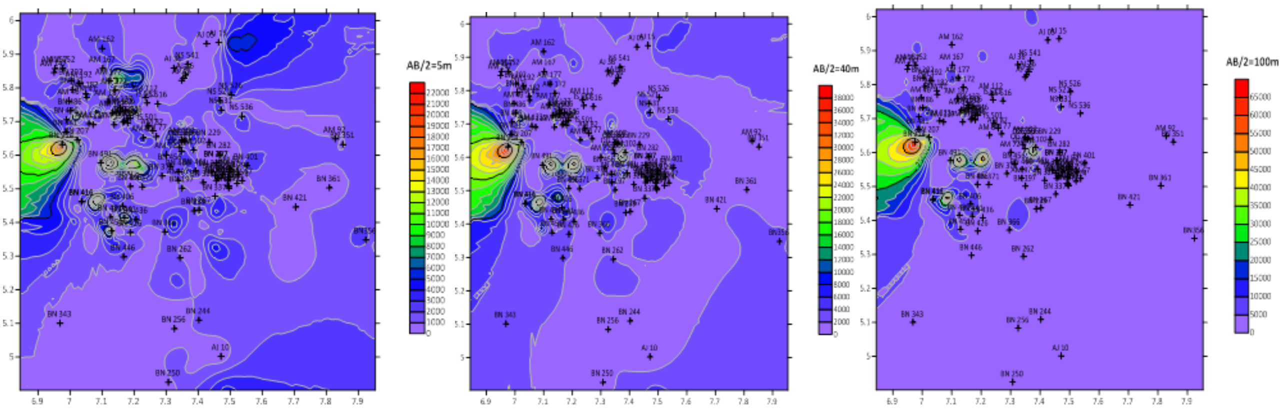
Figure 6: Spatial Variation of Aquifer Conductivity across the study area

3.4 Iso- resistivity (Resistivity Depth Slices) Interpretation across the study area

Based on the well-established assumption that the effective depth of transmission is approximately equal to 2/3 of half the current electrode separation (AB/2), the resistivity depth slices of across the study area were used to generate Iso-resistivity values (Table 4). Several iso-resistivity maps showing depth variations of resistivity at specified intervals of AB/2 of 5m, 40m, 100m,150m, 250m, 300m, 350 m, 400 m, and 500m were thus generated as shown in table 4 and figure 7. The generated maps revealed a high consistency with the western part having very high resistivity with values between 20,000-65,000Ωm. There seems to be a fairly progressive decrease in resistivity with depth suggesting a highly resistive overburden and upper layers to less resistive (or conductive) layers at deeper intervals. However, it must be noted that an iso-resistivity map is a qualitative interpretation tool which shows possible variations in resistivity with depth at the given electrode spacing across a region but may not give the true resistivity of a definite or unit geo-electric layer (Mbonu et al., 1991).

Table 4: Representative of selected Downward Continuation of Resistivity across the Study Area

VES. No.	Lat. (^{0}N)	Long. (^{0}E)	AB/2 (m)													
			5	10	15	40	60	100	150	200	250	300	350	400	450	500
AJ 01	5^{0}59.001	7 27.314	210	200	140	40	50	70	100	140	145	170	180	220	260	300
AJ 02	5 54.960	7^0 26.255	130	80	45	50	60	65	62	61	58	56	55	-	-	-
AJ 03	5 56.612	7 18.470	700	800	850	1000	1400	1800	2000	2100	2200	2300	2400	2450	2500	2600
AJ 04	N5 51.484	7 24.085	70	30	35	60	90	190	200	300	600	650	700	800	900	1000
AJ 05	N5 55.854	7 25.554	170	100	40	12	18	30	35	40	60	70	80	95	100	110
AM 40	N5 46.824	7 04.089	2200	2800	3200	4000	3100	3000	2900	3050	3150	3170	3130	3120	3000	2950
AM 41	N5 46.253	7 03.054	3500	3500	3600	3400	3300	3200	3250	3600	3650	3700	3800	3900	4000	4100
AM 42	N5 49.993	7 01.385	610	800	1000	1900	2200	2800	2500	2400	2300	2200	1300	1600	1550	1400
AM 43	N5 59.4	6 59.293	800	700	750	1500	2500	4000	4500	5000	5500	6000	5950	5850	5750	5500
AM 44	N5 39.564	E6 59.051	1100	1300	1350	2400	3000	5000	5500	6000	6500	7000	7100	7200	7300	7400
BN 195	N5 28.114	E7 20.087	1300	2000	2500	3000	3500	5000	5500	5300	3000	3500	2000	1800	1700	1000
BN 196	N5 28.995	E7 21.00	1000	1000	1050	1200	1500	2100	3000	3500	4000	4500	5000	5100	5400	5500
BN 197	N5 30.089	E7 20.988	3200	3200	3100	3000	2800	2700	2750	2500	2000	1800	1600	1500	1400	1000
BN 198	N5 44.784	E7 11.187	1100	1600	1700	1800	2000	2200	2100	1200	1100	950	900	500	400	300
BN 199	N5 44.736	E7 10.911	1200	1400	1500	2000	2700	2800	3000	2900	2850	1700	700	600	550	500
IS 501	N5 41.153	E7 14.568	100	9	8	25	40	70	100	105	120	125	200	250	300	350
IS 502	N5 42.156	E7 14.478	190	200	250	700	1000	1100	1100	1050	1000	950	700	650	200	140
IS 503	N5 44.111	E7 13.172	800	700	400	150	140	130	135	140	200	250	300	350	400	450
IS 504	N5 42.445	E7 13.045	400	200	40	25	40	70	80	75	60	55	50	30	25	20
IS 505	N5 43.934	E7 11.313	450	350	180	16	18	28	40	70	80	100	120	140	160	200
NS 517	N5 43.084	E7 32.425	2700	5000	5500	4000	2000	1100	900	500	300	200	40	35	30	20
NS 518	N5 46.207	E7 28.332	450	510	510	190	11	8	9	12	13	16	17	20	25	30
NS 519	N5 54.925	E7 26.010	1200	1250	1150	1600	2100	3000	3400	3500	3300	2900	2700	1700	1600	1500
NS 520	N5 28.721	E7 28.165	4200	3000	2200	3000	3200	3300	3250	2500	2400	3100	3300	3800	4000	4500
NS 521	N5 45.693	E7 28.011	1500	1800	1100	800	1000	2000	2500	2800	3000	4000	5000	5500	6000	6500
OG 544	N5 41.441	E7 13.051	1200	1500	1050	1000	450	160	90	95	100	120	140	160	190	200
OG 545	N5 42.929	E7 09.6093	650	110	150	400	600	800	850	840	830	700	650	400	250	200
OG 546	N5 42.584	E7 11.256	3500	4000	4500	3000	1900	1600	1700	2100	2200	2700	2800	2900	3000	4000
OG 547	N5 41.056	E7 14.577	1500	2500	3500	8000	8500	7000	5500	3000	1500	1300	1100	1000	950	900
OG 548	N5 43.752	E7 10.649	1700	1600	1100	600	200	150	160	170	180	200	250	300	350	400



