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Research Article

RELATIONSHIP BETWEEN GEOELECTRICAL AND HYDROGEOLOGICAL PARAMETERS IN THE PLATEAU REGION OF ENUGU STATE, NIGERIA

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ABSTRACT
Geophysical surveys involving the use of Vertical Electrical Soundings (VES**)** were carried out in the vicinity of 34 boreholes in the Plateau region of Enugu State Nigeria, with an aim to relate geoelectric properties to hydrogeologic parameters. The study area lies between latitudes 6° N and 7° N and longitudes 7° E and 7°30'E in the Southeastern part of Nigeria. The VES data were interpreted in terms of the apparent resistivity and thickness of subsurface layers. These parameters were then correlated with the available borehole data. Significant correlations between the transverse resistance and transmissivity as well as between the apparent resistivity and borehole yield were derived. It can be inferred from the study that the geoelectrical sounding method can used for making preliminary estimates of transmissivity and borehole yield in areas within the region where wells have not been drilled.
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Keywords: *Enugu Plateau, Transmissivity, Borehole Yield, Transverse Resistance, Aquifer*

INTRODUCTION
The determination of aquifer properties is best made on the basis of data obtained from test pumping wells. These properties are important in determining the natural flow of water through an aquifer and its response to fluid extraction. An alternative approach for estimating aquifer characteristics is the use of surface geoelectrical methods. Many investigators have studied the relationship between electric and hydraulic parameters of aquifers.

Mazac *et al.,* (1985) analyzed the correlation between aquifer and geoelectrical parameters on both the saturated and unsaturated zones of the aquifers. Louis *et al.,* (2005) estimated aquifer transmissivity on the basis of monitoring the variations of the ground water resistivity. Transmissivities, formation factors and permeability have also been estimated from empirical/semi-empirical correlations, often using simple linear relations (Kelly 1977; Schimschal, 1981; Chen *et al.,* 2001).

The analytical relations between aquifer transmissivity and Dar-Zarrouk parameters have been developed and various data sets tested (Sri Niwas and Singhal, 1981). An inverse relationship between porosity and hydraulic conductivity were used to explain the direct correlations between formation factor and hydraulic conductivity (Heigold *et al.,* 1979; Urish, 1981).

This paper presents a study that was conducted in the plateau region of Enugu State, Nigeria, to examine the relationship between hydrogeological and geophysical characteristics of the sandstone aquifers. The objective was to correlate surface resistivity data with aquifer properties in order to develop groundwater exploration model for the region.

The Study Area
The Plateau region (Nsukka-Udi-Awgu Plateau) falls within latitudes 6° N and 7° N and longitudes 7° E and 7°30'E (Figure 1)

The plateau is very extensive, some 48km wide in Nsukka area and 16km in Udi and Awgu (Figure 2). The region also shows undulating relief with a high central zone, which lies over 370m above mean sea level. Some isolated peaks may reach over 580m. Apart from the residual hills, the Plateau is also characterized by low density of drainage and wide, flat bottom dry valleys. The dry valleys are thought to be former river valleys that later got dried up by infiltration into the False bedded Sandstones (Ajali Sandstones). The land slopes to the east and west and there are beautiful Cuestas. The scarp face of the Cuesta is formed by resistant sandstones of the Lower Coal Measures (Mamu Formation), while the less

resistant False bedded Sandstones, form the gentler upper slopes and the crest. The plateau region is associated with the Ajali Sandstone and Nsukka Formation. The sandstone usually underlies areas of height above 300m while the Nsukka Formation is characterized by abundant residual hills (Figure 2)

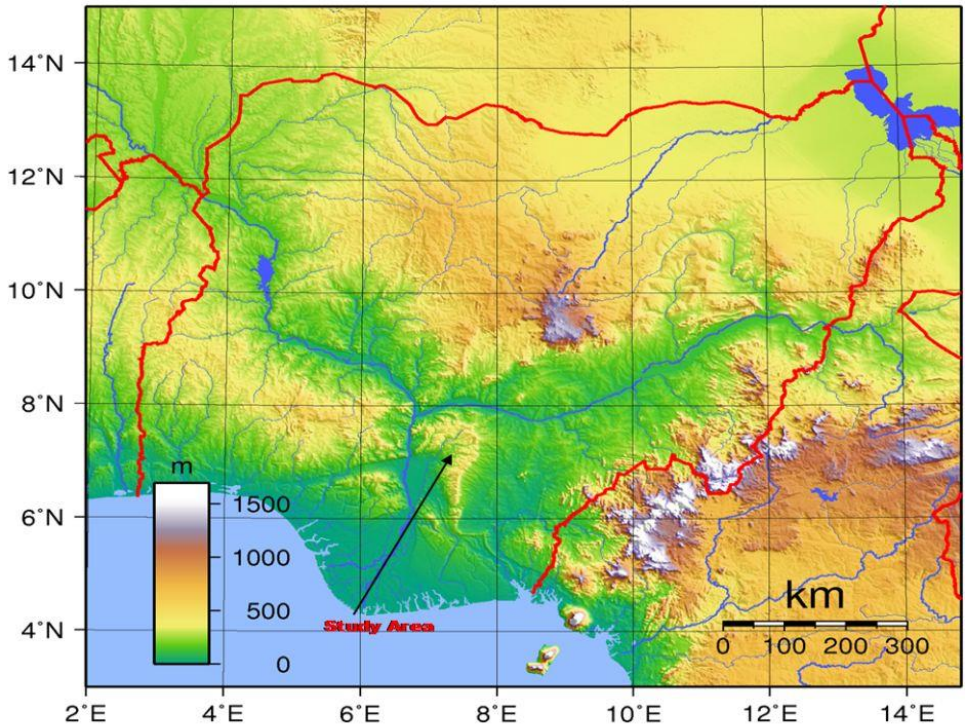


Figure 1: Topographic Map of Nigeria Showing the Nsukka – Udi Plateau (Wikimedia, 2015)

