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Appraisal of the Aquifer Hydraulic Characteristics from Electrical Sounding Data in Imo River Basin, South Eastern Nigeria: the Case of Imo shale and Ameki Formations

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Abstract

Twenty three vertical electrical sounding data sets were obtained from various parts of the study area in the middle Imo River Basin, using a maximum current electrode separation of 1000 meters. The litho-stratigraphic units within the study area are Imo Formation & Ameki Formation. 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 longit udinal conductance in porous media) was used to determine aquifer hydraulic characteristics. The following values of hydraulic conductivity and transmissivity were obtained for the various formations: For aquifers located within Imo Formation the mean of the hydraulic conductivity K_{mean}= 2.65 m/day, while the mean of the transmissivity T_{mean}=46.63m^2/day; K_{max}= 3.13m/day, K_{min}=2.09m/day; T_{max}=87.68 m^2/day, T_{min}=15.54 m^2/day. For aquifers located within Ameki Formation, K_{mean}=2.70m/day; T_{mean}=80.59 m^2/day; K_{max}=4.65m/day; T_{max}= 167.14 m^2/day; K_{min}=1.25m/day and T_{min}=6.08 m^2/day. The aquifer thicknesses are (15m—49m) for Imo Formation, (2m—55m) for Ameki Formation.

Keywords: Imo River Basin, aquifer hydraulic characteristics, Dar-Zarrouk parameters.

1. Introduction

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, 1986). It is known to contain several aquiferous units. Since the mid 1980's, some researchers from the academia have carried out geological/geochemical investigations. Uma (1986) carried out a study on the ground 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. (Uma,1989). 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. Twenty three vertical electrical soundings (VES) have been obtained at various locations within the study area.

1.1 The Study Area

Figure 1 shows the location map of Imo River Basin where the study area is situated. The study area lies between latitudes 5°42′N and 5°45′ and longitudes 7°10′ and 7°27.′ Some major communities within the study area include: Anara, Okwelle, Okwe, Umuna, Amuro, Nunya, Umuduru, Obiohuru. A network of motorable roads in the area made the collection of data possible.

