World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

Evaluation of aquifer characteristics at Kingsley Ozumba Mbadiwe university and environs

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World Journal of Advanced Research and Reviews, 2024, 22(03), 2064–2081

Publication history: Received on 16 May 2024; revised on 26 June 2024; accepted on 28 June 2024

Article DOI: https://doi.org/10.30574/wjarr.2024.22.3.1682

Abstract

Aquifer characteristics evaluation enables the determination of aquifer's ability to recharge as well as discharge. However, knowledge of aquifer characteristics has been scarce at Kingsley Mbadiwe University and Its Environs. Thus, geophysical and hydrogeological investigations involving vertical electrical sounding (VES), pumping test and well logging were conducted in KOMU, Imo State Nigeria, to evaluate the aquifer characteristics as well as the groundwater protective capacity of the area. Twenty-Five (25) VES, using the Schlumberger configuration, were carried out. The vertical electrical sounding data were processed using a combination of curve matching and computer modeling using the IP2WIN software. The aquifer resistivity across the study area varies from 90 Ωm at 5 Star Hotel Obiohia, KOMU (VES 24) to 5872 Ωm beside the Stadium KOMU (VES 9). The depth to the water table across the study area varies from 1.43 m at Medical Centre KOMU (VES 13) to as high as 82.7m at Faculty of Sciences KOMU (VES 2) Southeastern parts of the study area. The aquifer thickness across the study area varies from 2.18m at 5 Star Hotel Obiohia, KOMU Environs (VES 24) to 126m at Benahllis Hotel, KOMU Environs (VES 14). The groundwater potentials of the studied area range from fair to good, with the areas underlain by the Benin Formation having better groundwater potentials, according to the interpretation of a variety of aquifer characteristics.

Keywords: Aquifer characteristics; Vertical Electrical Sounding; Curve matching; Resistivity; Protective capacity.

1. Introduction

Achieving environmental sustainability is one of the primary goals of the Sustainable Development Goals (SDG) and the Millennium Development Goals (MDG), which is closely related to having access to clean, low-carbon surroundings and drinking water (UN 1988; Choko *et al.* 2018). Nevertheless, obtaining clean drinking water for households and residential use has proven to be extremely difficult in many developing nations, particularly in sub-Saharan Africa (UN 1988; Choko *et al*. 2018). Groundwater is the most practical supply of drinkable water in most parts of Nigeria because public utilities, such as pipe-borne water projects, have nearly completely collapsed. The majority of Nigeria's rural population depends on surface water sources and rainfall to meet their domestic water needs, as over half of them lack access to clean water (UN 1988; Ejiogu *et al*. 2019). Regrettably, pollution from underlying anthropogenic sources usually degrades the quality of surface water sources and rain. It is well recognized that the world's sedimentary basins are the primary sources of groundwater (Ekwe and Opara 2012; Ejiogu *et al*. 2019). Thin clay layers act as hydraulic barriers between several aquifer units found in the sedimentary basins of southeast Nigeria, including the sediments of the Imo River hydrological basin (Uma 1989). To assist in addressing the groundwater resources of the area both qualitatively and quantitatively, it is now essential to conduct a thorough exploration of the research area's groundwater resources. First and foremost, we must explain and understand what an aquifer is.

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- An aquifer is a ground water reservoir composed of geologic units that are saturated with water and sufficiently permeable to yield water in a usable quantity to wells and springs. Sand and gravel deposits, sandstone, limestone, fractured, crystalline rocks are examples of geologic units that form aquifers.
- Aquifers can provide two important functions which are to transmit groundwater from areas of recharge to areas of discharge and to provide a storage medium for useable quantities of groundwater.

There are two types of aquifers which are Unconfined and Confined Aquifers.

- Unconfined aquifer is one in which water table varies in undulating form and in slope, depending on areas of recharge and discharge and permeability. Contour maps and profiles of the water table can be prepared from elevations of water in wells that tap the aquifer to determine the quantities of water available and their distribution and movement.
- Confined aquifers also known as artesian aquifer occur where groundwater is confined under pressure greater that atmospheric by overlying relatively impermeable strata. Water enters a confined aquifer in an area where the confining bed rises to the surface. Water may also enter by leakage through the confining bed. Confined aquifers display only small changes in storage and serve primarily as conduits for conveying water from recharge areas to locations of natural or artificial discharge.

