

Geophysical Sounding for the Determination of Aquifer Hydraulic Characteristics from Dar- Zurrock Parameters: Case Study of Ngor Okpala, Imo River Basin, Southeastern Nigeria.

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ABSTRACT

Hydrogeophysical evaluation of Ngor-Okpala area and environs, Southeastern Nigeria was carried out to determine the nature, type, frequency and hydraulic parameters of the aquifers of the area. A total of twenty-eight (28) vertical electrical soundings (VES) were acquired with a maximum electrode separation of $AB/2=500\text{m}$, using the ABEM Terrameter SAS 4000. Three (3) parametric soundings were carried out at the locations of existing boreholes. The VES data were analyzed using a combination of curve matching techniques and the OFFIX 3.1 Software. The layer parameters thus obtained from the analysis were used together with borehole electric logs and pumping test data at existing boreholes to estimate aquifer hydraulic parameters using Dar-Zurrouk parameters. Results revealed an average of six (6) geoelectric units, with the depth to the water table varying between 18-62m, while aquifer thickness ranges from 24m to 84m. Similarly, hydraulic conductivity ranges from 9.21m/day to 10.27m/day with a mean value of 9.76m/day, while the transmissivity values ranges from $310.72\text{m}^2/\text{day}$ – $1203\text{m}^2/\text{day}$ with an average of $600\text{m}^2/\text{day}$. These findings are indicative of a fairly homogenous geological environment with very high water yielding capacity and vulnerability of aquifer contamination.

(Keywords: Hydrogeophysical, Hydraulic parameters, Aquifer, hydraulic conductivity, transmissivity, Nigeria)

INTRODUCTION

The sedimentary sequences of southeastern Nigeria including those of the Imo River Basin are known to contain several aquiferous units. The study area is drained by the Oramiriukwa, Ogochia and some tributaries of Imo River from

the eastern part of the study area. The groundwater recharge is prolific due to high yearly average rainfall and high porosity and connectivity of the aquiferous zones. However, the characteristics of these aquifers such as transmissivity, hydraulic conductivity and storage potentials are not fully known and it has not been possible to design management strategies for optimal exploitation of these aquifers. The problem is further compounded by the poor knowledge of the aquifers (the geometry and nature of their hydraulic boundaries) being tapped. Although numerous boreholes have been drilled at various parts of the Imo river basin, there has not been any systematic and comprehensive study to establish the nature and distribution of the aquifers beneath the basin (Uma, 1989).

The determination of aquifer characteristics of hydraulic conductivity and transmissivity is best made on the basis of data obtained from well pumping test. These properties are important in determining the natural flow of water through an aquifer and its response to fluid extraction. However, in the case of limited pumping test data, these parameters may be estimated using the Dar- Zurrock parameters from geophysical sounding. Estimation of aquifer hydraulic parameters using Dar-Zurrock parameters is well known and has been extensively discussed by earlier scholars (Keller and Frischnechck., 1979; Koefoed, 1977; Niwas and Singhal,1981). A number of authors have recently attempted the prediction of aquifer hydraulic properties in Nigeria from surface electrical resistivity soundings (Onuoha and Mbazi, 1988; Mbonu et al., 1991; Ekwe, et al., 2006; Igboekwe et al., 2006; Onu and Ibezim,2004; among others). The study area which lies within latitudes $5^{\circ} 17'N$ to $5^{\circ} 26'N$, and longitudes $7^{\circ} 05'E$ to $7^{\circ} 14'E$ is located within Ngor - Okpala area and environs, of Imo State, Nigeria (Figure 1).

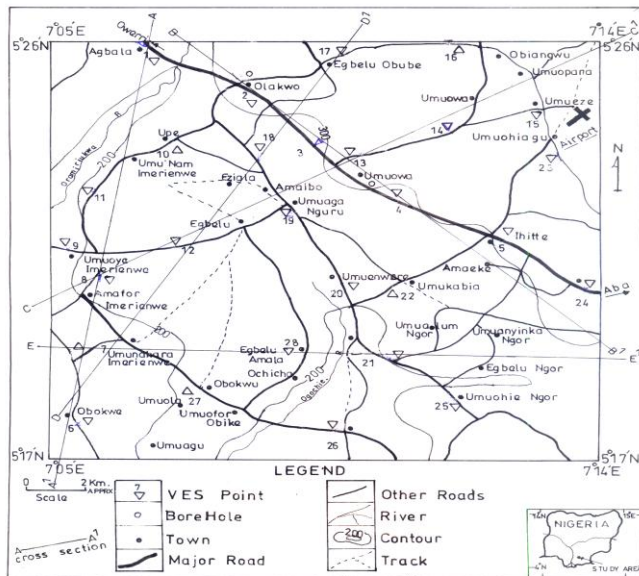


Figure 1: Location Map of the Study Area Showing VES Points and Borehole Points.

The study area is underlain by the Benin Formation (coastal plain sands) of southeastern Nigeria. High productivity of many boreholes already drilled in the area supports the prolific nature of the Benin Formation of southeastern Nigeria. However, most of these boreholes penetrated the shallow unconfined aquifer with the attendant risk of possible contamination. For a detailed and proper water resources management program, it is therefore necessary that data input from a variety of sources be used. In the present study, we attempted to define the aquifer geometry of the study area, infer their relationship with the geology, and to correlate some aquifer properties determined from pumping test with those calculated from results of surface geoelectric sounding from vertical electrical sounding.

Geological Framework

The project area lies on the southwestern part of Imo State, Nigeria and is located within latitudes $5^{\circ}17' N$ and $5^{\circ}26' N$ and longitudes $7^{\circ}05' E$ and $7^{\circ}14' E$. The study area belongs to the coastal sedimentary lowlands of the southeastern Nigeria hydrological province. It has a tropical climate with high temperature and seasonal rainfall. Two seasons are prominent in the area namely: dry and rainy seasons. The mean rainfall varies between 152mm to 2032mm. Geomorphologically,

the major river in the study area is the Imo River with tributaries which include Oramiriukwa and Ogochia Rivers. All these rivers are within the sandy coastal plain strata of Benin Formation (Miocene – Recent). Major erosional activities are common during the heavy rainy seasons around the Ogochia River because of the unconsolidated and loose nature of the sand. The western part is drained by Imo River and its tributaries, while the valleys are narrow and steep. The terrain is undulating and has a low topographical trend. However, the northern part is devoid of any river channel and has a high elevation.