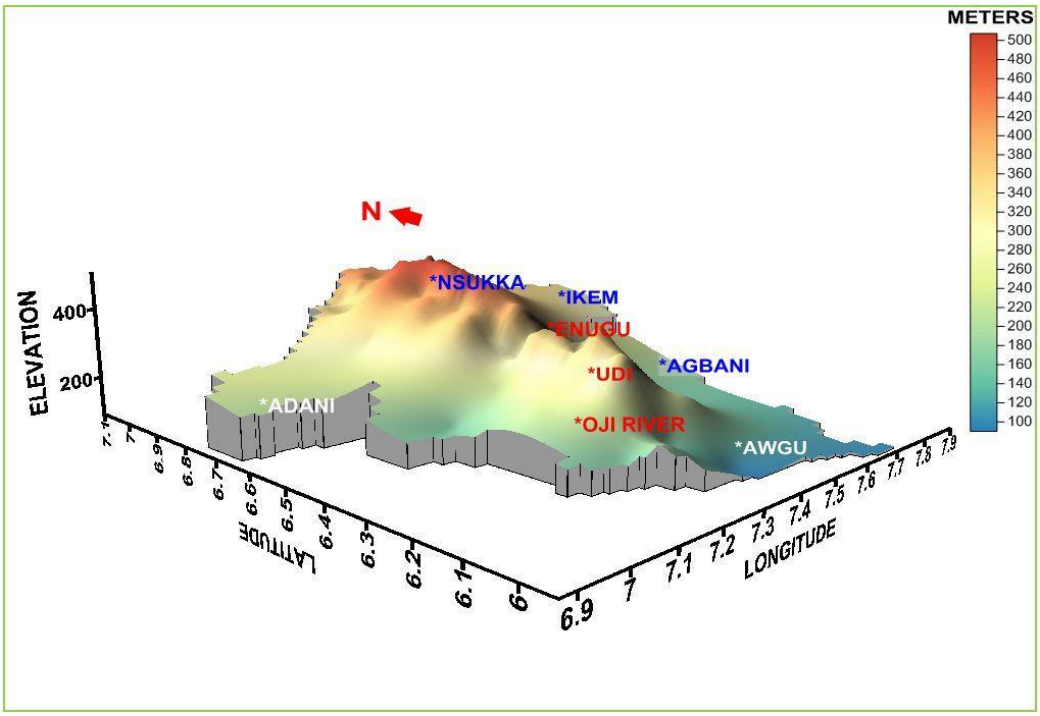


Figure 2: Surface Map of Enugu State Showing the Nsukka – Udi Plateu

Geology

Two main geologic formations outcrop in the study area. These are the Nsukka Formation (Damian) and Ajali sandstone (Upper Maaastritchian).

The Nsukka Formation lies conformably on the Ajali sandstone. The formation was first described by Tattam (1944) as the "Upper coal measures. The lithology is mainly interbedded shales, siltstones, sands and thin coal seams which have become lateritized in many places where they characteristically form resistant cap rocks.

The Ajali Sandstone (upper Maastritchian) is about 451.m thick (Agagu *et al.,* 1985) and consists lithologically of medium to coarse –grained, poorly consolidated white sands with characteristic cross bedding and clay intercalations. The sandstone is conformably underlain by shaley units of Mamu Formation which consists of mudstone, sandy shale and fresh water sandstones and provides the shaley impermeable base on which the waters of Ajali aquifer are trapped

