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# Evaluation of the Aquifer Hydraulic Characteristics from Electrical Sounding Data in Imo River Basin, South Eastern Nigeria: the Case of Ogwashi- Asaba Formation.

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**ABSTRACT:** *Thirty two vertical electrical sounding data sets were obtained from various parts of the study area, located within latitudes 5° 30''N and 5° 45''N, and longitudes 7° 00''E and 7° 30''E, in the middle Imo River Basin. The litho-stratigraphic unit of Ogwashi-Asaba Formation was investigated. The sounding data were analyzed with the RESIST software to delineate the sub-surface layering. Three soundings were made at existing boreholes for comparison. The concept of Da-Zarrouk parameters (transverse unit resistance and longitudinal conductance in porous media) was used to determine aquifer hydraulic characteristics. The following values of hydraulic conductivity and transmissivity were obtained for the formation: $K_{mean}$= 6.71m/day; $T_{mean}$=327.91m$^2$/day; $K_{max}$=19.71m/day; $T_{max}$=2906.52m$^2$/day; $K_{min}$=1.13m/day; $T_{min}$= 8.01m$^2$/day. The aquifer thicknesses range from 18m to 148m for the Formation. It was established from the study that thick productive aquifers are located in the Ogwashi-Asaba Formation.*

**Keywords:** *Imo River Basin, Da-Zarrouk parameters, Aquifer hydraulic characteristics.*

## I. Introduction

Determination of aquifer characteristics is essential to the solution of several hydrological and hydrogeological problems. Fluid transmissivity, transverse resistance, longitudinal conductance, hydraulic conductivity and aquifer depth are very useful in describing subsurface hydrology. Much geophysical investigation of groundwater is directed towards the determination of the spatial distribution of the above mentioned aquifer hydraulic parameter (Mendosa et al., 2003). Aquifer characteristics calculated from existing boreholes are usually correlated with surface resistivity measurements based on their relationship with pore space and heterogeineity (Rubin and Hubbard, 2005; De Lima et al., 2005; Niwas et al., 2006).

The Imo River Basin is based on a bedrock of a sequence of sedimentary rocks of about 5480m thick and with ages ranging from Upper Cretaceous to Recent (Uma, 1989). It is known to contain several aquiferous units. The characteristics of these aquifers such as transmissivity, hydraulic conductivity and storage potentials are not clearly understood. Since the mid 1980's, some researchers from the academia have carried out geological/geochemical investigations. Uma (1989) carried out a study on the groundwater resources of the Imo River Basin using hydro-geological data from existing boreholes. He concluded that three aquifer systems (shallow, middle and deep) exist in the area. His data were, however too sparse to make any general statement on the hydraulic characteristics of the middle Imo River Basin aquifers. Geophysical investigations on groundwater resources in the Imo River Basin were also carried out in different sections of the basin. While the contributions made by these workers are remarkable, more work still needs to be done, particularly in the area of geophysical studies, which so far have covered only a small fraction of the area of the basin. The present study is aimed at the estimation of geometry, hydraulic conductivity and transmissivity of the aquifers within the Ameki and Imo shale Formations of the Imo River Basin using the electrical resistivity method. Thirty vertical two electrical soundings (VES) were obtained at various locations within the study area.

### 1.1 The Study Area

Figure 1 shows the location map of the Imo River Basin where the study area is situated. The study area (Figure 2) lies between latitudes 5°30′N and 5°45′ and longitudes 7°00′ and 7°30′. Some major communities within the study area include: Amarauku, Atta, Ikeduru, Nnarambia, Umuahia, Ogbe, Obowo and Nkwerre. The Ogwashi-Asaba formation (Oligocene to Miocene) consists in the Coastal Plain Sand which is composed of non-indurated sediments. It is generally made up of clays, sands, grits and seams of lignite alternating with gritty clay (Dessauvagie, 1972).This formation is characterized by its up dip and down dip pinch outs within the Imo River Basin. The Imo River Basin has a large amount of recharge; estimated at 2.5 billion m$^3$ per annum, coming mainly from direct infiltration of precipitation. Average annual rainfall is about 2000mm (Onwuegbuche, 1993).

