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Investigation of Variation in Resistivity with depth in Parts of Imo River Basin, South-eastern Nigeria

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***Abstract*:** *Schlumberger configuration of electrical resistivity survey was used to obtain 88 vertical electrical sounding data from various locations in parts of Imo River Basin to determine the variation of resistivity of the subsurface at various depths. The resultant apparent resistivity values were processed to obtain the respective resistivities of the different layers and their layer thicknesses. The VES data were further processed with the Arch-View 3.2a GIS software to obtain Iso-Resistivity maps at different levels of sounding at the various points. Each map represents a slice of resistivity variation at the depth of investigation corresponding to AB/2 = 2m, 4m, 10m, 100m, 200m, 300m respectively. The depths correspond to approximately 1.33m, 2.67m, 6.67m, 66.6m, 133.3m and 200m respectively.*
Keywords: *Schlumberger configuration, electrical resistivity, GIS software, Iso-Resistivity maps*

I. Introduction

Geophysical investigation is the most effective tool for indirectly mapping the subsurface rock formations and structures. A lot of problems connected with groundwater exploration can be solved with the help of geophysical methods. These include the location of water bearing formations and estimation of their depths and thicknesses; delineation of weathered zones, valley fills, freshwater- saline water interfaces, and groundwater flow directions[1]. Exploitation of this resource requires rapid and cost effective techniques of locating sustainable water bearing units (aquiferous zones) in a region (location of study area) where abortive boreholes are prevalent. Geophysical approach has, among others, been used to locate thesezoneswith great successes [2][3][4]..

There are five main methods of geophysical survey, namely: magnetic, gravity, seismic, electrical (self-potential, electromagnetic, resistivity and induced polarization) and well logging methods. Of these methods the electrical resistivity method is the most widely used method in groundwater research. This is due to the fact that the electrical properties, especially the resistivities, of geologic formations vary significantly between their dry and saturated states [5].

In vertical electrical sounding (VES) the goal is to observe the variation of resistivity with depth. The technique is best adapted to determining depth and resistivity for flat-lying layered rock structures, such as sedimentary beds, or the depth to the water table. The Schlumberger configuration is most commonly used for VES-investigations, where the current and potential pairs of electrodes have a common mid-point, but the distances between adjacent electrodes differ. The mid-point of the array is kept fixed while the distance between the current electrodes is progressively increased. This causes the current lines to penetrate ever greater depths, depending on the vertical distribution of conductivity [6].

Surface electrical resistivity surveying is based on the principle that the distribution of electrical potential in the ground around a current-carrying electrode depends on the electrical resistivities and distribution of the surrounding soils and rocks. The usual practice in the field is to apply an electrical direct current (DC) between two electrodes implanted in the ground and to measure the difference of potential between two additional electrodes that do not carry current. Usually, the potential electrodes are in line between the current electrodes, but in principle, they can be located anywhere. The current used is either direct current, commutated direct current (i.e., a square-wave alternating current), or AC of low frequency (typically about 20 Hz). All analysis and interpretation are done on the basis of direct currents. The distribution of potential can be related theoretically to ground resistivities and their distribution for some simple cases, notably, the case of a horizontally stratified ground and the case of homogeneous masses separated by vertical planes (e.g., a vertical fault with a large throw or a vertical dike). For other kinds of resistivity distributions, interpretation is usually done by qualitative comparison of observed response with that of idealized hypothetical models or on the basis of empirical methods [7].

Mineral grains comprised of soils and rocks are essentially nonconductive, except in some exotic materials such as metallic ores, so the resistivity of soils and rocks is governed primarily by the amount of pore water, its resistivity, and the arrangement of the pores. To the extent that differences of lithology are accompanied by differences of resistivity, resistivity surveys can be useful in detecting bodies of anomalous materials or in estimating the depths of bedrock surfaces. In coarse, granular soils, the groundwater surface is generally marked by an abrupt change in water saturation and thus by a change of resistivity. In fine-grained soils, however, there may be no such resistivity change coinciding with a piezometric surface. Generally, since the resistivity of a soil or rock is controlled primarily by the pore water conditions, there are wide ranges in resistivity for any particular soil or rock type, and resistivity values cannot be directly interpreted in terms of soil type or lithology. Commonly, however, zones of distinctive resistivity can be associated with specific soil or rock units on the basis of local field or drill hole information, and resistivity surveys can be used profitably to extend field investigations into areas with very limited or nonexistent data. Also, resistivity surveys may be used as a reconnaissance method, to detect anomalies that can be further investigated by complementary geophysical methods and/or drill holes.