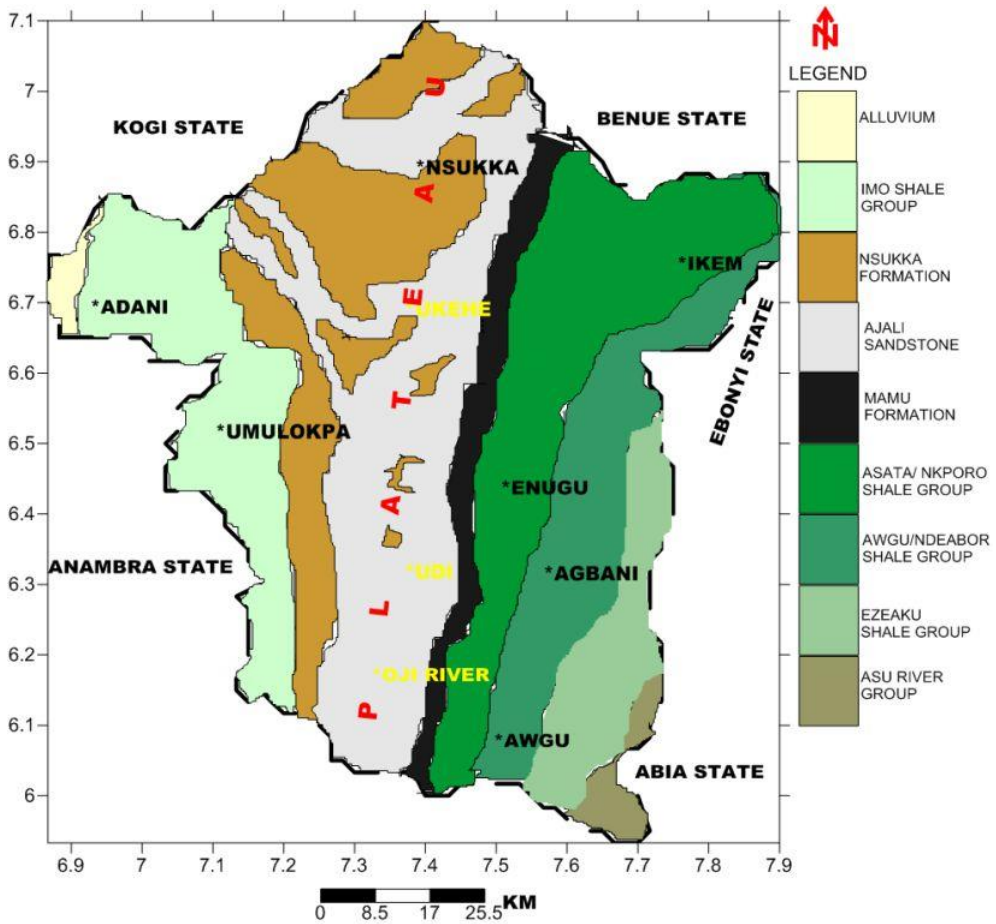


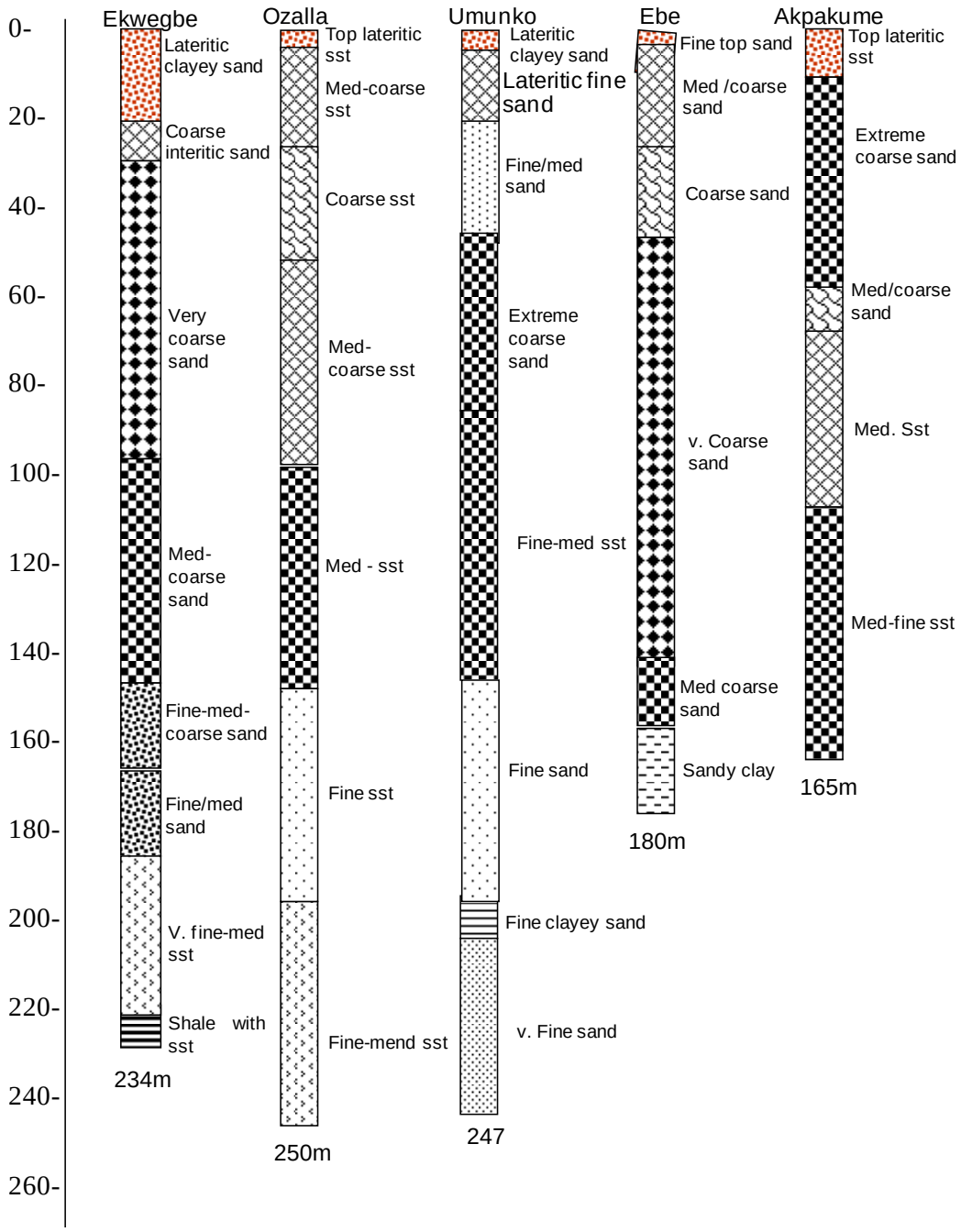
Figure 3: Geologic Map of Enugu State Showing the Plateau Region

hydrogeology

The Ajali sandstone is the most aquiferous geologic formation in the study area followed by the sandy members of Mamu and Nsukka Formation. Within these formations, various hydrologic units exist as perched, water table, semi confined and confined aquifers. Well records in parts of the study area (Figures 4-5) show that the aquifers are mostly sand/sandstones with sandy clay and clay/shale as semi-confining aquitards or aquicludes respectively. Confined conditions exist over the Ajali sandstone in areas overlain by the Nsukka Formation. The various unconfined aquifer units in the study area occur in the Ajali sandstone.