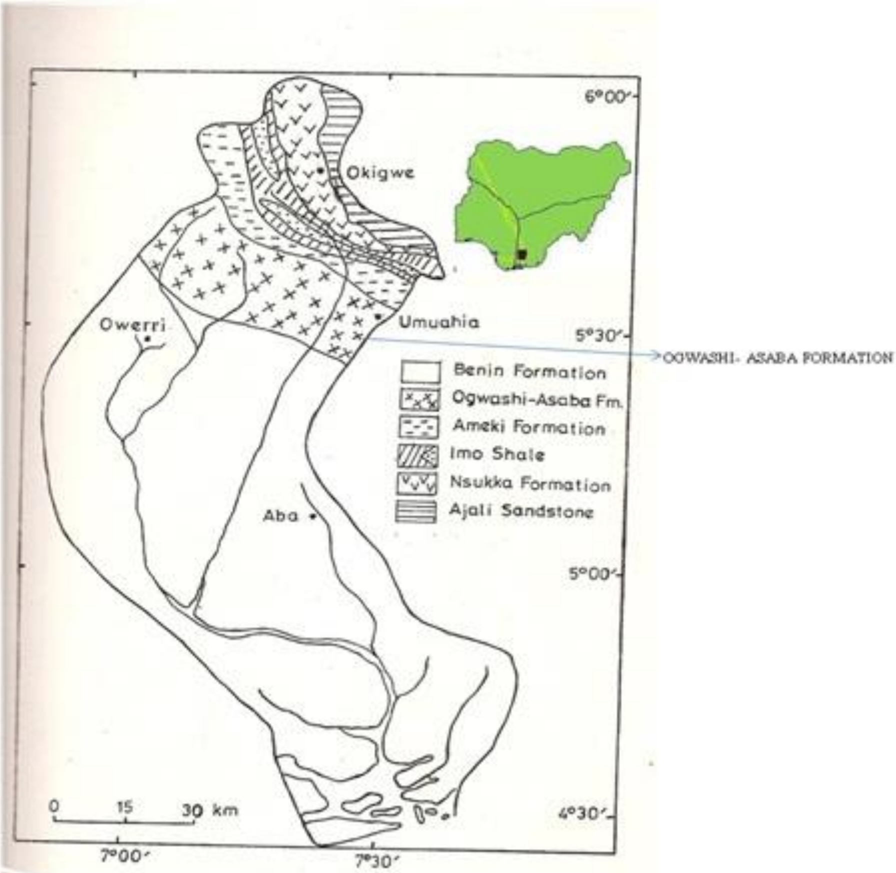


Figure 1 : Geology Map of Imo River Basin (After Uma, 1989)