The electrical resistivity method has some inherent limitations that affect the resolution and accuracy that may be expected from it. Like all methods using measurements of a potential field, the value of a measurement obtained at any location represents a weighted average of the effects produced over a large volume of material, with the nearby portions contributing most heavily. This tends to produce smooth curves, which do not lend themselves to high resolution for interpretations. Another feature common to all potential field geophysical methods is that a particular distribution of potential at the ground surface does not generally have a unique interpretation. Although these limitations should be recognized, the non-uniqueness or ambiguity of the resistivity method is scarcely less than with the other geophysical methods. For these reasons, it is always advisable to use several complementary geophysical methods in an integrated exploration program rather than relying on a single exploration method.

II. Geology Of The Study Area

The study area is located between latitudes 5^o 05"N and 5^o 45"N, and longitudes 7^o 00"E and 7^o 30"E, within the Imo River Basin. This covers parts of four geologic formations in the Basin. These include the Coastal Plain Sands of the Benin Formation, Ogwashi-Asaba Formation, Bende-Ameki Formation, and Imo Shale. The location map of the study area is shown in Fig. 1. The Ogwashi-Asaba formation is subsumed within the coastal plain sands.

The Imo River Basin is based on a bedrock of a sequence of sedimentary rocks of about 5480m thick and with ages ranging from Upper Cretaceous to Recent [8]. 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 (225-65 M.Y.B.P.) [9]. Generally, there are two different classes of formations underlying the Imo River Basin. About 80% of the basin consists in 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. 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. The generalized regional stratigraphy is shown in Table 1.

Table 1: Generalized stratigraphy of the Imo River Basin [10].

Age	Formation Name	Maximum approx. Thickness (m)	Character
Miocene-Recent	Benin	2000	Unconsolidated, yellow and white sandstones, 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 units.
Paleocene	Imo	1200	Blue to dark grey shales and subordinate sandstones. It includes two sandstones-the Umuna and Ebenebe sandstones.