The geology and geomorphology of the study area have been described in details by various authors (Onyeagocha, 1980; Amajor, 2005; Short and Stauble, 1965; Evamy et al., 1978; Uma, 1989; Reyment, 1965). Ngor Okpala and environs is underlain entirely by the Benin Formation (Figure 2). The Benin Formation is partly marine and continental. The Benin Formation consists of thick friable sands with linter intercalations of clay beds and lenses. The sand units are mostly coarse grained (Short and Stauble, 1967; Onyeagocha, 1980). The Formation has variable thickness and ranges from about 200m at the edge of its contact with the Older Ogwashi – Asaba Formation to about 2000m. Over 90% of the area is sand to sandstone with minor shale intercalations (Reyment, 1965).

MATERIALS AND METHODS

Two methods were used to evaluate the geological and hydrogeological potentials of the study area. Firstly, a detailed geological mapping of the study area was carried out followed by a direct current resistivity survey using the vertical electrical sounding method. Since resistivity is a fundamental electrical property of rock materials closely related to their lithology, the determination of the subsurface distribution of resistivity from measurements on the surface yields useful information on the structure and composition of buried formations. Vertical electrical sounding using the Schlumberger array with maximum electrode separation of 1000m was used in acquiring the resistivity data. The ABEM Terrameter SAS 4000 was used, which transmits a well-defined and regulated square wave that minimizes induction effects and attenuation.

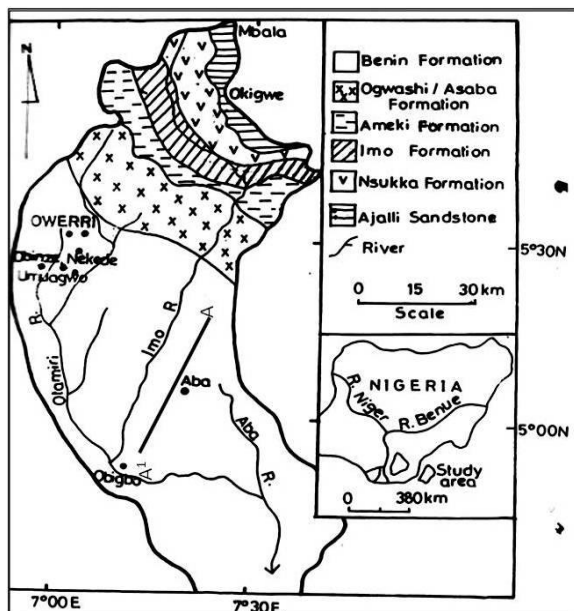


Figure 2: Geology Map of Imo River Basin Showing the Study Area (after Uma,1989).

The locations of the sounding points are shown in Figure 1. Three of the soundings (parametric soundings) were made at the sites of existing boreholes for comparative purposes. The existing boreholes beside which soundings were conducted are located at Ulakwo, Umuowa, and Umuohiagu with VES station numbers as 2, 21, and 23. The observed field data was converted to apparent resistivity values by multiplying with the Schlumberger geometric factor. The geometric factor for the Schlumberger array is given by the relationship:

$$G = \pi \left(\frac{a^2}{b} - \frac{b}{4} \right) \dots \dots \dots (1)$$

where a = half current electrode spacing and b = potential electrode spacing.

The data obtained is usually plotted as a graph of apparent resistivity against half electrode spacing. The electrode spacing at which inflection 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 inflection occurs (Vingoe,1972). This approximation has found useful applications in computer iterative modeling. Parameters such as apparent resistivity and thickness obtained from both partial curve matching were used as input data for computer

iterative modeling (Zohdy, 1976; Koefoed, 1977). Detailed quantitative interpretation was done using the OFFIX 3.1 software.

Similarly, Information from existing boreholes was utilized in this study for the purpose of correlation with the vertical electrical sounding data and information from geologic mapping. Such information acquired and used were pumping test data, electric logs, litho-logs, etc. These informations were used to enhance the evaluation of the groundwater hydraulic parameters.

Estimation of aquifer hydraulic parameters

It is a standard practice to estimate aquifer hydraulic parameters using Dar-zurrock parameters. Niwas and Singhal (1981) established an analytical relationship between aquifer transmissivity and transverse resistance on one hand, and between transmissivity and longitudinal conductance on the other hand. From Darcy's law, the fluid discharge Q is given by the relationship:

$$Q = KIA \dots \dots \dots (2)$$

and from Ohm's law, $J = \sigma E \dots \dots \dots (3)$

Taking into account a prism of aquifer material having a unit cross-sectional area and thickness h, Niswas and Singhal (1981) combined Equations (2) and (3) to get the relationship given as:

$$T = K\sigma R = \frac{KS}{\sigma} \dots \dots \dots (4)$$

where K = hydraulic conductivity, I = hydraulic gradient, A = cross sectional area perpendicular to the direction of flow, J = current density, E= electric field intensity, σ = electrical conductivity (inverse of resistivity), T = Aquifer, transmissivity from borehole, R = Transverse resistance of the aquifer, and S = Longitudinal conductance. S and T are often referred to as the Dar-Zurrock parameters. Similar studies have been carried out by so many other authors (Henriet, 1977; Onuoha and Mbazi,1988; Mbonu, et al.,1991. Igbokwe, et al., 2006. Ekwe, et al., 2006).

Quantitative interpretations of vertical electrical sounding data often lead to the generation of geoelectric layers. The information from these geoelectric layers enhances the identification and

interpretation of layer parameters which includes aquifer depth, thickness, and frequency. These layer parameters thus obtained together with existing pumping test information in drilled wells were then used to calculate the longitudinal conductance (S) and the transverse resistance (T) distribution. The transverse resistance is the product of the aquifer apparent resistivity and aquifer thickness while the longitudinal conductance is the product of the aquifer thickness and the apparent resistivity of the aquifer. These parameters (Da-Zurrock Parameters) were further applied in the estimation of hydraulic conductivity and transmissivity of the aquifers of Ngor- Okpala area. In trying to establish the relationship between the Da-Zurrock parameters and the layer parameters from the VES interpretations, aquifer materials (prospective sand/sandstone units) above the identified water table in the area were not considered in the calculation as this often constitutes a high degree of error in the estimation of the hydraulic parameters.

In areas of similar geologic setting, the product $K\sigma$ (diagnostic parameter) remains fairly constant (Niswas and Singhal, 1981, Onuoha and Mbazi, 1988). Thus knowing K values for existing boreholes and σ values extracted from the sounding interpretation for the aquifer at borehole locations, it has been possible to determine transmissivity and its variations from place to place, including those areas without boreholes. We have utilized these established relationships between aquifer hydraulic parameters and electrical resistivity sounding data to determine hydraulic conductivity and transmissivity of the aquifers within the study area.