Semi-confined situation exists in places and usually comprise interbedded thick sequence of sand (aquifer) and sandy-clay or clayey-sand aquicludes (Figure 5). Various aquifers in this group occur in the upper to middle horizons of Ajali sandstone and in the upper section of the Mamu Formation.

Perched aquifer conditions occur mostly in the lateritic/red earth cover over the Nsukka Formation and in the upper sandy units of the Nsukka Formation. The perched aquifer is generally thin and measurements in dug holes gave thickness values ranging from 3m to about 8m with an average of about 4.6m (Uma, 2003).



M Figure 4: ure 5: Well Records Showing Deep Unconfined Units in the Study Area

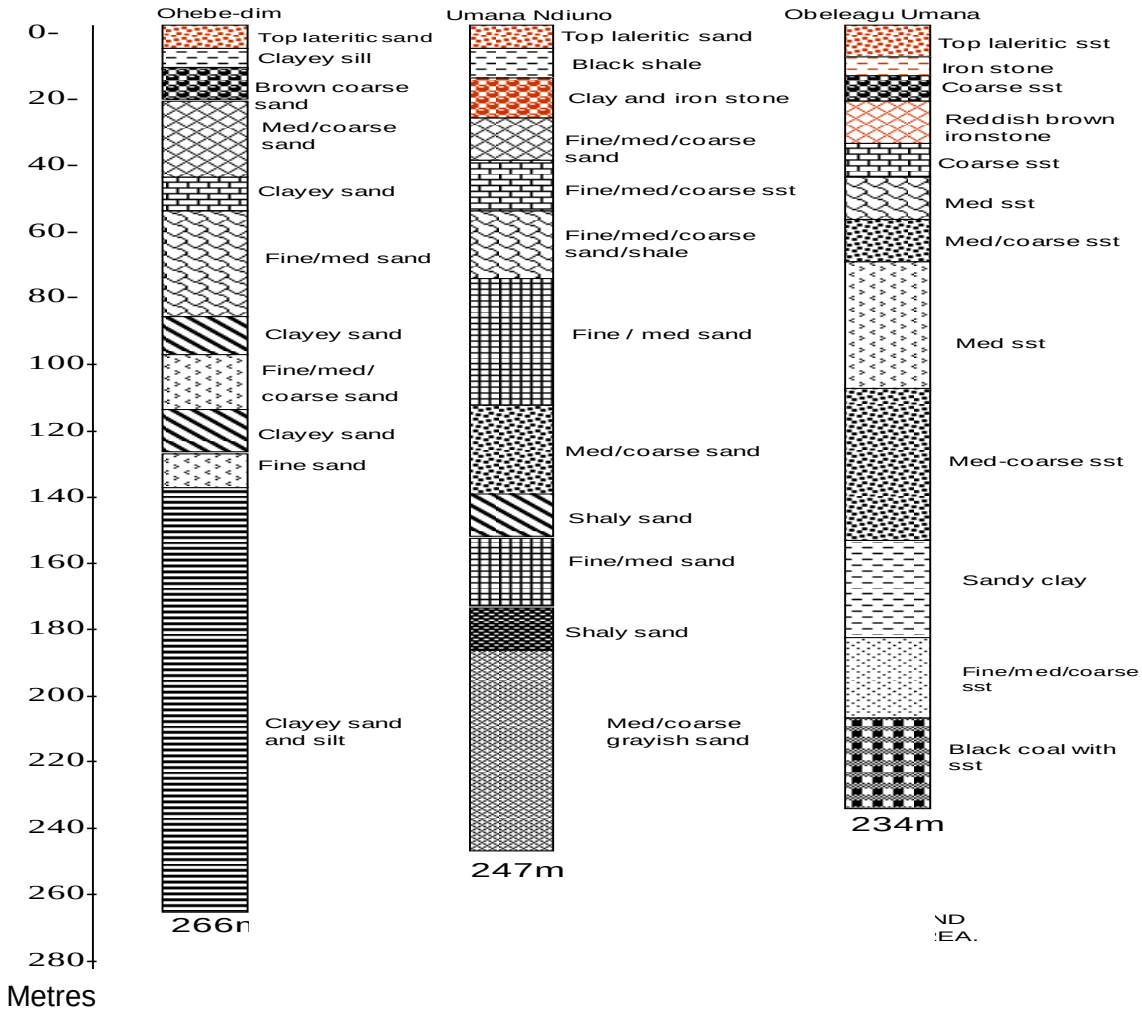


Figure 5: Well Records Showing Confined and Semi Confined Units in the Study Area

Heoretical Considerations

The Schlumberger array method of vertical Electric Sounding VES has been used throughout this study. In the Schlumberger array, four electrodes (two current A and B and two potential M and N) are placed along a straight line on the land surface such that the outside (current) electrode distance (AB) is equal to or greater than five times the inside (potential) electrode distance (MN). Assuming the medium below the surface of the earth to be homogeneous and isotropic of resistivity ℓ, the potentials V_M and V_N as measured at M and N, respectively, are given by

$$V_M = \frac{\ell I}{2\pi}\left(\frac{1}{\left(a - b/2\right)} - \frac{1}{\left(a + b/2\right)}\right) \qquad 1$$

$$V_N = \frac{\ell I}{2\pi}\left(\frac{1}{\left(a + b/2\right)} - \frac{1}{\left(a - b/2\right)}\right) \qquad 2$$