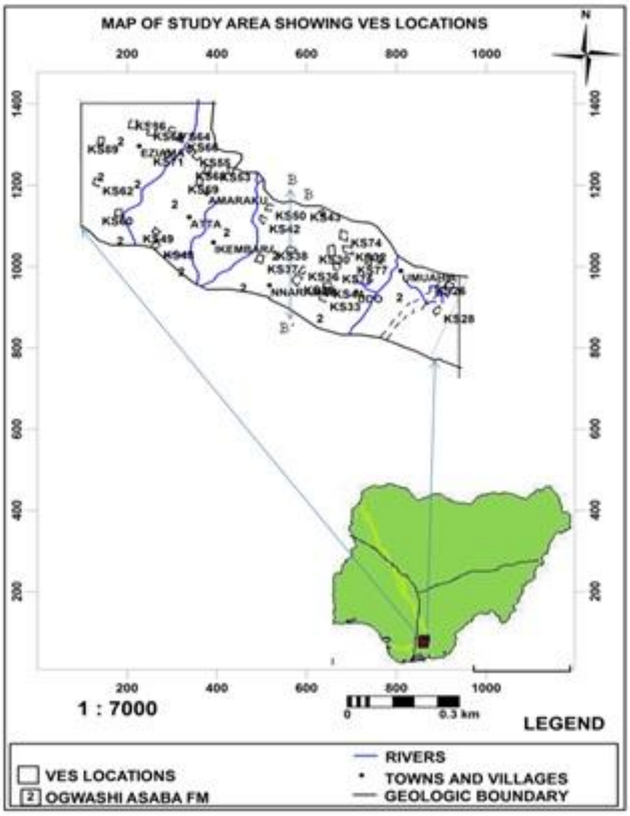


**Figure 2: Geology Map of the Study Area Showing VES locations**

## II. Methodology

Geoelectric resistivity method has been used extensively for structural, hydrological, geothermal investigations ( Majumdar and Das, 2011). Geoelectrical investigations were employed to delineate formations, distinguish between sandy, shale, clay, and other layers and establish the depth to the water table, and determine the nature of the overburden. Schlumberger resistivity sounding method was used in this research. Thirty two vertical electrical soundings were carried out to establish the characteristics of the aquifers in the study area. Modeling of VES results was done using the RESIST software, which is an iterative inversion-modeling program. Analysis of the resulting apparent resistivity versus the half-current electrode separations yielded layered earth models composed of individual layers of specified thickness and apparent resistivity. The ABEM Terrameter SAS 4000, was used to obtain VES data from the field. The VES locations are shown in figure 2 coded KS.

### 2.1 Aquifer Hydraulic Characteristics from Vertical Electrical Sounding Data

The primary purpose of the resistivity method is to measure the potential differences on the surface due to the current flow within the ground. Since the mechanisms which control the fluid flow and electric current and conduction are generally governed by the same physical parameters and lithological attributes, the hydraulic and electric conductivities are dependent on each other .

To obtain a layer parameter, a unit square cross sectional area is cut out of a group of n-layers of infinite lateral extent. The total transverse resistance R is given by:

$$R = \sum_{i=1}^{n} h_i \ \rho_i \qquad (1)$$

For a horizontal, homogeneous and isotropic medium

$$\rho = (R_1 - R_2)/(h_i - h_2) \qquad (2)$$

where $h_i$ and $\rho_i$ are respectively the thickness and resistivity of the $i^{th}$ layer in the section. The total longitudinal conductance S is:

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \qquad (3)$$

The longitudinal layer conductance $S_i$ can also be expressed by

$$S_i = \sigma_i h_i \qquad (4)$$

where $\sigma_i$ is the layer conductivity. Conductivity in this case is analogous to the layer transmissivity, T, given by:

$$T = K_i h_i \qquad (5)$$

$K_i$ is the hydraulic conductivity of the $i^{th}$ layer of thickness $h_i$. R and S of equations 1 and 3 are called the Dar Zarrouk parameters, which have been shown to be powerful interpretational aids in groundwater surveys (Zohdy et al, 1974)

According to the fundamental Darcy's law, the fluid discharge, Q, is given by

$$Q = KIA \qquad (6)$$

Where K is the hydraulic conductivity, I is the hydraulic gradient, A is the cross-sectional area perpendicular to the direction of flow. Ohm's law gives:

$$j = \sigma E \qquad (7)$$

where j is the current density; and $\sigma$ is the electrical conductivity, which is the reciprocal of the resistivity, $\rho$. For aquifer material having unit cross-sectional and thickness h, the two fundamental laws can be combined to give, according to Niswass & Singhal (1981):

$$T = K \sigma R = K S/\sigma = K h \qquad (8)$$

Where T is the transmissivity; R is the transverse resistance of the aquifer, K is the hydraulic conductivity and S is the longitudinal conductance.

It has also been shown by Niwas and Singhal (1981) that in areas of similar geologic setting and water quality the product $K\sigma$ remains fairly constant. Thus, knowledge of K from some existing boreholes and of $\sigma$ from VES sounding can be used to estimate $K\sigma$ for the same geologic zone. Hence, the aquifer hydraulic conductivity and transmissivity for the entire area can be estimated. This relationship forms the basis for the determination of aquifer hydraulic parameters used in this study.