(a) (b) (c)

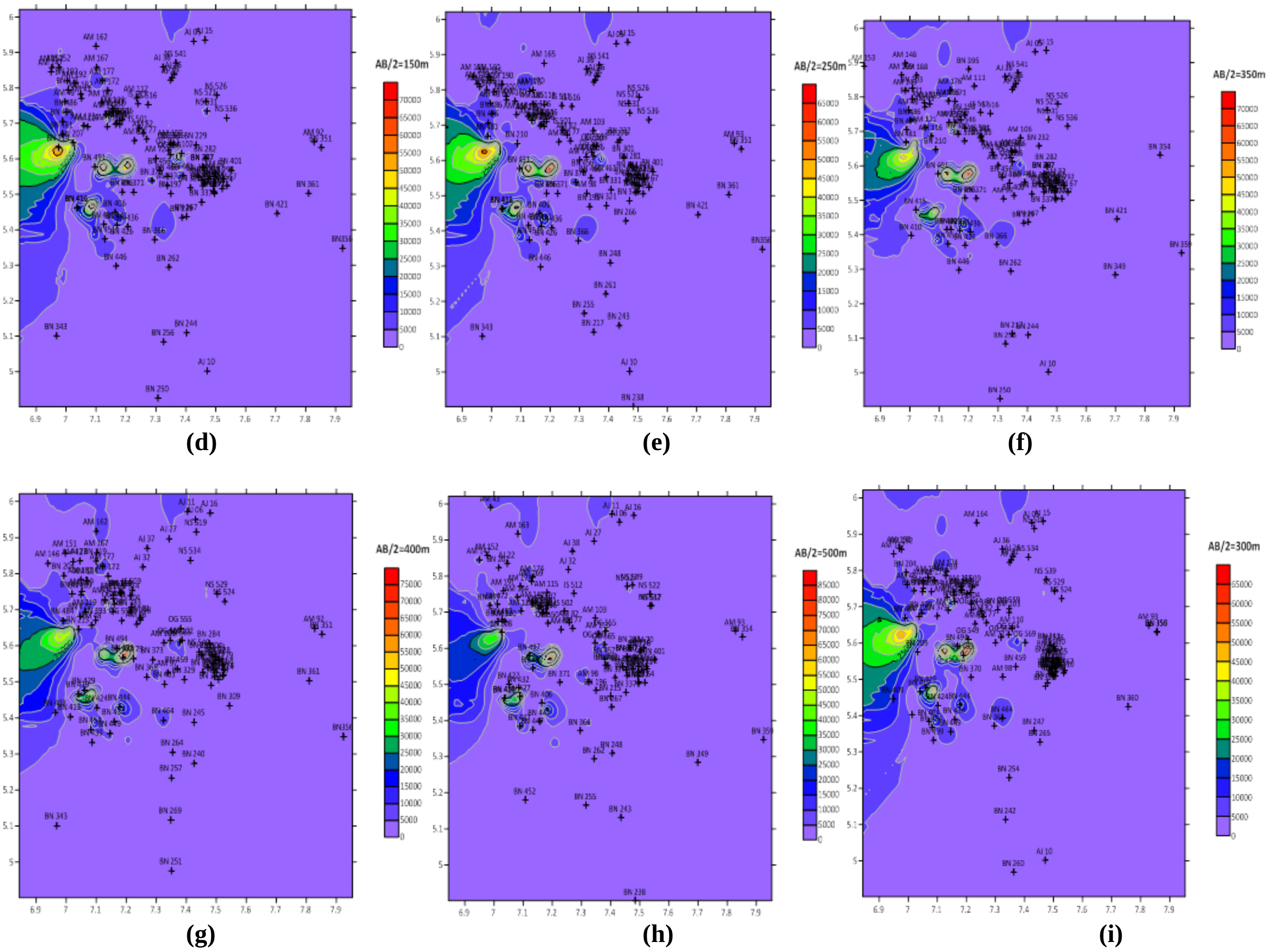


Figure 7: Iso –resistivity modelling of the study area: (a) AB/2= 5m (b) AB/2= 40m (c) AB/2 = 100 m(d) AB/2 = 150 m (e) AB/2 = 150 m(f) AB/2 = 250 m (g) AB/2 = 350 m (h) AB/2 = 400 m (i) AB/2 = 500m