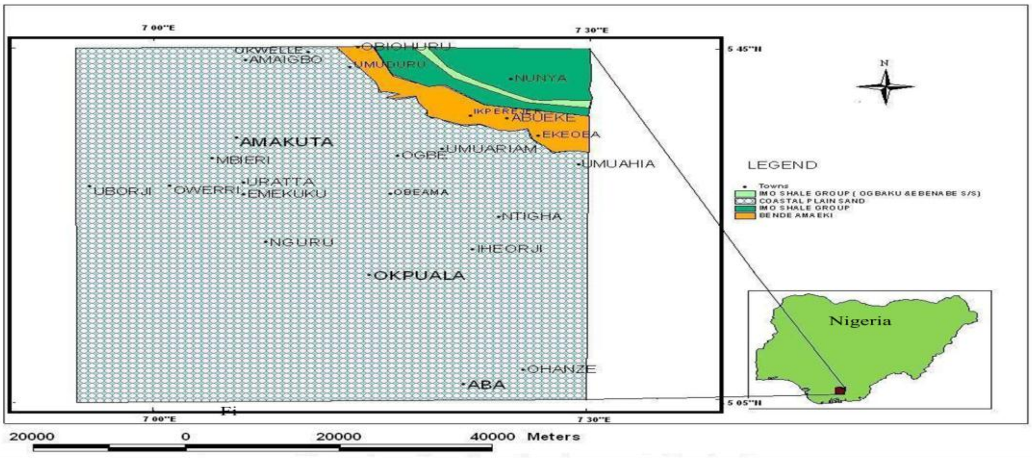

Figure 1: Geology Map of the Study Area

III. Methodology

The Schlumberger configuration was used in the resistivity survey. The ABEM Terrameter SAS 4000 was used to obtain VES data from the field. SAS stands for Signal Averaging System – a method whereby consecutive readings are taken automatically and the results are averaged continuously. The ABEM Terrameter SAS 4000 delivers high voltages and currents. In the resistivity surveying mode, the Terrameter SAS 4000 operates with a battery powered, deep-penetration resistivity meter with an output sufficient for a current electrode separation of 2000 meters under good surveying conditions. A maximum current electrode separation of 1000m was used in this research. The SAS 4000 is equipped with a PC –compatible microcomputer and controlled by four knobs, and the results of measurements and calculations are digitally displayed on a liquid crystal display on its panel. The program allows the user to specify the measuring parameters in detail. A total of 88 VES data set were obtained in the various locations. Modeling of VES results was done using the RESIST software, which is an iterative inversion-modeling program. Analysis of the resulting apparent resistivity versus the half-current electrode separations yielded layered earth models composed of individual layers of specified thickness and apparent resistivity. The VES results, Table 1, were further processed with the Arch-View 3.2a GIS software to obtain Iso-Resistivity maps at different levels of sounding at the various points.

Table 1: Apparent Resistivity Values for Some Selected AB/2 spreads.

VES NO	VES STATION	COORDINATES		AB/2 = 2.00 m	AB/2 = 4.00.m	AB/2 = 10.00m	AB/2 = 40.00m	AB/2 = 60.00m	AB/2 = 100m	AB/2 = 150m	AB/2 = 200m	AB/2 = 250m	AB/2 = 300m
		NORTH-INGS	EASTI-NGS										
KS1	OKWELLE 1	192328	524631	1018	1069	496	699	967	1316	1668	1960	1979	1904
KS2	OKWELLE 2	192101	525385	1377	869	1069	963	891	673	322	180	134	93
KS3	UMUNNA 1	193625	527164	164	204	251	249	205	134	89	53	41	31
KS4	OKWE 1	194011	528398	240	58	36	103	136	150	128	101	81	53
KS5	OKWE 2	194534	529866	405	75	79	405	502	520	433	390	293	207
KS6	OKWE 3	194887	531171	139	92	56	69	71	59	52	37	32	31
KS7	UMUNNA 2	195957	532768	34	33	62	121	149	198	185	146	112	92
KS8	AMURO 1	196535	533894	31	10	16	47	55	57	48	26	20	12
KS9	AMURO 2	197628	535422	19	10	6	15	19	33	39	49	61	70
KS10	UMUNNA 3	194590	532056	138	25	12	55	65	79	84	89	94	100
KS11	OBIOHURU 1	193434	530967	338	125	218	930	1185	1821	1876	1624	1456	1210
KS12	OBIOHURU 2	192063	530712	537	310	585	1210	1548	1727	1801	1469	1201	1002
KS13	ORJI	190453	530273	398	361	364	1402	2093	2960	3374	3519	3372	3061
KS14	IKPEREJERE	178912	545625	620	439	368	1277	2097	3265	4025	3811	3515	3232
KS15	UMUDIKE ELUAMA	178516	547311	1034	1456	2162	4311	5894	7081	6403	4670	3656	2843
KS16	UMUDIBIA ELUAMA	178555	548770	418	809	2025	7056	9365	11000	10225	8648	6395	4898
KS17	ABUEKE	178411	550335	1326	769	549	1080	1480	2100	1907	1529	1228	944
KS18	EKEOBA	174718	554389	1610	477	160	492	801	1328	1485	1954	1780	1519
KS19	AMAOGWU G-WU	176000	553668	8	10	22	39	24	14	9	5	4	3
KS20	NUNYA 1	186622	550846	778	50	66	136	114	48	25	17	16	17
KS21	NUNYA 2	187804	549394	271	221	531	571	496	364	271	197	155	119
KS22	EZIAMA	189225	530008	218	138	380	1388	1915	2801	2398	1878	--	--