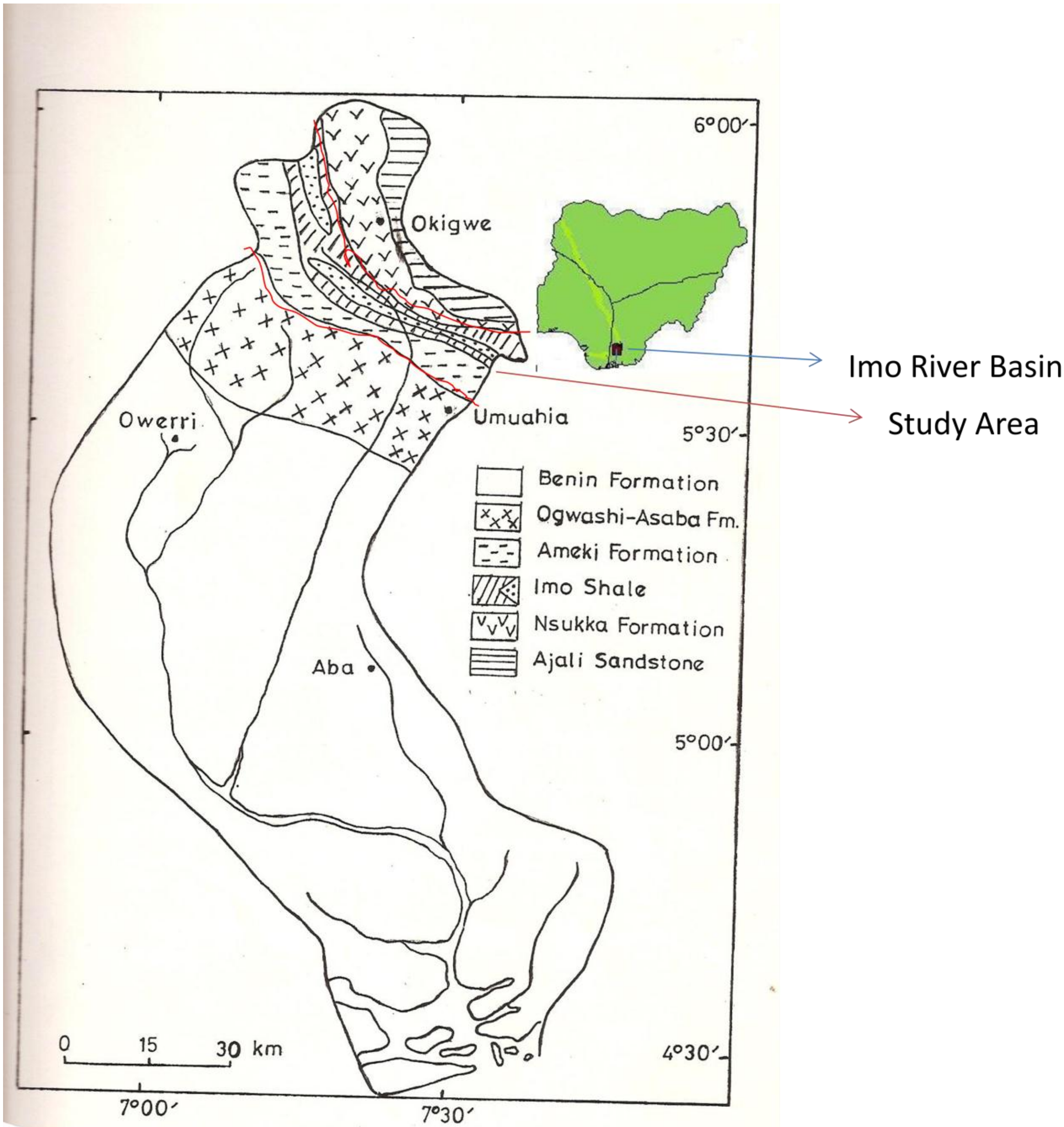

Figure 1 : Geology Map of Imo River Basin (After Uma, 1989)

1.1.1 Geology of the Study Area

Two geologic formations are covered in the study area, namely: Imo shale and Ameki formations respectively. Imo shale consists of a thick sequence of blue and dark grey shales with occasional bands of clay-ironstones and subordinate sandstones (Swardt and Casey, 1961). It dips at angles 17^o to 25^o to the south-west and South (Uma, 1986). It includes three constituent sandstones: the Igbabu, Ebenebe and Umuna Sandstones with the last two outcropping in the Imo River Basin. The Umuna sandstone is composed of thick sandstone units and minor shales and is generally less than 70m thick. The Ebenebe Sandstone occurs as a lens in the northwestern extremity of the Imo River Basin. It is similar in lithology to the Umuna sandstone but is relatively thicker with a maximum thickness of 130m (Uma, 1986). Ameki Formation (Eocene) consists of sand and sandstones. The lithologic units of the Ameki Formation fall into two general groups (Reyment, 1965; Whiteman, 1982 and Arua, 1986); an upper grey-green sandstones and sandy clay and a lower unit with fine to coarse sandstones, and intercalations of calcareous shales and thin shelly limestone.

2. Methodology

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. Twenty three vertical electrical sounding was carried out to establish the characteristics of the aquifers in the study area of the Imo River Basin under study. 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. Figure 2 shows the map of the study area showing VES locations.

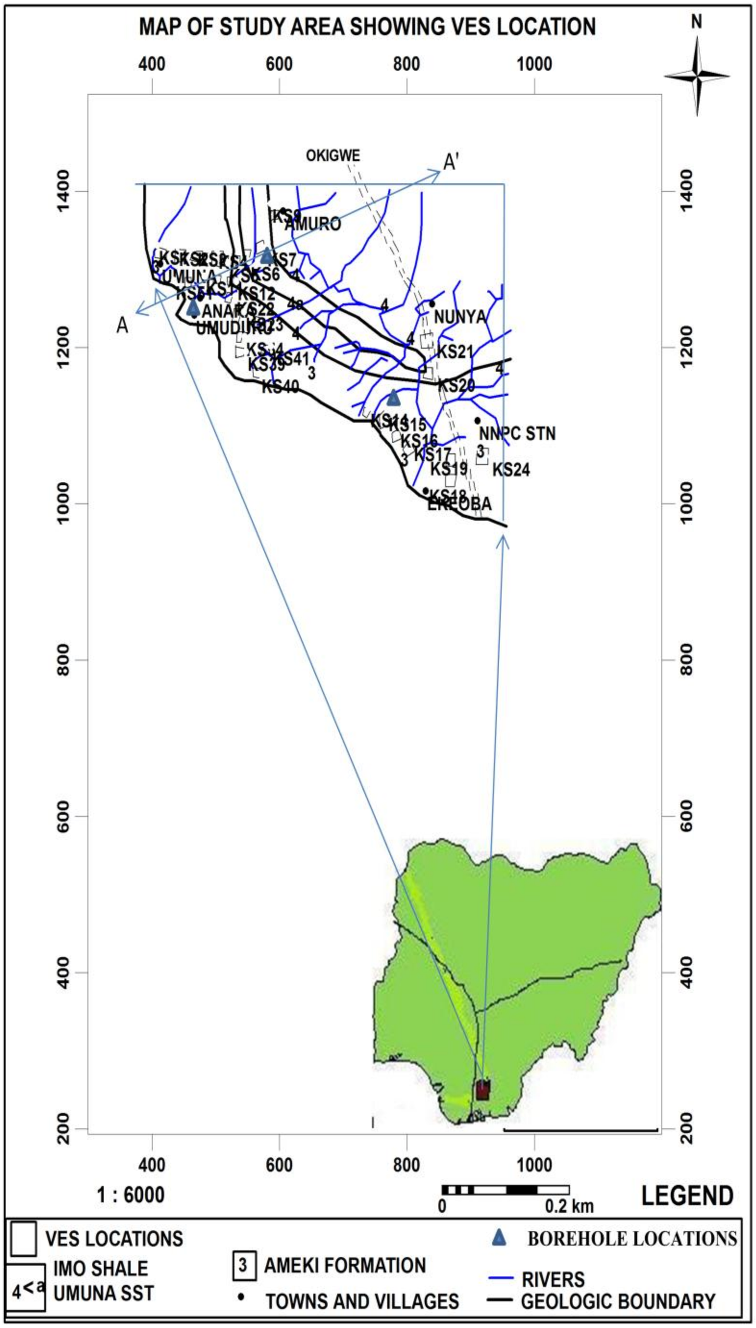

Figure 2: Map of the Study Area showing VES locations.