RESULTS AND INTERPRETATION

Vertical Electrical Sounding

Data acquired from vertical electrical sounding using the Schlumberger array were processed and interpreted using a combination of curve matching and computer iterative modeling. Results of the computer interpretation are presented in Table 1. The study area is characterized by five major sounding curve types. These include A-type, K-type, H-type, AK-type and HK-type curves. The vertical electrical sounding points and their interpreted curve types are shown in Table 1 below. It is observed that the study area is predominantly of K-type curve

and a hybrid of HK-type that indicate the Benin Formation (coastal plain sand) signature. It also comprises of a multi-layer medium of AK-type and A-type curves. Figure 3 shows a typical geo-electric type curve obtained in the study area.

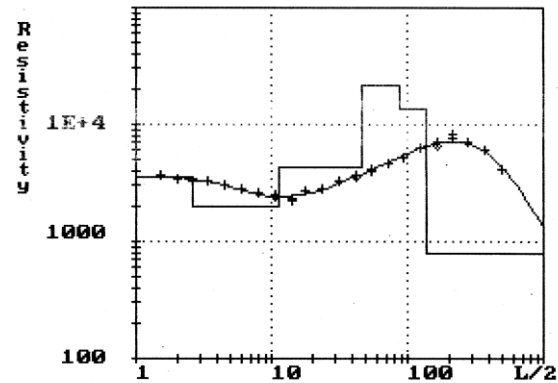


Figure 3: Typical Geo-Electric Type Curve Observed in the Study Area.

Several hydrogeophysical maps which include aquifer depth, aquifer thickness, aquifer hydraulic conductivity maps, among others were generated from the resistivity data. The apparent resistivity map shows that the apparent resistivity is high towards the N-E direction of the study area with the highest point at the flank of Agbala after Oramiriukwa River, while the apparent resistivity is low towards the western part of the map around Umuohie Ngor (Figure 4). This area has the lowest apparent resistivity, indicating shaly sand formation. Generally, aquifer resistivity in the area increases from the southwest to northeast.

Similarly, water table depth varies between 18m and 62m with a regional average depth of 35m. The depth to the water table tends to be low around Umunakara and high at Umuohiagu (Figure 5). The trend of the water table depth revealed that the eastern part of the study area has lower water table depth while the western part indicated a higher water table depth. Similarly, the aquifer thickness varies between 31.7m at Ulakwo to 126m at Ndokwu Umuoye with a regional mean value of 94.5m. The mean aquifer thickness of 94.5m in the study area is indicative of prolific groundwater potentials.

Table1: Summary of Results of Interpreted Layer Parameters from the Study Area.

Ves No	Location	No of layers	Curve type	Layer resistivity (ohm-m)							Layer depth (m)						Layer thickness (m)						Fitting error (%)
				p1	p2	p3	p4	p5	p6	p7	d1	d2	d3	d4	d5	d6	t1	t2	t3	t4	t5	t6	
1	Agbala	7	HK	2870	664	6740	4800	10000	3810	420	1.4	5.2	23.5	60.3	82.3	118	1.9	3.3	18.3	36.8	22	35.7	4.1
2	Ulakwo	7	AK	136	317	960	9200	1150	404	223	1.4	5.2	13.7	41.3	73.0	109	1.4	3.8	8.5	27.6	31.7	36	0.5
3	Ulakwo/umuowa Rd	6	AK	162	1150	453	1870	4600	1410	-	0.9	4.3	10.8	31.4	106.0	157	0.9	3.4	6.5	20.6	74.6	51	0.3
4	umuowa	7	HK	1350	263	6640	4410	2300	1750	940	3.4	8.4	37.4	86.2	134	193	3.4	5.0	29.0	48.8	47.8	59.0	0.48
5	ihitte	7	AK	247	7780	1830	8300	5640	3790	940	2.0	8.2	39.4	82.3	127	171	2.0	6.2	31.2	42.9	44.7	44.0	0.3
6	Obokwe	6	AK	496	860	2470	7860	5160	1750	-	1.1	4.5	33.9	87.2	143	-	1.1	3.4	29.4	53.3	55.8	-	0.75
7	umunakara	6	AK	730	4460	2940	6730	6060	547	-	3.0	9.3	61.1	113	173	-	3.0	6.3	51.8	51.9	60.0	-	0.8
8	Amafor	6	AK	3320	5000	8200	42000	13800	1420	-	3.4	26.5	46.3	89.6	127	-	3.4	21.1	21.8	43.3	37.4	-	7.0
9	Ndokwu Umuoye	6	HK	300	92	3220	3790	4910	333	-	0.9	2.2	30.8	94.7	157	-	0.9	1.3	28.6	63.9	62.3	-	0.1
10	Upe	6	AK	371	8300	2750	7720	3800	749	-	2.2	4.6	57.1	120	180	-	2.2	2.4	52.5	62.9	60.0	-	0.35
11	Umunam	6	AK	3350	14000	19100	51900	28100	7900	-	2.3	19.3	69.1	129	194	-	2.3	17	49.8	59.9	65.0	-	9
12	Umuoye /Nguru Rd	6	HK	2500	1790	3010	24600	6100	642	-	0.8	6.0	34.9	95.9	141	-	0.8	5.2	28.9	61.0	45.1	-	1.56
13	Airport Rd1 Umuowa	6	AK	548	900	3140	11300	5110	525	-	1.4	4.1	32	122	165	-	1.4	2.7	27.9	90.0	43.0	-	0.25
14	Airport Rd2 Umuowa	7	AK	1120	1580	2420	6480	7390	4110	890	0.6	15.6	34.1	104	172	219	0.6	15	18.5	69.9	68.0	47.0	0.35
15	Umuohiagu/ Umuenze	6	QH	5800	2040	850	3110	3970	72600	-	0.6	3.5	18.3	58.9	139	-	0.6	2.9	14.8	40.6	80.1	-	5.5
16	Eke Obiangwu	6	AA	1530	3740	7250	26400	19500	42000	-	0.8	7.7	14.8	91.8	143	-	0.8	6.9	7.1	77.0	51.8	-	6
17	Egbelu / Umuchoko	6	AK	4170	7500	14700	16400	7060	1540	-	3.0	38.4	92.4	144	207	-	3.0	35.4	54	51.6	63.0	-	0.5
18	Amaibo Nguru	6	AK	940	1930	4140	15900	5040	601	-	0.9	9.6	54.4	116	167	-	0.9	8.7	44.8	61.6	51.0	-	0.3
19	Orie Nguru Mkt Sq	7	HK	1750	323	800	7150	5760	4460	1890	0.7	2.1	16.5	87.6	143	193	0.7	1.4	14.4	71.1	55.4	-	0.48
20	Umuewere	6	HK	2900	1180	4330	28800	12600	1720	-	1.0	4.2	34.4	86.9	148	-	1.0	3.2	30.2	52.5	61.1	-	0.3
21	G.H. Umuneke	6	HK	3580	1970	4300	21400	13800	785	-	2.6	11.4	46.1	89.4	139	-	2.6	8.8	34.7	43.3	49.6	-	0.75
22	Umukabia Mkt	7	AK	1430	1090	3200	9300	6740	4260	660	0.8	2.3	54.0	102	141	180	0.8	1.5	51.7	48.0	39.0	39.0	0.8
23	Umuohiagu Mkt	5	QH	2120	1100	407	1120	2590	-	-	0.7	2.8	11.8	48.7	-	-	0.7	2.1	9.0	36.9	-	-	1.0
24	Umuechem Umuhu	6	HK	377	1910	1530	4140	2640	870	-	2.7	8.8	62.5	113	175	-	2.7	6.1	53.7	50.5	62.0	-	0.1
25	Umuehie Ngor	6	AK	477	1780	3940	3580	2610	830	-	1.8	29.7	83.4	135	183	-	1.8	27.9	53.7	51.6	48.0	-	0.35
26	Umueme Obike	6	AK	583	2150	3750	4890	2890	830	-	1.0	33.7	93.0	151	201	-	1.0	32.7	59.3	59.0	50.0	-	0.5
27	Obokwu Obike	6	AK	556	1470	3270	10600	4780	782	-	1.7	22.3	69.6	132	179	-	1.7	21.6	47.3	62.4	47.0	-	3.5
28	Egbelu Amala	6	HK	2710	980	2730	6980	2300	495	-	2.7	10.9	67.8	127	204	-	2.7	8.2	56.9	59.2	77.0	-	1.2