## III. Results and Discussion

### 3.1 Aquifer Characterization of the Study Area

The various aquifer characteristics within the study area are shown in Table 1. In order to reveal the geologic sections in different parts of the study area, a profile, BB′, was selected as shown in figure 2, which traverses Ibeme (KS50), Umueze (KS42), Obohia (KS37) in Ogwashi-Asaba Formation. The section shows the presence of sands and sandstone, figure 3. There is a correlation between the VES result and the lithologs of boreholes drilled at locations KS32 (Avutu Obowo), KS37 (Nkwo Obohia) and KS42(Umueze) in Figure 4. They both show fine-medium and coarse-grained sand. They indicate the presence of productive aquifers in the area. According to the geology of the area, the formation is made up of clays, sands, sandstones. KS37 at Nkwo Obohia features the most productive aquifer system discovered in the study, with saturated thickness of 147m, consisting of thick sandstones. Depth to the water table across the study area was deduced from the VES result. The mean depth to the water table of the aquifers in this zone is 60.57m. The depth to the water table at KS37 is quite small at 2.5m which obviously confirms the shallow unconfined aquifer system reported for the area in literature (Uma, 1989).

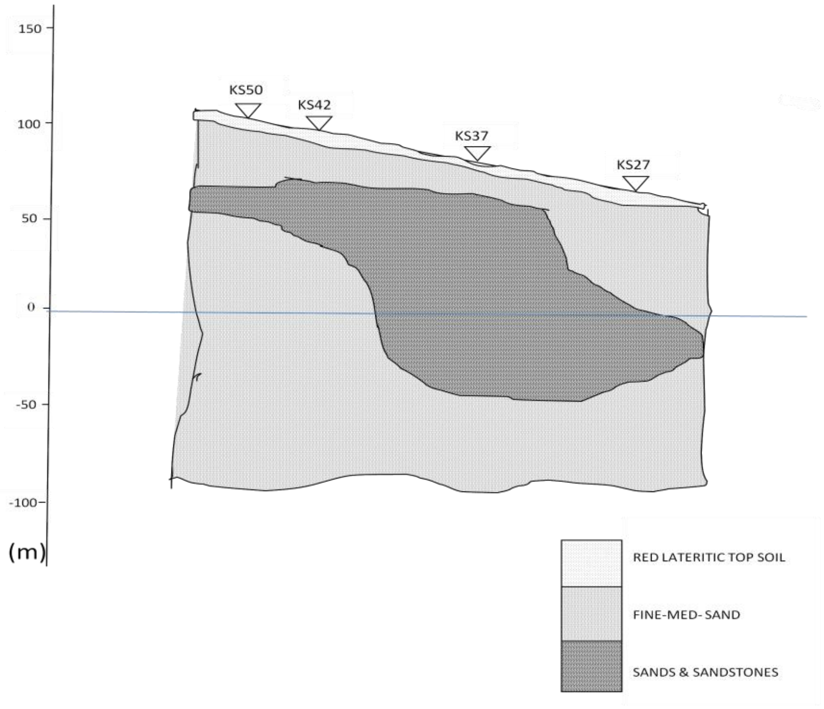


**Figure 3: Interpretative Cross-Section along BB'**

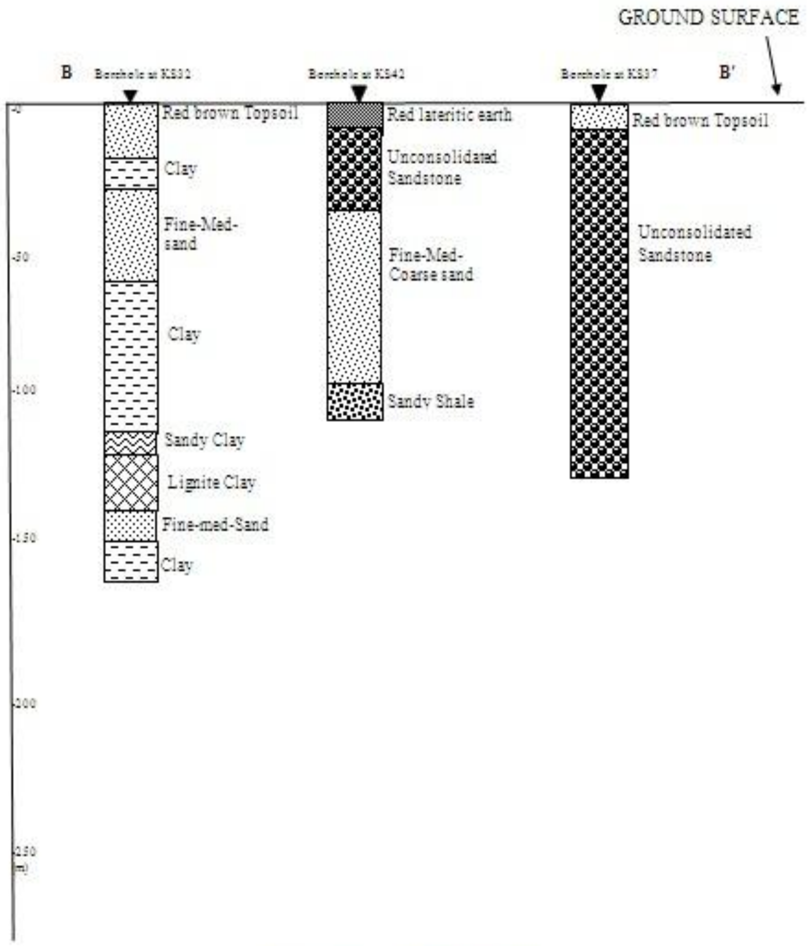


