

Bridging the Gap between Available Aquifer Test Data and Missing Aquifer Hydraulic Characteristics using a Simple Graphical Approach.

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ABSTRACT

Values of aquifer parameters are best estimated through pumping tests but are costly and time consuming. Electrical resistivity survey carried out at the vicinity of a borehole where pumping test have been acquired provides a cost-effective and efficient alternative to estimate aquifer parameters. In this paper, a graphical linear relationship was established from a set of data and subsequently used in places where pumping test is not available for the determination (estimation) of aquifer hydraulic parameters. A comparison of this method with existing data proved that hydraulic conductivity can be accurately predicted using this approach. The main advantage of the estimation method presented here is its simplicity and accuracy.

(Keywords: simple graphical linear relationship, aquifer parameter estimation, geo-electrical data)

INTRODUCTION

For a proper assessment and management of groundwater resources, a thorough understanding of the complexity of its processes is quite essential; therefore, quantitative description of aquifers has become vital in order to accurately assess groundwater resources.

Aquifers are best characterized by their hydraulic conductivity (K), transmissivity (T), porosity (Φ) and storativity (S), that influences groundwater flow and pollutant migration (Freeze and Cherry, 2002).

The estimation of parameters of groundwater systems such as hydraulic conductivity and hydrodynamic dispersion coefficients has been an active research area in hydrogeology and hydraulics studies over the past few decades.

Generally accepted methods for the estimation of parameters, such as pumping tests and permeameter tests (Bear *et al.*, 1968) and Bear (1979), are either performed on limited areas of the experimental site or are based on laboratory tests on a few soil samples because the high monetary as well as time requirements limit the implementation of field tests over the entire experimental area.

Hydraulic conductivity and aquifer depth are fundamental properties describing subsurface hydrology. As a result, many investigation techniques are commonly employed with the aim of the estimation of spatial distribution of hydraulic parameters such as hydraulic conductivity, transmissivity and aquifer depth.

The objective of this study is to find the relationship between aquifer properties and surface electrical resistivity parameters in Umuahia-South Local Government Area of Abia State Nigeria, and to estimate hydraulic conductivity and transmissivity from the interpreted surface electrical resistivity parameters.

For this purpose, surface geophysical methods have been used for aquifer zones delineation and evaluation of the geophysical character of the aquifer zones in the area.

From the available pumping tests in the study area; a graphical linear relationship was established between geophysical parameters and aquifer hydraulic parameters and subsequently used in places where pumping test is not available for the estimation of aquifer hydraulic parameters at other places in the study area.

The study have shown that the integration of aquifer parameters calculated from the existing boreholes locations and surface resistivity

parameters extracted from surface electrical measurements can be highly effective not only for aquifer hydraulic conductivity estimation but also for a group of hydraulic parameters.

LOCATION AND BRIEF GEOLOGY OF STUDY AREA

Geologically, Umuahia-South lies in the South eastern part of the Cenozoic Niger Delta Basin of Nigeria (Figure 1). Cenozoic Niger Delta sedimentary basin was formed from the interplay between subsidence and deposition arising from a succession of sea transgressions and regressions (Hosper, 1965; Short and Stauble, 1965); which gave rise to the deposition of three lithostratigraphic units in the Niger Delta. These units are Marine Akata Formation, Paralic

Agbada Formation, and the Continental Benin Formation (Figure 2).

The Akata and Agbada Formations are the source and reservoir rocks respectively for petroleum in the Niger Delta while the Benin Formation serves as the aquifer for all the groundwater supplies. The overall thickness of these Cenozoic sediments is about 10,000 meters.

In this present study, the Oligocene to Recent Benin Formation which is the surface outcrop of Umuahia-South area serves as the aquifer for all the boreholes (Figures 2 and 3). The study area is the only Benin hydrogeological setting in Abia State that comprises sediments of the Oligocene to Recent Ogwashi-Asaba Formation and Miocene to Recent Coastal Plain Sands.