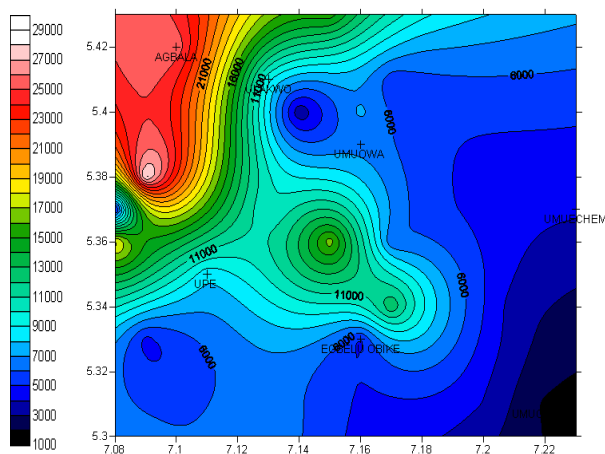


Figure 4: Map of the Study Area Showing Aquifer Apparent Resistivity in ohm meters.

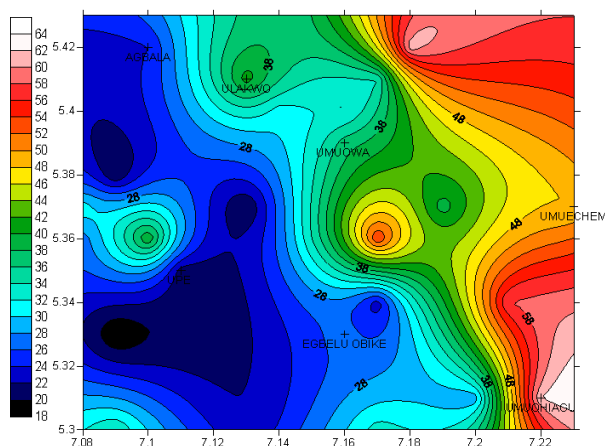


Figure 5: Map of the Study Area Showing Aquifer Depth in metres.

Iso- Resistivity Modeling

The iso-resistivity modeling of the study area revealed a multi- aquifer system with an average of two aquifers (between the depth range of 0m and 200m) and aquifer frequency of 70-90%. These results were obtained from 10 different iso-resistivity depth probes (using the principle of downward continuation of resistivity data) (Figure 6).

Similarly, it was observed that aquifer conductivity of Ulakwo increased within the 20-25m depth interval indicating shaly signatures (formation). However, between 30m to 40m, the formation at Ulakwo and Agbala changed to medium to coarse sand with Umuoia and the northern part of Agbala indicating high resistivities which is interpreted as saturated unconfined aquifer. However, at the depth of 200m, it was revealed that shale was dominant because of the low

resistivity signatures. In summary, the result generally revealed a progressive increase in resistivity with depth with occasional shale intercalations.

Aquifer hydraulic characteristics

Results of the estimated Dar-Zurrock parameters indicated that the longitudinal conductance varies between 0.0029 - 0.0429 while the transverse resistance varies between 53760 at Umuoia to 3587190 at Agbala (Figure 7). The diagnostic Constant ($K\delta$) was used to delineate the lithostratigraphic units within the area. On the basis of $K\delta$ product, the whole area was revealed to be hydrologically homogeneous with $K\delta$ values ranging from 0.00086 - 0.0011 indicating the Benin Formation. From these results it was inferred that the area is a single unit lithostratigraphically. This constant was also used to estimate the hydraulic conductivity and transmissivity for all the sounding locations across the study area (Table 2).

Results of the hydraulic conductivity values obtained from the study revealed that Ihitte town and its environ has the highest hydraulic conductivity value of 10.27m/day while Amaigbo Nguru has the lowest hydraulic conductivity value of 9.21m/day. Results of the study revealed that the study area has a fairly uniform hydraulic conductivity ranging from 9.21m/day to 10.27m/day with a mean value of 9.80m/day while the transmissivity values ranges from 310.72m²/day – 1203m²/day with an average of 600m²/day (Figures 7 and 8).

Correlation of Geoelectric Section with Borehole Logs

Four electric logs and litho-logs were used to correlate with geo-electric sections of the study area. These electric logs were acquired from different parts of the study area where wells have been previously drilled.

The result of the correlative analysis of the hydro-geophysical parameters of Ulakwo using VES2, electric log and borehole litho-log revealed that the aquiferous layer ranges from 31.7 – 106m from the VES data, 42 -197m in strata log, while electric log indicated its aquifer depth at 40m - 199m (Figure 9).