2.1 Aquifer Hydraulic Characteristics from Vertical Electrical Sounding Data

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 ρ_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 where σ_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. The differential form of Ohm's law gives:

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

where j is the current density; and σ is the electrical conductivity, which is the reciprocal of the resistivity, ρ. 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 Niswass 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 σ 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.

3. Results and Discussion

3.1 Interpretative Cross-Sections Across The Study Area

In order to reveal the geologic sections in different parts of the study area a profile, AA′ was selected as shown in Figure 3. Profile AA′ is in the SW-NE direction. It traverses Okwelle (KS1, KS2), Umunna (KS3), Okwe (KS4, KS5) in Ameki Formation and Amurro (KS8, KS9) in Imo Shale. The section reveals four discontinuous layers: the top soil is underlain by clay, sand, sandy shale and shale, with shale forming the oldest sediment and deepest layer. From the figure a productive aquifer can be observed at locations KS1 and KS2. There are also possible aquifers at locations KS3—KS7 because of the presence of sandy shale. Figure 4 shows the lithology logs from boreholes located in Okwelle (KS 1), Okwe (KS 5) and Eziama Osuama (KS 22), within the study area. The geo-electric section obtained from VES results (Figure 3) compared closely with the borehole lithologs obtained from some boreholes drilled in the study area (Figure 4).

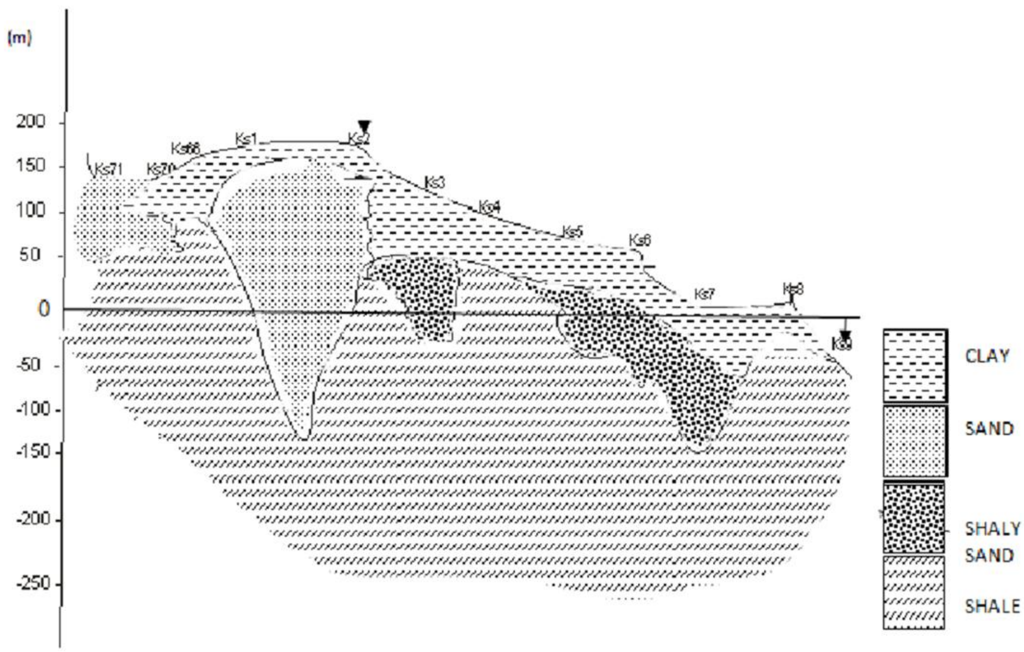

Figure 3: Interpretative Cross-Section Along AA′

3.1.1 Depth to the Water Table

The various aquifer characteristics within the study area are shown in Table 1. Depth to the water table across the study area was deduced from the VES result. The deductions show that the water table is shallow in the areas within Imo Shale formation; KS6, KS7, KS8, KS20 and KS21. The aquifer system is confined between shale aquitards in locations KS6 and KS7, while the chances of actually finding productive aquifers in KS8 and KS9 are quite remote, since the geologic section indicates mainly shales. There is no indication that the Umuna sandstones as known from the geology of this area were reached by the soundings reflected in this profile. The confined aquifer system shown agrees with the work of Uma (1989). There is an obvious discontinuity of the confined aquifer system at KS3 (Umuna 1). Here again no sandstones are indicated, but mainly shale and clay units. Locations KS1, KS2, KS3, KS4 and KS5 along the profile fall within Ameki formation. Productive aquifers are evident at locations KS1 and KS2 with respective aquifer thicknesses 42.3m and 38.6m.

