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Mapping of aquifer hydraulic properties in Ogbeje and Umeghe in Abraka, Delta State Nigeria: insights from geophysical and hydrogeological methods

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Abstract

Vertical Electrical Sounding (VES), Pumping test, well logging and grain size analysis were conducted with the aim of studying the subsurface geophysical formation in order to determine aquifer characteristics such as hydraulic conductivity, transmissivity and other parameters for groundwater exploration purposes around Ogbeje and Umeghe, Abraka Delta State. Nine (9) VES stations were occupied and the results obtained from the computer iterations suggest 4 to 5 geoelectric layers. The aquiferous layers was found at depth ranging from 20.0 m – 38.3 m with resistivity ranging from 2200 Ωm to 8500 Ωm and thickness varying between 6.7 and 20.0 m. The VES study reveals the possibility of having a maximum drill depth to water table of about 38 m. The results obtained from the pumping test and well logging was used to estimate the transmissivity value of T = 0.0722 m^2/min, storativity S = 0.00063, specific capacity of the well = 0.39 m^2/min and hydraulic conductivity, K= 8.5 m/day while the result from the grain size analysis gave hydraulic conductivity as K_{min}= 12.96 m/d to K_{max} = 26.96 m/d respectively. Thus, these results indicate that the aquifer is capable of producing sufficient amount of water for both domestic and industrial purposes for the people in the area.

1. INTRODUCTION

Major components of groundwater study and modeling involve the evaluation and estimation of aquifer transmissivity and storage coefficient as well as the geometry of the water-bearing zone. One of the suitable methods for determining accurate values of the aquifer hydraulic characteristics is the application of the pumping test technique (Sattar et al., 2016). Extensive pumping test is costly and therefore, it is rarely carried out in practice. Surface geoelectric measurements offer an alternative approach for the evaluation of some of the aquifer properties for extensive groundwater studies (Ekanem et al., 2020, Iserhien-Emekeme et al., 2017; Ofomola, 2014). Adopting only geoelectrical methods, do not substitute completely for trial drilling to determine groundwater conditions, yet in many situations, it can minimize the number of trial wells by giving a superior selection of the location of test borehole points (Yadav and Abolfazli, 1998). In hydrogeological studies, hydraulic conductivity is a very important parameter, but also quite difficult to determine. This work therefore aims at the modelling of aquifer hydraulic parameters using Vertical Electrical Sounding (VES), grain size analysis, well logging and pumping test data. This is with a bid to evaluate the aquifer potential and groundwater development resources for both domestic and industrial purposes. Several methods have been employed to estimate soil hydraulic conductivity, both from laboratory analysis, indirect methods such as grain size analysis and from hydraulic tests. Besides the grain size, other factors that could affect hydraulic conductivity include degree of compaction, porosity and shape of the grains (Ige *et al.*, 2018). Changes in groundwater table are dependent on the hydraulic conductivity, empirical estimation of the hydraulic properties of aquifer to establish its viability becomes necessary. Investigating the different soil parameters that affect hydraulic conductivity from different methods give a better understanding of hydraulic conductivity and improve the estimations accuracy (Chung et al., 2018). Hydraulic conductivity is a physical property of an aquifer/soil which measures the capacity of the material to transmit fluid through pore spaces and fractures in the presence of an applied hydraulic slope. High values of hydraulic

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conductivity is an indication of permeable material through which water can flow easily. It is also dependent on the intrinsic permeability of the aquifer, the extent of saturation, as well as the density and viscosity of the fluid (Rosenberry et al., 2021). Transmissivity is the time rate of horizontal flow of groundwater through an aquifer. It is typically used to determine the water that an aquifer can deliver to a pumping well. It can be calculated directly from the aquifer's average horizontal permeability or hydraulic conductivity and thickness. Storativity is the quantity of water transmitted from storage space per unit decrease in hydraulic head per unit area of the aquifer, and it is a dimensionless quantity.

1.1. The study area

The study area is situated within latitude 5° 46'8''N to 5° 46' 10'' N and longitude 6° 8'45'' E to 6°7'42'' E in Ethiope East Local Government Area of Delta State, Nigeria (Figure 1). The area of study has the features of Benin Formation characterised by gentle flat slope. The elevation of the area is about 22 m to 30 m above sea level. The town which is a fast growing one is located between Obiaruku and Abraka with people migrating from Orogun, Amai, Otorho, Oria, Obiaruku, Eku and Kwale which has resulted to increase in population. This increase in population has resulted in the inadequacy of potable water in the area. This problem of lack of water and failure of some boreholes dug by government and individual has led to the need to assess aquifer geohydraulic properties for improved and better yield.

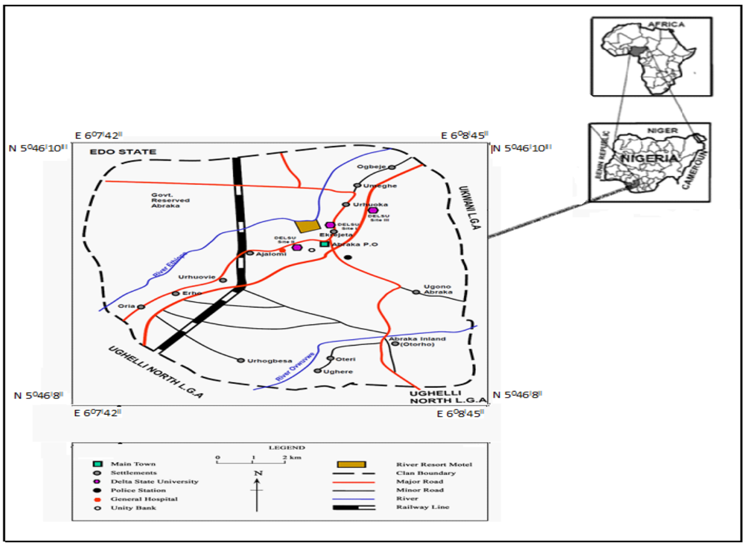

Figure 1: Location map of the study area (Ogbeje and Umeghe)

2. MATERIALS AND METHODS

In this study, the vertical electrical sounding, pumping test, electric well logging and grain size analysis were used to determine the aquifer hydraulic properties in the area.