From which

$$\ell = \pi\left(\frac{a^2}{b} - \frac{b}{4}\right)\frac{\left(V_M - V_N\right)}{I} \qquad 3$$

Denoting ($V_M - V_N$) by ΔV, and acknowledging the fact that, in reality, the medium is anisotropic, the apparent resistivity ℓ_a measured by the Schlumberger array is given by.

$$\ell_a = \pi \left(\frac{a^2}{b} - \frac{b}{4}\right)\frac{\Delta V}{I} \qquad 4$$

If a and b are measured in metres and V and I in millivolts and milliamperes respectively, ℓa would be in ohm – metres.
Equation 4 may be written as

$$\ell_a = \frac{K\Delta V}{I} \qquad 5$$

Where, $K = \pi \left(\frac{a^2}{b} - \frac{b}{4}\right)$ 6

is the geometric factor for the Schlumberger array. Keller and Frischknecht, (1966), have shown that by keeping the distance b less than 40% of a, the electric field E at the center of the spread is what is being measured by the Schlumberger array with an error of about 5%.

Estimates of Longitudinal Conductance and Transverse Resistance from VES

The transverse resistivity and the longitudinal conductance of the aquifer were determined from the layer parameters as:

$TR = \sum hi.\ell i$ 7

and

$S = \sum hi/\ell i$ 8

Using the relationship of Mailet (1947), where ℓi, hi, TR and S are layer resistivity, thickness, transverse unit resistance and longitudinal conductance respectively

Estimating Aquifer Transmissivity

The transmissivity of an aquifer layer is the product of the hydraulic conductivity and its thickness. In the present study however, transmissivity was estimated from specific capacity data obtained from wells drilled mostly in the sandstone aquifers within the study area using the statistically derived linear relationship between transmissivity and specific capacity developed by Mace *et al*., (2000) i.e.

$Tr = 1.03(Sc)^{1.08}$ 9

Where Tr and Sc are the transmissivity and specific capacity respectively.

Data Acquisition and Interpretation

In the present study, vertical electrical soundings where conducted nearby 34 existing boreholes located in the plateau region of the state where pumping test have been conducted. The locations of the boreholes are shown in Figure 6.

Survey lines were located along existing roads and paths, avoiding physical obstacles like buildings and fences, and the axes of the soundings were aligned parallel to the geologic strike in order to reduce the effects of lateral variations.

Also, traverse lines were kept as straight as possible and electrical cable installations were avoided to minimize the influence of electromagnetic induction.

A preliminary interpretation of the sounding curves using partial curve matching (Orellana and Mooney, 1966; Koefoed, 1979; Keller and Frischknecht, 1966) provided the initial estimates of the resistivities and thickness (layer parameters) of the various geoelectric layers which then served as starting points for fast computer-assisted interpretation based on optimization technique. The computer program OFFIX, was used to interpret all the data sets obtained.

Analysis of Ves Curves

The study of apparent resistivity curves prepared from the VES data show two major types of curves. These are designated as Types I and II. Type I curves comprise mainly of “AH”; “HA”; “HAA”, and

"AAK" curves with layer resistivity relationships as $\ell_1 < \ell_2 < \ell_3 > \ell_4$; $\ell_1 > \ell_2 < \ell_3 < \ell_4$; $\ell_1 > \ell_2 < \ell_3 < \ell_4 < \ell_5$; and $\ell_1 < \ell_2 < \ell_3 < \ell_4 > \ell_5$ respectively, following the classification by Keller and Frischknecht (1966) . Type II curves comprise mainly of "AK"; "AAA"; and "AAAK" curves with layer resistivity relationships; $\ell_1 < \ell_2 < \ell_3 > \ell_4$, $\ell_1 < \ell_2 < \ell_3 < \ell_4 < \ell_5$, and $\ell_1 < \ell_2 < \ell_3 < \ell_4 < \ell_5 > \ell_6$, respectively.

The type I curve generally show (i) a relatively thin surface layer of about 1 – 2m thick of lateritic soil existing below the ground surface (ℓ_a between 250 and 3000 ohm-m), followed by (ii) the presence of sandy clay/shale in some places (ℓ_a between 500 and 2000 ohm-m) and (iii) a sandy formation of varying grain size (medium to coarse) and thickness. The ℓ_a values may decrease with depth depending on the saturated condition. The field curves of type I were mostly obtained from the VES conducted in the area underlain mostly by the Nsukka Formation.

The type II curve is also composed of thin surface layer of lateritic soil, followed by a sandy formation of varying grain size and thickness. The type II curves are characterized by steeply rising terminal branch, indicating a highly resistive base (up to 40,000 ohm-m in some places). These curves were obtained from soundings conducted in areas underlain by the Ajali Formation and to a lesser extent, the Nsukka Formation.

