Determination of Aquifer Hydraulic Characteristics from Surface Electrical and Borehole Measurements in Ozoro, Nigeria

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ABSTRACT: Surface electrical and borehole measurements were undertaken in order to establish the hydraulic characteristics of alluvial aquifer in Ozoro, Delta State. Ten vertical electrical sounding data were acquired using Schlumberger Configuration. Borehole measurements which included pumping test, well logging and the distribution of grain size analysis were also carried out. The results of the electrical sounding indicate that the aquiferous layer is located between the fourth and fifth layers with resistivity ranged from 53.5 Ωm - 1279 Ωm. The aquifer thickness ranged from 7.67 m - 49.4 m and transmissivity values ranged from 41.4 - 330.5 m^2/day. The average hydraulic conductivity (k) value obtained is 6.2 m/day. The borehole lithology, resistivity and spontaneous potential log indicate the subsurface lithology to consists of top soil (brownish), clayey sand, clay, fine sand and gravelly sand. The Cooper Jacob solution was used in the analysis of the borehole pumping experiment and the obtained hydraulic conductivity, transmissivity, storativity and specific capacity are 6.8 m/day, 0.067 m^2/min (96.48 m^2/day), 25.47 and 0.364 m^2/min (524.6 m^2/day) respectively. Also, the grain size distribution analysis using the Hazen approximation gave hydraulic conductivity as 11.55 m/day. The results showed that all three methods are applicable for determining aquifer hydraulic parameters.

KEYWORDS: Hazen approximation, Hydraulic conductivity, Pumping test, Benin formation, Resistivity logging

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I. INTRODUCTION

The importance of having access to quality water supplies cannot be over emphasized. The increasing necessity of global groundwater availability evaluation has led to rising awareness in groundwater management study. Hence the knowledge of aquifer parameter is very necessary for groundwater resource management (Lachassagne, 2020; Anomohanran and Orhiunu, 2018; Khadri and Pande, 2016). Among these parameters are hydraulic conductivity, transmissivity, permeability and storativity. Hydraulic conductivity measures the ease of water flow through the porous medium and is mostly dependent on the characteristics of the medium and the nature of fluid including density and viscosity (Schwartz and Zhang, 2003). Transmissivity which is an important hydraulic characteristic contributing to the overall local and regional groundwater hydrology and the management of solute transfer, is the groundwater flow rate under a unit hydraulic height. That means transmissivity, is the product of the layer thickness and aquifer hydraulic conductivity.

Conventional geotechnical methods, though expensive and provide information in discrete points have been most often used to determine these properties. However, the combination of surface electrical and borehole measurements is widely applicable in recent time. Pumping test is needed to estimate the transmissivity of an area or location and the results are analyzed by matching mathematical model special type curves to changes in water level response data (Jimoh *et al.*, 2018; Valigi *et al.*, 2021). The aquifer hydraulic conductivity can also be determined by soil grading analysis. Sieve analysis can be employed for aquifer hydraulic characteristics estimated using specialized empirical formula (Kango *et al.*, 2019). The vertical electrical sounding (VES) gives reliable information of aquifer condition and groundwater quality. Thus the understanding of aquifer characteristics is very necessary for groundwater resource development. These aquifer parameters are best obtained through surface electrical and borehole measurement standard techniques (George *et al.*, 2017; Ofomola, 2014; Anomohanran and Iserhien-Emekeme, 2014). For many years, people of Ozoro have depended largely on groundwater for their local, industrial and agricultural activities. The general objective of the study is to determine the hydraulic characteristics of alluvial aquifer from surface electrical measurement and borehole geophysical techniques in the area.

II. LOCATION AND GEOLOGY OF THE STUDY AREA

Ozoro town is the headquarters of Isoko-North Local Government Area of Delta State Nigeria. The study area lies between latitude N05^{0}31^{1}097^{I1} to N05^{0}33^{1}1.25^{I1} and longitude E006^{0}13^{1}5.8^{I1} to E006^{0}14^{1}2.24^{I1} with terrain elevation above

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sea level between 16 m and 18 m. Ozoro is about 116 km from Asaba, the state capital and 52 km from Warri an industrial and densely populated town in the State (Figure 1).

A. Stratigraphic Setting of the Niger Delta

Ozoro is within Niger Delta region of Nigeria which consists of three formation strata, the Benin, Agbada, and Akata formations. The Benin formation stretches through the coastal plain sand which outcrop in Benin, Onitsha and Owerri. from 0 to 2100 m depth (Zohdy and Jackson, 1973). The sand and sandstone are fine to coarse and mostly granular in texture, partly consolidated and has high water bearing capacity. The Agbada formation underlies the Benin formation and consists of mainly sandstone and siltstones (Short and Stauble, 1967). The thickness is between 3000 m to 5000 m.

The Akata formation consists of mainly marine shale and sand beds. The study area displays the characteristics of the seaward slopping flat and undistinguished Sombreiro-Warri Deltaic plain (Short and Stauble, 1967). The thickness is between 3 to 5 km. The Akata formation consists of mainly marine shale and sand beds. The study area displays the characteristics of the seaward slopping flat Sombreiro-Warri Deltaic plain (Short and Stauble, 1967) which is beneath the Benin formation. The prolific aquiferous units generally encountered in the modern Niger Delta are hosted in the Benin formation. The Sombreiro-Deltaic plain has a succession ranging from silts, medium to coarse grained sand, sandy clay and clay bands. This progression is the present day expression of the Benin formation in borehole sections.

III. METHOD OF DATA ACQUISITION AND PROCEDURES

Ten VES were carried out for this investigation (see Figure 2). Two electrodes (AB) introduced current to the ground and the established potential difference were measured through another pair of electrodes (MN). Both set of electrodes are connected to the Terrameter where the averaged apparent resistivity of the ground is measured. The set-up is systematically moved from one station to another equidistance from the fixed position until the study area was fully covered. The field data were iterated with the application of IP2Win software.

It uses the curve matching techniques where the field data plot is compared with corresponding theoretical curves which has been computed for various layer resistivity. The computer model generates the true layer resistivity, depth and thickness. The obtained values were used to generate the geoelectric section of the area by using the Surfer 13 software. However in this research work, hydraulic conductivity was estimated from empirical study using the exponential law function to calculate the hydraulic conductivity (k) with resistivity data (ρ_i) as shown in Eqn. 1 (Juandi and Syahil, 2017).

$$lnk = 0.068ln\,\rho_i + 6.02 \quad (1)$$

Also, a 30 m borehole was drilled for lithological structure of the subsurface and pumping test to determine the hydraulic characteristics of the aquifer. A 5.5 hp capacity pump was installed in the single test well using a 2 inch pipe for inlet into the drilled well and outlet through flow meter for the discharge into the earth surface.