2.1 Vertical Electrical Sounding Procedures

The field array method of Vertical Electrical Sounding was employed to meet the specific objectives of this study. The method requires that the current electrode spacing is much greater than the potential electrode which ensures deep penetration into the subsurface. The array also has the advantage of logistics and reduced manpower. The field equipment is mainly a Self Averaging Sensitive (SAS 1000) Terrameter. Nine resistivity soundings were carried out with the maximum electrode separation of 150 m (Figure 2) in order to establish the characteristics of the aquifers in the study area.

In this study, hydraulic conductivity was estimated from empirical data using the exponential law function expressed according to Juandi and Syahil (2017) as:

$$\ln ln\, k = 0.078\, ln\rho_i + 6.04 \quad (1)$$

where ρ_i is the resistivity of the subsurface.

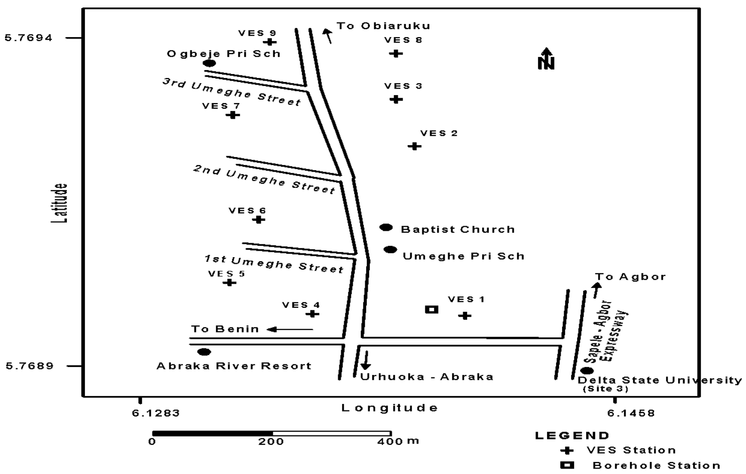

Figure 2: Base map showing acquisition strategy of the study area (Ogbeje and Umeghe)

The apparent resistivity values obtained from the VES were then plotted against electrode spacing on a bi-log paper. Qualitatively, visual assessment of these curves produced interpretation of the subsurface resistivity variations. Quantitative interpretation of the sounding curves was conducted by partial curve matching technique (Gouet et al., 2020) using 2-layer master curve and the equivalent auxiliary curves. This requires segment by segment interpretation of a multi-layer curve starting from small electrode spacing and continuing progressively to large electrode spacing. Geoelectric results from this manual analysis were enhanced upon the application of computer iteration technique using the Velpen, 1988). The results were then presented as geoelectric sections, depth to aquifer map and isoresistivity map, using the SURFER 8 computer software. During the pumping test, water was pumped from a borehole and the pumping rate recorded. For pumping test analysis, the principle involves the release of stress to an aquifer by water extraction from a well and measuring the drawdown as a function of time of the aquifer reaction to the stress.

Before pumping was started, the well head was opened and the calibrated Dipmeter was used to measure the static water level. The pump was then lowered to appreciable depth and connected to the generator set. The water discharge was collected in a calibrated 20 liters container and stop watch is set to zero start time. Pumping was then started, and the results of the measured drawdown based on the scheduled time was recorded on the data sheet. The time and water level discharge was measured and recorded simultaneously. A submersible pumping machine of 5.5 hp capacity was installed in the test well and used to power the pump. The well was pumped at a constant rate of 0.073 m^3/min. At some interval of time, the depth of the water level in the well was measured. This procedure was carried out in the borehole and the drawdown was determined. The difference between the water level at a given time and the water level before pumping commenced gives the drawdown. The difference in the height of the water level before and after pumping was plotted against time of pumping on a semi-logarithmic graph sheet for the well. The graph gave an estimate of the drawdown per log cycle of time (ΔL) and the time intercept (t_o). These values were introduced into the Cooper-Jacob equations to estimate the transmissivity, hydraulic conductivity of the aquifer and specific capacity of the well. The aquifer properties were estimated from the graph by deducing the drawdown per log cycle and the time pumping started. Residual drawdown method was employed in this study based on the characteristics of data available (that is, single well pumping test data). The drawdown was calculated from the equation shown in equation 2 (Cooper and Jacob, 1946).

$$\Delta S = \frac{2.303Q}{4\pi T} \qquad (2)$$

where, Q is constant discharge in m^3/day and ΔS = change in draw down in meters.

During the pumping test and after the test, data were collated and analyzed to determine the following aquifer parameters.

(i) Specific Discharge (V)

This is applicable when referring to the provision of adequate water supply of a well. Specific discharge is the ratio of pumping rate over drawdown (Q/ΔS).

(ii) Transmissivity (T)

This is computed by fitting a straight line to drawdown on an arithmetic axis against time on a logarithmic axis. It can also be obtained quantitatively by employing the Cooper Jacob equation:

$$T = \frac{2.303Q}{4\pi}\Delta\left(h - h_o\right) \qquad (3)$$

where Q is discharge and Δ(h-ho) = ΔS the change in drawdown.