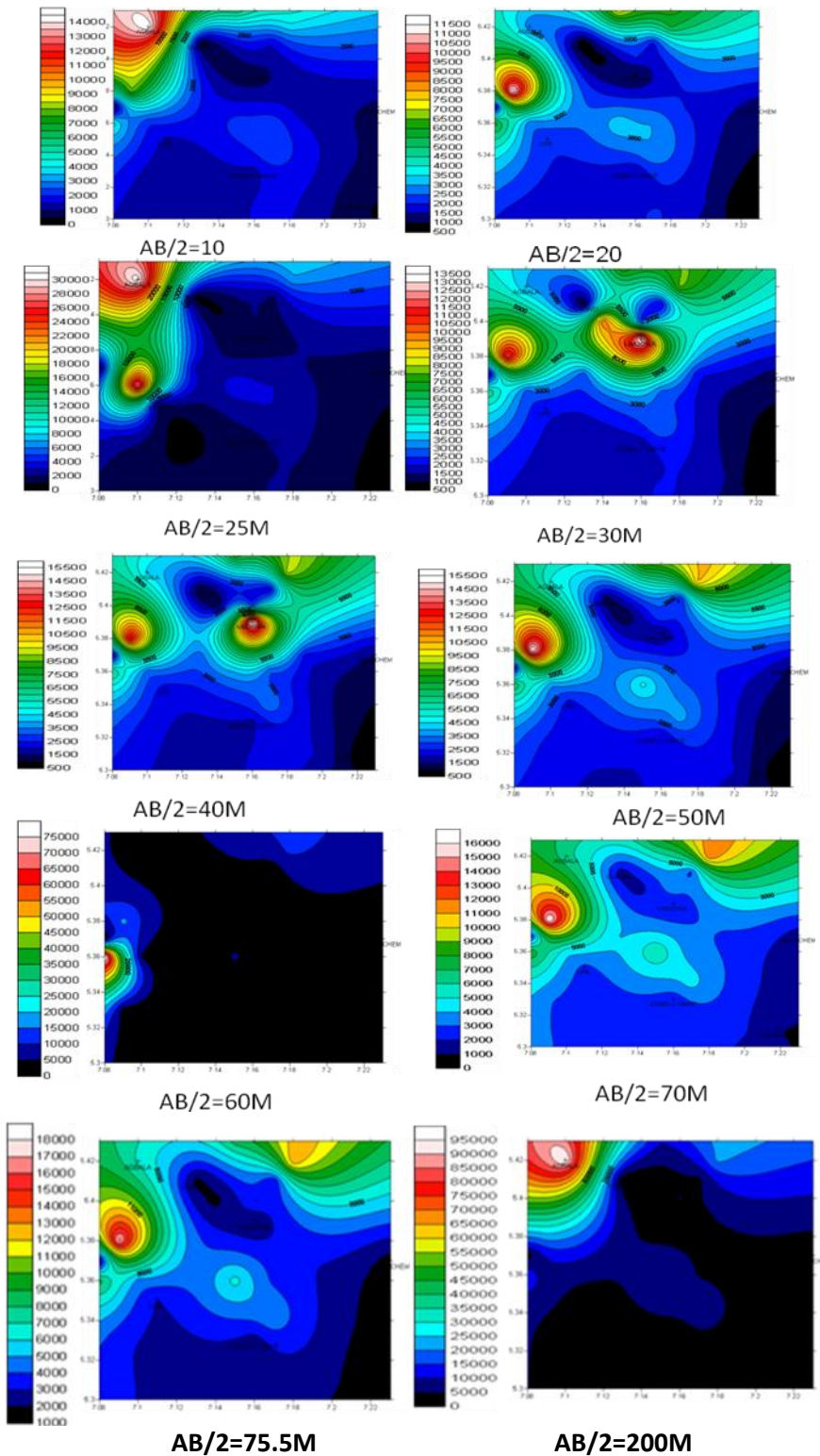


Figure 6: Iso-Resistivity Models of the Study Area Showing the Variation of (Downward Continuation) Apparent Resistivity with Depth in ohm meters.

Table 2: Summary of the Results of the Aquifer Hydraulic Parameters Interpreted from the Geo-Electric Sections in the Study Area.

Ves No	Location	Depth to water table (m)	Aquifer thickness (m)	Apparent resistivity (Ohm-m)	Aquifer conductivity, σ (Ohm-m)	Transverse resistance (ρxh)	Longitudinal Conductance (h/ρ)	Transmissivity, $y_1(k)$ values from wells	$k\sigma$ value	Hydraulic conductivity (m/day)	Transmissivity M^2/day
1	Agbala	24	58.8	20,513	0.000049	1206264	0.0029	-	0.00048	9.85	579.00
2	Ulakwo	41	31.7	3770	0.00027	119509	0.0084	16.24	0.0026	9.80	310.72
3	Ulakwo/ Umuowa Rd	31	74.6	2626	0.00038	195900	0.0284	-	0.0037	9.72	724.83
4	Umuowa Town	37	48.8	3775	0.00027	184220	0.0129	-	0.0026	9.82	478.97
5	Ihitte Okwe	39	74.1	4890	0.00021	362349	0.0152	-	0.0021	10.27	760.93
6	Obokwe Ozuzu	34	53.3	5180	0.00019	276094	0.0102	-	0.0019	9.84	524.58
7	Umunakara	18	103.7	5243	0.00019	543699	0.0198	-	0.0019	9.96	1033.03
8	Amafor	27	65.1	21,333	0.000049	1388778	0.0031	-	0.00048	10.24	666.61
9	Ndokwu	31	126.2	3973	0.00025	501393	0.0318	-	0.0024	9.54	1203.34
10	Upe town	21	115.4	4757	0.00021	548958	0.0243	-	0.0021	10.00	1152.81
11	Umunam	20	109.7	32,700	0.000031	3587190	0.0034	-	0.00030	9.81	1076.16
12	Umuoye /Nguru Rd	40	61.0	11,237	0.000088	685457	0.0054	-	0.00086	9.66	589.49
13	Airport Rd 1 Umuowa	32	90.0	6517	0.00015	586530	0.0138	-	0.0015	9.78	879.80
14	Airport Rd II Umuwa	34	68.0	5100	0.00020	346800	0.0133	-	0.0020	10.20	693.60
15	Umuohiagu/ Umuzeze	58	80.1	3540	0.00028	283554	0.0226	-	0.0027	9.56	765.60
16	Eke Obiangwu	61	77.0	17,717	0.000056	1364209	0.0044	-	0.00055	9.74	750.32
17	Egbelu / Umuchoko	38	105.6	12,720	0.000079	1343232	0.0083	-	0.00077	9.79	1034.29
18	Amaibo Nguru	20	61.6	8377	0.00012	516023	0.0074	-	0.0011	9.21	567.63
19	Orie Nguru Mkt Sq	40	55.4	4473	0.00022	247804	0.0124	-	0.0022	9.84	545.17
20.	Umuewere	34	52.5	15,243	0.000066	800258	0.0034	-	0.00064	9.76	512.17
21	General Hosp. Umuneke	23	43.3	13,169	0.000076	570218	0.0033	6.05	0.00074	9.75	421.96
22	Umukabia Mkt	54	48.0	5890	0.00017	282720	0.0082	-	0.0017	10.01	480.62
23	Umuohiagu Mkt	62	48.0	1120	0.00089	53760	0.0429	7.00	0.0087	9.74	467.71
24	Umuechem Umuhu	48	62.0	2770	0.00036	171740	0.0224	-	0.0035	9.70	601.09
25	Umuhie Ngor	29	51.6	2978	0.00034	153665	0.0173	-	0.0033	9.83	507.10
26	Umueme Obike	33	58.0	3420	0.00029	198360	0.0170	-	0.0028	9.58	555.41
27	Obokwu Obike	22	62.4	6217	0.00016	287941	0.0100	-	0.0016	9.95	460.71
28	Egbelu Obike	27	59.2	4003	0.00025	236978	0.0148	-	0.0024	9.61	568.75