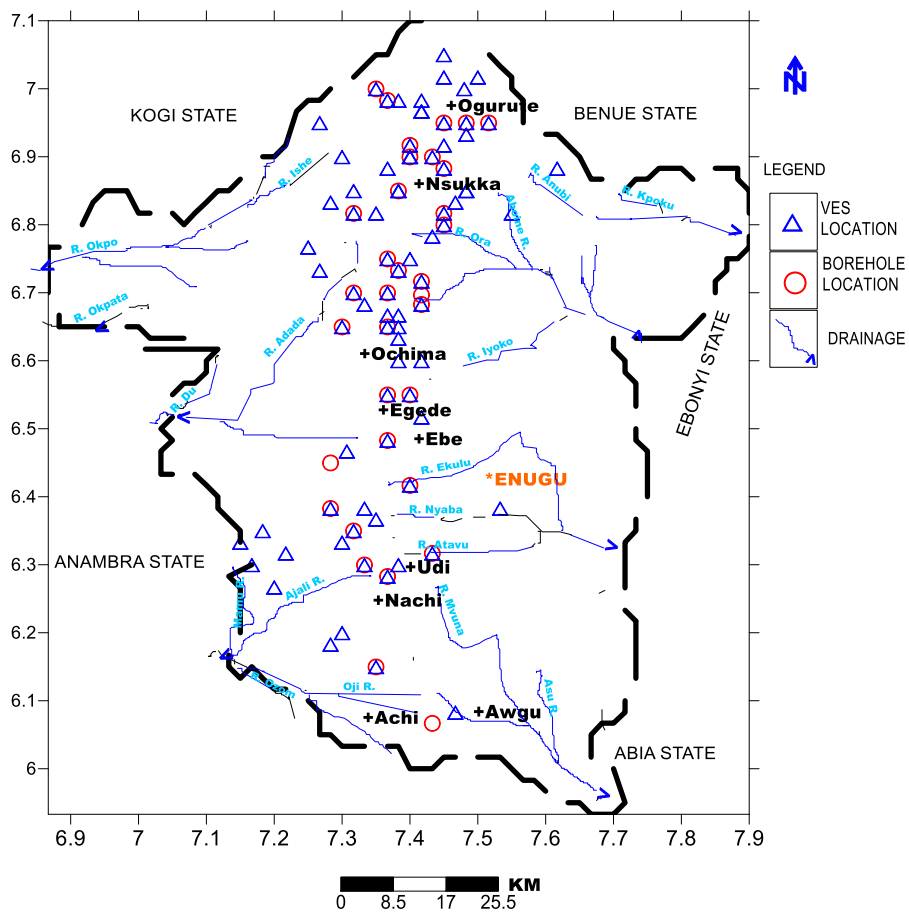


Figure 6: Map of Enugu State Showing Drainage, Borehole and VES Locations

RESULTS AND DISCUSSION

Geoelectric Cross-Section along N-S Axis

The results of some of the sounding interpretation together with geological data were used to construct a cross-section along the N-S axis of the study area (Figures 7 & 8). A comparison of the sounding results with borehole information (Figures 4 & 5) show that the first two geoelectric layers correspond to latertic soil and sandy shale overburden with depths ranging from 15 to 30 metres (Figure 7). The upper part of

this overburden contains ironstones and laterites while the lower part is made up of sandy shale and sand that is ferruginous in some places. This layer is virtually absent in Figure 8. The third (or fourth in some places) geoelectric layer, whose composition is mainly medium to fine grained sands has been identified as the aquiferous layer with apparent resistivities ranging from 1700 to 30,000 ohm-m. The last is the highly resistive layer with apparent resistivities of over 30, 000 ohm-m, corresponding to geoelectric basement.