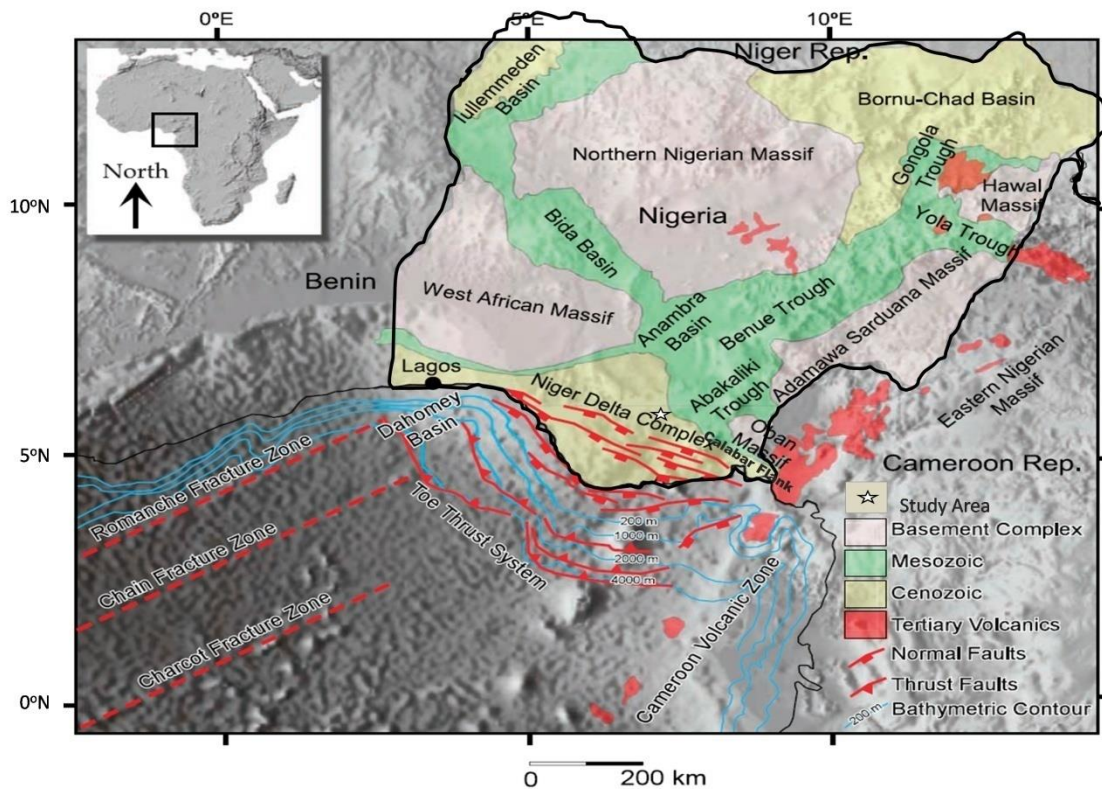


Figure 1: Location Map of Niger Delta Region showing Main Sedimentary Basins and Tectonic Features.

The Miocene to Recent Benin Formation is made up of sands which are mostly medium to coarse grained, pebbly, moderately sorted with local lenses of poorly cemented sands and clays. But generally, Benin Formation consists of shale/sand sediments with intercalation of thin clay beds (Asseez, 1976 and Murat, 1972).

The high permeability and the intercalation of the sands with clays/clayey shale layers of Benin

Formation, with underlying Bende-Ameki Formation of paralic delta front setting are indicative of a multi-aquifer system (Figure 2).

Petrographic analysis of Benin Formation indicates that the composition of the rocks is as follows: 95-99% quartz grains, 1-2.5% of Na+K-mica, 0 -1.0% of feldspar and 2-3% of dark colored minerals (Onyeagocha 1980).

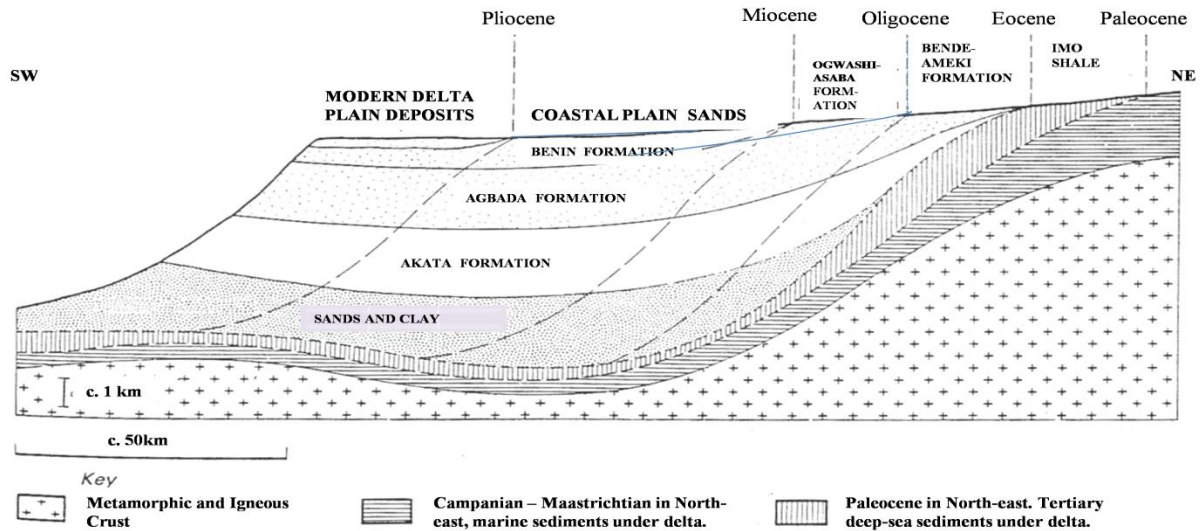


Figure 2: A Schematic Longitudinal Cross Section Showing the Diachronous Nature of Common Lithofacies of Anambra Basin and Niger Delta.

(*Curved broken lines represent successive positions of the delta front with time).

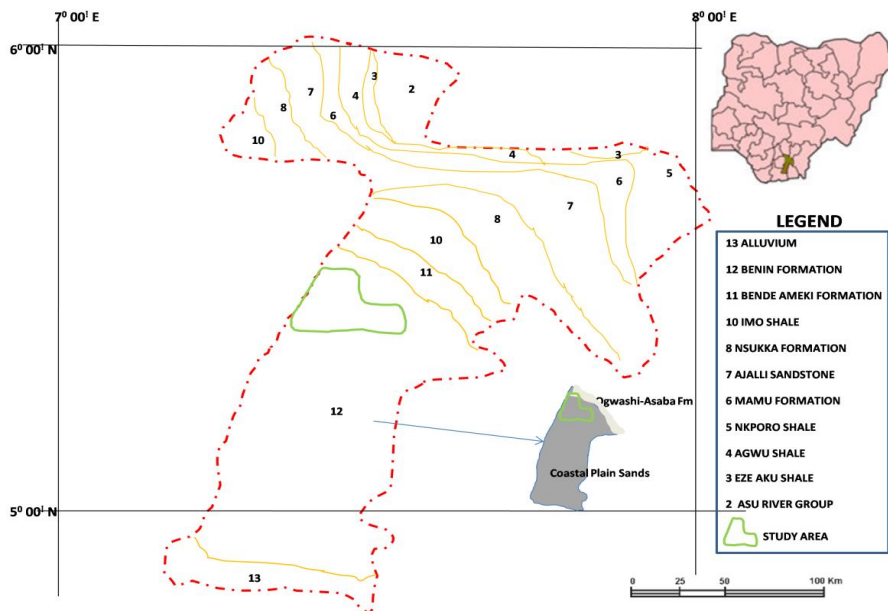


Figure 3: Geologic Map of Abia State showing the Study Area.