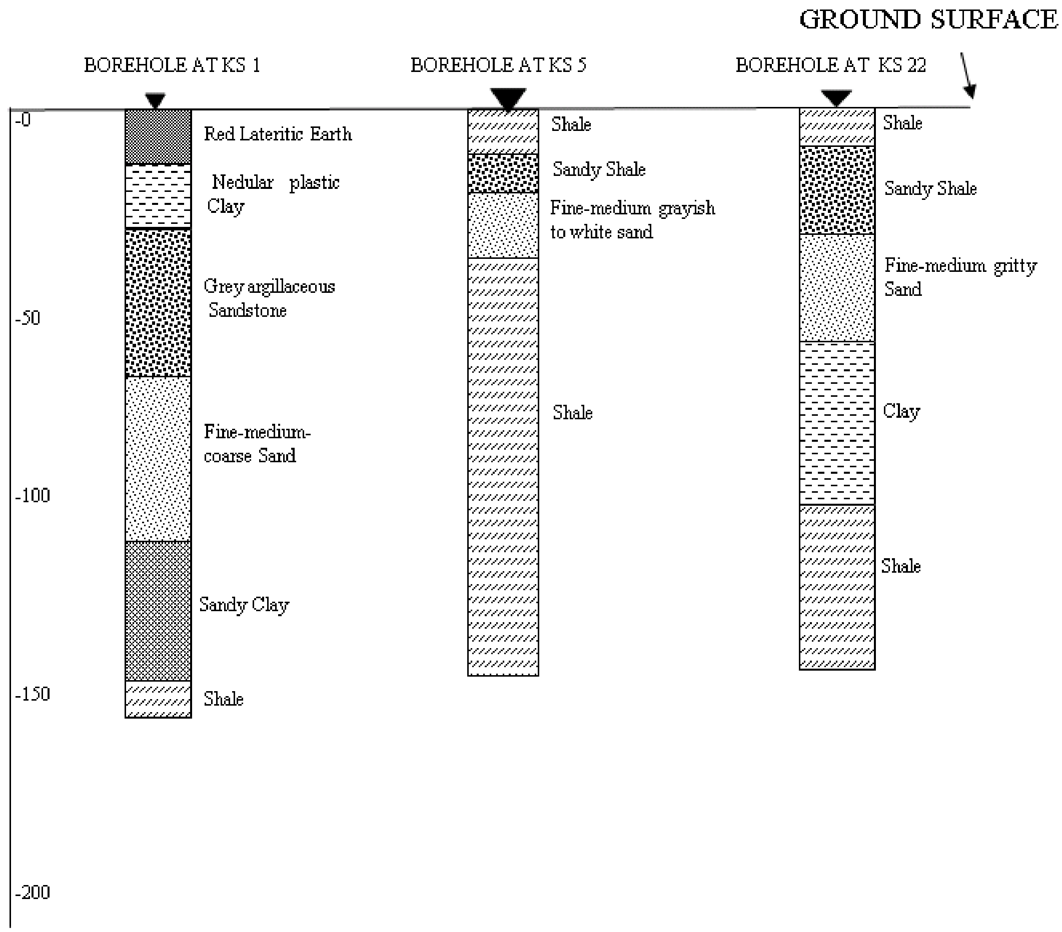

Figure 4: Lithologs of some Boreholes within the Study Area

3.1.2 Hydraulic Characteristics of the Aquifer Systems

The hydraulic characteristics of the several aquifer types within the study area were established using the concept of Dar-Zarrouk parameters (transverse unit resistance (R) and longitudinal conductance (C) in porous media dicussed in section 2.1. According to Ekwe et al., (2006), the Kσ product for 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, for aquifers located within Imo Formation the mean of the hydraulic conductivity K= 2.65 m/day, while the mean of the transmissivity T=46.63m^2/day. The maximum K= 3.13m/day, while the minimum K=2.09m/day. The maximum T=87.68 m^2/day, while the minimum T=15.54 m^2/day. For aquifers located within Ameki Formation, K_{mean}=2.70m/day; T_{mean}=80.59 m^2/day; K_{max}=4.65m/day; T_{max}= 167.14 m^2/day; K_{min}=1.25m/day and T_{min}=6.08 m^2/day. Low values for K and T imply low potential for aquifer productivity. Comparing these figures with those obtained by Uma (1989) for the Ameki Formation: K_{mean}=4.31m/day; T_{mean}=194.75m^2/day; K_{max}=8.16m/day; T_{max}= 464.21 m^2/day; K_{min}=2.07m/day and T_{min}=52.67m^2/day; these values from the work of Uma are only for the confined aquifer system of the Ameki formation.

Figure 5 shows the map of the hydraulic conductivity obtained for the study area showing areas with high and low hydraulic conductivities. This is typical of the values obtained by Umar (1989). Figure 6 shows the map of Transmissivity for the study area. These are indicative of the productive potential of the aquifers. Figure 7 shows the map of the depth to the water table. Figure 8 shows the map of the aquifer thickness. Figure 9 shows the map of Kσ values estimated for the study area.

4. 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. Over areas in the outcrop surface of the Imo Shale geologic formation, most of the layers consist of shale interspersed with clay, and some sandstone. Over areas within the Ameki geologic formation, most of the layers consist of shale, clay and sand, and sandstones. The aquifers in the Imo Shale formation have generally less productive potential than those in the Ameki formation.