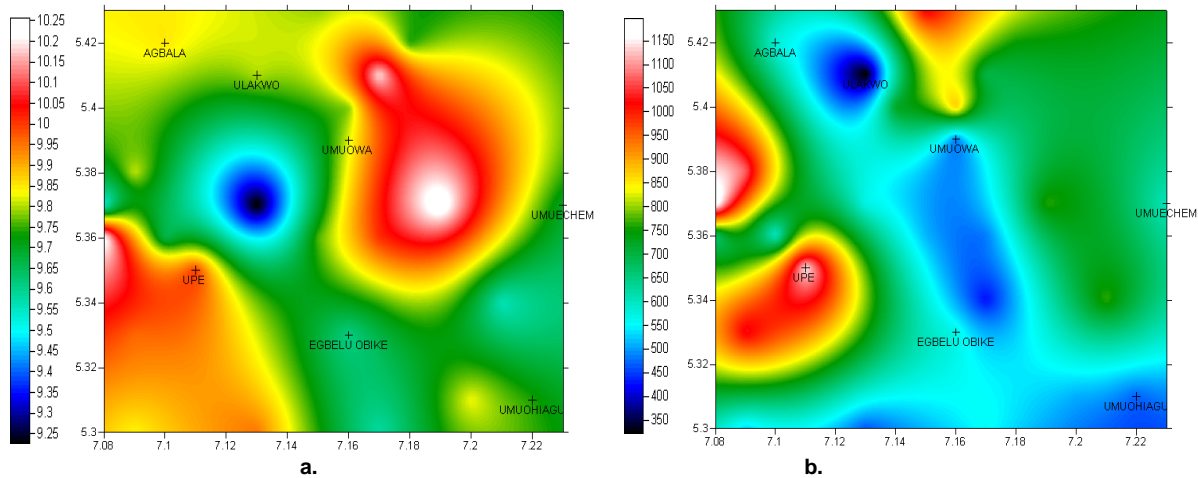


Figure 7: a) Map of the Study Area Showing the Variation of Aquifer Hydraulic Conductivity in the Area. b) Map of the Study Area Showing the Variation of Aquifer Transmissivity in the Area.

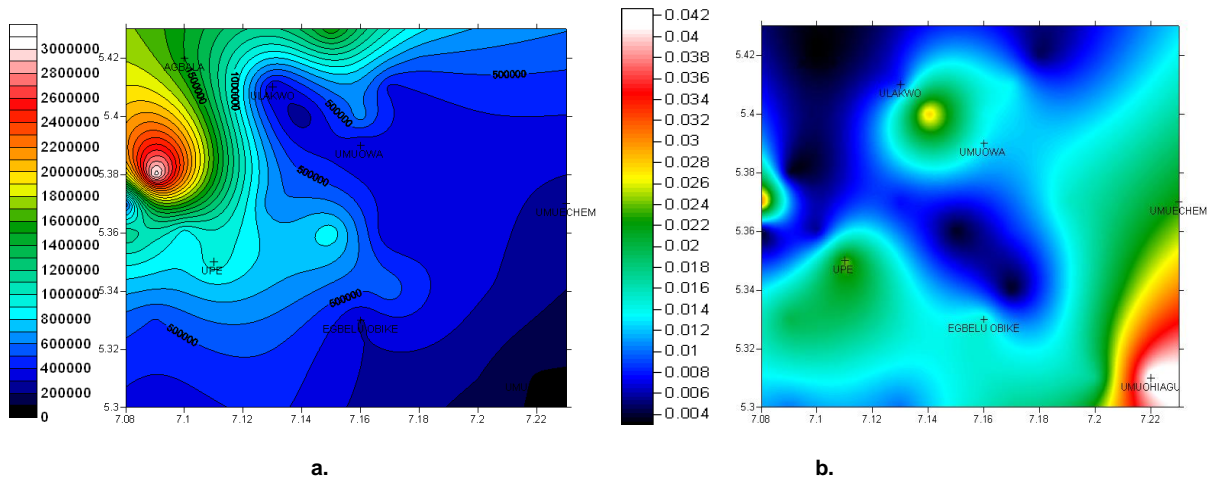


Figure 8: Map of the Study Area showing the Da- Zurrock Parameters. a) The Variation of Transverse Resistance across the Area. b) Variation of Longitudinal Conductance across the Area.

The correlation has also confirmed the occurrence of an average of two aquifers with the upper aquifer and the lower aquifer separated by thin lenses of clay. Similarly, for Umuowa area, the results revealed that the aquifer thickness indicated from VES 4 ranges from 37.4m - 193m, litho- log has thicknesses ranging from 43.3 - 140m, while electric log indicated its aquifer thickness as 35m - 145m. Hence, the average aquifer thickness obtained from the study (Table 1) ranges from 55m to 159.3m. Finally, well-to-well correlation of Ulakwo and Umuowa areas was carried out using lithologs from Ulakwo and Umuowa respectively as shown in Figure 9. It was observed that the aquifer thickness ranges from 44m -130m at Ulakwo and 45 -140m at

Umuowa. This also has confirmed the reliability of the result obtained from surface geophysical sounding (Table 1) indicating the ranges of the aquifer depth and the aquifer thickness.