The present study area (Umuahia-South) lies within latitudes $5^{\circ} 26'$ and $5^{\circ} 34'$ N, and longitudes $7^{\circ} 22'$ and $7^{\circ} 33'$ E (Figure 3). It has high relative humidity values over 70%, and is characterized by high temperatures of about $29^{\circ} - 31^{\circ}$ C. The area is part of the sub-equatorial belt with average annual rainfall of about 4000mm per annum.

The wet season starts from Mid-April to October and dry season from November to Mid-April, and has double maxima rainfall peaks in July and September with a short dry season of about three weeks between the peaks locally known as the August break.

Umuahia-South Local Government Area of Abia state, Nigeria is bounded in the north and north-east by Umuahia North, in the south by Isiala Ngwa North, in the east by Ikwuano Local Government Areas respectively and the Imo River demarcates it with Imo State in the western part (Figure 4).

The area is endowed with natural springs and streams including Imo River on the western flank which flow in a southerly direction and empty into the Atlantic Ocean.

On the other hand, Anya River (though small compared to the Imo River) traverses the Southeastern flank of Umuahia-South. This Anya River is a main tributary of the great Kwa Ibo river of Akwa-Ibom and Cross River States of Nigeria.

METHODOLOGY

The Vertical Electrical Sounding (VES) method of electrical resistivity survey was employed using the Schlumberger electrode configuration involving four electrodes spacing with two current electrodes 'AB/2' widely spaced outside and two potential electrodes 'MN/2' closely spaced within them all along the survey line as shown in Figure 5.

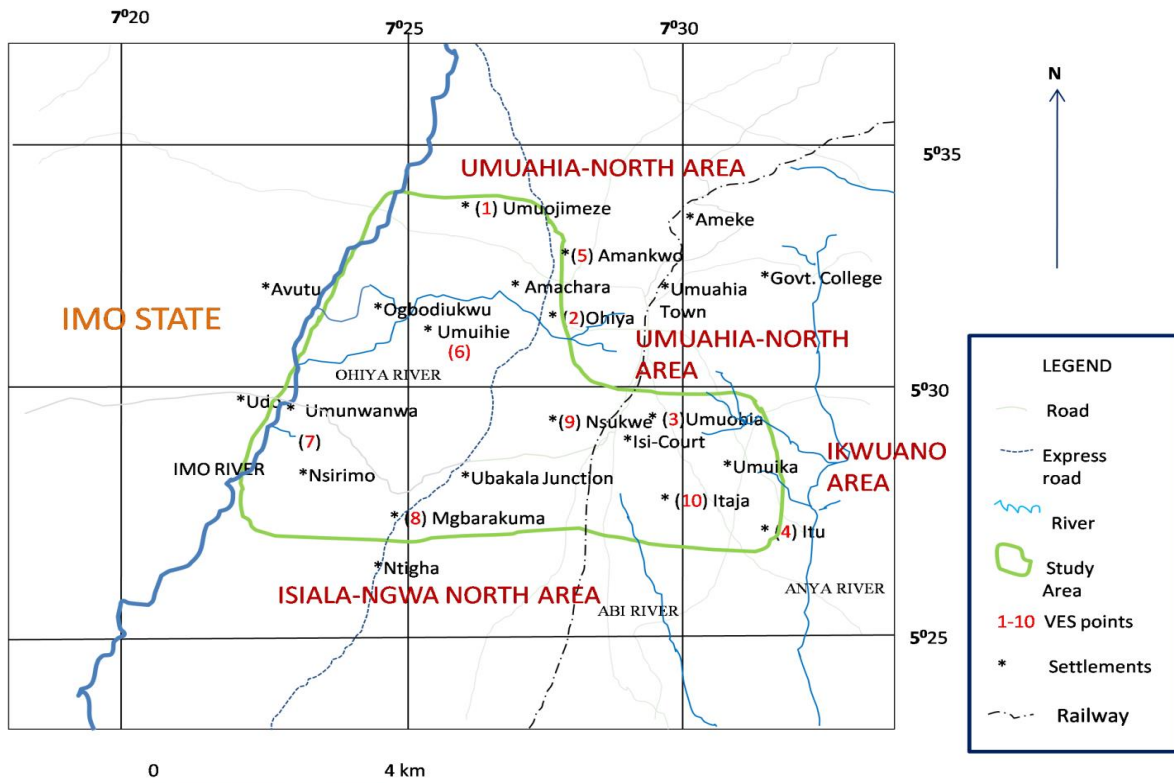


Figure 4: Map of the Study Area showing VES points, Major Rivers and Drainage Patterns.

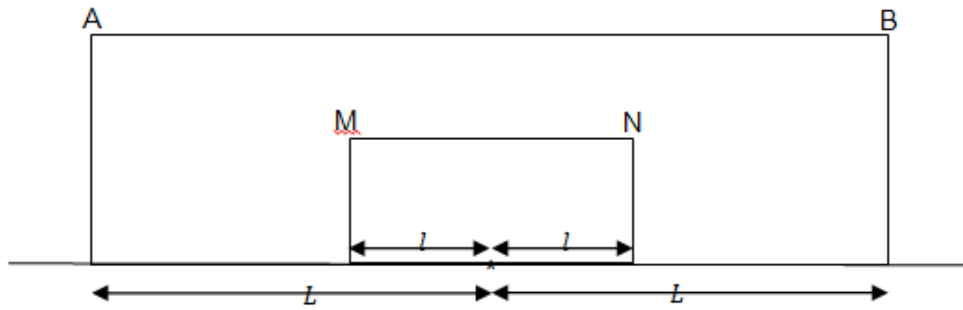


Figure 5: Schematic Diagram of the Schlumberger Electrode Configuration Used.