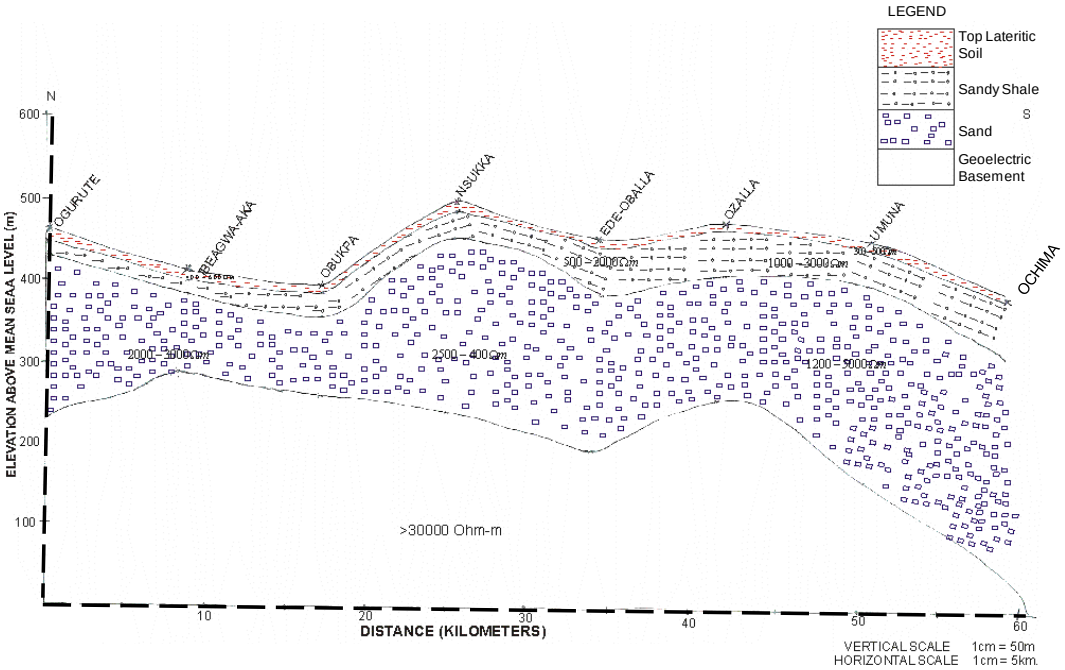


Figure 7 Resistivity Profile across Ogurute to Ochima Constructed from VES

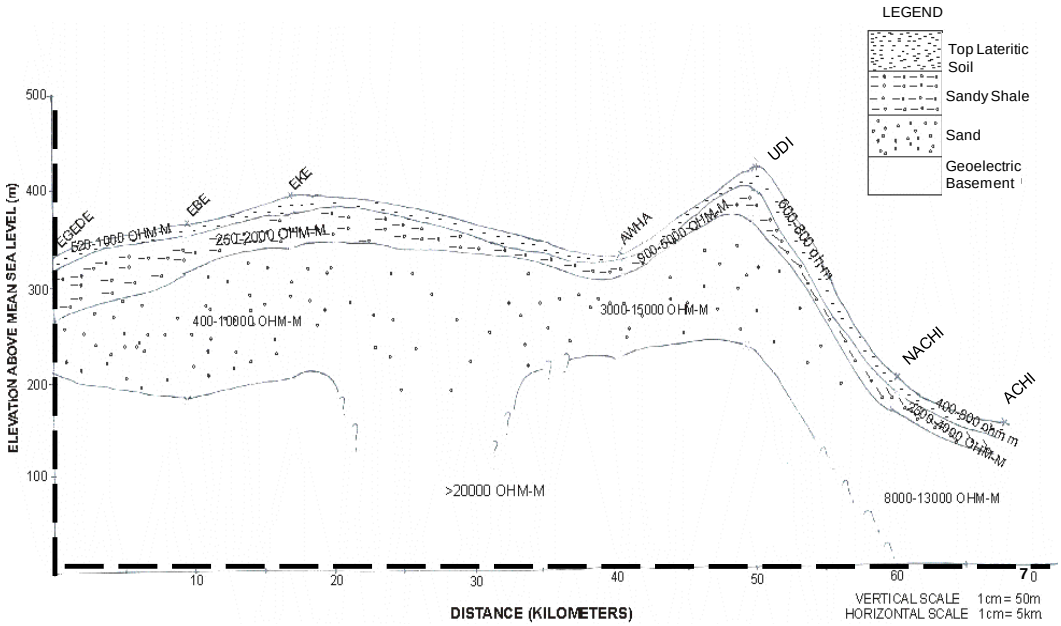


Figure 8 Resistivity Profile across Egede to Achi Constructed from VES

Transverse Resistance Versus Transmissivity

Vertical electrical soundings conducted nearby existing boreholes where well records were available allowed the determination of transmissivily values for correlation purposes. Table 1 and figure 9 show transmissivity (Tr) versus transverse resistance, (TR) plot with

Tr. (m^2/day) = 0.001TR – 20.485 10

Equation 10 is an empirical relation between Tr and TR obtained by using linear regression techniques, with a correlation coefficient of 0.713, from the range of values used. The relationship suggest that the information obtained from vertical electrical sounding data can be used for pre-drilling estimation of transmissivity in the study area

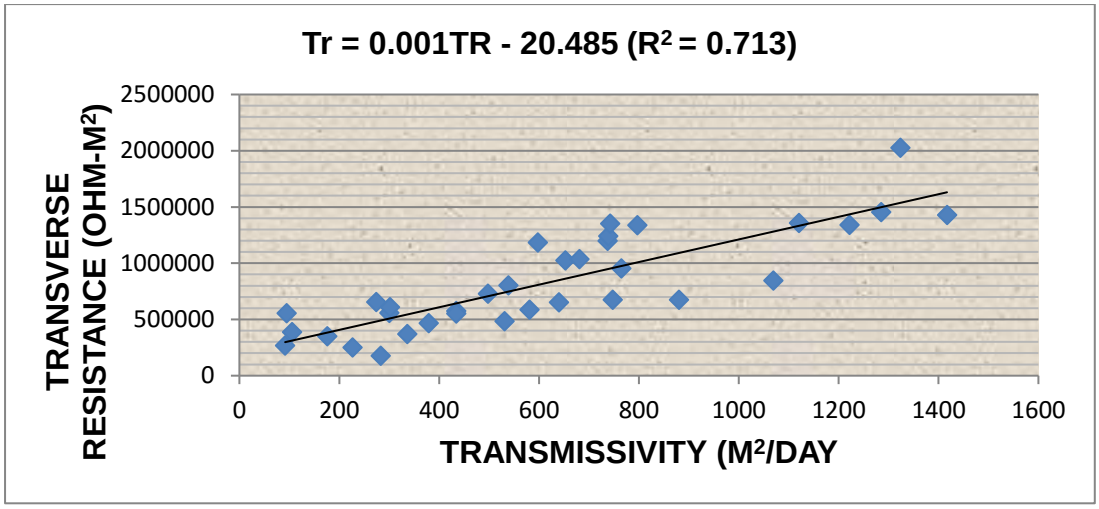


Figure 9: Plot of Transverse Resistance versus Transmissivity

Aquifer Resistivity Versus Borehole Yield

An attempt was also made to find general functional relationship between the apparent resistivity ℓ_a of the aquifer as interpreted from the Schumberger depth sounding curves and the yield of boreholes, Yd.