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Transmissivity (T) is the product of hydraulic conductivity and aquifer thickness, T = kb. It is the measure of the quantity of water that that can flow horizontally through a unit width by a full saturated thickness of the aquifer under a hydraulic gradient.

(iii) Storativity

Quantitatively, the storativity of an aquifer is defined by $2.25Tt/r^2$, or S = Ssb when confined. It is a property of the aquifer that describes the volume per unit surface area per unit reduction in hydraulic head of water transmitted from storage.

(iv) Hydraulic Conductivity (K)

This is the quantitative measurement of the aquifer permeability. It is the degree or measure of water to pass through a unit thickness of an aquifer. The relationship between hydraulic conductivity K and transmissivity T is given by the expression:

$$T = Kb \qquad (4)$$

where, b is saturated thickness of the aquifer obtained from the Vertical Electrical Sounding results

Grain Size Analysis

Five representative samples were collected during borehole drilling operations in the area and taking to the Geotechnical Laboratory of the Delta State University Abraka. The samples were collected and described at intervals of 5 m to a depth of 25 m. The samples labeled A - E were subjected to mechanical dry sieve analysis, in order to construct the grain-size distribution curves. Several sieves with mesh sizes ranging from 0.063 mm to 1.180 mm were used. The soil was first dried in an oven at 105°C to remove water content, weighed, and then washed in a fine-grained sieve to remove materials smaller than 0.063 mm. The material was then dried and weighed to calculate the amount that has been washed away. Thereafter, the sieves of different sizes were vertically stacked in decreasing order and the sample poured into the top, largest sieve. The stack, was then moved in a circular motion with a vertical tapping impulse for a given time. Afterwards, the stack of sieves was set apart and the amount of material trapped in each sieve was weighed. The result is divided by the total weight of the sample so as to calculate the percentage of grains corresponding to different sizes. This procedure is referred to as sieve analysis, and the percentages of grains forming the sample and corresponding to different sizes form a grain-size distribution (GSD) of the initial sample (Lambe and Whitman, 1969; McCarthy, 2001). The grain-size diameters d_{10} was read off from the grain-size distribution curves and used to determine the conductivity values of uniform sands with the empirical formula as proposed by Hazen (1982). Hazen formula was basically constructed for the calculation of hydraulic conductivity of uniformly graded sand. It can also be used for fine sand to gravel range, if the value for uniformity coefficient of the sediment is less than 5 and effective grain size is between 0.1 and 3 mm, this is sand to gravel range. The proposed formula is given by:

$$K = C(d_{10})^2 \qquad (5)$$

where K is hydraulic conductivity (cm/s). C is Constant. If K is in cm/s and D_{10} in mm, C = 1 (Freeze and Cherry, 1979), d_{10} is effective diameter (mm) defined as the diameter such that 10 % by weight of the porous matrix consists of grains smaller than it. The strongest correlation between hydraulic conductivity and particle-size distribution parameters is that of the log of hydraulic conductivity with the 10 % finer particle size. After plotting, the d_{10} value was obtained and substituted into Hazen's formula to obtain the hydraulic conductivity. However, the value of hydraulic conductivity so obtained is only an estimate (Lopez et al., 2015).

2.2. Geophysical Borehole Logging

The borehole drilled in the study area was followed suite to the various layers. This gave important information on how the layer strata are arranged in a profile. Subsurface electrical logging was carried out in an uncased borehole to a depth of 30 m. The electrical resistivity logging was carried out using SAS 1000 terrameter, SAS200 logging probe which was lowered into the well through a calibrated tape. Both electrical resistivity and spontaneous potential logging were carried out by lowering the probe into the well at an interval of 2 m. These values were recorded in millivolts for spontaneous potential and ohm-meter for resistivity. The obtained data was then plotted on a graph and analyzed to determine the lithology of the subsurface.

3. RESULTS AND DISCUSSION

The results of the borehole logging, vertical electrical sounding, pumping test and grain size analysis are presented.

3.1. Lithological Evaluation

The lithologic log obtained from the drilled borehole and the electrical log are presented in figure 3. The log showed that the first layer is composed of lateritic topsoil which is about 2 m thick. The layer underneath is the lateritic sand which is reddish in colour, unconsolidated and 4 m thick. These portions show a resistivity log value of -2.81 to 0.8 Ωm and a spontaneous potential value 0.171 to 0.184 mV. At a depth of about 14 to 26 m, the lithology changes to fine - medium grain sand that is brownish in colour. The resistivity log value increases slightly from those of the above formation to a range of 0.068 to 2.86 Ωm. The SP value also rises slightly and more stable within this formation. After the 26 m mark to where the logging stopped, the lithology encountered is the medium - coarse grain sand which is

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also brownish in colour. This formation is considered the best to source for groundwater for domestic purposes. This is seen from the stability of the resistivity values and increase in the SP log values which depicts a better quality than the overlying layer.