5. Acknowledgements.

The authors wish to acknowledge with gratitude the Anambra-Imo River Basin Authority, the Imo State Rural Water Supply Agency, and UNICEF Owerri for giving us access to their information resources. Special thanks to Engr. Emeka Udokporo of FLAB Engineering and Mr. A. O. Kanu of the Abia State Water Board, who made a lot of useful material available and helped in many other ways; also Mr. R. C. Oty of the Anambra- Imo River Basin Authority, and Mr. R. N. Ibe of the Ministry of Public Utilities, Owerri for their tremendous help in the work.

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

VES #	LOCATION	DEPTH TO WATER TABLE (m)	AQUIF-ER THICK-NESS h (m)	APPAR-ENT RESISTI-VITY ρ (Ω-m)	TRANS-VERSE RESIST-ANCE, R ρh(Ω-m²)	Kσ	HYDR-AULIC CONDU-CTIVIY K(m day⁻¹)	TRANSM-ISSIVITY KσR (m² day⁻¹)
KS1	OKWELLE 1	61.7	42.3	2150.0	90945	0.0017	3.66	154.61
KS2	OKWELLE 2	2.5	38.6	1141.0	44004	0.0025	2.85	110.01
KS3	UMUNA 1	34.4	32.6	278.0	9063	0.0103	2.86	93.35
KS4	OKWE 1	9.6	20.9	594.0	12415	0.0041	2.44	50.90
KS5	OKWE 2	7.9	19.6	2110.0	41356	0.0012	2.53	49.63
KS6	OKWE 3	10.9	15.5	790.0	294.5	0.0112	3.13	32.98
KS7	UMUNA 2	20.8	37.6	440.0	16544	0.0053	2.33	87.68

KS8	AMURO 1	5.9	16.3	255.0	4157	0.0085	2.17	35.33
KS9	AMURO 2	61.6	40.4	130	5252	0.0161	2.09	84.55
KS10	UMUNA 3	5.8	24.6	371	9127	0.0196	7.27	178.85
KS11	OBIOHURU 1	16.5	18.7	5000.0	93500	0.0008	4.00	74.80
KS12	OBIOHURU 2	20.3	33.7	2700.0	90990	0.0008	2.16	72.79
KS13	ORJI	56.8	25.1	3880.0	97388	0.0008	3.10	77.91
KS14	IKPEREJERE	35.0	22.1	3140.0	69394	0.0007	2.20	48.58
KS15	UMUDIKE ELUAMA	45.1	21.4	2380.0	50932	0.0013	3.10	66.21
KS16	UMUDIBIA ELUAMA	26.0	43.9	4170.0	183063	0.0004	1.67	73.23
KS17	ABUEKE	13.2	24.7	8600.0	212420	0.0004	3.44	84.97

KS18	EKEOBA	7.5	30.2	13300.0	401660	0.0003	3.99	120.50
KS19	AMAOGWUGW-U	7.4	5.6	203.0	1137	0.0147	2.98	167.14
KS20	NUNYA 1	4.8	7.7	550	4235	0.0056	3.07	23.72
KS21	NUNYA 2	1.8	5.0	2220.0	11100	0.0014	3.12	15.54
KS22	EZIAMA OSUAMA	17.6	20.5	1210.0	24805	0.0007	0.85	17.36
KS23	UMUEZEAL-AEGBE UMUDURU	20.2	54.1	3040.0	164464	0.0008	2.43	6.08