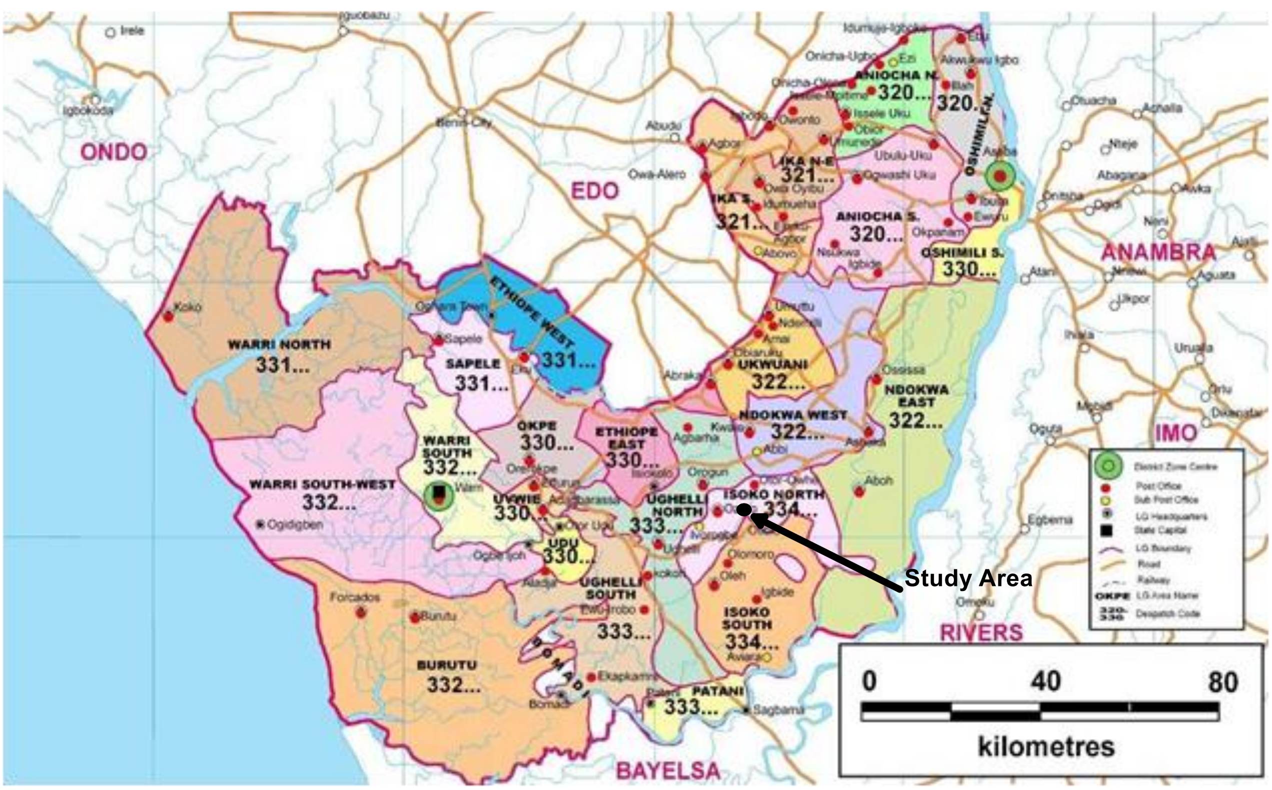

Figure 1: Delta State map showing the study area.

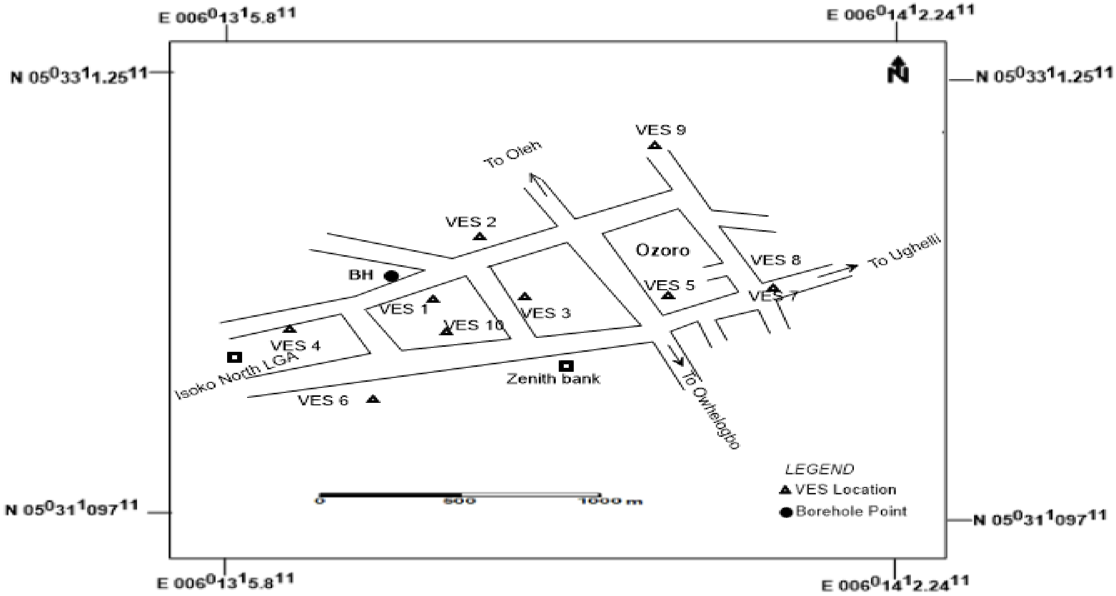

Figure 2: Base map of the study area showing the VES locations and the borehole point.

Continuous pumping was done from the drilled well at a rate of 0.462 m^3/mins and depth of water level taken at specific time gap. Drawdown values were calculated by the difference between the level of water at a specific time and the level before pumping started. This process was done until a constant water level was achieved. The machine was switched off and the well recharged time and corresponding depths were measured. A graph of water level difference before and after pumping against pumping time was plotted on a linear - log paper. The drawdown per log cycle of time (Δs) and the time intercept (t_o) were deduced from the graph and introduced into the Cooper- Jacob equation to estimate the aquifer storativity, transmissivity and specific capacity.

The hydraulic conductivity (k) was calculated by getting the thickness of the saturated zone of the drilled well. Also using SAS 1000 terrameter, SAS 200 logging probe and a calibrated tape, the subsurface electrical logging was carried out in the drilled well. Resistivity and spontaneous potential logs were generated at an interval of 2 m. These values were recorded in millivolts for spontaneous potential and ohm-meter for resistivity. Soil samples were collected at 3 m interval during the drilling operation for grain size distribution analysis. The drilled cuttings were collected into a sampling bag and then taken to the Engineering Geology Laboratory of the Delta State University Abraka, Nigeria where they were dried and taken through the required soil test. Drying of the soil samples in an oven at 105°C was done and then washed in a sieve leaving only materials bigger than 0.063 mm. This determines the soil type by noting the material that consist of sand, gravel, silt or clay. A graph of sieve cumulative percentage passing against the sieve diameter was plotted for each sample and the ten percentile (d_{10}) estimated. This is the effective diameter (mm) such that 10% by weight of the porous matrix consists of grains smaller than it. Hydraulic conductivity was calculated using Eqn. 2 (Hazen, 1892) given as:

$$\mathrm{K} = \mathrm{C_H}(d_{10})^2 \qquad (2)$$

where K is hydraulic conductivity (cm/s), C_H is Constant and if k is in cm/s and d_{10} in mm, C = 1 (Freeze and Cherry, 1979).