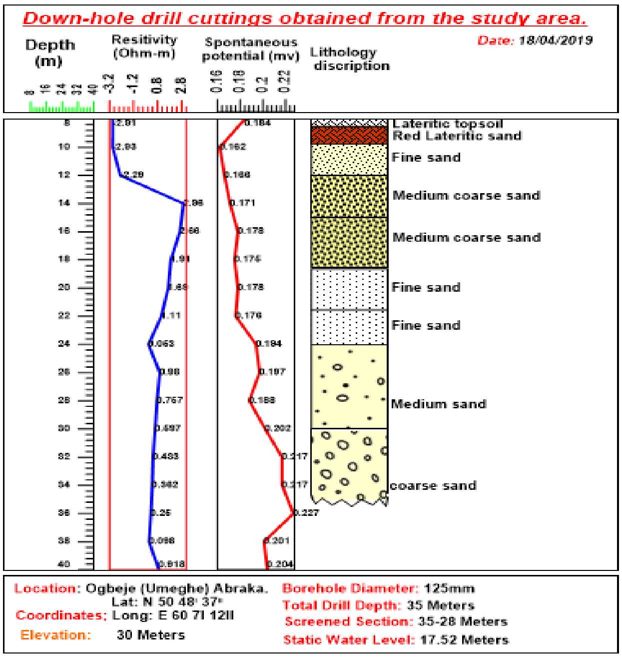

Figure 3: The borehole well log plotted against a lithologic log in the area

3.2 Vertical electrical sounding results

Nine (9) VES stations were occupied in the area. The summary of the geoelectric parameters obtained from the VES curves interpretation are presented in Table 1. The curves were characterized according to their locations, which represent the layering of the subsurface.

Table 1: Summary of result obtained from computer iteration

VES	Number of layers	Resistivity	Thickness	Depth	Inferred lithology
1	1	307.6	0.5	0.5	Laterite/topsoil
	2	5760.3	1.0	1.5	Laterite sand
	3	9929.6	2.8	4.3	Fine to coarse grain sand
	4	7059.1	18.0	22.3	Fine to medium grain sand
	5	9785.8	---	---	Medium to coarse sand
2	1	2900	1.0	1.0	Laterite/topsoil
	2	3385.7	0.5	1.5	Laterite sand
	3	8746.8	1.6	3.0	Fine to coarse grain sand
	4	9166.7	20.0	23.1	Fine to coarse grain sand
	5	9777.7	---	---	Medium to coarse gravely sand
3	1	3047.8	0.9	0.9	Laterite/topsoil
	2	2296.1	1.3	2.2	Laterite sand
	3	7115.0	3.3	5.5	Fine to coarse grain sand
	4	3447.7	12.4	17.9	Fine grain sand
	5	9934.3	---	---	Medium to coarse gravely sand
4	1	4132.3	0.8	0.8	Laterite/topsoil
	2	1162.6	0.5	1.3	Laterite sand
	3	4539.9	3.8	5.1	Fine to medium grain sand
	4	8213.8	13.9	19.0	Fine to coarse grain sand
	5	7880.8	---	---	Medium to coarse sand
5	1	3190	1.0	1.0	Laterite/topsoil
	2	8107.3	7.7	8.6	Laterite sand
	3	11831.4	14.0	22.6	Fine to coarse grain sand
	4	11611.3	---	---	Medium to coarse sand

6	1	5482.9	1.0	1.0	Laterite/topsoil
	2	2961.9	0.4	1.4	Laterite sand
	3	4587.7	12.0	13.4	Fine to medium grain sand
	4	7770.3	15.0	28.3	Fine to coarse grain sand
	5	10269.3	---	---	Medium to coarse sand
7	1	1148.2	0.8	0.8	Laterite/topsoil
	2	947.8	1.2	2.0	Laterite sand
	3	11648.0	2.3	4.4	Fine to coarse grain sand
	4	3454.8	6.7	11.0	Fine to medium grain sand
	5	7568.2	---	---	Medium to coarse gravely sand
8	1	2332.5	1.0	1.0	Laterite/topsoil
	2	1169.9	0.4	1.4	Laterite sand
	3	2279.3	3.5	4.9	Find sand
	4	5932.3	9.7	14.6	Fine to medium grain sand
	5	3046.2	16.2	31.2	Fine to medium grain sand
	6	6226.6	---	---	Medium to coarse sand
9	1	2625	0.6	0.6	Laterite/topsoil
	2	4675.9	0.5	1.1	Laterite sand
	3	2986.3	4.7	5.7	Fine grain sand
	4	1985.3	19.9	25.5	Fine grain sand
	5	6225.5	---	---	Medium to coarse sand

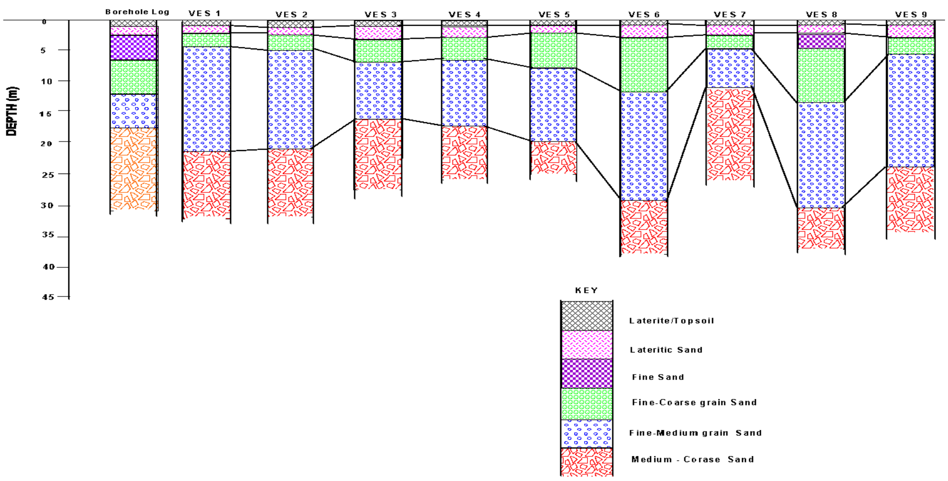

Figure 4: Geoelectric section obtained from VES at Ogbeje and Umeghe, Abraka

Figure 4 shows the geoelectric section across the VES stations in the area in comparison with the borehole log. Geoelectric sections show the distribution of the resistivity of the various delineated layers with respect to depth. Also, it shows the lateral continuity of the geoelectric layers across the VES stations in the indicated directions and the variations of thickness of each layer. The parameters utilized in generating the sections are resistivity values and layer thicknesses. Geoelectric sections give an insight of the subsurface geologic sequence and structural disposition in a two dimensional form. Five distinct geoelectric layers namely laterite/topsoil, laterite sand, fine sand, fine to medium grain sand and fine to coarse grain sand is observed.