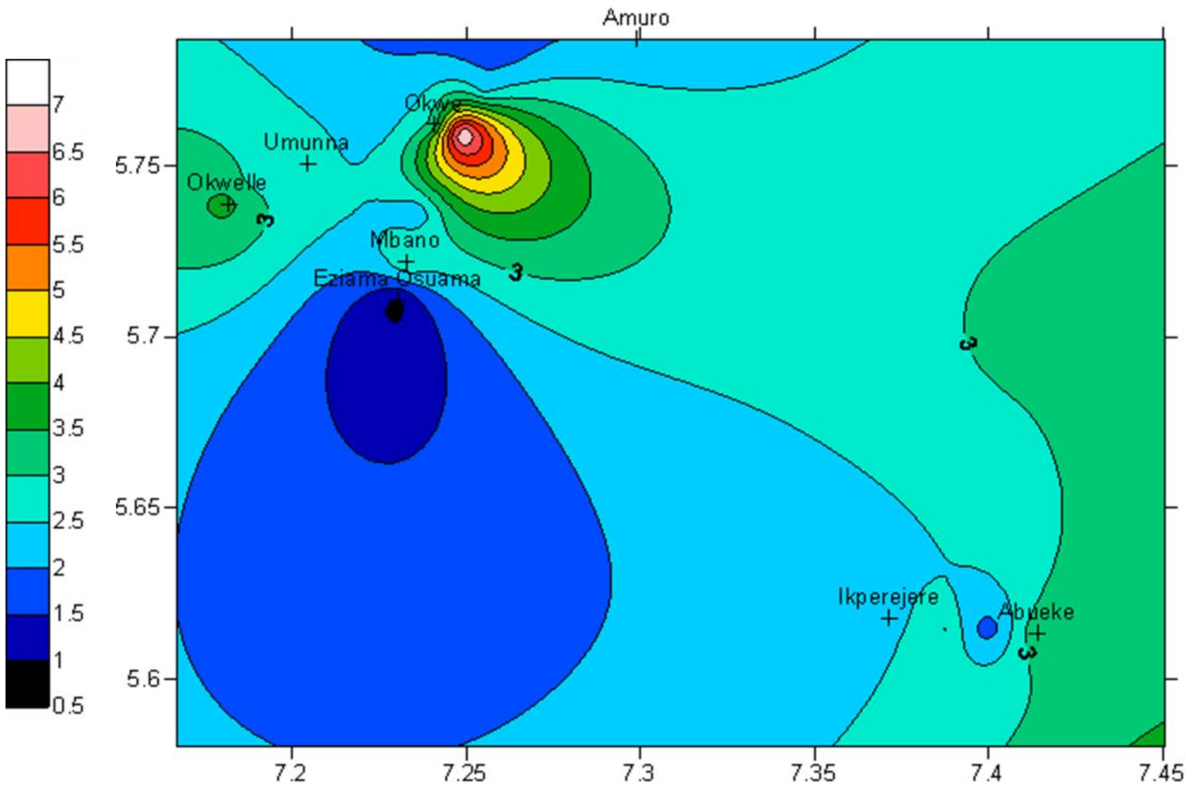

Figure 5 : Map of Hydraulic conductivity for the Study Area

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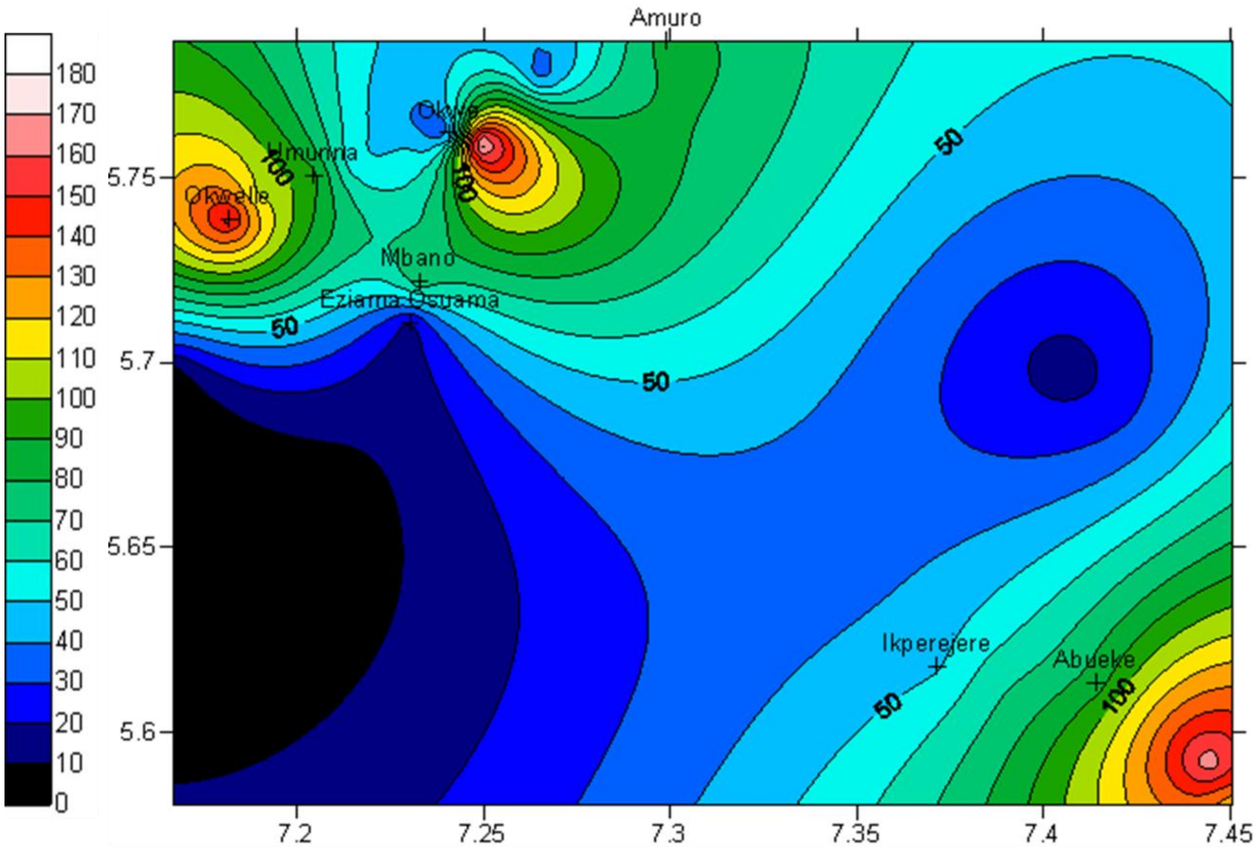