IV. RESULTS AND DISCUSSION

A. *Vertical Electrical Sounding*

The summary of the resistivity, depth and thickness of the various layers are presented in Table 1.

The area has 4 to 5 geoelectric layers consisting of topsoil, clayey sand, clay, fine sand and gravelly sand respectively. The first layer consists of topsoil with resistivity ranging from 51.1 Ωm to 509 Ωm and thickness ranging from 0.22 m to 10. 2 m. The second layer consists of clayey sand with resistivity ranging from 48.5 Ωm to 2463 Ωm and thickness ranging from 0.167 m to 13.9 m. The third layer consists of fine sand with resistivity value ranging from 123 Ωm to 1279 Ωm and thickness value ranging 2.92 m to 49.4 m.

The fourth layer consists of gravelly sand in VES 1, 2, 4, 6, 8, 9 and 10 with resistivity value ranging from 287 Ωm to 4313 Ωm except that of VES 3, 5 that consists of clay with resistivity value ranging from 35 Ωm to 53.5 Ωm and VES 7 consists of fine sand with resistivity value of 928 Ωm. The precise thickness of this layer cannot be established due to termination of the current electrode separation. The fifth layer consists of gravelly sand in VES 5, 7 and 10 with resistivity value ranging from 1092 Ωm to 7865 Ωm.

B. *Geoelectrical Sections*

Using the information from the borehole log and the results of vertical electrical sounding, an illustration of the geoelectrical section of the area was produced as shown in Figures 3 and 4.

Comparing the geoelectric sections with the borehole log, it is observed that they have similar content but varies in structure and depth to the various soil types. Figures 3 and 4

Table 1: Summary of aquifer model parameters.

Location	Layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Curve type	Geotechnical implication
VES 1	1	274	0.5	0.5		Topsoil
	2	48.5	0.42	0.92		Clayey sand
	3	567	23.3	24.2	HK	Fine sand
	4	4313				gravelly sand
VES 2	1	180	5.66	5.66		Topsoil
	2	611	6.96	12.6		Clayey sand
	3	182	28.2	40.8	KH	Fine sand
	4	3860				gravelly sand
VES 3	1	180	0.5	0.5		Topsoil
	2	119	10.1	10.6		Clayey sand
	3	1279	49.4	60.1	HK	Fine sand
	4	35				Clay
VES 4	1	115	0.227	0.227		Topsoil
	2	71.6	1.59	1.82		Clayey sand
	3	123	12.4	14.2	HK	Fine sand
	4	287				gravelly sand
VES 5	1	51.1	0.609	0.609		Topsoil
	2	354	1.59	2.2		Clayey sand
	3	732	2.92	5.12	AKH	Fine sand
	4	53.5	7.67	12.8		Clay
	5	1486				gravelly sand
VES 6	1	320	2.79	2.79		Topsoil
	2	206	3.73	6.52		Clayey sand
	3	704	35	41.5	HA	Fine sand
	4	1472				gravelly sand
VES 7	1	195	0.5	0.5		Topsoil
	2	1574	0.167	0.667		Clayey sand
	3	293	13.2	13.9	KHA	Fine sand
	4	928	47.6	61.5		Fine sand
	5	7865				gravelly sand
VES 8	1	509	1.99	1.99		Topsoil
	2	338	11.8	13.8		Clayey sand
	3	440	21.8	35.6	HA	Fine sand
	4	809				gravelly sand
VES 9	1	282	10.2	10.2		Topsoil
	2	2463	13.9	24.1		Clayey sand
	3	168	33.7	57.8	KH	Fine sand
	4	2211.9				gravelly sand
VES 10	1	137	0.5	0.5		Topsoil
	2	335	6.74	7.24		Clayey sand
	3	854	8.14	15.4	AA	Fine sand
	4	1016	16.9	32.3		gravelly sand
	5	1092				gravelly sand

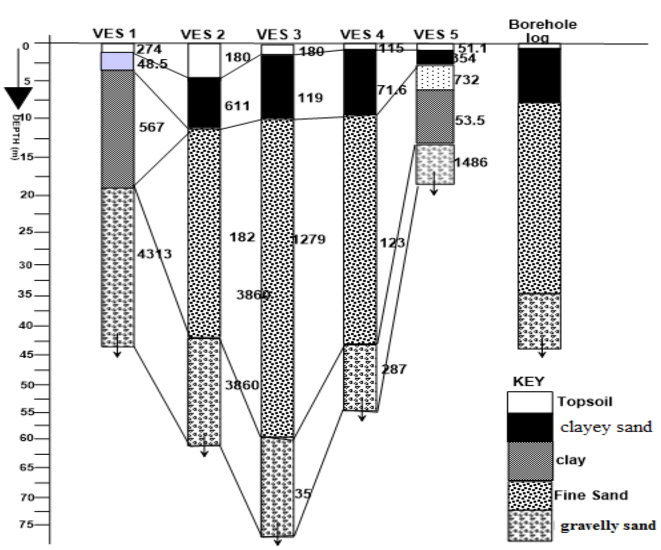

Figure 3: Geoelectric section across VES 1 to VES 5.

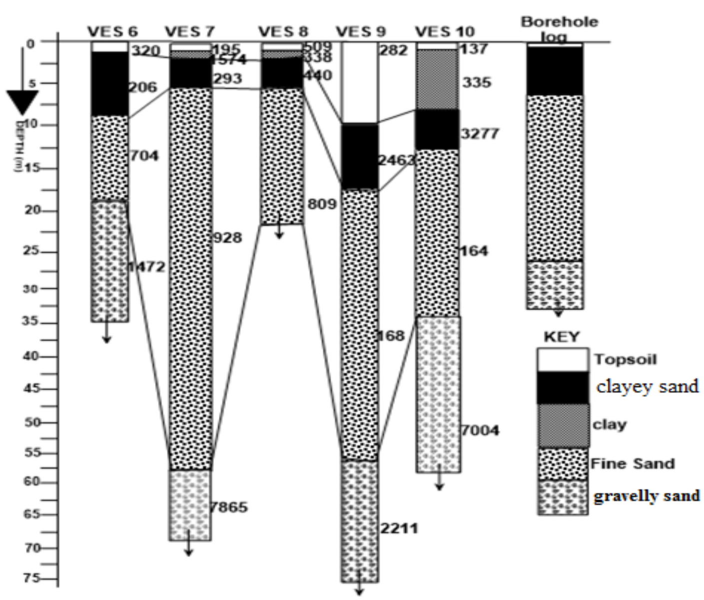

Figure 4: Geoelectric section across VES 6 to VES 10.

show that the area is underlain by four to five geoelectric layers. This includes topsoil, clayey sand, clay, fine sand and gravelly sand. It is observed that the fine sand layer is the most predominant layer found within the study location. Lower resistivity zones have more confined aquifer systems while higher resistivity is inferred as area with higher interaction of groundwater and surface water (Aduojo *et al.*, 2020).