The first layer consists of laterite/topsoil resistivity values ranging from 200 – 2500 Ωm and thickness varying from 0.5-1.1 m. The second layer consists of lateritic sand with resistivity ranging from 308-5500 Ωm and thickness varying from 0.4-7.7 m. The third layer consists of fine sand with resistivity ranging from 1100 - 9965 Ωm and thickness of 1.6-14.0 m. The fourth layer consists of fine to coarse sand with resistivity ranging from 2200-8500 Ωm and thickness varying from 6.7-20.0 m. The fifth layer is coarse gravely sand with resistivity ranging from 6225 - 11611 Ωm, the exact thickness of this layer cannot be determined as the current electrode separation terminates within this layer.

3.3 Second order geoelectric parameters from vertical electrical sounding

The aquifer parameters from the Vertical Electrical Sounding presented in Table 2 shows the aquifer characteristics in the area. The aquifer resistivity across the VES stations ranges from 2986 Ωm for VES 9 to 11831 Ωm for VES 5 while the thickness varies from 6.7

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m for VES 7 to 20 m for VES 2. Also, the aquifer transmissivity ranges from 57 to 170 m^2/day in VES 7 and VES 2 respectively. The longitudinal conductance was also estimated to range from 0.0011833 Ω^{-1} (VES 5) to 0.0066638 Ω^{-1} (VES 9). The values for diagnostic factor are $K\sigma_{min}$ = 0.0010145 $(\Omega day)^{-1}$ (VES 5), and $k\sigma_{max}$ = 0.00401835 $(\Omega m)^{-1}$ (VES 9).

The values for transmissivty, longitudinal conductance and diagnostic factors were used to generate contour maps across the area (Figures 5 to 7). Figure 5 shows that the transmissivity is highest in the northeastern part of the area, around VES 9 and lowest in the western flank. High transmissivity reflects high transverse resistance with good ground water potential making the northeastern part more productive for groundwater resource development. Also, the longitudinal conductance flow vector map (Figure 6) shows groundwater flow direction from Ogbeje in the northeast to the Umeghe/Urhuoka in the southwest. This suggests that dumpsite should not be contemplated in Ogbeje area. The contour map of the diagnostic factor (Figure 7), provides a comprehensive distribution pattern of the ratio of the transmissivity to transverse resistance, Kσ, which is an indication that the water in the Benin Formation is not brackish or saline (Udoinyang and Igboekwu, 2012)

Table 2: Dar Zarrouk Parameters at Ogbeje and Umeghe, Abraka

VES	Aquifer Resistivity ρ (Ωm)	Aquifer Thickness (h)m	Aquifer depth (m)	Aquifer Conductivity σ =1/ ρ $(\Omega m)^{-1}$	Longitudinal Conductance S = σh	Transverse Resistance R=h ρ	Hydraulic conductivity (a constant/ σ)	Transmissivity T_r = kh	Diagonostic Parameters kσ
1	7059	18	22.3	0.00014	0.0025	127062.0	8.38	150.9	0.0012
2	9167	20	23.1	0.00011	0.0022	183340.0	8.55	171.1	0.0009
3	3448	12.4	17.9	0.00029	0.0036	42755.2	7.93	98.3	0.0023
4	8214	13.9	19	0.00012	0.0017	114174.6	8.48	117.9	0.0010
5	11831	14	22.6	0.00008	0.0012	165634.0	8.73	122.2	0.0007
6	7770	15	28.3	0.00013	0.0019	116550.0	8.44	126.7	0.0011
7	3455	6.7	11	0.00029	0.0019	23148.5	7.93	53.1	0.0023
8	3046	16.2	31.2	0.00033	0.0053	49345.2	7.85	127.2	0.0026
9	2986	19.9	25.5	0.00033	0.0067	59421.4	7.84	156.0	0.0026

K is 8.5 m^2/day from pumping test

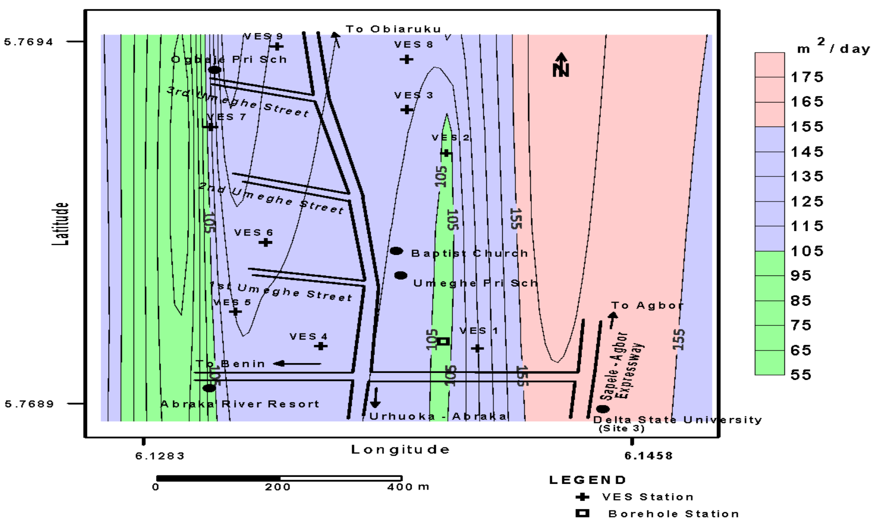

Figure 5: Transmissivity contour map of the study area.