3.4.1 Iso-resistivity Map (AB/2 = 5 m)

The generated iso-resistivity map for AB/2 = 5 m shown in figure 7arevealed that most parts of the study area especially within the northern, eastern, southwestern and the central areas are underlain by relatively low resistive materials with the exception of the western area. These low resistive areas with magenta color codes in figure 7a have resistivity values ranging between 0- 1000Ωm. The Iso-resistivity model of the study area at this half current electrode spacing with effective depth of penetration of 3.33 m (10.87 ft) generally revealed that across the study area, the resistivity values increased from about 200Ωm (magenta) to 38,000Ωm (red). The range of resistivities shown by the magenta color may be an indication of silt/ shale/clay units while the other colors in the map may represent areas underlain by sand/sandstone units.

3.4.2 Iso-resistivity Map (AB/2 = 40 m)

The iso-resistivity contour map for AB/2 = 40 m in figure 7b below shows that some parts of the study area within the northern, eastern and southwestern axes are underlain by relatively low resistive materials. The resistivity of the study area at this spacing with sufficient depth of penetration 26.67 m (86.93ft) shows that the resistivity of sounding points increases from value > 0 (magenta) to about 56000 Ωm (red).

Low/medium resistivity values of the range of 0 - 2000Ωm (in magenta color) was noticed within the southern, eastern, central and northwestern parts of the study area. The areas of very high resistivity with values of 20,000- 50,000Ωm were noticed to be restricted to the western part of the map of the study area while the areas represented by blue colours have medium resistivity values ranging between 5000-20,000Ωm. The range of resistivities shown by the magenta color may be an indication of silt/ shale/clay units while the other colors in the map may represent areas underlain by sand/sandstone units.

3.4.3 Iso-resistivity Map (AB/2 = 100 m)

The iso-resistivity map for AB/2 = 100 m in figure 7c below shows that most parts of the study area are underlain by relatively low resistive materials. The resistivity of the study area at this spacing with effective depth of penetration of 66.67m revealed that the resistivity values at the sounding points increase from 0 to as high as 65,000Ωm. At this depth range, the study area became more shaly as over 95% of the study area is covered by low to medium resistivities (areas covered by magenta colour) ranging from 0-5000Ωmwhile very high resistivity values were restricted to the western part of the study area. In general, the range of resistivities shown by the magenta color may be an indication of silt/ shale/clay units while the other colors in the map may generally represent areas underlain by sand/sandstone units.

3.4.4 Iso-resistivity Map (AB/2 = 150 m)

The iso-resistivity map for AB/2 = 150 m in figure 7drevealed that most parts of the study area within the northern, eastern and southwestern axes are underlain by relatively low resistive materials. The resistivity of the study area at this spacing with effective depth of penetration given as 100 m(≈ 326 ft)revealed that the degree of shaliness increased across the area as the areas covered by magenta colours (representing low-medium resistivities) increased across the study area. The magenta coloured areas have resistivity values ranging between 0-5000Ωm. High resistivities with values ranging between 5000- 50,000Ωm are generally restricted to the western axis of the study area.

3.4.5 Iso-resistivity Map (AB/2 = 250 m)

The iso-resistivity map for AB/2 = 250 m as shown in figure 7erevealeda similar pattern with the values at the depth AB/2 = 150 m with most of the area underlain by relatively low-to-medium resistive materials. These low-medium resistivities layers are represented by the magenta colour. The effective depth of penetration at this depth interval is 166.67 m with the resistivity values varying between 0- 55,000Ωm. Similarly, it was revealed that the degree of shaliness increased with depth across the study area with the highly resistive zones with resistivity values ranging between 5000- 50,000Ωm restricted to the western axis of the study area. These areas with high resistivities possibly represent sand/sandstone units.

3.4.6 Iso-resistivity Map (AB/2 = 300 m)

The iso-resistivity map for AB/2 = 300 m is shown in figure 7f. This map revealed a similar pattern with the values at the depth AB/2 = 250 m with most of the area underlain by relatively low-to-medium resistive materials. Similarly, it was revealed that amount of shale/clay units increased with depth across the study area with the highly resistive zones with resistivity values ranging between 5000- 50,000Ωm restricted to the western axis of the study area. These areas with high resistivities are therefore believed to be sand/sandstone units.

3.4.7 Iso-resistivity Map (AB/2 = 350 m)

The iso-resistivity map for AB/2 = 350 m in figure 7g revealed a similar pattern with the values at the depth AB/2 = 300 m with most of the area underlain by relatively low-to-medium resistive materials. Similarly, it was also revealed that the amount of shale/clay units increased at this depth with the high resistive zones restricted to the western axis of the study area. These areas with high resistivities are therefore believed to be sand/sandstone units.

3.4.8 Iso-resistivity Map (AB/2 = 400 m)

The iso-resistivity map for AB/2 = 400 m in figure 7h revealed a similar pattern with AB/2 = 350 m. The resistivity values of the study area at this half current electrode spacing with effective depth of penetration given as 266.67 m also showed a similar pattern with the values at the depth of AB/2 = 350 m with most of the area underlain by relatively low-to-medium resistive materials. In addition, it was revealed that the amount of shale/clay units increased at this depth with the high resistive zones restricted to the western axis of the study area. These areas with high resistivities are therefore believed to be sand/sandstone units.