	OSUAMA												
KS23	UMUEZEAL A UMUDURU	187779	522952	1199	1678	3010	7308	8535	7967	5840	--	--	--
KS24	UMUOKEHI UMUAHIA	175472	557890	1890	1880	1840	1880	2740	2741	2000	2000	1900	1900
KS25	FAULKS RD, ABA	125638	544503	2330	1133	1542	1006	547	210	162	348	255	307
KS26	AFARA-UKWU, UMUAHIA	168315	557877	962	1089	1311	2793	3071	3086	2390	1185	440	238
KS27	OBOKWU NGURU,	164201	530389	1995	1980	1950	2040	2400	2360	2330	2505	3000	3100
KS28	UMUOVOR, OLD UMUAHIA	165110	555410	492	898	1244	2803	3763	3111	2992	3134	2683	2435
KS29	UMUIKE LOWA	153926	546313	1908	2356	3212	5943	5108	5725	1909	859	603	486
KS31	100 WORKS L/O OWERRI	168585	510539	470	858	1055	949	1230	1886	2039	1851	1704	1453
KS32	AVUTU OBOWO	170118	545078	181	257	399	901	1142	1120	927	669	459	332
KS33	UMUGHARA ONICHA	167088	540071	408	719	1225	2742	3568	4791	5676	5782	5270	4909
KS34	OBIBIEZENA	156051	511975	624	861	708	1520	2546	2586	2779	2315	2032	2003
KS35	NNARAMBI A	168508	533985	508	961	2370	4360	3850	5910	9520	9160	11210	12680
KS36	OGBE	169345	535735	335	527	1138	3710	4990	7540	12120	18000	18870	17250
KS37	NKWO OBOHIA	172246	530001	386	529	1554	17140	29270	30610	35840	47500	50500	46860
KS38	UMUMBIRI OPARANADI M	173902	534823	829	1069	1125	2598	3119	3888	3662	3645	2886	2750
KS39	UMUEZEAL A AMA	185305	531386	564	898	997	132	75	44	89	101	50	246
KS40	UMUERIM UMUNAKAN U	183186	532985	276	629	1202	1567	1102	1237	1189	977	661	645
KS41	UMUARO UMUNUMO	184425	535949	1543	2331	2132	1300	1577	2111	2338	2729	2699	3028
KS42	UMUEZE	182456	530388	3790	3760	3730	4690	4020	3620	3720	4450	4850	4775
KS43	UMUANUNU NSU	180934	539767	519	1346	2281	2956	413	332	2508	2527	2932	2140
KS44	UMUAGBA ONICHA	168741	540113	8893	10742	10263	8881	9343	7909	4322	2560	2248	1463
KS45	UMUDURU IKPEREJERE	155685	509897	491	615	1139	1806	2105	2234	1956	3124	1313	994
KS46	UMUWIWU UMUIHI	155494	509711	1994	2088	2158	2262	2432	2964	3974	4274	3148	3162
KS47	AMAOGU AMAINYINT A	171917	546440	4030	4160	4230	5670	5433	5000	4226	4135	4080	4100
KS48	UMUCHOKO AMACHARA	173112	514599	1037	1341	1136	2057	2740	4760	6297	6860	5999	4930
KS49	ABOH EBIKORO	175927	514671	295	432	776	677	1494	2322	3405	3727	3225	--
KS50	NNEATO UMUOKE	180849	531448	4723	5101	6051	4106	4631	5059	4741	4206	4007	3587
KS51	ISIEBU	190363	528456	117	163	103	45	45	46	100	297	322	384
KS52	AGWUNADI M AMAUKWU	180849	531448	2399	4200	6127	3776	3177	4060	4356	2956	2814	2677
KS53	UMUZOHO EZIHE	186757	525107	142	168	250	745	920	1556	1567	1258	774	--
KS54	UMUEZEAL AKUMUNK WO	186248	531524	650	904	959	1748	1905	1400	859	662	710	573
KS55	EZIAMA OSUAMA	189241	522955	219	138	395	1523	1769	2840	3969	1795	--	--
KS56	UMUEZEAL A EGBE	187763	530004	1199	1464	2955	6612	4278	8535	7362	5742	--	--
KS57	IKPA MBEKE	186457	531490	359	544	299	24	14	10	20	22	33	45
KS58	ODONIHEME	186713	530357	150	187	315	746	1173	1414	961	5652	882	--