C. *Resistivity Maps*

The aquifer resistivity contour map of Ozoro is presented in Figure 5. From the map, the resistivity increases towards VES 7, 8, 9 directions. It therefore implies that the layer towards VES 7, 8, 9 is more productive and will be of concern in the development of groundwater. The aquifer thickness contoured map (Figure 6) shows that VES 9 has the highest

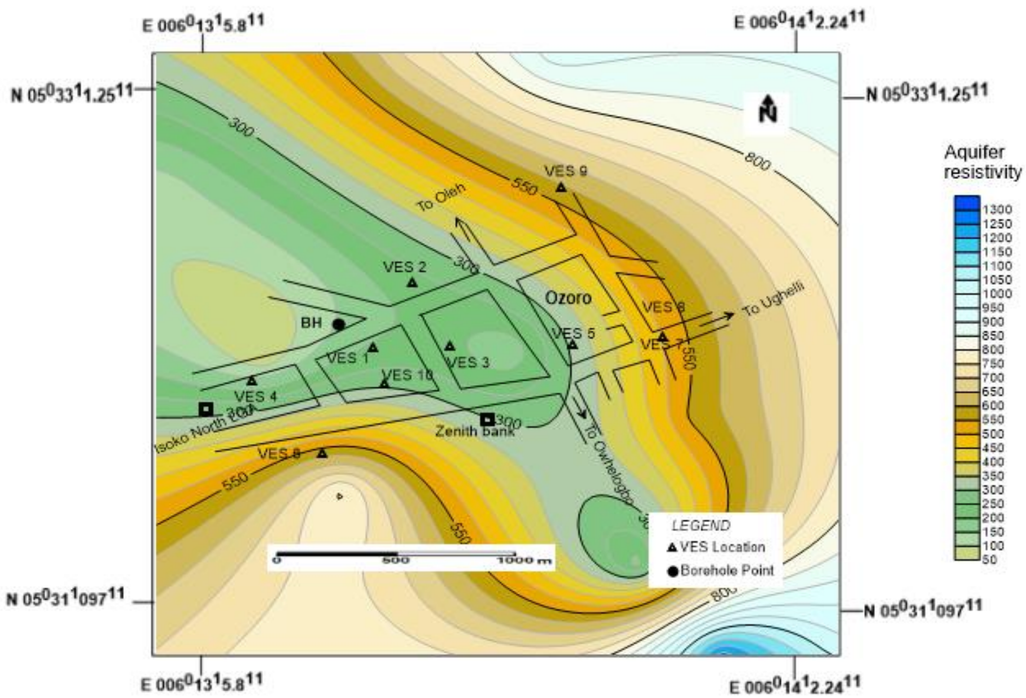

Figure 5: Aquifer resistivity map.

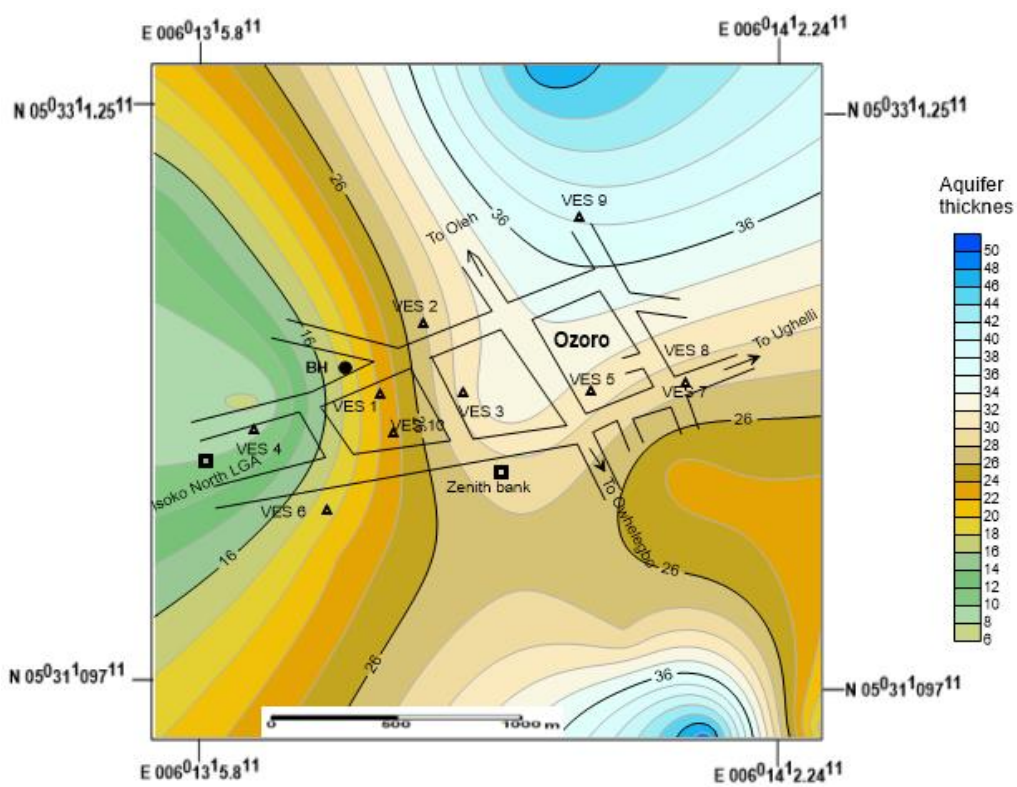

Figure 6: Aquifer thickness map.

aquifer thickness which is an indication of high volume of groundwater as against VES 4 with the lowest aquifer thickness.

D. The Aquifer Hydraulic Characterisation

The first order geoelectric parameters from the resistivity data were also used to obtain the Dar-Zarrouk parameters (Table 2) and generate hydrogeological maps (aquifer resistivity, longitudinal conductance, aquifer thickness and transmissivity).

Table 2 shows that the Dar Zarrouk parameters of Ozoro have aquifer resistivity ranges from 53.5 Ωm – 1279 Ωm and aquifer thickness varies from 7.67 – 49.4 m. Also the aquifer conductivity varies from $0.78\times 10^{-3}(\Omega m)^{-1}$– $8.13\times 10^{-3}(\Omega m)^{-1}$ while the longitudinal conductance varies from 1.66×10^{-3}– 20.06×10^{-3}. However, the minimum transmissivity value is 41.4 m^2/day in VES 5 while the maximum was found in VES 3 with transmissivity value of 330.5 m^2/day. Also the diagonostic parameter was determined as shown in Table 2. The results reveal that the probability of good yield groundwater is high and the area is good for boreholes sinking due to the increase in transmissivity. The average hydraulic conductivity within the study area was calculated to be K = 6.2 m/day. This value corresponds with Atakpo (2009) who modelled groundwater flow in Isoko South with hydraulic conductivity value ranging from 4.6 m/day to 8.8 m/day. Hence, the areas having the high transmissivity are good for productive borehole.