A maximum half current electrode spacing 'AB/2' of 500m and a maximum half potential electrode spacing 'MN/2' of 55m was used in the study.

The study area was transformed into a regular grid where ten nodal points were chosen as sounding stations at intervals of 4km. Out of the ten sounding stations, three were done at the vicinity of existing boreholes for comparative analysis.

With the location of the sounding point, the Garmin GPS 72 was used in determining the coordinates in longitude, latitude and elevation height above mean sea level.

Then the ABEM Terrameter SAS 4000 which was used in the data acquisition was deployed to the position where direct current (DC) from the terrameter was passed into the ground using two metal stakes (current electrodes 'AB/2') linked by insulated cables. The current developed a ground potential difference whose voltage was determined using two other electrodes 'MN/2', which were kept in line with the pair of current electrodes.

The observed field data which is the ratio of the resulting voltage to the imposed current is only a measure of resistance of the subsurface (ground resistance). This is read off directly from the terrameter and is used to compute the corresponding apparent resistivity in Ohm-meters by multiplying with the geometric factor 'values as functions of electrode spacing', which then gives the required apparent resistivity results as functions of depths of individual layers:

$$\rho_a = \pi R \left(\frac{L^2 - l^2}{2l} \right)$$

Where ρ_a = Apparent resistivity,

R = Resistance in ohms.

L = 'AB/2' = Half current electrode spacing (m).

l = MN/2 = Half potential electrode spacing (m).

$$\pi \left(\frac{L^2 - l^2}{2l} \right) = \text{Geometric factor (K)}$$

The sounding curves for each point was obtained by plotting the computed apparent resistivity against the half current electrode spacing (AB/2) on a log-log graph scale paper. The sounding curves were used for the conventional partial curve matching technique and use of auxiliary point diagrams (Zohdy, 1976); and based on this, initial estimates of the resistivities and thicknesses of the various geoelectric layers were obtained and used for computer iteration using RESIT software package.

RESULTS AND DISCUSSION

Since groundwater accumulates in sedimentary rocks (sands, gravels, silt, limestone, etc.), and in weathered overburden, joints, fractures and faults zones in crystalline basement rocks. The electrical resistivity of subsurface materials (rocks, minerals, etc.) can be determined by the subsurface resistivity distribution to the ground which is at times related to the physical conditions of interest such as lithology, porosity, degree of water saturation and presence or

absence of voids in the rocks (Ako, 2002). The VES method of electrical resistivity gives detailed information of vertical succession of individual thicknesses, resistivities and their different conducting zones. In each case, the VES was used to delineate the subsurface stratigraphy based on resistivity differences; from those values the aquifer thickness and other parameters were obtained as shown in Table 1.

Aquifers Parameters of the Study Area

The resistivity and thickness of an aquiferous medium is directly related to transmissivity and hydraulic conductivity of the aquifer. The integration of these two data can give an indication of the groundwater potential of the area. Maillet (1947) shows that after obtaining the true thickness; alongside the resistivity of an aquifer from the surface resistivity measurements, the transverse unit resistance 'R' and longitudinal conductance 'S' are calculated (Table 3) using what he called the Dar-Zarrouk variable 'R' and Dar-Zarrouk function 'S'.

$$R = h\rho \quad (1)$$

$$S = h/\rho \quad (2)$$

Where h and ρ = thickness and resistivity of individual layers respectively.

The longitudinal conductance 'S' of Equation (2) can also be computed as:

$$S = \sigma h \quad (3)$$

Where ' σ ' is layer conductivity.

Conductivity as expressed here is analogous to the layer transmissivity 'T'.

$$T = Kh \quad (4)$$

Where K and h = hydraulic conductivity and thickness of individual layers, respectively.

Recall from Equation (3) that $S = \sigma h$;

$$\text{Therefore, } S/\sigma = h \quad (5)$$

Recall also, from Equation (4) that $T = Kh$;

$$\text{Therefore, } T/K = h \quad (6)$$

Table 1: VES Location Points and their Corresponding Aquifer Characteristics.

VES Station Location	GPS Reading			Aquifer Resistivity (Ω m)	Aquifer Thickness (m)	Longitudinal Conductance S (Siemens)	Aquifer Conductivity σ	Aquifer Transverse Unit Resistance R (Ω m ²)
	Elevation (m) m.s.l	Latitude °N	Longitude °E					
2 Ohiya	139	5°31.304'	7°27.508'	483.5	218.5	S ₃ = 0.4519	0.0021	105644.75
3 Umuobia (Isi Court)*	151	5°29.273'	7°28.931'	811.5	226	S ₄ = 0.2785	0.0012	183399
4 Okwu	141	5°28.106'	7°30.803'	1007.2	98.0	S ₂ = 0.0973	0.0010	98705.6
5 Amankwo	138	5°32.516'	7°27.503'	776	27.0	S ₄ = 0.0348	0.0013	20952
6 Umuihe	102.8	5°30.506'	7°25.200'	413.3	200.0	S ₂ = 0.4839	0.0024	82660
7 Umunwanwa	122.9	5°29.320'	7°24.156'	450.3	224.1	S ₃ = 0.4977	0.0022	100912.2
8 Mgbarakuma *	151	5°28.324'	7°25.160'	473	196.0	S ₃ = 0.4144	0.0021	92708
9 Nsukwe	146	5°29.224'	7°26.960'	475.9	172.0	S ₃ = 0.3614	0.0021	81854.8
10 Itaja*	150	5°28.132'	7°30.526'	855 340	52.0 77.0	S ₅ = 0.0608 S ₆ = 0.2265	0.0012 0.0029	44460 26180

*VES carried out in the vicinity of boreholes were pumping tests were acquired.