Figure 6 : Map of Transmissivity for the Study Area

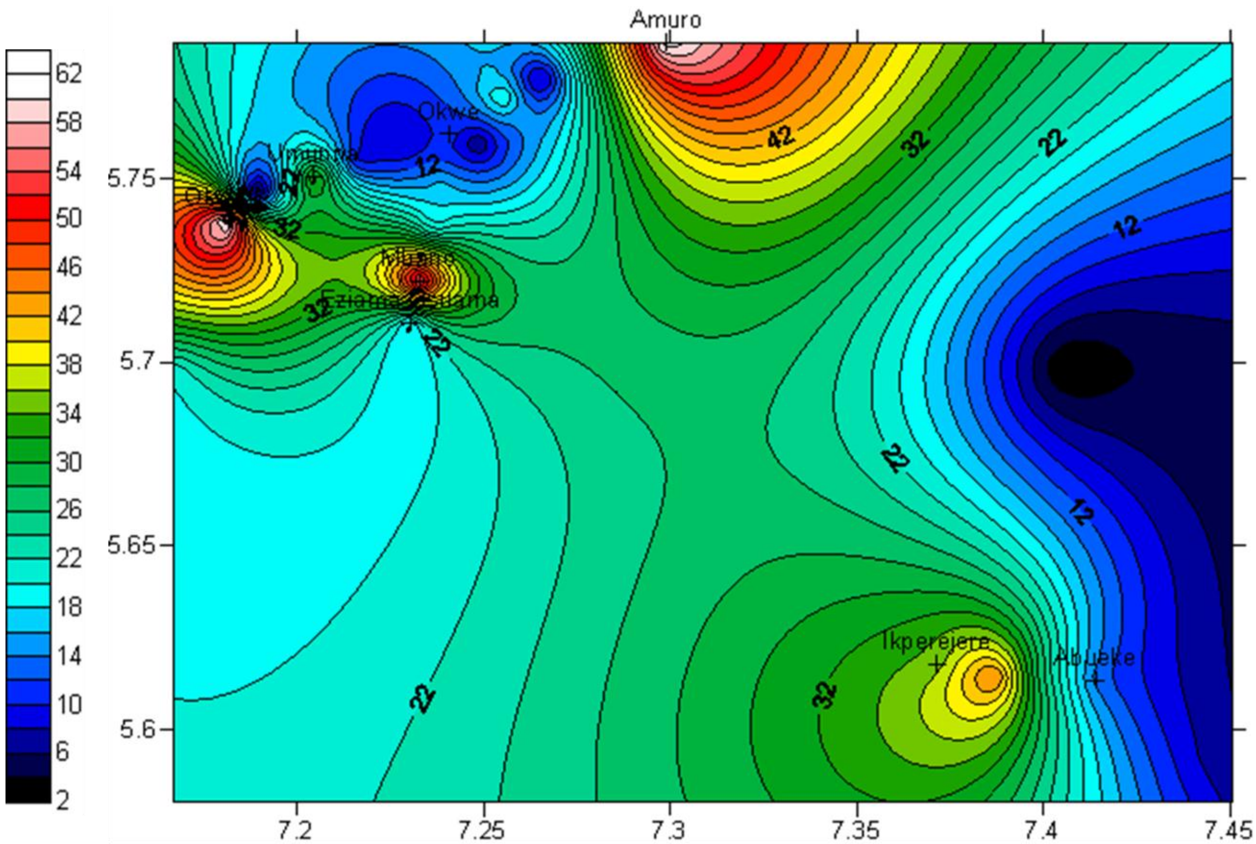

Figure 7: Map of Depth to water table for the Study Area

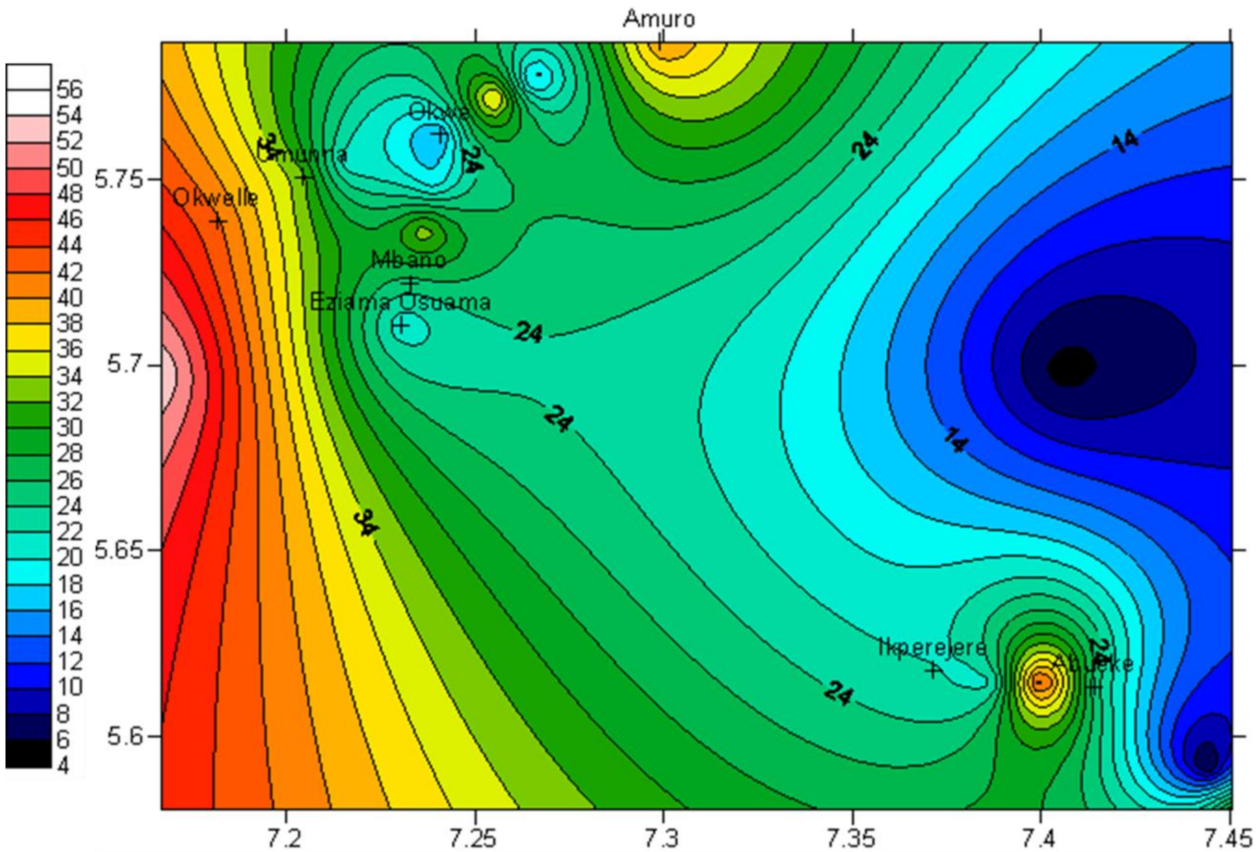