Map of the longitudinal conductance (Figure 7) shows that the aquifer is well protected from pollution. Static water level measurements were taking around Ozoro. Ten hand dug

Table 2: Dar Zarrouk Parameters obtained across the VES points.

VES	Aquifer Resistivity ρ (Ωm)	Aquifer Thickness (h)m	Aquifer Depth d(m)	Aquifer Conductivity σ = 1/ ρ (10 ^-3Ωm)-1	Longitudinal Conductance S = σh (10 ^-2)	Transverse Resistance R=h ρ	Hydraulic conductivity (K)(m/day)	Transmissivity Tr = kh (m^2/day)	Diagnostic Parameter Kσ (10 ^-2)
1	567	23.3	24.2	1.76	4.10	13211.1	6.33	147.5	1.11
2	182	28.2	40.8	5. 49	15.49	5132.4	5.86	165.3	3.21
3	1279	49.4	60.1	0.78	3.86	63182.6	6.69	330.5	0.52
4	123	12.4	14.2	8.13	10.08	1525.2	5.71	70.8	4.64
5	53.5	7.67	12.8	1.86	14.34	410.3	5.39	41.4	1.00
6	704	35	41.5	1.42	4.97	24640.0	6.43	225.1	0.91
7	928	47.6	61.5	1.08	5.13	44172.8	6.55	311.8	0.71
8	809	21.8	35.6	1.24	2.69	17636.2	6.49	141.5	0.80
9	168	33.7	57.8	5.95	20.06	5661.6	5.83	196.5	3.47
10	1016	16.9	32.3	0.98	1.66	17170.4	6.59	111.4	0.65

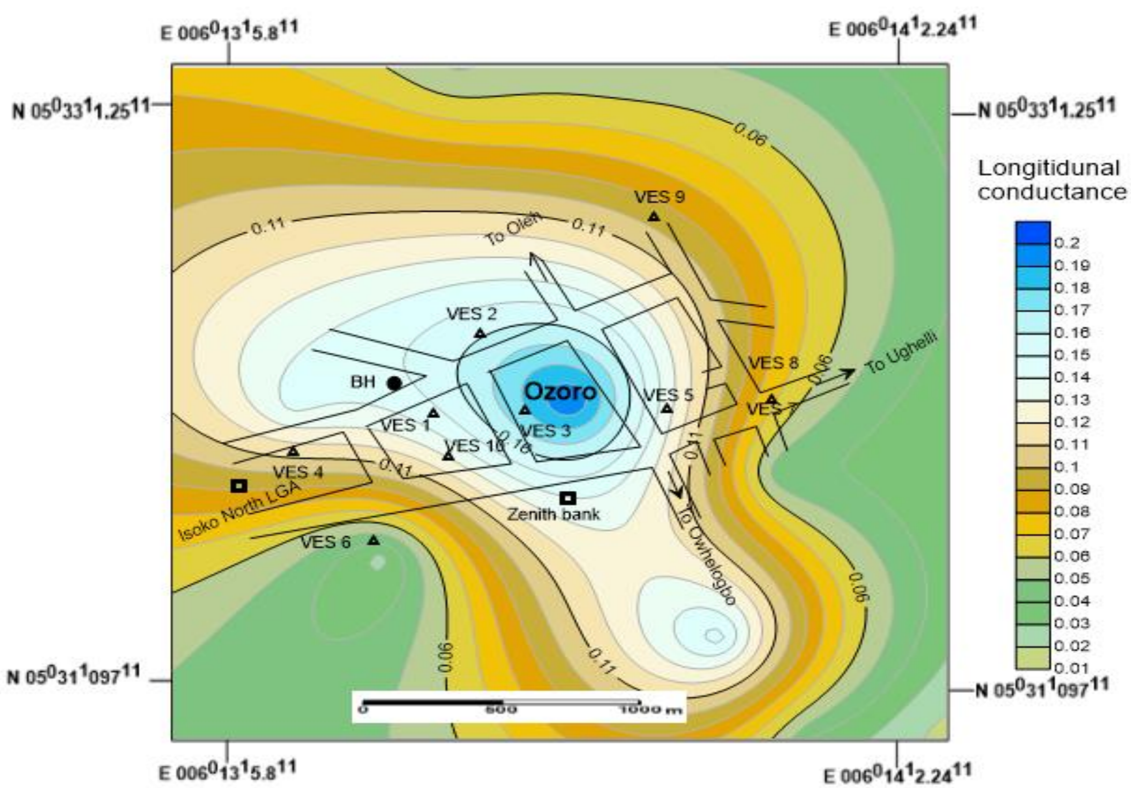

Figure 7: longitudinal conductance contour map.

wells were studied to determine water flow direction and hydraulic head of the well as shown in Table 3.

Figure 8 shows the contour map of the static water level. Following the contour interval of the map the red arrow head represent the geometry of water flow direction of the study area. From the map, the static water level ranges from 2.0 m to 2.6 m, 1.1 m to 1.9 m and 0.9 m to 1.0 m, for high, moderate and low static water level respectively. Thus, it is observed that groundwater flows from the south towards the north central in the study location, therefore the static water level is high at well 4 and low at well 7 (black colour region).

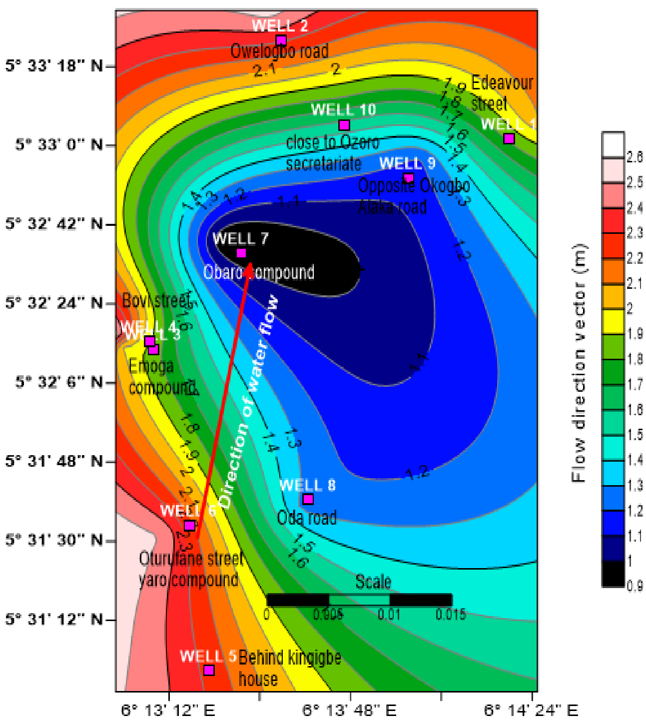

Figure 8: Contour map of the static water level of Ozoro.

Table 3: Static water level from hand dug well measurements.