Now, substituting the value of 'h' in Equation (5) into Equation (6), we obtain:

$$T/K = S/\sigma ;$$

$$\text{Therefore, } T = KS/\sigma \quad (7)$$

Recall from equation (5) that $S/\sigma = h$; and from Equation (1) that $R = h\rho$,

$$\text{Therefore, } R/\rho = h, \quad (8)$$

Now, substituting the value of 'h' in Equation (5) into Equation (8), we obtain:

$$R/\rho = S/\sigma ;$$

$$\text{Therefore, } \sigma R = S\rho \quad (9)$$

Recall also, from Equation (2) that $S = h/\rho$;

$$\text{Therefore, } S\rho = h \quad (10)$$

By substituting the value of $S\rho$ in Equation (10) into Equation (9), we obtain:

$$\sigma R = h \quad (11)$$

Now, from the above derivations, transmissivity 'T' can be expressed as:

$$T = KS/\sigma = Kh = K\sigma R \quad (12)$$

Dar-Zarrouk parameters have since been used in the estimation of aquifer hydraulic characteristics (Johnson 1977, Niwas and Singhal 1981a, b).

In areas of similar geologic setting and non-varying water quality, (Niwas and Singhal 1981a)

were able to show that that the product of both conductivities 'K σ ' remains fairly constant.

If values of 'K' are obtained from existing boreholes, and the values of ' σ ' are obtained from VES data interpretation within the vicinity of a borehole. Then, the transmissivity can be estimated, and its variation determined from one location to the other where no borehole is located by using parameters 'R or S' and the choice of parameter is dependent upon the values of ' σ ' and 'h'.

Present study shows VES Stations 2,6,7,8, and 9 are within area of similar geologic setting and water quality, while VES 3, 4, and 5 are of same geologic setting and water quality, but VES 10 have both characteristics (Table 1).

Estimation of Aquifer Hydraulic Parameters of the Study Area

The determination of aquifer hydraulic parameters, transmissivity (T), and hydraulic conductivity (K) through analysis of pumping test has been done in some parts of the study area by the State Water Board (Table 2). The average field hydraulic conductivity (K) derived from the pumping test was further used to calculate the transmissivity (T) of the same boreholes from data (thickness) acquired through surface resistivity soundings (Table 2), and subsequently used in places where pumping test is not available for the determination (estimation) of aquifer hydraulic parameters using graphical approach (Figure 6).

Table 2: Hydraulic Parameters of the Study Area.

Data Location / Number	Average Field Hydraulic Conductivity (m/d)	Calculated hydraulic parameters based on pumping test (SWB 1988).		Calculated hydraulic parameters based on surface resistivity soundings 'VES' (Present Study).	
		Screen length (m)	Transmissivity (m ² /d)	Thickness of Aquiferous zone. (m)	Transmissivity (m ² /d)
Mgbarakuma GW2/VES8	10.80	12	129.6	196	2116.8
Itaja GW6/VES10	8.45	15	126.75	52	439.4
Umuobia (Isi Court) GW8/VES 3	8.65	12	103.8	226	1954.9

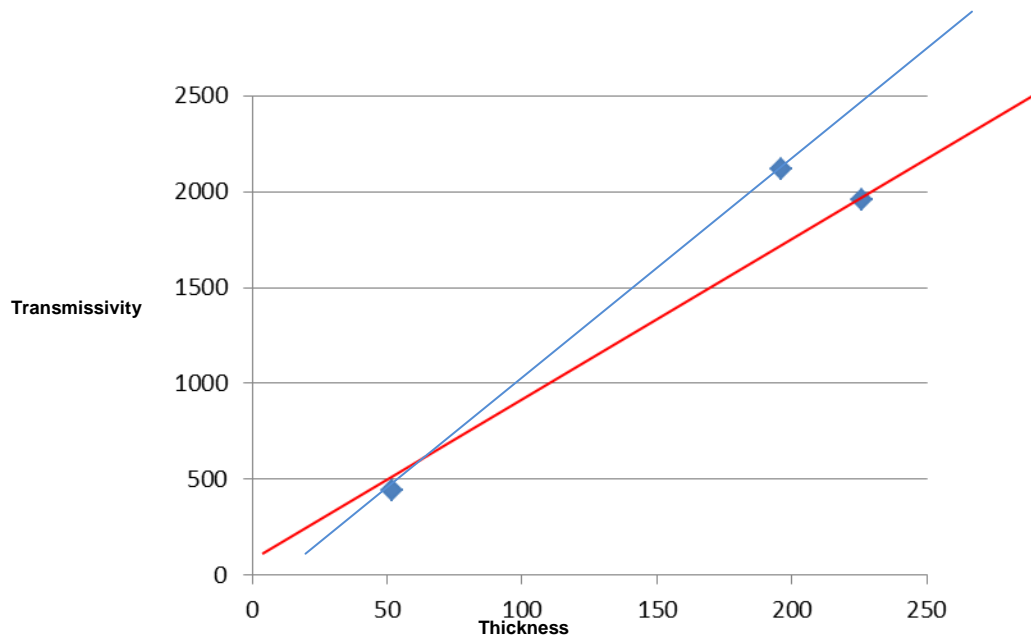


Figure 6: A plot of Aquifer Transmissivity versus Thickness.

Statistical estimation of aquifer hydraulic parameters based on existing data has been done using linear regression analyses and correlation coefficients (Davis 1986; Brown 1998; and Edet et al., 2005).