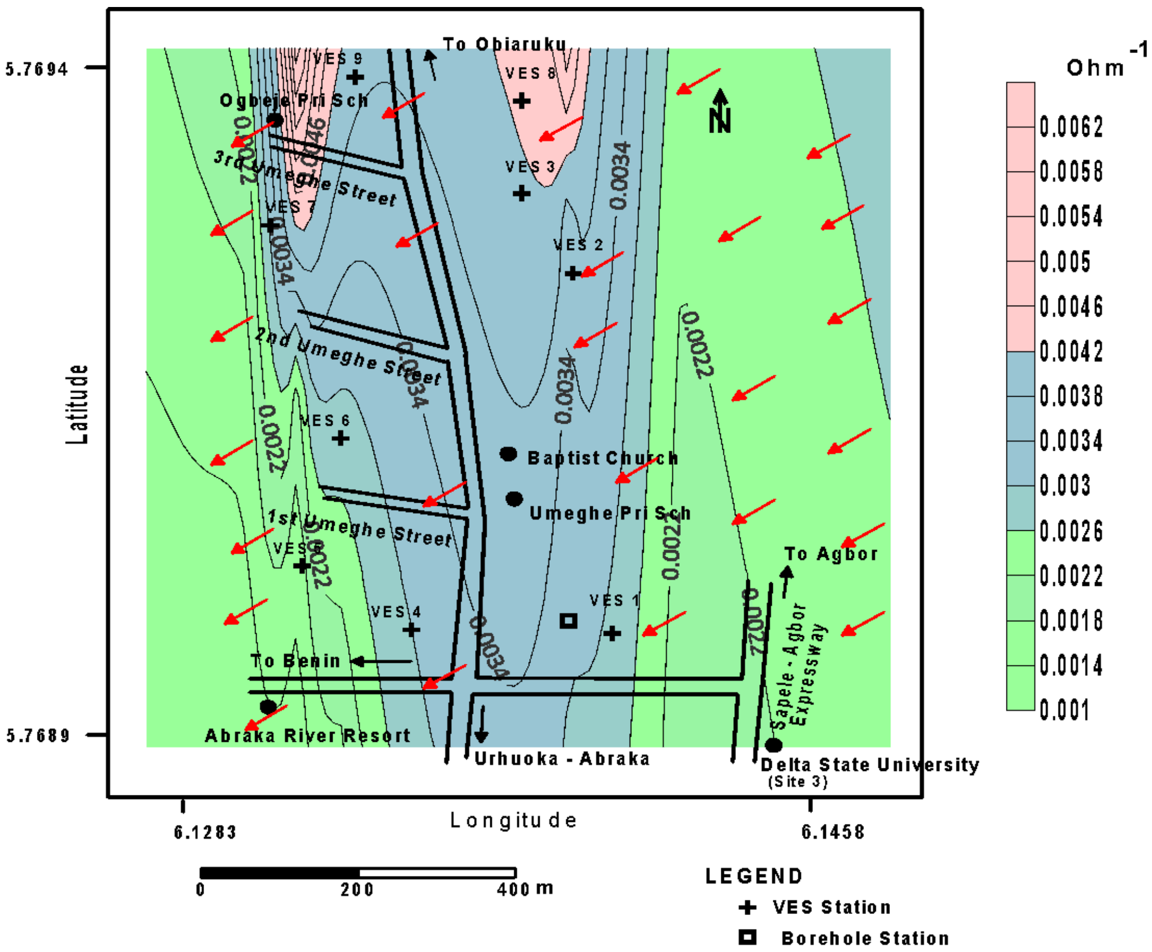

Figure 6: Longitudinal conductance flow vector of the study area.