3.4.9 AB/2 = 500 m

The iso-resistivity map for AB/2 = 500 m in figure 7i revealed that most parts of the study area are underlain by relatively low resistive materials. The resistivity values of the study area at this half current electrode spacing with effective depth of penetration given as333.33 m also showed a similar pattern with the values at the depth of AB/2 = 350 m with most of the area underlain by relatively low-to-medium resistive materials. In addition, it was revealed that the amount of shale/clay units increased at this depth with the high resistive zones restricted to the western axis of the study area. These areas with high resistivities are therefore believed to be sand/sandstone units.

3.5Spatial variation of Aquifer Geometric Properties

3.5.1 Aquifer Depth

The spatial map of the aquifer depth across the study area as shown in figure 8revealed a high spatial variation. The aquifer depth ranges from 10m around the areas underlain by the Benin Formation to as high as 320m in areas underlain by the Ameki, Nsukka, Ogwasi/Asaba and Imo Shale Formations respectively with a mean value of 89.3m. The areas with high aquifer depths represented by red colours in the map are generally difficult with respect to groundwater exploitation.

Citation: Terhemba Theophilus Emberga, *et al.*, Regional Hydro-geophysical Study of the Groundwater potentials of the Imo River Basin Southeastern Nigeria using Surficial Resistivity Data. Australian Journal of Basic and Applied Sciences, 13(8): 76-94.DOI: 10.22587/ajbas.2019.13.8.12

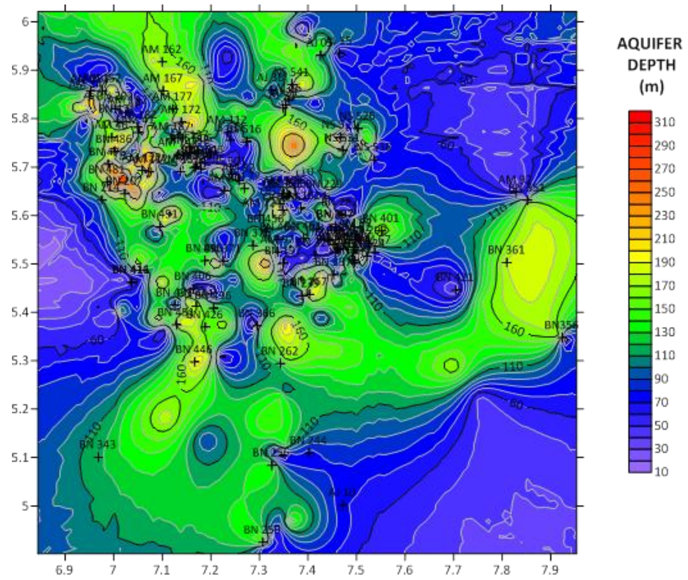


Figure 8: Aquifer depth map of the study area

3.5.2 Aquifer Thickness

The aquifer thickness across the study area is highly variable as shown in figure 9. Aquifer thickness across the study area ranges from 0- 125m. The spatial variation contour map of the aquifer thickness across the study area thus revealed that the northwestern, part of the northeastern and the northern zones of the study area exhibited high aquifer thicknesses with areas around Aguneze having the highest aquifer thickness with values as high as 130 m record. Low aquifer thickness values were however recorded in parts of the central, northeastern, southeastern and northern areas of the study area. These low aquifer thickness areas represented with blue colour codes has the lowest value of 2.6m around Maranatha Secondary School Umuezealama Mbano. These areas with extremely low aquifer thicknesses might not be very productive and therefore citing of boreholes at the specified depth is not recommended.

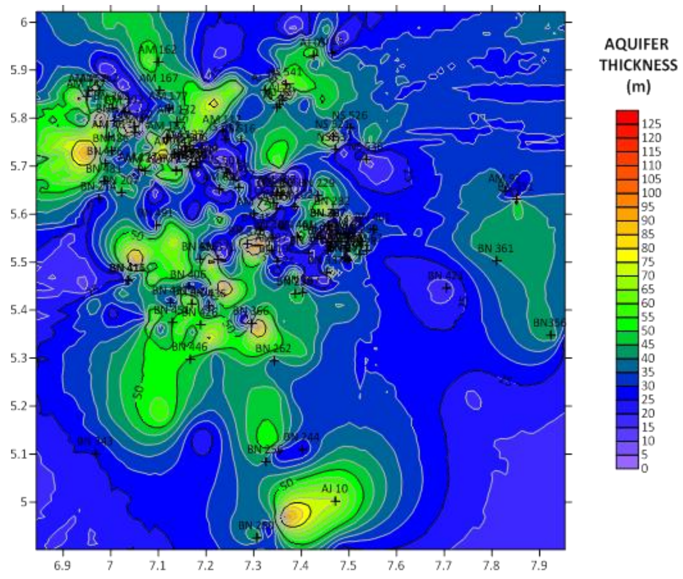


Figure 9: Aquifer thickness map of the study area

3.5.3Estimation of Aquifer Lateral Extent

The geo-electric logs from various locations were correlated with another borehole in formations extracted from litho-logs in drilled boreholes and logs from borehole geophysical logging. The main objective of this correlation is to infer possible spatial variation in geology across the study area (Figure 10). It is believed that this correlation will aid in the understanding of the regional lithostratigraphy of the study area. In addition, to attempt an estimation of the nature, type, lateral extent and continuity of the aquifers of the study area, correlation of the geo-electric sections with litho-logs and electric logs at selected well locations were carried out. A few of these correlations for Nkwofada, Umuechi OgborUgiri Umukabia, Amaraku, and Umuelemai are presented below:

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(a)Nkwofada Arondizogu (AM 165)