Location	Longitude (degree)	Latitude (degree)	Elevation (m)	Static water level (m)	hydraulic head (m)
WELL 1	6.24031	5.55184	15	2.10	12.90
WELL 2	6.22555	5.55856	16	2.55	13.45
WELL 3	6.21736	5.53746	16	2.01	13.99
WELL 4	6.21707	5.53798	16	2.58	13.42
WELL 5	6.22093	5.51548	17	2.36	14.64
WELL 6	6.21965	5.52543	19	2.49	16.51
WELL 7	6.22302	5.54401	21	0.90	20.10
WELL 8	6.22733	5.52717	25	1.28	23.72
WELL 9	6.23377	5.54917	22	1.19	20.81
WELL 10	6.22965	5.55282	10	1.77	8.23

This same approach was also adopted by Oborie and Nwankwoala (2017) who determined groundwater flow direction in Yenagoa metropolis. From the transmissivity contour map (Figure 9), VES 9 has high transmissivity, indicating that the area has high yield of water and is productive.

The pumping test data obtained from the field is presented in Table 4. A graph of drawdown against time was plotted on a semi-logarithmic graph paper (Figure 10).

The pumping rate (discharge, Q) of the drilled well is 0.462 m³/min with well radius of 0.11 m. Time of pumping t_0 = 2 min and the well has an aquifer thickness of 14.4 m. From Figure 10, the drawdown per log cycle is 1.27 m. Using the Cooper-Jacob equations (Cooper and Jacob, 1946) the transmissivity (T), specific capacity (Sy), storativity (S) and hydraulic conductivity (k) were obtained as follows:

$$T = \frac{2.3\,Q}{4\pi \times \Delta S} = \frac{2.3 \times 0.462\ m^3/min}{4\pi \times 1.27\ m} = 0.067\ m^2/min = 96.48\ m^2/day$$

For specific capacity,

$$Sy = \frac{Q}{\Delta S} = \frac{0.462}{1.27} = 0.364\ \text{m}^2/\text{min} = 524.16\ \text{m}^2/\text{day}$$

For storativity,

$$S = \frac{2.3\,Tt_0}{r^2} = \frac{2.3 \times 0.067\ m^2/\min \times 2\ min}{0.11^2\ m} = 25.47$$

Hydraulic conductivity, K:

$$K = \frac{T}{b} = \frac{0.067 m^2/min}{14.4\ m} = 0.0047\ m/min$$

Hence, converting the hydraulic conductivity to units of m/day,

$$K = 0.0047 \times 24 \times 60 = 6.8\ m/day$$

Table 4: Result of pumping test analysis.

S/N	Time of Pumping (min)	Water level (m)	Drawdown (m)	Discharge (m³/min)
1	0	1.60	0	0.462
2	1	1.90	0	0.462
3	2	2.23	0.4	0.462
4	4	2.26	0.6	0.462
5	6	2.45	0.8	0.462
6	8	2.76	1	0.462
7	10	3.13	1.4	0.462
8	20	3.22	1.6	0.462
9	30	3.38	1.8	0.462
10	40	3.69	1.9	0.462
11	50	3.82	2.0	0.462
12	60	3.87	2.27	0.462
13	120	3.87	2.27	0.462
14	240	3.87	2.27	0.462
15	300	3.87	2.27	0.462
16	400	3.87	2.27	0.462
17	550	3.87	2.27	0.462
18	600	3.87	2.27	0.462
19	700	3.87	2.27	0.462
20	720	3.87	2.27	0.462

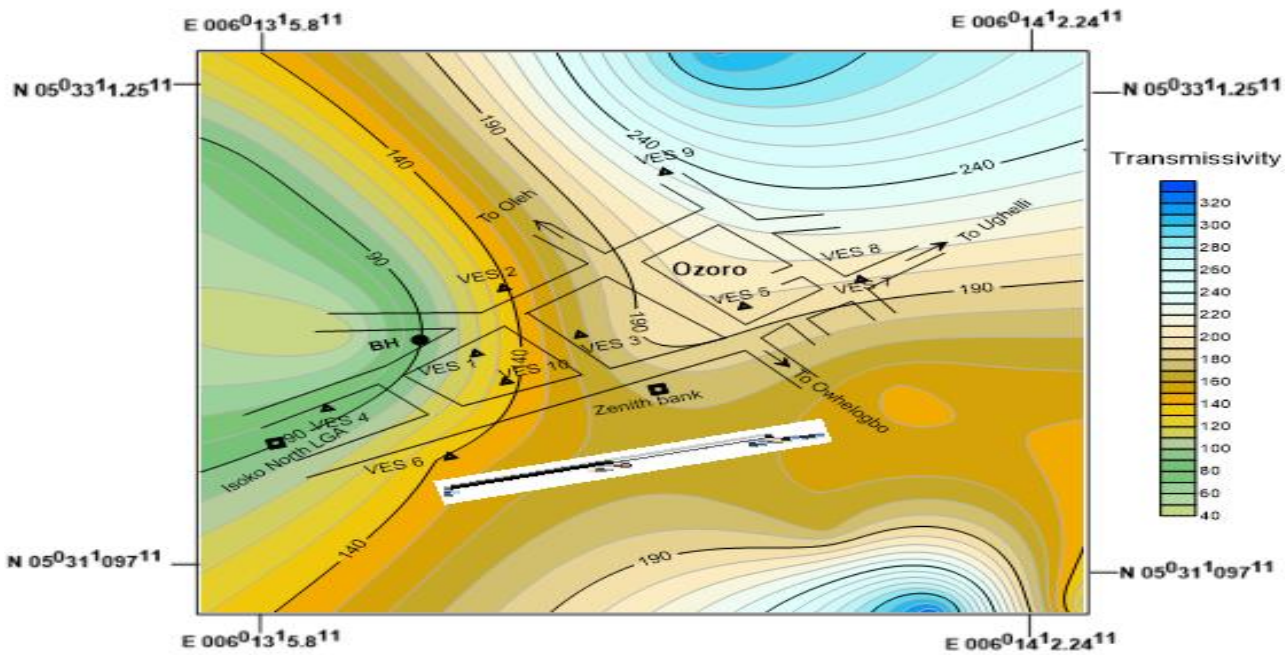

Figure 9: The transmissivity contour map.

E. Lithological Evaluation using Borehole Record

In order to ascertain the geological setting of the study area, a drilled depth of 30 m was encountered and cuttings obtained at 2 m interval to determine the lithological characteristics of the area. The lithology obtained after analyzing the drilled cuttings is shown in Figure 11.

From the lithological log, the first layer consists of top soil which is brownish in colour, unconsolidated and extends from 0 to 8 m. The next layer is clayey sand that is greyish in colour and extends from 9 m -12 m. This area is well compacted making the strata consolidated. The third layer consists of clay that is also greyish in colour and extends to a depth of 12 m to 16 m. The fourth layer is made up of fine sand which is whitish in colour and extends from 18 m to 20 m. At 22 m to 30 m depth, a gravelly sand layer was encountered.