**Figure 4: Profile BB′ (N—S)**

### 3.2 Hydraulic Characteristics of the Aquifer Systems

The hydraulic characteristics of the aquifer type within the study area were established using the concept of Dar-Zarrouk parameters (transverse unit resistance (R) and longitudinal conductance (C) in porous media. According to Ekwe et al. (2006), Uboma-Obowo-Umuagu is homogeneous hydrologically with Kσ values varying between 0.0102 and 0.0316, with a mean value of 0.0209 representing the Ogwashi Asaba Formation. Anara-Obohia-Amogwugwu has a mean Kσ value of 0.0047 representing Ameki Formation, while Imo Formation has a mean Kσ value of 0.00315. From these values, the hydraulic conductivities of the various VES locations were estimated. From the analysis of Table 1, the following values of hydraulic conductivities and transmissivity were obtained for the aquifers withing Ogwashi-Asaba Formation: $K_{mean}$= 6.71m/day; $T_{mean}$=327.91m$^2$/day; $K_{max}$=19.71m/day; $T_{max}$=2906.52m$^2$/day; $K_{min}$=1.13m/day; $T_{min}$= 8.01m$^2$/day. The highest values of K and T obtained for the study are for KS37 at Nkwo- Obohia. This indicates that this location has the greatest potential for productive aquifers because of its high transmissivity.

Figure 5 shows the contour map of the hydraulic conductivity obtained for the study area showing areas with high and low hydraulic conductivities. Figure 6 shows the contour map of transmissivity for the study area. These are indicative of the productive potential of the aquifers. Figure 7 shows the contour map of the depth to the water table. Figure 8 shows the contour map of the aquifer thickness. Figure 9 shows the contour map of Kσ values estimated for the study area.