A careful analysis of the correlation between the geo-electric section, litho-log and borehole geophysical log at this location revealed a fairly good correlation with respect to the stratigraphy as captured by the various logs (Figure 10a). The topsoil with a resistivity value of 368Ωm was interpreted as lateritic ironstone. Hydro-stratigraphically, whereas the geo-electic section delineated the aquiferous layer to be between the depth range of 99-175 m with a thickness 75 m, the borehole litho-log revealed that the aquifer is at the depth range 72-90 m with a thickness of18 m. However, the electric log showed that the aquifer lies between the depths of 52-88 m with a thickness of36m (Figure 10a). However, while the results of the borehole logs identified the aquiferous units as whitish/grey sandy clay the geo-electric log gave a resistivity value of 2080 Ωm for the aquifer unit thus suggesting that the aquifer materials are made up of clean sand/sandstones. The borehole logs and the geo-electric section, therefore, showed a fair correlation. The slight variation in this correlation may be as the result of the problems of equivalence and suppression for which the method is associated with(Zohdy.,1976).

(b)Umuehie Ogbor Ugiri (IS 507)

The first layer in the geo-electric section is interpreted as lateritic soil with apparent resistivity value of 380 Ωm (Figure 10b). The interpretation of the correlation assigned a resistivity value of 2,050Ωm to the aquiferous layer. It further revealed the aquifer geo-material to of this layer to be composed of sand/sandstone with a thickness of 48 m (lying between the depth ranges of 76-124m).On the other hand, the litho-log and the electric-logs revealed that the aquiferous units are made up of a brownish mixture of clay and sand with a thickness of 6 m (lying between the depth ranges of 75-88 m) and 16 m (lying between the depth ranges of 88-104m) respectively. Similarly, the geo-electric section, the litho-log and the electric log revealed a fairly good correlation.

(c)Umukabia, Ohuu (BN 226)

At this location which is underlain by the Benin Formation, the geo-electric log identified the aquifer geo-material to be made of sand/sandstones with a thickness 59 m (lying between the depth ranges of 29-88 m).This layer was assigned a resistivity value of 1,250 Ωm. Similarly, the borehole logs identified the aquiferous units as whitish sand of thickness 12 m (lying between the depth ranges of 26-38 m) for the strata-log and 18 m (lying between the depth ranges of 20-38 m) for the electric-log. The borehole logs(litho-log and electric log) and the geo-electric log displayed a good correlation (Figure 10c). In addition, the both the borehole logs and the geo-electric log revealed that the identified aquiferous unit may be a confined aquifer bounded by shale/clay layers.

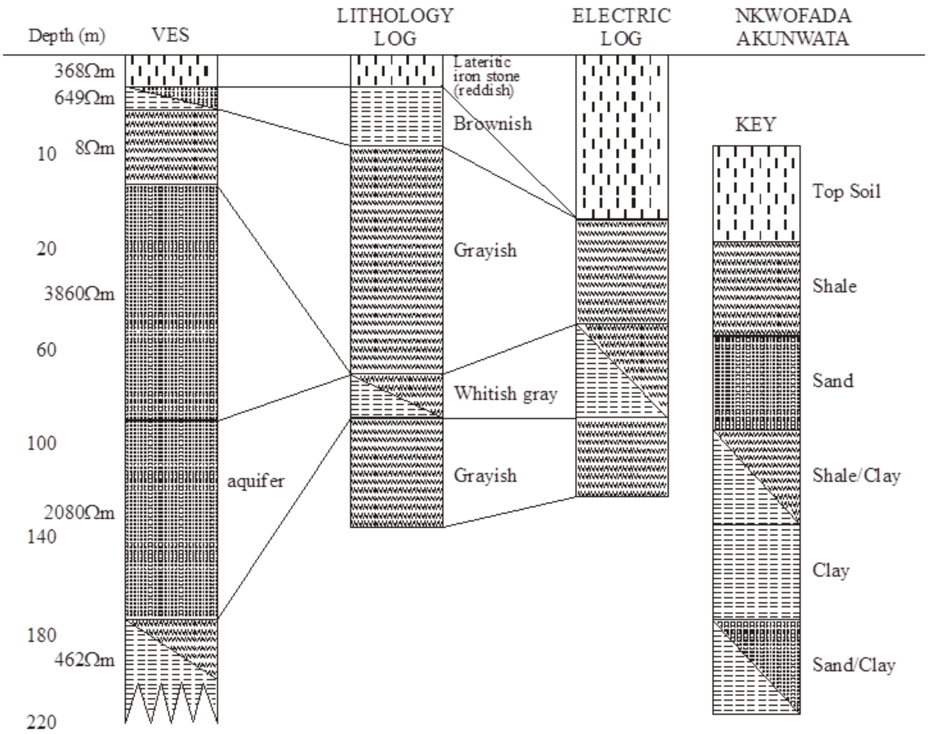
(d)Amaraku, IsialaMbano (AM 80)

The first layer of the geo-electric section with resistivity 212 Ωm is interpreted as reddish lateritic sand (figure 10d). The aquiferous layer as identified by the geo-electric section is sand with a thickness of 45 m (at the depth range of 62-107 m) and resistivity value of 1360 Ωm. The strata-log identified the aquifer unit as made up of fine grained whitish sand of thickness 30 m (lying between the depths of 78-108 m). The geo-electric log therefore correlated perfectly well with that of the strata-log. The aquifer units as indicated by both logs are underlain by an electrically conductive layer of shale. Amaraku and its environments, by this correlative interpretation therefore is believed to be prolific in groundwater potentials.