There is a gentle rise in the rate of increase after 18.35 m from the resistivity log which is an indication of a higher resistivity of the formation fluid than the previous layers. From the graph it is observed that the spontaneous potential increase from 0.212 mV at 8 m to 0.232 mV at 12 m. The SP decreases

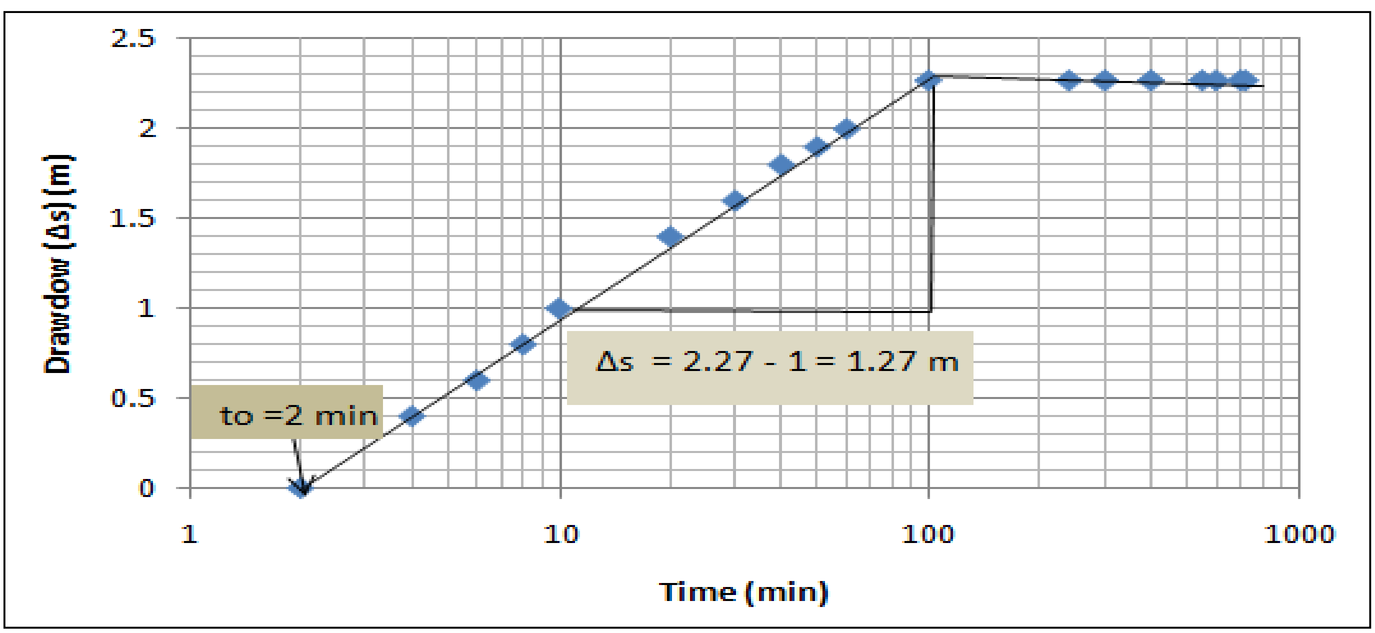

Figure 10: Graph of drawdown against time.

simultaneously from 0.22 mV at a depth of 13 m to 0.202 mV at a depth of 20 m. From the depth of 22 m – 30 m the SP log shows more stable characteristics depicting the fact that there is better water yield than the top layers. Thus, the results of the lithology description disclosed that the yield of water for domestic purpose begins from the fine sand layer down to the medium fine sand with depth ranging from 18 m to 30 m.

F. *The Grain Sizes Results (Sieve Analysis)*

Sieve analysis curves for cuttings retrieved from borehole were plotted as shown in Figure 12. The hydraulic conductivity was estimated using the Hazen approximation:

$$k = C\,(d_{10})^2 \qquad (3)$$

where k is hydraulic conductivity in m/day, d_{10} is the effective grain size in cm, C is a coefficient that is based on the aquifer matrix and equals 6 for this study environment. (Uma *et al.*, 1989; Akpoborie and Efobo, 2014).

From the graph d_{10} ranges from 0.57cm to 0.74 cm. The estimated value of hydraulic conductivity K in the study area ranges from 16.84 m/day to 28.39 m/day, giving a differential value of 11.55 m/day. A comparison of the results of the various methods is presented in Table 5. The results of hydraulic conductivity show close agreement and correspond with Atakpo (2009) who modelled groundwater flow in Isoko South with hydraulic conductivity value ranging from 4.6 m/day to 8.8 m/day.

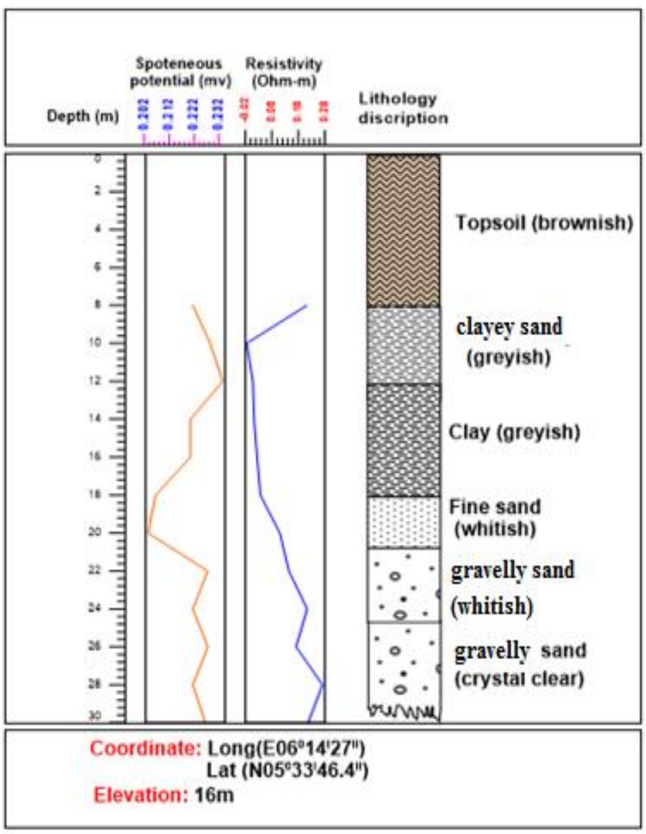

Figure 11: Plot of Down-hole geophysical logs and lithological log.

Table 5: comparison of results of the aquifer parameters obtained from the VES, pumping test and grain size methods.

Method	Transmissivity (m^2/ day)	Storativity	Specific Capacity (m^2/day)	Hydraulic Conductivity (m/day)
VES	41.4−330.5	-	-	6.2
Borehole	96.48	25.47	524.16	6.8
Grain size				11.55

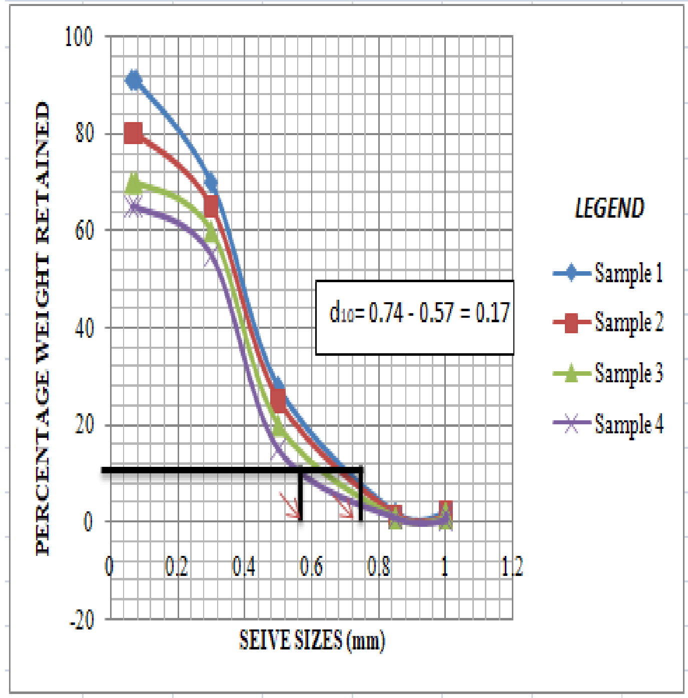

Figure 12: Grain size curves from screened horizons.