The data on the boreholes (table 1) produced a significant correlation coefficient of 0.601 between ℓ_a and borehole yield in m^3/h. Figure 10 show the plot of borehole yield versus aquifer resistivity. The least square regression fit between the two indicates the following empirical relationship:

Yd (m^3/h) = 0.005ρa + 54.54 11

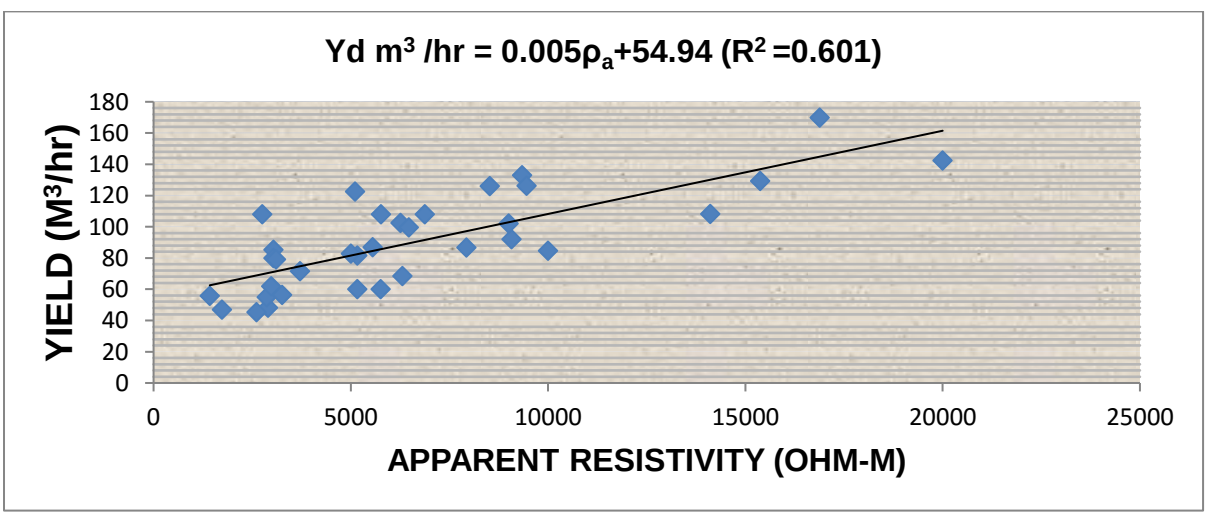


Figure 10: Plot of Borehole Yield versus Apparent Resistivity

Table 1: Geoelectrical and Hydrogeological Data Used for the Obtaining the Empirical Relationship

S.No	Borehole Location	Logitude	Latitude	Aquifer Resistivity (OHM-M)	Transverse Resistance (OHM-M^2)	Transmisivity M^2/Day	Borehole Yield M^3/H
1	ACHI	7.35	6.150	5550	552683	94.28	86.85
2	AGUOBUOWA	7.283	6.383	6875.33	1198142	737.07	108
3	AKPAKUME	7.300	6.650	15375.8	1335500	796.62	129.3
4	AKU	7.317	6.700	2898.5	1239937	738.57	48.2
5	AMACHRA	7.450	6.950	5760.7	952116	765.06	107.93
6	AMUFIE	7.483	6.950	6257.25	1428097	1416.95	102.44
7	AWHUM	7.400	6.550	16882.2	1024000	652.59	169.93
8	EBE	7.367	6.483	3710.59	585033	580.58	71.6
9	EDE-OBALLA	7.450	6.800	5167	727748	497.79	81.6
10	EGEDE	7.367	6.550	20000	1350000	742.14	142.5
11	EHA-ALUMONA	7.450	6.817	10000	650000	640.12	84.6
12	EKWEGBE	7.417	6.717	5751.23	556609	300	60
13	ETTE	7.450	7.110	9072.3	843296	1068.92	92
14	1BEAGWA-AKA	7.400	6.917	2866.47	2025083	1323.25	54.87
15	ITCHI	7.367	6.983	3035.25	573274	434.39	85.3
16	IWOLO	7.283	6.450	1424.26	1182000	597.23	55.8
17	LEJJA	7.367	6.750	9000	370000	336.29	102
18	NACHI	7.333	6.300	5108.62	349262	176.14	122.6
19	NGWO	7.400	6.417	5000	267500	91.6	82.83
20	NSUKKA	7.383	6.850	9342.5	1452195	1285.28	133.08
21	OBIMO	7.317	6.817	3038.56	175043	282.92	80
22	OBUKPA	7.400	6.900	6467.37	1340024	1221.92	99.7
23	OCHIMA	7.367	6.650	1730.5	674321	880.39	47
24	OGURUTE	7.417	6.697	3105.27	550752	434.39	79.2
25	OHEBE-DIM	7.367	6.700	5164	607126	301.51	60
26	UMABI	7.367	6.283	2977.63	1356902	1120.31	62
27	OVOKO	7.450	6.883	9453.3	672900	747.79	126.25
28	OZALLA	7.383	6.733	7927.6	653000	274.02	86.8
29	UDI	7.433	6.317	2608.07	249154	226.3	45.4
30	UGBAIKE	7.516	6.950	14107.2	1036226	680.94	108.2
31	UMANA NDIUNO	7.317	6.350	8523.83	802667	538.85	126
32	UMUNKO	7.417	6.683	3258.9	385045	105.17	56.4
33	UNADU	7.350	7.000	2751.2	482846	530.79	108
34	IHEAKPU-AWKA	7.433	6.900	6303.13	466571	379.1	68.4

Summary and Conclusion

An integrated approach of hydrogeological and geoelectrical soundings surveys has been used to study the relationship between the geoelectrical and hydraulic parameters in the Plateau region of Enugu State Nigeria. Electrical resistivity and borehole data from 34 locations were used to correlate the aquifer apparent resistivity with its borehole yield and aquifer transverse resistance (TR) with its transmissivity (Tr).

Significant relationship exists between transverse resistance and transmissivity similarly, aquifer apparent resistivity was found to be related to borehole yield. These empirical relations developed in this study can be used for pre-drilling estimation of transmissivity and the yield of prospective boreholes in the region.

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