	UMUELEMA I												
KS59	UMULUWE AJIRIJA	183344	534036	515	1124	1663	2694	3585	4569	3662	10268	4438	7287
KS60	UMUODIMO DU ORODO	180641	507501	1161	1411	1182	2231	2953	4318	5029	5534	5572	4540
KS61	UMUOHIAG U	157988	523336	3080	3050	3010	1880	1630	1600	1625	1550	2000	2858
KS62	OKWUDOR	191639	506091	769	1034	728	1654	2243	3261	4000	4235	4776	4155
KS63	UMUOMA AMUCHA	184724	506177	1439	1809	1972	3006	3962	4557	5318	5956	6647	4445
KS64	OFEIYI UMUDI	193219	517154	1990	1970	1940	1980	2840	2850	2880	2445	1970	1960
KS65	OBINUHU NKWERRE	195019	516680	138	273	2169	3060	2062	659	88	90	356	825
KS66	UMUGARA NKWERRE	190358	519088	2800	1359	1420	748	487	233	166	374	337	236
KS67	DURUEZE, UMUOZU	190104	519188	3114	4573	5666	3890	4389	3140	2348	2013	1780	1093
KS68	UMUDIWEB UUMUOPAR ADIM	187611	520830	1570	3693	5620	3152	2651	3091	5624	8385	7515	6071
KS69	ABBA	185453	520014	3650	3700	3750	4590	3783	3150	3450	3050	2600	2740
KS70	UMUANYA-AMAIGBO	190967	518068	217	319	544	805	1097	1078	1050	1094	1435	1582
KS71	UMULEKE-AMAIGBO	190500	516223	1604	2954	3095	3289	4036	5897	4818	3905	2932	1985
KS72	UMUOZU	190358	519088	505	658	849	2140	2210	3686	3303	3262	3451	2759
KS73	ABAJAH	185587	519930	1763	2140	1028	499	887	643	742	789	2280	--
KS74	AVUTU-OBOWO	173737	545627	2819	1148 4	1323 5	4708	3113	2926	3277	2273	1429	--
KS75	UMUARIAM	171948	541939	282	790	1959	2420	1899	4499	6759	2937	3327	4032
KS76	OTOKO	171688	540042	1238	2683	2354	2570	1040	575	601	569	334	--
KS77	AFOR UMUOKEH	173968	545263	878	1094	3704	6854	2263	2140	1284	6385	7740	--
KS78	OKWELLE-OJIAMA	193261	524620	615	1015	1724	2223	2096	2811	1907	2099	1616	344
KS79	OKWE	194354	529340	126	192	255	331	269	31	102	402	39	98
KS80	NKWO-UMUCHEKE	195362	529032	293	282	398	795	373	214	165	166	144	--
KS81	UMOKO-OKWELLE	192974	524741	987	2332	904	348	178	168	174	103	97	142
KS82	AMANO-UMUAGWO	193029	525879	1136	1500	2221	852	181	36	25	21	9	6
KS83	OKWE LGA HQTRS	196579	528827	2500	2520	2970	3160	2870	2980	2950	2380	2080	2150
KS84	UMUEZEAL A-UMUNA	196870	534218	189	205	118	11	10	10	10	6	5	5
KS85	AFOR-EZIUHU, UMUNA	195102	532555	2475	2390	2340	3450	2690	2650	2650	1985	1970	2110
KS86	UMUDIMOH A-AMAIKE	194721	511981	1995	2534	2345	5454	4018	3809	3024	4030	3032	2963
KS87	AMANATOR -IHITTE,	195531	511394	428	557	336	23	1	4	9	73	131	--
KS88	AMIKE	195053	512092	85	143	204	362	442	491	417	345	161	151
KS89	UMUEZE-AMIKE	195163	512203	168	269	511	1150	1387	2282	2829	3229	3403	3212
KS90	NAZE	159633	512175	473	592	628	1634	2150	2207	2475	2212	2148	2116

IV. Results And Discussion

Maps of the respective AB/2 spreads are shown in Figures 2, 3, 4, 5, 6 and 7 respectively. Each map represents a slice of resistivity variation at the depth of investigation corresponding to AB/2 = 2m, 4m, 10m, 100m, 200m, 300m respectively. The depths correspond to approximately 1.33m, 2.67m, 6.67m, 66.67m, 133.33m and 200m respectively. These have been assumed to be two thirds of AB/2. The maps were derived from data in Table 1 which shows the apparent resistivity values for selected AB/2 spreads above.

The map for AB/2 = 2m indicates lower values of resistivity (0-991Ωm) around the parts of the study area within the Imo Shale, covering Amuro (KS 9), Umuna (KS 7), Nunya (KS 21); also, parts of the Ameki geologic formation covering Obiohuru (KS 12), Orji (KS 13), Ikperejere (KS 14), Abueke (KS 17). The areas shaded red have predominantly lower resistivities. The values of resistivity in areas within the Imo Shale are closer to the lower limit within this range, while the values of resistivity around Owerri are closer to the upper limit. The values of resistivity around Umuahia are also within this range, although they are closer to the middle and upper limit than the lower limit. This agrees with the geology of the area. At a low depth corresponding to AB/2=2m the formation is mainly low resistivity clay and shale. Imo Shale consists mostly of shale and some clay, with intercalations of standstone. Areas around Owerri fall within the coastal plain stands with generally higher resistivities.