**Table 1: Aquifer Characteristics at the Various VES Locations in the Study Area.**

| VES # | LOCATION | DEPTH TO WATER TABLE (m) | AQUIFER THICKNESS h (m) | RESISTIVITY ρ(Ω-m) | TRANSVERSE RESISTANCE,R ρh (Ω-m$^2$) | Kσ | HYDRAULIC CONDUCTIVITY K(m day$^{-1}$) | TRANSMISSIVITY KσR (m$^2$ day$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| **KS26** | AFARA-UKWU, UMUAHIA | 36.3 | 18.2 | 9541.0 | 173646 | 0.0008 | 7.63 | **138.92** |
| **KS28** | UMUOVOR, OLD UMUAHIA | 23.8 | 26.2 | 7310.0 | 191522 | 0.0006 | 4.39 | **114.91** |
| **KS30** | UMUOSOCHIE, OBOWO | 3.0 | 10.9 | 490 | 5341 | 0.0062 | 3.04 | **33.11** |
| **KS32** | AVUTU OBOWO | 17.4 | 29.3 | 5770.0 | 169061 | 0.0013 | 7.50 | **219.78** |
| **KS33** | UMUGHARA ONICHA | 23.7 | 43.5 | 14200 | 617700 | 0.0005 | 7.10 | **308.85** |
| **KS35** | NNARAMBIA | 13.0 | 112.0 | 11254.0 | 1260448 | 0.0002 | 2.25 | **252.09** |
| **KS36** | OGBE | 13.0 | 122.0 | 23568.0 | 2875296 | 0.0002 | 4.71 | **575.06** |
| **KS37** | NKWO OBOHIA | 2.5 | 147.5 | 98526.0 | 14532585 | 0.0002 | 19.71 | **2906.52** |
| **KS38** | UMUMBIRI OPARANADIM | 40.7 | 29.0 | 11400.0 | 330600 | 0.0003 | 3.42 | **99.18** |
| **KS42** | UMUEZE | 60.2 | 20.5 | 4010.0 | 82205 | 0.0005 | 2.01 | **45.10** |
| **KS43** | UMUANUNU NSU | 37.9 | 57.1 | 3211.0 | 183348 | 0.0013 | 4.17 | **55.00** |
| **KS44** | UMUAGBA ONICHA | 11.6 | 24 | 17000.0 | 408000 | 0.0008 | 13.60 | **326.40** |
| **KS48** | UMUCHOKO AMACHARA | 19.4 | 100.6 | 1399 | 140739 | 0.0061 | 8.53 | **858.51** |
| **KS49** | ABOH EBIKORO | 55.0 | 30.3 | 5036 | 152591 | 0.0019 | 9.57 | **289.92** |
| **KS50** | NNEATO UMUOKE, IBEME | 122.0 | 57.0 | 4040.0 | 230280 | 0.0006 | 2.42 | **138.17** |
| **KS53** | UMUZOHO EZIHE | 30.3 | 17.8 | 8300 | 147740 | 0.0004 | 3.32 | **59.10** |
| **KS55** | EZIAMA OSUAMA | 4.3 | 2.1 | 5450.0 | 11445 | 0.0007 | 3.82 | **8.01** |
| **KS60** | UMUODIMODU ORODO | 13.2 | 66.8 | 399.9 | 26713 | 0.0061 | 2.44 | **162.95** |
| **KS62** | OKWUDOR | 36.2 | 28.9 | 10500.0 | 303450 | 0.0008 | 8.40 | **246.76** |
| **KS63** | UMUOMA AMUCHA | 40.0 | 62.0 | 7800.0 | 483600 | 0.0016 | 12.48 | **773.76** |
| **KS64** | OFEIYI UMUDI | 51.6 | 34.1 | 2710.0 | 92411 | 0.0017 | 4.61 | **157.10** |
| **KS65** | OBINUHU NKWERRE | 23.0 | 47.5 | 3210.0 | 152475 | 0.0043 | 13.80 | **655.64** |
| **KS66** | UMUGARA NKWERRE | 35.5 | 193.5 | 188 | 36378 | 0.0060 | 1.13 | **218.27** |
| **KS68** | UMUDIWEBU-UMUOPARADIM | 65.0 | 47.0 | 25000.0 | 1175000 | 0.0002 | 5.00 | **235.00** |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **KS69** | ABBA | 21.7 | 73.3 | 2800.0 | 205240 | 0.0005 | 1.68 | **102.62** |
| **KS70** | UMUANYA-AMAIGBO | 14.9 | 24.4 | 2400 | 58560 | 0.0013 | 3.12 | **76.13** |
| **KS71** | UMULEKE-AMAIGBO | 36.6 | 19.3 | 10200.0 | 196860 | 0.0013 | 13.26 | **255.92** |
| **KS74** | AVUTU-OBOWO | 58.0 | 21.0 | 1200.0 | 25200 | 0.0013 | 1.56 | **32.76** |
| **KS75** | UMUARIAM | 42.0 | 53.0 | 8608.2 | 456235 | 0.0016 | 13.77 | **729.96** |
| **KS77** | AFOR UMUOKEH | 59.4 | 31.6 | 3570.0 | 112812 | 0.0004 | 1.43 | **45.12** |
| **KS86** | UMUDIMOHA-AMAIKE | 88.4 | 49.6 | 6590.0 | 326864 | 0.0002 | 1.32 | **65.37** |
| **KS89** | UMUEZE-AMIKE ORLU | 41.3 | 21.1 | 10800.0 | 227880 | 0.0030 | 32.40 | **683.60** |

## IV. Conclusion

The diagnostic features of the Kσ product proved useful in the study. It was used to estimate the hydraulic conductivity and the transmissivity for the sounding locations across the study area. The hydraulic conductivity varies between 1.13m/day (KS66) and 19.71 m/day (KS37).The highest transmissivity value was obtained at Nkwo Obohia in Mbaise area, along profile BB′, with 2906.52 $m^2$/day. The aquifer there consists of thick coarse sands and sandstones with a thickness of 122m.