However, we used the graphical approach by plotting the calculated values (Table 2) based on surface resistivity soundings, and determining the slope through a line of best fit in a graphical representation ($y = mx$, $y/x = m$); where y = transmissivity, m (slope) = hydraulic conductivity and x = aquifer thickness (Figure 6). This estimation is in line with area of similar geologic setting and water quality.

Recall that VES Stations 2,6,7,8 and 9 are within area of similar geologic setting and water quality, while VES 3, 4 and 5 are of same geologic setting and water quality, but VES 10 exhibit both characteristics (Table 1).

Therefore line of best fit was made to pass through the resistivity-calculated value (transmissivity) of VES 10 and the resistivity-calculated upper VES values (transmissivity) of the two different geologic settings.

In the graph below, the blue line is that of VES Station 8, while that of VES Station 3 is red. Since VES Stations 2, 6, 7, 8, and 9 are within area of similar geologic setting and water quality, the intercept of the blue line (slope) is used in the estimation of aquifer hydraulic parameters of VES Stations 2, 6, 7, and 9. While, the intercept of the red line (slope) is used in the estimation of aquifer hydraulic parameter of VES Stations 4 and 5 (Figure 6).

Based on the graphical illustration in Figure 6 above, the aquifer hydraulic parameters such as hydraulic conductivity, and transmissivity are determined (estimated) once the aquifer thickness is known. This method was used in estimating the aquifer hydraulic parameters of the study area as shown in Table 3.

This method is indeed an alternative approach in determining hydraulic conductivity since pumping tests are not normally run due to their high cost and lack of equipment. The estimated data presented here are representative and can be of significant value as a guide to groundwater resource development in the study area because a comparison of the available pumping test data with this present study shows reliable approximations as shown in Table 4.

Table 3: Calculated (Estimated) Hydraulic Parameters using the Graphical Approach.

Data Location / Number	Thickness of Aquiferous zone in x-axis. (m)	Calculated (estimated) hydraulic parameters based on surface resistivity soundings (VES) using the graphical approach.	
		Transmissivity in y-axis (m ² /d)	Hydraulic Conductivity as slope "m" (m/d)
2 Ohiya	218.5	2360	10.80
3 Umuobia (Isi Court) *	226	1954.9	8.65
4 Okwu	98	840	8.57
5 Amankwo	27.0	210	7.78
6 Umuihe	200.0	2150	10.75
7 Umunwanwa	224.1	2410	10.75
8 Mgbarakuma *	196	2116.8	10.80
9 Nsukwe	172.0	1840	10.70
10 Itaja *	52	439.4	8.46

Table 4: A Comparison of Hydraulic Parameters from Pumping Test Data with the Data Estimated from Present Study.

Data Location / Number	Calculated hydraulic parameters based on pumping test (SWB 1988).			VES estimated hydraulic parameters using the graphical approach (Present Study).		
	Average Field Hydraulic Conductivity (m/d)	Screen length (m)	Transmissivity (m ² /d)	Estimated Hydraulic Conductivity (m/d)	Thickness of Aquiferous zone. (m)	Transmissivity (m ² /d)
Apumiri	10.80	12	129.6	10.80	196	2116.8
Itaja	8.45	15	126.75	8.45	52	439.4
Umuobia (Isi Court)	8.65	12	103.8	8.65	226	1954.9

Recall that the aim of this study is to estimate aquifer parameters through a cost-effective and efficient alternative method. One may say that the conclusions reached above in Table 4 are not justifiable because aquifer transmissivity still cannot be determined where there is no knowledge of hydraulic conductivity k from pumping test, and the transmissivity values calculated from the pumping test results compared with those estimated from the graphical

approach in Tables 2 and 4 (e.g., 129.6/2116.8; 103.8/1954.9) are not in agreement.

Therefore, in order to estimate aquifer hydraulic parameters (transmissivity) that are analogous to pumping test; a transmissivity factor was determined using the formula:

$$T_f = \frac{T_{pt}}{T_{rs}} \quad (13)$$

Where T_f = Transmissivity factor ,

T_{pt} = Transmissivity calculated based on pumping test, and

T_{rs} = VES (resistivity sounding) estimated transmissivity from graphical approach.

The determined transmissivity factor was subsequently used in multiplying the surface resistivity calculated (estimated) transmissivity values determined through graphical approach for various VES locations. The result is the aquifer parameter (true aquifer transmissivity) that is analogous to what could have been obtain through pumping test.

$$\text{True aquifer transmissivity} = T_f * T_{rs} \quad (14)$$

Recall that VES Stations 2, 6, 7, 8, and 9 are within area of similar geologic setting and water quality, while VES 5 and 3 are of same geologic setting and water quality (Table 1). Since VES Stations 2, 6, 7, 8, and 9 are within area of similar geologic setting and water quality, and VES 8 was carried out in the vicinity of a borehole where pumping test have been acquired; therefore the transmissivity factor (Table 5) is used in determining the transmissivity of VES Stations 2, 6, 7, and 9. While, the transmissivity factor of VES 3 is used in determining the transmissivity of VES Stations 4 and 5 (Table 5).

$$\text{So, the transmissivity factor of VES 8} = \frac{129.6}{2116.8} = 0.0612245$$

$$\text{While, the transmissivity factor of VES 3} = \frac{103.8}{1954.9} = 0.0530973$$

The determined transmissivity factor was used in multiplying the surface resistivity calculated (estimated) transmissivity of the graphical approach in accordance to area of similar geologic setting and water quality, and the result is the aquifer transmissivity (true aquifer transmissivity) that is analogous to what could have been obtain through pumping test (Table 6).