There are locations that feature higher resistivity values such as Umuagba – Onicha (KS 44), Umueze (KS 42), Umuohiagu (KS 61). They are all located within the coastal plain sands. Fig. 2 shows the Iso-Resistivity map for AB/2 = 2.00m. It represents the resistivity pattern at a depth of 1.33m. This gives an indication of the nature of the resistivity of the top soil in the study area. Fig. 3 shows the Iso-resistivity map at AB/2 = 4.00m, which corresponds to the resistivity pattern at a depth of 2.67m. Higher resistivities can be observed at some locations between Nnarambia and Umuahia in Ogwashi-Asaba formation.

There is a noticeable shift in the spatial variation of resistivity for AB/2 =10m (Fig. 4). This is obvious from the fact that at greater depths the resistivity variation is different. Comparing the maps for AB/2 = 2m and AB/2 = 10m it can be seen that for Owerri and Umuahia the resistivity increases. The Iso-Resistivity map for AB/2 = 10m is shown in Fig. 4, which corresponds to the resistivity pattern at a depth of 2.67m. The shift in resistivity is clearly seen in the two maps from 2000 to 2500Ωm. The increasing trend in resistivity with depth can be explained by the fact that at shallow depth in most of the areas we have clay and shale streaks and sandy shales or sandy clay. The area corresponding to Imo Shale and some parts of Ameki Formations feature the lowest resistivities, which indicate the presence of clay or shale (<500Ωm). Areas with resistivities 500-1000 Ωm could be interpreted as sandy clay for lower depth; or sandy shale at greater depth. Areas with resistivities 2000-8000 Ωm could be interpreted as sand. Based on this, we can see from the iso-resistivity maps that areas south of Nnarambia which fall within the Benin Formation are largely sandy. The highest resistivities are located within the Ogwashi-Asaba Formations, particularly between Nnarambia (KS35) and Avutu-Obowo (KS75), and also between KS75 and KS26 (Umuahia). According to the geology of the area, Ogwashi-Asaba is characterized by unconsolidated sandstones with carbonaceous mudstones, sandy clays and lignite seams.

For AB/2 = 100m there is a location that features a marked increase in resistivity, at Nkwo Obohia (KS 37). There is a general indication of an increase of resistivity with depth. Fig. 5 shows the Iso- Resistivity map for AB/2 = 100m, which corresponds to the resistivity pattern at a depth of 66.67m.

Fig. 6 shows the Iso-resistivity map for AB/2=200m. This represents the resistivity pattern at a depth of about 133m. The map shows that at the depth represented, areas with the highest resistivity are located within the middle of the study area, around the KS37 in the Ogwashi Asaba Formation. This implies that most of the sandstones are located around there since the resistivity range >10542Ωm are around it. There is also an indication that much of the areas within the Benin Formation from the middle down are mainly sands and sandstones.

Figure 7 shows the Iso-Resistivity map for AB/2=300m, representing a depth of about 200m. The very high resistivity at KS37 is also evident here. The Benin Formation features mainly sand and pebbly sandstones.