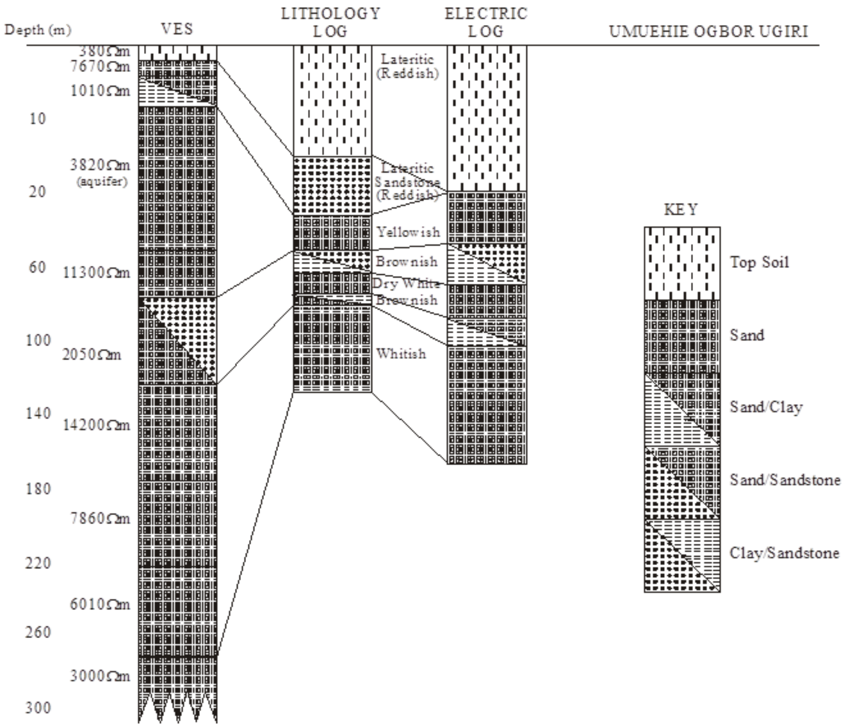
(e)Umuelemai, Mbano(BN 391)

The geo-electric log as this location identified the aquifer unit as composed of sand/sandstone with a thickness of 28 m (between the depth ranges of 78-106 m). The resistivity value of this layer is given as 1760 Ωm. Similarly, the strata-log also identified the aquifer geo-material as sandstone with a thickness of 16 m (at the depths of 30-46 m). There is therefore a near perfect correlation between the geo-electric section and the strata-log at this location. The aquifer unit as revealed by the geo-electric log is underlain by an electrically conductive layer of shale.

Citation: Terhemba Theophilus Emberga, *et al.*, Regional Hydro-geophysical Study of the Groundwater potentials of the Imo River Basin Southeastern Nigeria using Surficial Resistivity Data. Australian Journal of Basic and Applied Sciences, 13(8): 76-94.DOI: 10.22587/ajbas.2019.13.8.12

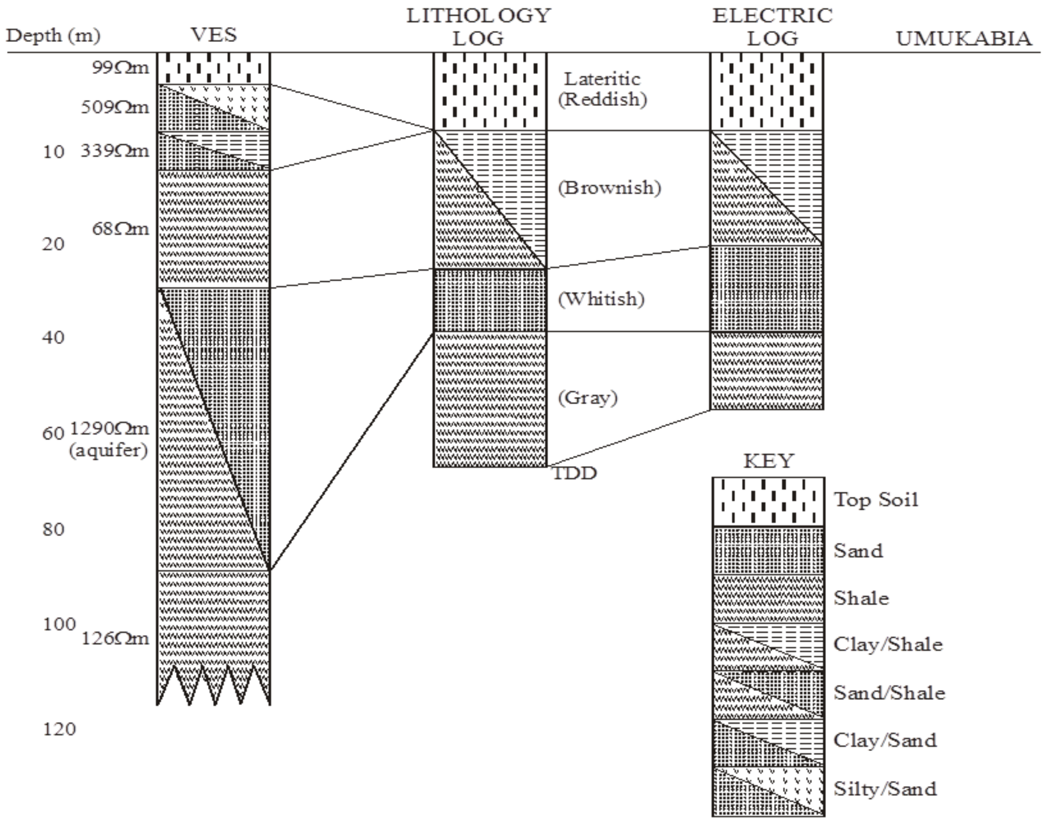


(a)