## Acknowledgements

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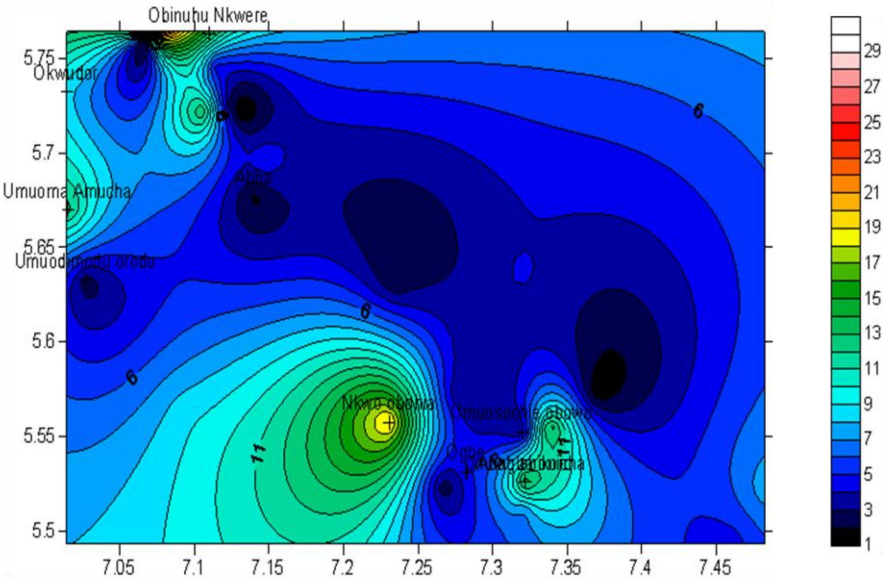