Geologic (Interpretative) Cross-Sections

Four interpretative geologic cross sections were used to establish the variations of aquifer parameters with geology in the study area. The four interpretative cross sections (profiles) are A-A¹, B-B¹, C-C¹, and D-D¹ as shown on the location map in Figure 1 above while some of the geologic models produced from the different cross sections are shown in Figure 10.

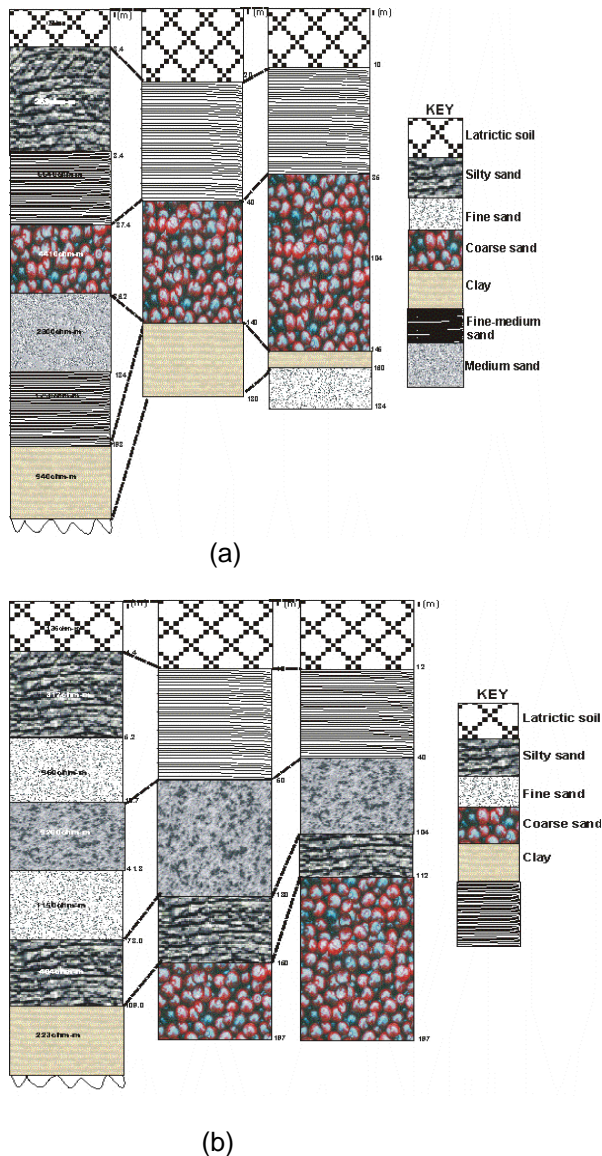


Figure 9: Correlation of VES Data, Litho-Log Section and Electric Log Data (a) Ulakwo and (b) Umuowa Boreholes.

Profile A-A¹ was taken along the southeast-northeast Flank of the study area. The depth to the water table is shallow at VES 7 with a mean depth value of 45m and deeper at VES 8. The aquifer thickness ranges from 25m to 153m. Lithological sequences are fine, coarse, medium sand and shale. Similarly, profile B-B¹ was taken along the northeast to northwest flank of the study area. The water table depth is shallow at VES 3 (Ulakwo/Umuowa Road) and deep at VES 13 (Airport Road 1). The mean water table depth of the cross section is 60m while the aquifer

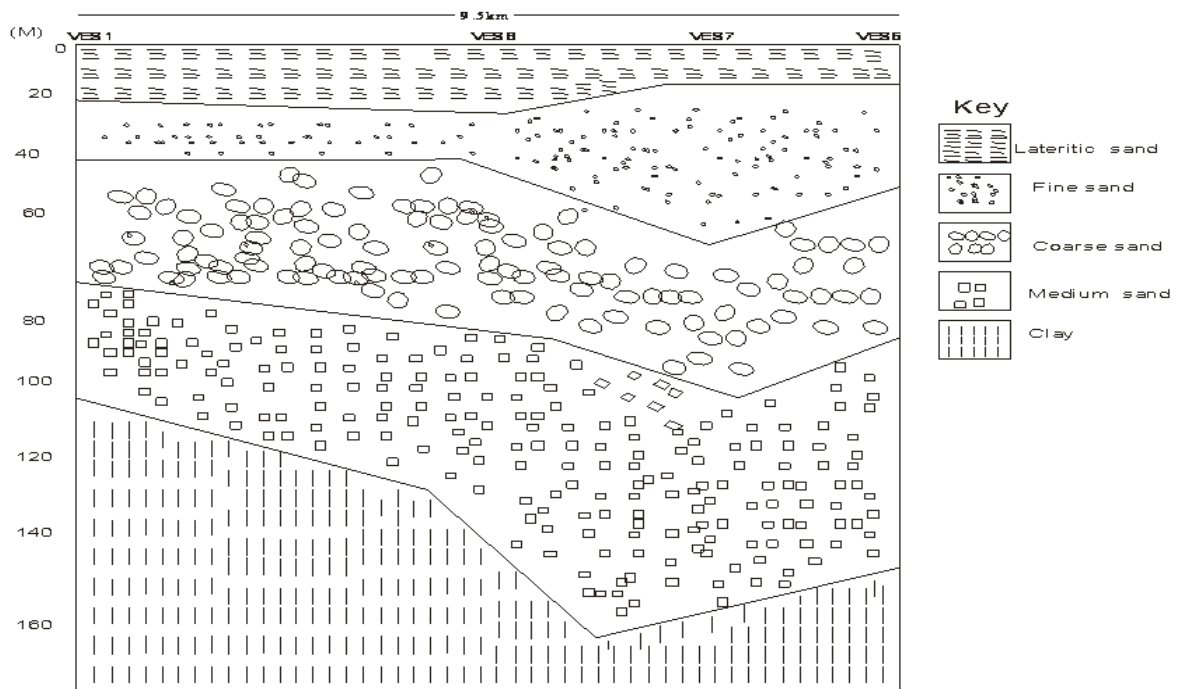
thickness ranges from 25m to 170m. The lithological sequences are lateritic soil, silty sand, fine, coarse, medium sand and shaly sand.