Figure 8: Map of Aquifer Thickness for the Study Area

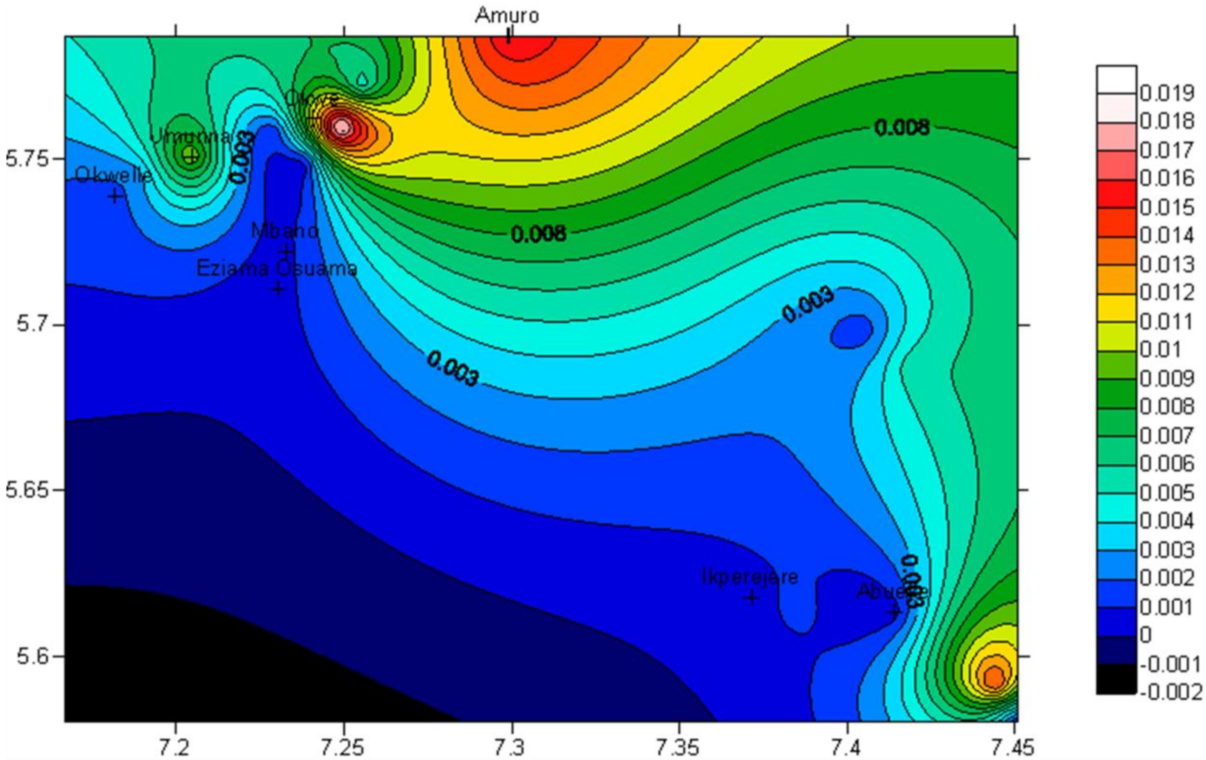

Figure 9: Map of Diagnostic Parameter, kσ, for the Study Area