Recall from Equation (4) that $T = kh$ and that $T/k = h$ in Equation (6,) therefore Transmissivity "T" is a function of aquifer thickness "h" and the hydraulic conductivity "h".

Based on the above, true thickness of aquifers in areas of similar geologic setting and water quality can still be obtained. This is done using the values of calculated (estimated) hydraulic conductivity based on graphical approach of surface resistivity soundings (VES) in Table 3; and calculated (estimated) true aquifer transmissivity derived through Transmissivity factor in Table 6 above. So from Equation (6), true aquifer thickness of the various VES stations are determined as shown in Table 7 below.

Table 5: Calculated Hydraulic Parameters from Pumping Test, VES Estimated Hydraulic Parameters and their Corresponding Transmissivity Factor.

Data Location / Number	Calculated hydraulic parameters based on pumping test (SWB 1988).			VES estimated hydraulic parameters using the graphical approach (Present Study).			Transmissivity Factor
	Average Field Hydraulic Conductivity (m/d)	Screen length (m)	Transmissivity (m ² /d)	Estimated Hydraulic Conductivity (m/d)	Thickness of Aquiferous zone. (m)	Transmissivity (m ² /d)	
3 Umuobia (Isi Court) *	8.65	12	103.8	8.65	226	1954.9	0.0530973
8 Mgbarakuma *	10.80	12	129.6	10.80	196	2116.8	0.0612245

Table 6: Calculated (Estimated) True Aquifer Transmissivity using Transmissivity Factor.

Data Location / Number	Calculated (estimated) aquifer transmissivity based on surface resistivity soundings (VES) using the graphical approach.	Transmissivity Factor	True Aquifer Transmissivity
2 Ohiya	2360	0.0612245	144.49
3 Umuobia (Isi Court)*	1954.9	0.0530973	103.79
4 Okwu	840	0.0530973	44.60
5 Amankwo	210	0.0530973	11.15
6 Umuihe	2150	0.0612245	131.63
7 Umunwanwa	2410	0.0612245	147.55
8 Mgbarakuma*	2116.8	0.0612245	129.60
9 Nsukwe	1840	0.0612245	112.65

Table 6: Calculated (Estimated) True Aquifer Thickness.

Data Location / Number	Calculated (estimated) aquifer transmissivity based on surface resistivity soundings (VES) using the graphical approach.	Transmissivity Factor	True Aquifer Transmissivity	Hydraulic Conductivity as slope "m" (m/d)	True aquifer thickness
2 Ohiya	2360	0.0612245	144.49	10.80	13.38
3 Umuobia (Isi Court)*	1954.9	0.0530973	103.79	8.65	12.00
4 Okwu	840	0.0530973	44.60	8.57	5.20
5 Amankwo	210	0.0530973	11.15	7.78	1.43
6 Umuihe	2150	0.0612245	131.63	10.75	12.24
7 Umunwanwa	2410	0.0612245	147.55	10.75	13.73
8 Mgbarakuma*	2116.8	0.0612245	129.60	10.80	12.00
9 Nsukwe	1840	0.0612245	112.65	10.70	10.53

CONCLUSION

The study have shown that surface geophysical methods are not only used for groundwater exploration or delineation of aquifer geometry, but can also be used both for qualitative and quantitative estimation of aquifer parameters, thus

reducing the huge expenses of carrying out pumping tests.

From the few available pumping tests in the study area; a graphical linear relationship was established between geophysical parameters and aquifer hydraulic parameters, and subsequently

used in the estimation of aquifer hydraulic parameters.

This method has proven to be cost effective and has rapidly characterized the aquifer system in the study area.

It is now convincing that the integration of aquifer parameters calculated from the existing boreholes locations, and surface resistivity parameters extracted from surface electrical measurements has shown to be highly effective not only for aquifer hydraulic conductivity estimation but also for a group of hydraulic parameters.