(b)

Citation: Terhemba Theophilus Emberga, *et al.*, Regional Hydro-geophysical Study of the Groundwater potentials of the Imo River Basin Southeastern Nigeria using Surficial Resistivity Data. Australian Journal of Basic and Applied Sciences, 13(8): 76-94.DOI: 10.22587/ajbas.2019.13.8.12



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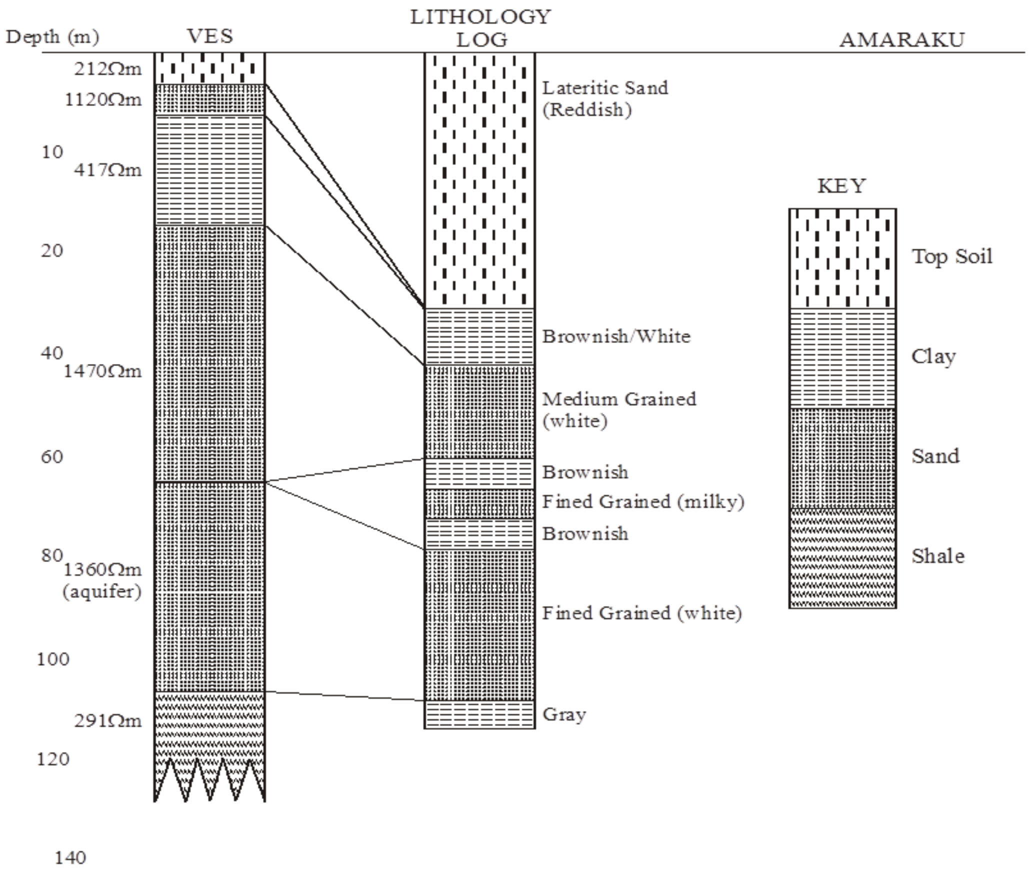

(d)

Figure10 (a – d): Correlation of geo-electric log, litho-Log Section and electric-Log of the study area: (a)Nkwofada Akunwata (b) Umuwhie Ogbo Ugiri (c) Umukabia (d)Amaraku (e)Umuelemai Mbano

3.6 Dar-Zarrouk Parameters of the study area

3.6.1 Transverse Resistance

Transverse resistance and longitudinal conductance are generally referred to as Dar-zarrouk Parameters. They have found a lot of application in hydrogeophysical and environmental geophysical studies. Transverse resistance is usually estimated in direct current resistivity studies by using the product of aquifer resistivity (Ωm) and aquifer thickness (m). The transverse resistance contour map of the study area is presented in figure 10 with values ranging from 0 to 75,000Ωm^2. The eastern and northern parts of the study area appear to have low transverse resistances with Okigwe and Onuimo areas having values of 6,006 $\Omega m^2$and 30000 Ωm^2respectively. These low transverse resistance values correspond to areas in magenta colours on figure 11. Similarly, parts of the central and northwestern areas appear to have high transverse resistance with Nwoagwu Amuda -Isuochi having the highest transverse resistance value of about 225,866.4 Ωm^2 which corresponds to the yellow/pink colour coded regions. The areas with magenta colours are likely to be unproductive since their transverse resistance values are low.