DISCUSSION

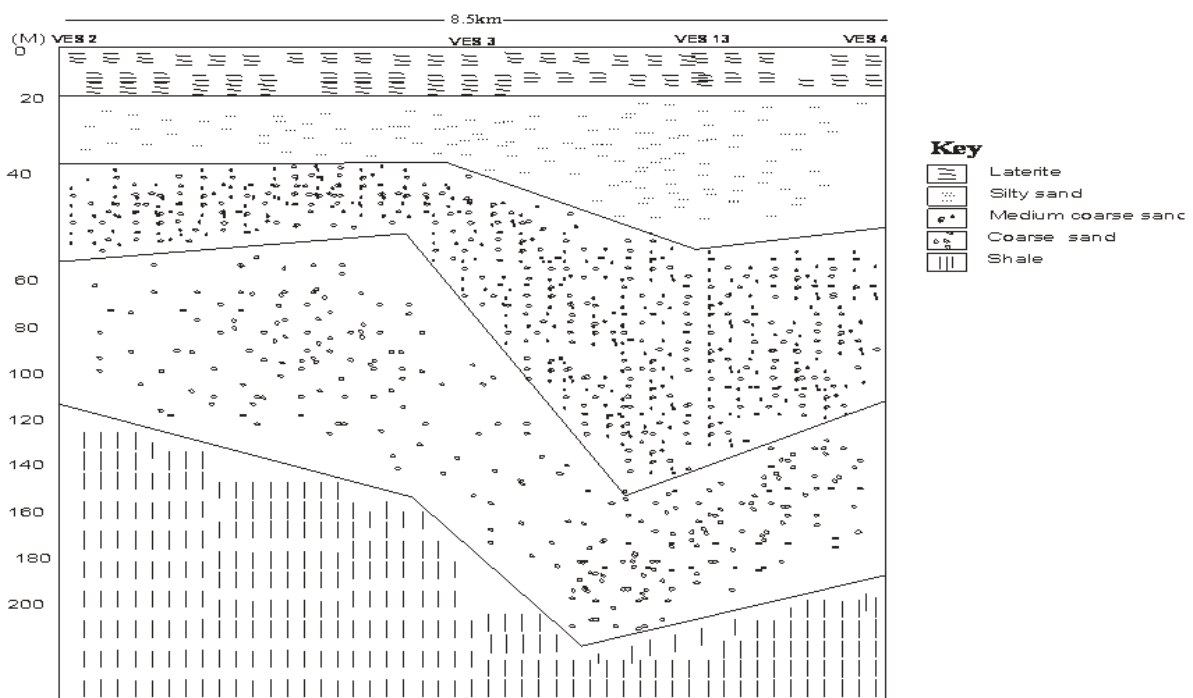
The hydrogeophysical survey revealed that the study area is underlain by Benin Formation. This Formation consists of fine sand, medium sand, coarse sand to gravel, with clay and silt lenses. Similarly, the study was used in evaluating the hydraulic parameters of the subsurface geology.

The modeled interpretation from computer analysis revealed the presence of five to seven geo-electric layers with an average of six layers. Similarly, six geoelectric curve types were encountered in the study area with the AK-type dominating the area. The shape of the geoelectric curve for each sounding gave an insight on the character of the beds or layers between the surface and the maximum depth of penetration. This is because the shape of a VES curve depends on the number of layers in the subsurface, the thickness of each layer, and the ratio of the resistivity of the layers. The aquifer depth in the study area varies between 18m and 62m with an average depth of 35m. Similarly, the aquifer thickness revealed that the highest aquifer thickness is at Upe and its environs, while the central part of the study area has the lowest thickness with lowest value at Ulakwo. The western area is predominantly of medium aquifer thickness. The aquifer thickness varies between 31.7m at Ulakwo to 126m at Ndokwu Umuoye with a mean value of 94.5m.

Downward continuation of the resistivity data using iso- resistivity maps derived at the following intervals of AB/2=10m, AB/2=20m, AB/2=25m, AB/2=30m, AB/2=40m, AB/2=60m, AB/2=70m, AB/2=75.5m and AB/2=200m were carried out to deduce the variation of resistivity at specific depths. The result showed that as the depth increases, the resistivity increases towards the northwest and at the central areas. A multi-aquifer system separated by clay lenses was deduced from the study area, with the aquifer demarcated into unconfined, semi-confined and confined aquifer. Etu- Efeotor and Akpokodje (1990) delineated one major aquifer in the study area with the aquifer containing clay lenses which separated them into sub-aquifer units.



A-A Cross section



B-B Cross section

Figure 10: Geoelectric Models Showing the Regional Hydrostratigraphy of the Area. a) Geoelectric Model along the A-A¹ Interpretative Cross-Section. b) Along the B-B¹ Interpretative Cross-Section.

The study area was also revealed to have a fairly uniform hydraulic conductivity ranging from 9.21m/day to 10.27m/day. The closeness of hydraulic conductivity values obtained from pumping tests and those estimated from sounding interpretations is a good indication of the reliability of this study. Though transmissivity of an aquifer could be determined from pumping test, but the result was obtained from the diagnostic constant derived from the study area which has a single aquifer system. This area has transmissivity values varying between 310.72m²/day and 1203m²/day. This shows that the study area is generally highly prospective for drilling productive boreholes. The average hydraulic conductivity and transmissivity values obtained are in line with previous authors (Ekwe, et al., 2006; Uma,1989).

Finally, four geological cross-sections were taken to evaluate results of the depth and thickness of the productive water bearing zones. It is inferred that the results obtained indicated high ground water resource potential in the study area.

CONCLUSION

The electrical resistivity sounding method is widely used for groundwater exploration. Two important limitations are however inherent in this method. These are the problems of equivalence and suppression (Zhohdy, 1976). However, computer oriented direct interpretation methods are capable of resolving the thickness and resistivities of various subsurface layers from the surface resistivity measurements. Similarly, the interpretation from computer modeling is free from human bias which is always present in the conventional curve matching techniques.

This study has also helped to provide data on the aquifer geometry and hydraulic conductivity(K), Transmissivity (T), aquifer thickness (h), depth to water table, and the Dar Zarrouk parameters: longitudinal unit conductance (S) and the transverse resistance (T_r) of the aquiferous zones. The estimated aquifer parameters revealed that the hydraulic conductivities (K) and transmissivity (T) values ranges from 9.21m/day to 10.27m/day and 310.72m²/day – 1203m²/day respectively. These findings are indicative of a fairly homogenous geological environment with very high water yielding capacity. Similarly, a good correlation was found to exist between the surface measured Dar Zarrouk parameters and such hydrological parameters as transmissivity,

and hydraulic conductivity of aquifer mapped. The zone with the highest transverse resistance (T_r) values is expected to give the highest borehole yield. Consequently, favourable areas for future groundwater development have been suggested on the above basis.

Finally, the close agreement of the interpretation of sounding data with geological information from the available boreholes gives an indication of the usefulness of the present study in evaluating aquifer hydraulic parameters in the scarcity of pumping test data.

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