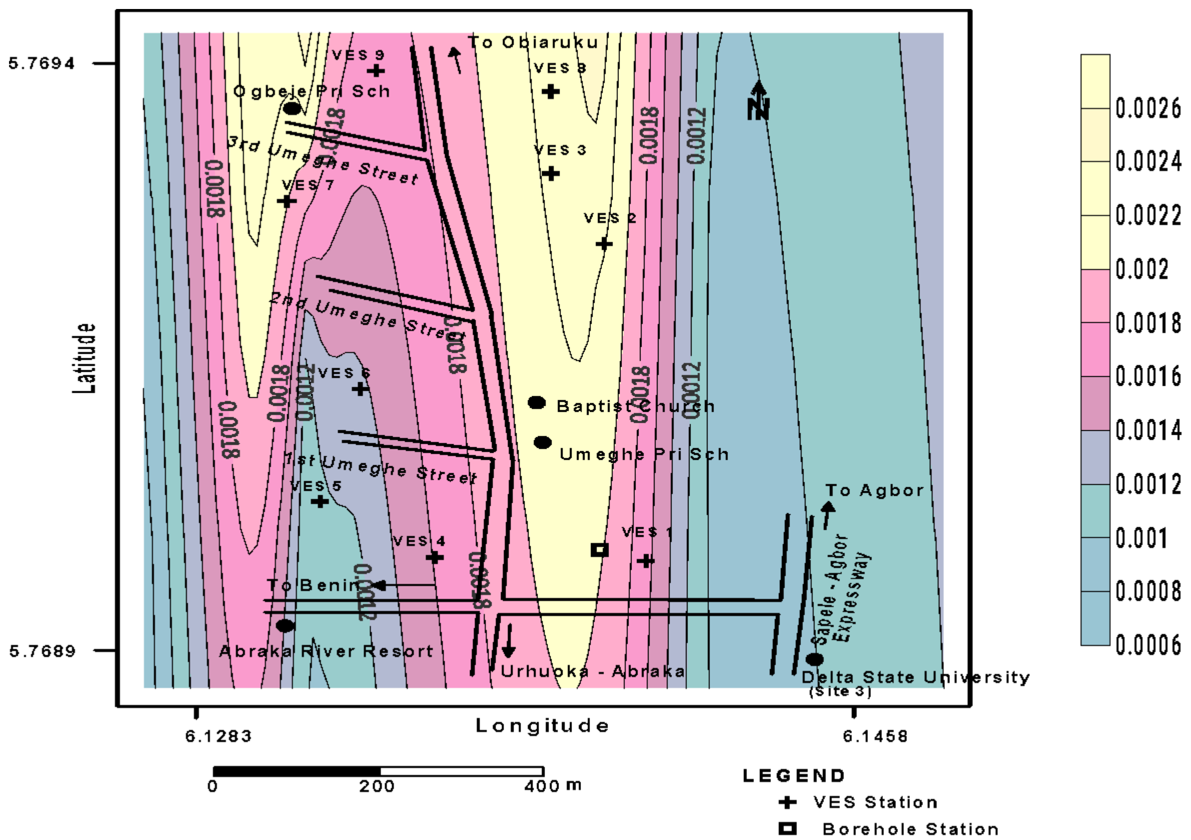

Figure 7: Diagnostic parameter contour map of the study area

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3.4 Pumping Test Analysis

The results of the pumping test carried out in the drilled well are shown in Tables 3 and 4. Figure 8 is a plot which shows the relationship between the water level and the time of pumping. The drawdown was plotted against the time since pumping began.

Table 3: Result of pump test analysis (drawdown) in Ogbeje and Umeghe

S/N	Time (t) since pumping began (min)	Falling Head (m)	Discharge Rate (m^3/mins)	Drawdown (m)
1	0.00	17.520	0.000	0.000
2	1	17.468	0.073	0.052
3	2	17.431	0.073	0.089
4	4	17.410	0.073	0.110
5	6	17.360	0.073	0.160
6	8	17.350	0.073	0.170
7	10	17.340	0.073	0.180
8	20	17.310	0.073	0.210
9	30	17.285	0.073	0.235
10	40	17.250	0.073	0.270
11	60	17.220	0.073	0.300
12	80	17.206	0.073	0.314
13	100	17.200	0.073	0.320
14	200	17.170	0.073	0.350
15	300	17.170	0.073	0.350
16	400	17.170	0.073	0.350
17	550	17.170	0.073	0.350
18	600	17.170	0.073	0.350
19	700	17.170	0.073	0.350
20	720	17.170	0.073	0.350

Table 4: Recovery test data obtained from the pumping well in Ogbeje and Umeghe

S/N	Time (t) since pumping stopped (min)	Water Rising Head (m)
1	720	17.170
2	721	17.430
3	722	17.510
4	723	17.520
5	724	17.520
6	725	17.520
7	726	17.520
8	727	17.520
9	728	17.520
10	729	17.520
11	730	17.520

Using the Cooper Jacobs's formula, with a power pump of constant pumping rate of 0.073 m^3/min, drawdown per cycle as 0.18 m (as deduced from the graph), time pumping started t_o = 2 secs and radius of the well to be 23m with aquifer thickness of 12.5m the transmissivity, storativity and hydraulic conductivity of the aquifer were estimated as follows:

$$T = \frac{2.3 \, x \, Q}{4\pi \, x \, \Delta s} = \frac{2.3 \, x \, 0.073 \, m^3/min}{4 \, x \, 3.142 \, x \, 0.185 \, m} = 0.0722 \text{ m}^2/\text{min}$$

= 103.968 m^2/day

For specific capacity of the well (BH)

$$S_{y} = \frac{Q}{\Delta s} = \frac{0.073}{0.185} = 0.395 \, (m^3/\text{min})/\text{m} = 568.8 \text{ m}^2/\text{min}$$

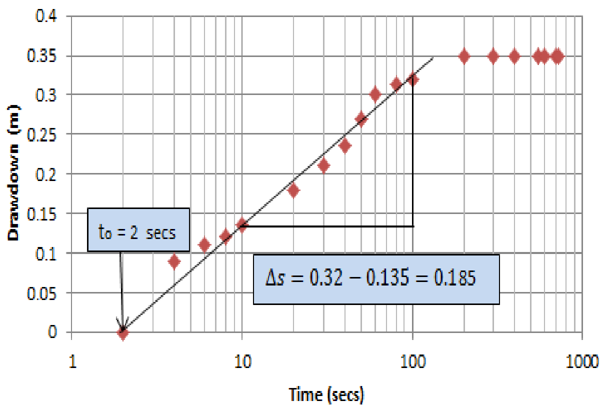

Figure 8: Graph of Drawdown against Time of pumping of Ogbeje and Umeghe Abraka

For storativity,

$$s = \frac{2.3 \, x \, T \, x \, t_0}{r^2} = \frac{2.3 \, x \, 0.0722 \, m^2/min \, x \, 2 \, secs}{23^2 m^2} = \frac{0.3358}{529} =$$