V. CONCLUSION

The aquifer hydraulic characteristics were determined using vertical electrical sounding, well logging, pumping test and grain size analysis. The static water level map revealed that the water flow direction is towards the central part of the area. The results of the VES gave the hydraulic conductivity as 6.2 m/day. From the pumping test the hydraulic conductivity, transmissivity, storativity and specific capacity were obtained as 6.8 m/day, 96.48 m^2/day, 25.47 and 0.364 m^2/mins (524.16 m^2/day) respectively. The hydraulic conductivity from grain size analysis was 11.55 m/day. These results are in fair agreement with other techniques and results of other studies in the Niger Delta area, and specify that the aquifer contain adequate quantity of water with enough hydraulic pressure to release potable water. It is recommended that the hydraulic conductivity of the grain size distribution analysis should be calculated with other indirect methods such as the Gustafson, Kozeny-Carman approximation to give more credence to the Hazen approximation used for this study.

REFERENCES

Aduojo, A.A.; A.E. Adebowole and O. Uchegbulam. (2020). Modeling groundwater total dissolved solid from derived electromagnetic data using multiple linear regression analysis: a case study of groundwater contamination. Modeling Earth System and. Environ. 6, 1863–1875 (2020). https://doi.org/10.1007/s40808-020-00796-9

Akpoborie, A.I. and Efobo, O. (2014). Groundwater conditions and hydrgeochemistry of the Benin Formation aquifer in the vicinity of Abraka, Nigeria. International Journal of water Resources and Environmental Engineering,6(1):19-31.

Anomohanran, O. and Orhiunu, M.E. (2018) Assessment of groundwater occurrence in Olomoro, Nigeria using borehole logging and electrical resistivity methods. Arab J Geosci 11, 219. https://doi.org/10.1007/s12517-018-3582-7

Atakpo, E. A. (2009). Groundwater and contaminant flow modeling in Olomoro area of Delta State. Journal of the Nigerian Association of Mathematical Physics, (15): 205-212.

Cooper, H.H. and Jacob, C.E. (1946). A generalized graphical method for evaluating formation constants and summarizing well field history. American Geophysical Union, Transactions, 27: 526-534.

George, N.J.; A.E. Akpan and F.S Akpan. (2017). Assessment of spatial distribution of porosity and aquifer geohydraulic parameters in parts of the Tertiary – Quaternary hydrogeoresource of south-eastern Nigeria. NRIAG Journal of Astronomy and Geophysics. 6(2), 422-433 https://doi.org/10.1016/j.nrjag.2017.09.001

Hazen, A. (1892). Some physical properties of sand and gravels, with special reference to their use in filtration, 24th Annual Report, Massachusetts State Board of Health, pub.Doc 34: 539-556

Ige, O. O.; D.O. Obasaju; C. Baiyegunhi; O. Ogunsanwo and T.L. Baiyegunhi. (2018). Evaluation of aquifer hydraulic characteristics using geoelectrical sounding, pumping and laboratory tests: A case study of Lokoja and Patti Formations, Southern Bida Basin, Nigeria" Open Geosciences, vol. 10, no. 1, pp. 807-820. https://doi.org/10.1515/geo-2018-0063

Iserhien-Emekeme, R.; M.O. Ofomola; M. Bawalla and O. Anomohanran. (2017). Lithological Identification and Underground Water Conditions in Jeddo Using Geophysical and Geochemical Methods. Hydrology, 4, 42; 1-15. https://doi.org/10.3390/hydrology4030042

Jimoh, R.A.; O.M. Bankole; K. Ahmed; *et al*. (2018). Use of geophysical logs in hydrogeological studies and borehole designs: case study of Apapa coastal area, Lagos, Nigeria. Applied Water Science 8, 191. https://doi.org/10.1007/s13201-018-0804-9.

Juandi, M and Syahril, S. (2017). Empirical relationship between soil permeability and resistivity, and its application for determining the groundwater gross recharge in Marpoyan Damai, Pekanbaru, Indonesia. Water Practice and Technology 12 660-666

Khadri, S.F.R., and Pande, C. (2016). Ground water flow modeling for calibrating steady state using MODFLOW software: a case study of Mahesh River basin, India. Model. Earth Syst. Environ. 2, 39. https://doi.org/10.1007/s40808-015-0049-7

Oborie, E. and Nwankwoala, H.O. (2017). Determination of Groundwater Flow Direction in Yenagoa, Bayelsa State, Nigeria. Journal of Scientific Achievements, 2(9): 23 – 27.

Ofomola, M.O (2014). Aquifer Characterization and groundwater quality studies in part of Niger Delta Area using geoelectric and hydrogeochemical methods. Nigeria Journal of Physics, 25:96–106.

Kango, R.; V. Shankar and M. A. Alam (2019). Evaluation of hydraulic conductivity based on grain size distribution parameters using power function model. Water Supply 19 (2): 596–602. https://doi.org/10.2166/ws.2018.106

Lachassagne, P. (2020). What is Groundwater? How to manage Groundwater Resources. Annals of Nutrition and Metabolism, 76(suppl 1):17–24. https://DOI: 10.1159/000515024

Schwartz, F.W. and Zhang, H. (2003). Fundamentals of Groundwater. John Wiley & Sons, New York. ISBN: 978-0-471-13785-6

Short, K.C. and Stauble, A.J. (1967). Outline of Geology of Niger Delta: American Association of Petroleum Geologist Bull., (51):761 – 779.

Uma, K.O.; B.C.E. Egboke and K.M. Onuoha. (1989). New statistical Grain-Size method for evaluating the hydraulic conductivity of sandy aquifers. Journal of Hydrology 108:367-386.

Valigi, D.; C. Cambi; R. Checcucci and L. Di Matteo. (2021). Transmissivity Estimates by Specific Capacity Data of Some Fractured Italian Carbonate Aquifers. Water, 13, 1374. https://doi.org/10.3390/w13101374

Zohdy, A. A. R. and Jackson, D. B. (1973). Recognition of natural brine by electrical soundings near the Salt Fork of the Brazos River, Kent and Stonewall Counties, Texas: U.S. Geological Survey Professional Paper 809-A, 14 .