Figure 5: Map of Hydraulic conductivity for the Study Area

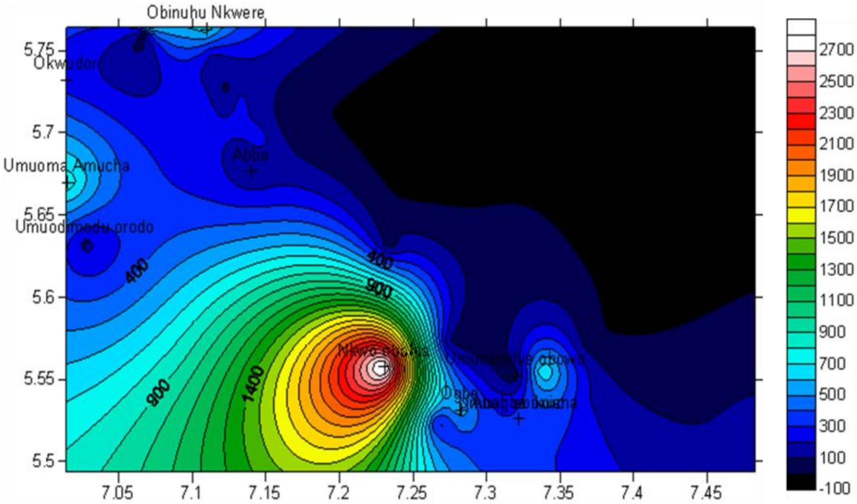


Figure 6: Map of Transmissivity for the Study Area

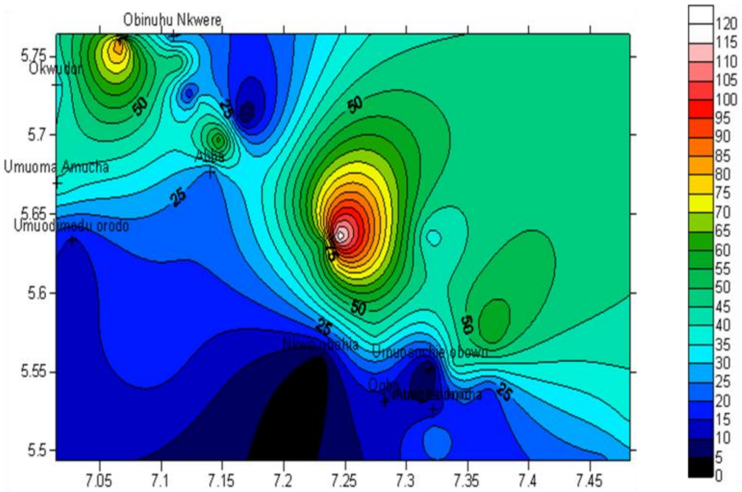


Figure 7: Map showing Depth to Water Table (m)

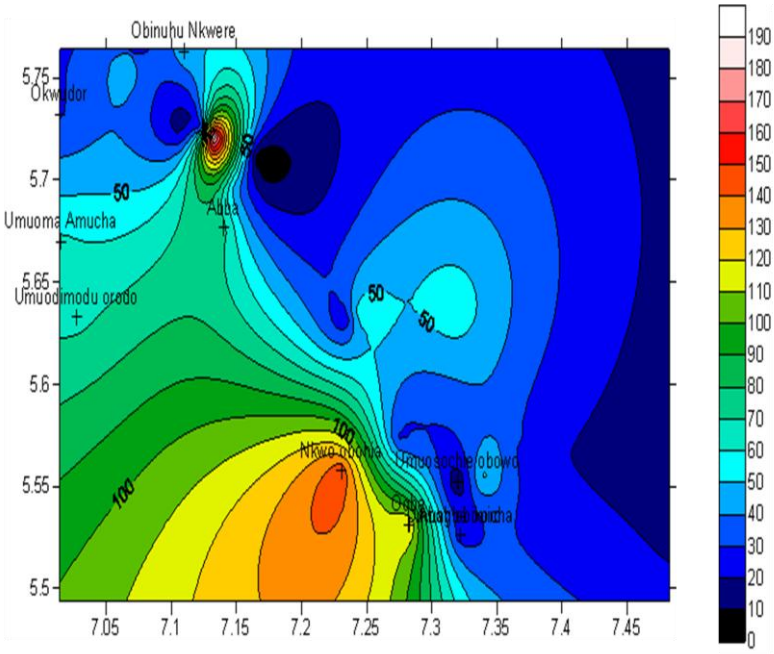


Figure 8: Map of Aquifer thickness(m) for the Study Area

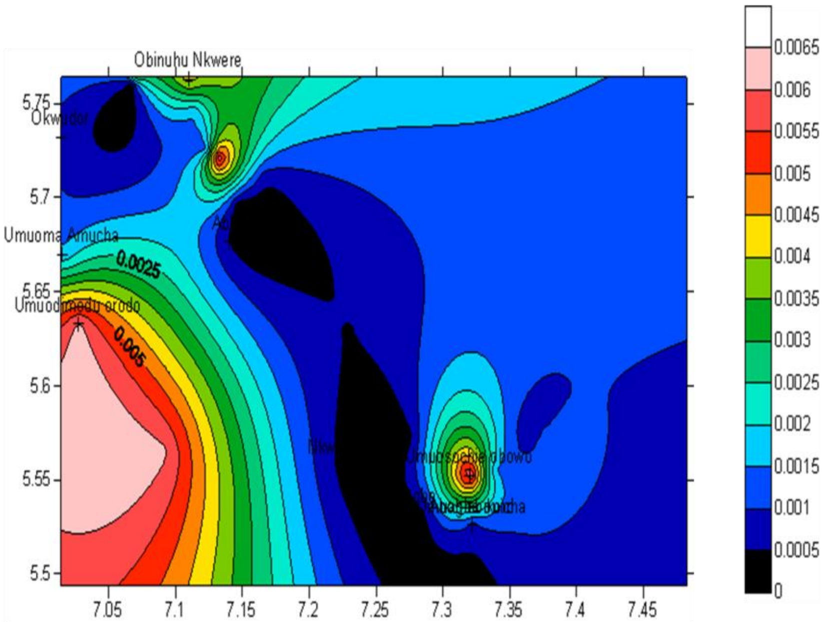


Figure 9: Map of Diagnostic parameter (Kσ)