0.00063

Estimating the hydraulic conductivity of the aquifer with average aquifer thickness of 12.5m from the VES results

$$K = \frac{T}{b} = \frac{0.0722 \, m^2/min}{12.5 \, m} = 0.005776 \, m/min$$

K= 8.5 m/day

Results of the aquifer parameters obtained from the drilled borehole, indicates that the Transmissivity, T is 103.968 m^2/day, Storativity, S is 0.00063, Specific Capacity is 568.8 m^2/min and Hydraulic Conductivity is 8.5 m/day. The results obtained were used to compute the amount of water that can be transmitted vertically and horizontally which is given as 0.0722 m^2/min. The parameter indicates that the transmissivity rate of the groundwater in the aquifer is high, the aquifer is prolific and a productive borehole (well). The values also agreed with the result of a similar survey carried out in Igun, Eku, and Oria-Abraka showing a transmissivity of the areas ranging between 0.068 and 0.070m^2/min (Anomohanran, 2013). The result is also in agreement with the work of Rajasekhar *et al*. (2014) who applied the principle of pump test method to derive the transmissivity of confined aquifer and obtained it as 0.065 m^2/min. The study shows that the storage coefficient of the aquifer in the area as 0.00013, this value correspond to the storage coefficient of a confined aquifer (Todd, 2004, Anomohanran, 2015, Anomohanran and Iserhien-Emekeme, 2014). The result is an indication that enough pressure exist within the aquifer to produce substantial quantity of water. Specific capacity of borehole (well) shows that it is productive as this study gives a specific capacity of 568.8 m^2/min, indicating that the well is capable of producing sufficient amount of water for the people in the area. Hydraulic conductivity

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of the aquifer in the area is 8.5 m/day (Table 2), the value also in agreement with the result of a similar survey using geoelectric soundings carried out at Orerokpe, shallow Benin Formation in Western Niger Delta, Nigeria (Aweto and Akopborie, 2015), which gave that the hydraulic conductivity values varied between 10.50 m/day and 45.71 m/day.

3.5 Grain Size Analysis Results

A plot of the passing percentage against the sieve or particle size (Figure 9) gives the grain size distribution curve of the different grain samples from which the d_{10} values for each samples is obtained and used to calculate the hydraulic conductivity. Samples were collected from five depths for grain size analysis.

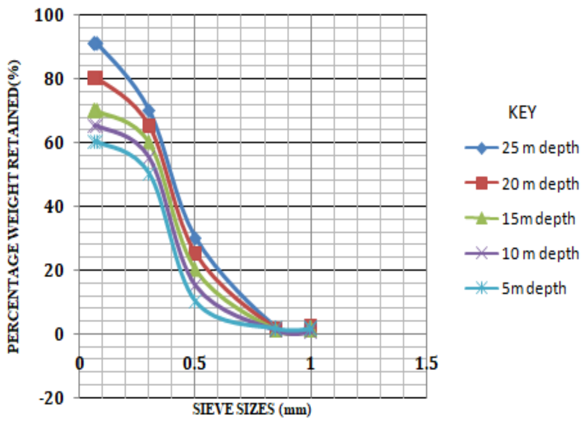

Figure 9: Plot of Grain Sizes in Each Sample

Sieve analysis curves for cuttings retrieved from the borehole at depths which ranges between 5 m and 25 m were plotted as shown in Figure 9. The curves show similarity for the five representative samples. Following Odong (2007) and Fetter (2001), hydraulic conductivity was estimated with the Hazen (1982):

$$K = C(D10)^2 \tag{6}$$

From Figure 8, D_{10} ranges from 0.50 to 0.72. So, following the Hazen approximation,

K_{min}= 6 x $(0.005)^2$ = 6 x 0.000025 = 0.00015 m/s = 12.96 m/d

Also,

K_{max}= 6 x $(0.0072)^2$ = 6 x 0.000052 = 0.000312 m/s = 26.96 m/d

where K is hydraulic conductivity in cm/s, D_{10} is the effective grain size in cm, C is a coefficient that is based on the aquifer matrix. The values of hydraulic conductivity K obtained with C = 6 following Uma, (1989); Akpoborie and Efobo, (2014). The estimated values of hydraulic conductivity K in the study area ranges from K_{min}= 12.96 m/d to K_{max}= 26.96 m/d respectively.

4. CONCLUSION

Vertical Electrical Sounding, pumping test and grain size analysis have been used to study aquifer hydraulic characteristics in part of Abraka area, Delta State. Five distinct geoelectric layers namely laterite/topsoil, laterite sand, fine sand, fine to coarse grain sand and fine to medium grain sand were observed. The first layer consists of laterite/topsoil resistivity values ranging from 200 – 2500 Ωm and thickness varying from 0.5-1.1 m. The second layer consists of laterite sand with resistivity ranging from 307.6-5500 Ωm and thickness varying from 0.4-7.7 m. The third layer consists of fine sand with resistivity ranging from 1100-9965 Ωm and thickness of 1.6-14.0 m. The fourth layer consists of fine to coarse sand with resistivity ranging from 2200-8500 Ωm and thickness varying from 6.7-20.0 m. The fifth layer is coarse gravely sand with resistivity ranging from 6225-11611.3 Ωm. Depth to aquifer in the area was in the range of about 11 – 28.3 m, and the results correlate with available borehole sinking records of 11.9 – 27.5 m. The pumping test results gave the aquifer transmissivity of 0.0742 m^2/min, storage coefficient of 0.00013, specific capacity of 0.395 m^2/min and hydraulic conductivity of 8.5 m/day. These are in agreement with results of other studies in neighboring communities. A similarity was reflected in the curves for the five representative samples obtained from grain size cutting in the study area. The estimated value of hydraulic conductivity K using the Hazen formula ranges from K_{min}= 12.96 m/d to K_{max}= 26.96 m/d, which gives an average of 19.96 m/day. The result is an indication that enough pressure exist within the aquifer to produce substantial quantity of water for the inhabitants in the area. The integrated methods have been successfully employed in modelling aquifer hydraulic properties in the study which will serve as a reference information for groundwater resource managers.

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