REFERENCES

1. Ako, B.D. 1996. *Applied Geophysics*. Obafemi Awolowo University Press Limited: Ile-Ife, Nigeria.
2. Amos-Uhegbu, C, M.U. Igboekwe, T.K. Eke, and R.U. Adindu. 2012.. "Groundwater Modelling, An Effective Tool in the Assessment of Groundwater Contamination: A Case Study of Umunwanwa in Umuahia-South, Abia State, Nigeria". *British Journal of Applied Science & Technology*. 2(4): 334-355.
3. Amos-Uhegbu, C., M.U. Igboekwe, G.U. Chukwu, K.O. Okengwu, and T. K. Eke. 2012. "Hydrogeophysical Delineation and Hydrogeochemical Characterization of the Aquifer Systems in Umuahia-South Area, Southern Nigeria". *British Journal of Applied Science & Technology*. 2(4):406-432.
4. Asseez, L.O. 1976. "Review of the Stratigraphy, Sedimentation and Structure of the Niger Delta". In: Kogbe, C.A. (ed.). *Geology of Nigeria*. Elizabeth Publ. Co.: Lagos, Nigeria. 259 – 272.
5. Bear, J., D. Zaslavsky, and S. Irmay. 1968 *Physical Principles of Water Percolation and Seepage*. UNESCO Press: Paris, France.
6. Bear, J. 1979. *Hydraulics of Groundwater*. McGraw-Hill Inc.,: New York, NY.
7. Brown, C.E. 1998. *Applied Multivariate Statistics in Geohydrology and Related Sciences*.
8. 1st edn. Springer: Heidelberg, Germany.
9. Carrera, J. and S.P. Neuman. 1986a. "Estimation of Aquifer Parameters under Transient and Steady State Conditions, 1, Maximum Likelihood Method Incorporating Prior Information". *Wat.Res.Res.* 22(2):199–210.
10. Carrera, J. and S.P. Neuman. 1986b. "Estimation of Aquifer Parameters under Transient and Steady State Conditions, 2, Uniqueness, Stability, and Solution Algorithm". *Wat. Res. Res.* 22(2):211–227.
11. Chukwu, G.U. 2010. "Electrical Resistivity Survey to Investigate Causes of Borehole Failure within Ikwuano/Umuahia Area of Abia State, SE Nigeria". Unpublished Ph.D. thesis. Michael Okpara University of Agriculture: Umudike. Nigeria.
12. Davis, J.C. 1986. *Statistics and Data Analysis in Geology*. 2nd edn. John Wiley and Sons: New York, NY.
13. de Lima, O.A.L. and S. Niwas. 2000. "Estimation of Hydraulic Parameters of Shaly Sandstone Aquifers from Geological Measurements". *Journal of Hydrology*. 235:12-26.
14. Dietrich, C.R. and G.N. Newsam. 1989. "A Stability Analysis of the Geostatistical Approach to Aquifer Transmissivity Identification". *Stochastic Hydrol. Hydraul.* 3(4):293–316.
15. Ekwe, A.C, I.N. Nnodu, K.I. Ugwumba, and O.S. Onwuka. 2011. "Estimation of Aquifer Hydraulic Characteristics of Low Permeability Formation from Geosounding Data: A Case Study of Oduma Town, Enugu State". *Online Journal of Earth Sciences*. 4(1):19- 26, 2010 ISSN; 1991-7708.
16. Freeze, R.A. 1972. "Regionalization of Hydrogeologic Parameters for use in Mathematical Models in Groundwater Flow." .In: *Hydrogeology*. J.E. Gill (ed.). Harpell's, Gardenvale: Quebec, Canada.
17. Frohlich, R. and W.E. Kelly. 1985. "The Relation between Transmissivity and Transverse Resistance in a Complicated Aquifer of Glacial Outwash Deposits". *Journal of Hydrology*. 79: 215-219.
18. Griffiths, D. H. and R.F. King. 1983. "Applied Geophysics for Geologists and Engineers". In: *The Elements of Geophysical Prospecting*. Pergamon Press: Oxford, UK.
19. Heigold, P.C., R.H. Gilkson, K. Cartwright, and P.C. Reed. 1979. "Aquifer Transmissivity from Surficial Electrical Methods". *Groundwater*. 17: 338-345.
20. Hosper, J 1965. "Gravity and Structure of the Niger Delta, Nigeria, West Africa". *Bull. Geol.Soc. Amer.* 76:407-422.
21. Huntley, D. 1986. "Relation between Permeability and Electrical Resistivity in a Granular Aquifer". *Groundwater*. 24:466-475.

22. Igboekwe, M.U., E.E. Okwueze, and C.S. Okereke. 2006. "Delineation of Potential Aquifer Zones from Geoelectric Soundings in KWA IBO River Watershed, Southeastern, Nigeria". *Journal of Engineering and Applied Sciences*. 1(4):410-421.
23. Johnson, H.K., 1977. "A Man/Computer Interpretation System for Resistivity Soundings over a Horizontally Stratified Earth". *Geophys., Prospect*. 25:667-691.
24. Kearey, P. and M. Brooks. 1991. *An Introduction to Geophysical exploration. 2nd Edition*. Blackwell Science, Cambridge University Press: Cambridge, UK.
25. Kelly, W.E. 1977. "Geoelectric Sounding for Estimating Hydraulic Conductivity". *Groundwater*. 15:420-425.
26. Kosinki, W.K. and W.E. Kelly. 1981. "Geoelectric Soundings for Predicting Aquifer Properties". *Groundwater*. 19:163-171.
27. Maillet, R. 1947. "The Fundamental Equations of Electrical Prospecting". *Geophysics*. 12:529-556.
28. Mbonu, P.D.C, J.O. Ebeniro, C.O. Ofoegbu and A.S. Ekine. 1991. "Geoelectric Sounding for the Determination of Aquifer Characteristics in parts of the Umuahia Area of Nigeria". *Geophysics*. 56:284–291,
29. Murat, R.C. 1972. "Stratigraphy and Palaeogeography of the Cretaceous and Lower Tertiary in southern Nigeria". In: Dessauvage, T.F. J. and Whiteman, A. (eds.). *African Geology*. UI Press: Ibadan, Nigeria. 635 – 641.
30. Niwas, S. and D.C Singhal, 1981a. "Estimation of Aquifer Transmissivity from Dar-Zarrouk Parameters in Porous Media". *J. Hydrol.*, 50:393-399.
31. Niwas, S. and D.C Singhal. 1981b. "Estimation of Aquifer Transmissivity from Dar-Zarrouk Parameters in Porous Media". *J. Hydrol.* 50:529-556.
32. Niwas, S. and D.C. Singhal. 1985. "Aquifer Transmissivity of Porous Media from Resistivity Data". *Journal of Hydrology*. 82:143-153.
33. Onyeagocha, A.C. 1980. "Petrography and Depositional Environment of the Benin Formation". *Nig. J. Min. Geol.* 17(2):147-151.
34. Short, K.C. and A.J. Stauble. 1967. "Outline of the Geology of the Niger Delta". *AAPG Bull.* 51:761-769.
35. Singh, C.L. 1984. "Role of Surface Geophysical Methods for Groundwater Exploration in Hard Rock Areas". *Proceedings of International Workshop on Rural Hydrology and Hydraulics in Fissured Basement Zones*.59-68.
36. Susan, H.S. and Y. Rubin. 2002. "Hydrogeological Parameter Estimation Using Geophysical Data: A Review of Selected Techniques". *Journal of Contaminant Hydrology*. 45:3-34.

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