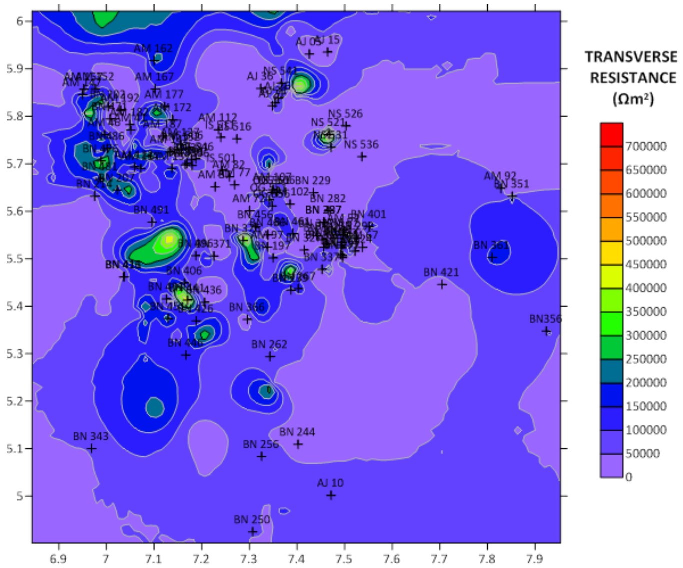

Figure 11: Transverse Resistance map of the study area

3.5.2 Longitudinal Conductance

Longitudinal conductance across the study area was estimated by taking the ratio of aquifer thickness (m) to aquifer apparent resistivity (Ωm). The distribution of longitudinal conductance values across the study area in figure 12 shows that part of the northern and central portions of the study area appear to have high longitudinal conductance especially around Onuimo and Ehime Mbano areas. The southern axes of the study area appear to have low longitudinal conductance with Umuokwara - Ihebinowerre having the lowest value of 0.00096 Ω^{-1}. This corresponds to the magenta coloured region. These areas with low longitudinal conductivity may are believed to be very productive. With the exception of these magenta coloured areas, other parts of the study area are expected to be underlain by thick and conductive materials having relatively higher longitudinal conductance thus making the area very poor aquifer materials.

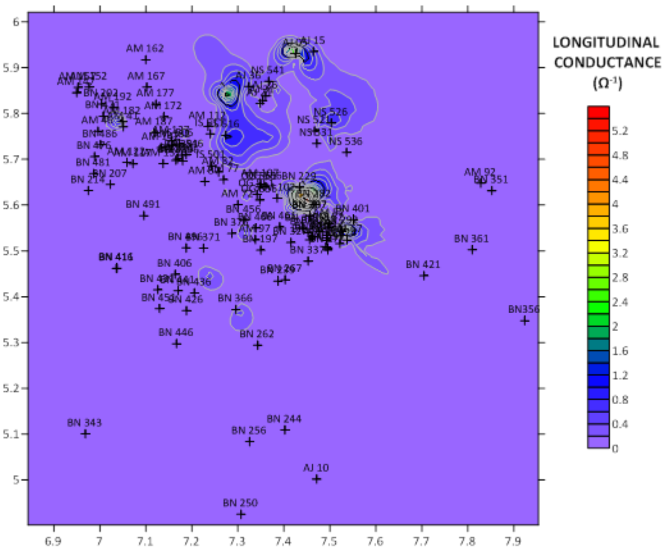

Figure 12: Longitudinal Conductance map of study area

4.0 SUMMARY, CONCLUSION AND RECOMMENDATION

The hydro-geophysical study of the Imo River Basin, Southeastern Nigeria using surficial resistivity data have been carried out with the objective of appraising the groundwater potentials of the area. Five hundred and sixty- nine (569) vertical electrical sounding (VES) were carried out with the objective of delineating the aquifer units and appraising their potentials using the ABEM^{TM} Terrameter (SAS) 4000.

Results of the study revealed that the geo-electric curves interpreted from the study area include the A, AH, AHA, AK, AKH, HKA,KHA etc with the dominant curve type being the AKH type. The layer resistivity varies across the study area thus reflecting the geological complexity of the study area with the aquifer resistivity values across the study area varying from as low as 16.38Ωm to as high as 10,000Ωm.Iso-resistivity maps generated at the depth intervals of AB/2 of 5m, 40m, 100m,150m, 250m, 300m, 350 m, 400 m, and 500m revealed a high consistency with the western part having very high resistivity with values between 20,000-65,000Ωm. In addition, there seem to be a fairly progressive decrease in resistivity with depth suggesting a highly resistive overburden and upper layers to less resistive (or conductive) layers at deeper intervals. Aquifer depth ranges from 10m around the areas underlain by the Benin Formation to as high as 320 m in the areas underlain by the Ameki, Nsukka, Ogwasi/Asaba and Imo Shale Formations with a mean value of 89.3m.Aquifer thickness across the study area is variable with a aquifer thickness across the study area ranging from 0- 125m.Transverse resistance and longitudinal conductance generally referred to as Dar-zarrouk Parameters were also estimated across the study area. The transverse resistance ranges from 0 to 75,000 Ωm^2 while the distribution of longitudinal conductance values across the study area revealed that he southern axes of the study area appear to have low longitudinal conductance with Umuokwara - Ihebinowerre having the lowest value of 0.00096 Ω^{-1}.

The high spatial variation of resistivity across the study area is possibly due to variations in the physic-chemical properties of the formations. These properties include the particle size of materials, porosity/permeability, water content, compaction, and chemical composition of the water as the result of the presence of dissolved solids. Similarly, the close correlation of the interpretation of resistivity data with borehole information is an indication of the applicability of the resistivity data in characterizing aquifers geo-materials. This is very true despite the limitations of the vertical electrical resistivity sounding method especially with respect to the challenges of equivalence and suppression.

The findings of this study revealed that the shale/clay across the entire area increased with depth. In addition, the aquifer potentials of the study area was revealed to be variable with the aquifer type, nature and characteristics generally controlled by the underlying geology. The areas with the highest transverse resistance values are expected to give the highest groundwater yield. Areas for future groundwater development have been suggested on the ground of high transverse resistance values. The Iso-resistivity maps revealed that the western section of the study area is the most productive area for ground water exploration. This is because the transverse unit resistance which is a product of aquifer thickness (h) and resistivity (Ω) are high in this area. It was there concluded that the southern part of the study area has a high aquifer potential when compared to the northern part. In addition, the Benin Formation was delineated as the formation with the greatest aquifer potentials in the study area. It is therefore recommended that a detailed groundwater exploration should be carried out before siting a borehole in the study area.

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