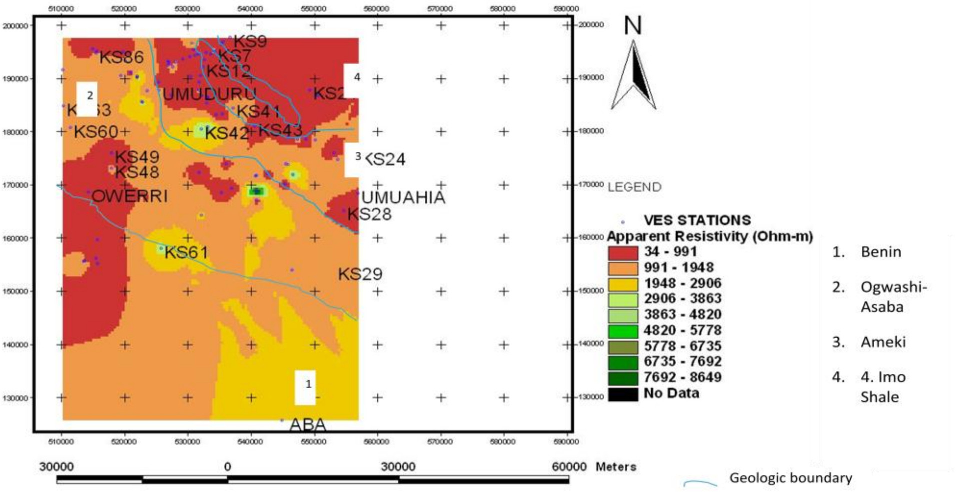

Figure 2: Iso-Resistivity Map for AB/2 = 2.00 m

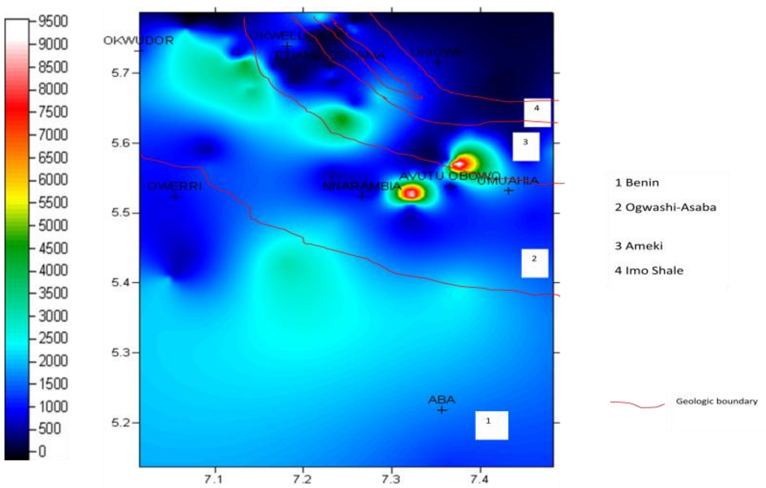

Fig. 3: Iso- Resistivity Map for AB/2 = 4.00m

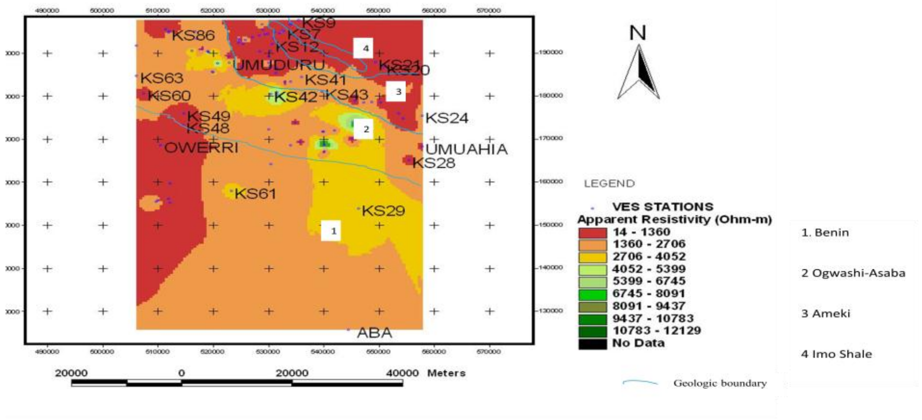

Figure 4: Iso-Resistivity Map for AB/2 = 10.00m

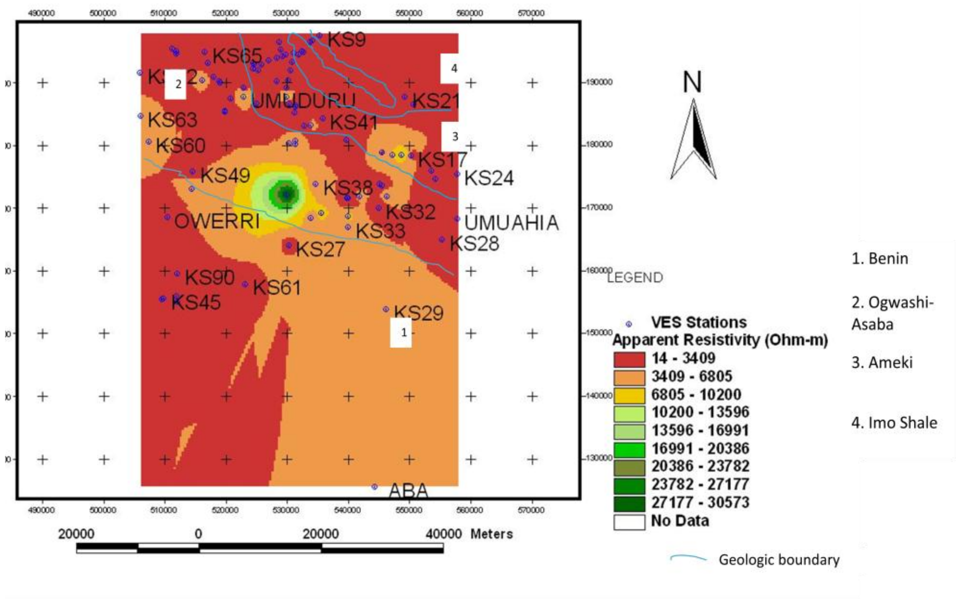

Figure 5: Iso-Resistivity Map for AB/2 = 100.00m

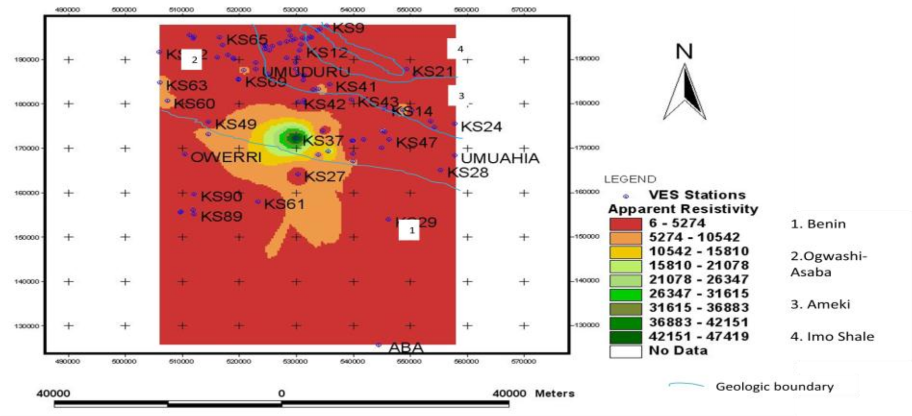

Figure 6: Iso- Resistivity Map for AB/2 = 200.00m

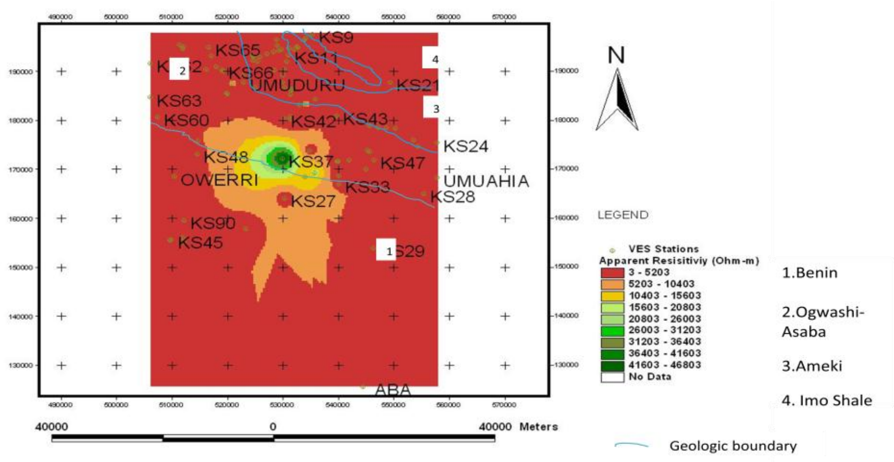

Figure 7: Iso-Resistivity Map for AB/2 = 300.00m

V. Conclusion

This work provides in graphic detail the resistivity patterns in the study area. The results of the interpretation of the VES data are in close agreement with the lithological information from borehole records.
Over areas in the outcrop surface of the Imo Shale geologic formation, most of the layers consist of shale interspersed with clay, and some sandstone. The presence of clay and shale can impede the downward movement of the contaminant front. Over areas within the Ameki geologic formation, most of the layers consist of shale, clay and sand, and sandstones. Over the areas within the Ogwashi-Asaba formation and the Benin Formation the layers consisted mainly of sand, sandstone, silt and sparsely distributed clay.

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