An urgent and practical scientific strategy is required for the management of groundwater resources. Determining an aquifer's parameters is one method for efficiently assessing its hydraulic features. Knowing the hydraulic properties of an aquifer (transmissivity, storativity, specific capacity, hydraulic conductivity, transverse resistance, longitudinal conductance, aquifer thickness, and depth provides firsthand information on the subsurface hydrology of the aquifer (Tijani *et al*., 2021). An efficient way to assess aquifer hydraulic properties such hydraulic conductivity, specific capacity, transmissivity, and storativity is through pumping tests. The standard approach for assessing the hydraulic characteristics of an aquifer is still pumping test analysis. The research area's hydraulic characteristics and groundwater potentials provide a number of hydrological and hydrogeological issues that require a thorough application of state-of-the-art exploration techniques. Worldwide, the use of surficial resistivity measurements has shown to be a very successful method for identifying and describing aquifer zones (Joshua *et al*. 2011). Also, electrical resistivity techniques have been applied in the study area for determining aquiferrous zones (Emberga *et al*. 2019). Additionally, some researchers have examined the aquifers' protective capabilities in the study area by utilizing resistivity techniques.

Accurately characterizing the subsurface hydrogeological properties of any place requires a number of hydraulic variables, including aquifer transmissivity, storage coefficient, and hydraulic conductivity (Emberga *et al*. 2019). However, the majority of the research region lacks easy access to information on the hydraulic properties, which works against sustainable management and vigorous groundwater use (Ekwe and Opara 2012). Normally, pumping test techniques are used to assess the geo-hydraulic parameters in drilled boreholes in order to determine the hydraulic characteristics of an aquifer. However, the lack of pumping test data in the majority of developing nations has resulted from high measurement costs and inadequate data management, making the use of non-evasive and affordable geophysical methods for aquifer characterization necessary. Direct current electrical resistivity techniques are then used to estimate the aquifer hydraulic characteristics. Consequently, hydrogeophysicists have used indirect surficial geo-sounding data to predict the hydraulic parameters of aquifers during the past few decades by creating analytically meaningful functional correlations between surface resistivity measurements and pumping test data (Niwas and Singhal 1981).

Since the electrical and hydraulic parameters of the aquifer are known to be correlated and because these attributes are tangentially connected to the porosity, permeability, and heterogeneity of the aquifer geo-materials, this strategy has proven to be highly successful (Agbasi and Edet 2016). As a result, numerous writers have approximated these aquifer hydraulic parameters from surface electrical soundings all over the world in succession (Kelly 1977). Additionally, a number of writers have effectively assessed aquifer hydraulic properties from Dar-Zarrouk parameters by employing information from vertical electrical resistivity sounding surveys conducted in southeast Nigeria (Mbonu *et al*. 1991). The inadequate calibration of the resistivity data with the local geology of the study region is a key drawback of the technique, despite the enormous success attained over the years with the application of surface resistivity data in the calculation of aquifer hydraulic parameters. In order to attain a high degree of predictive precision with this method, some parametric vertical electrical soundings near the accessible boreholes with pumping test data must be conducted in order to calibrate the analytical/empirical relationship derived from the Dar-Zarrouk parameters extracted from resistivity data with the local geology (Opara *et al*. 2012). Additionally, in order to compare the interpreted layer parameters from the resistivity data, available subsurface data from the study area must be correlated. Thus, in order to address this issue, the current study's objectives are to identify the aquiferous zones, as well as to calculate the study area's thickness, water table depth, and hydraulic characteristics by utilising the Dar-Zarrouk parameters derived from the direct current electrical resistivity technique.

The aim of this research is to determine the aquiferous zones, depth to water table and thickness of groundwater at Kingsley Ozumba Mbadiwe University and its environs.

1.1. Location climate and geology of the study area

The study area is at Kingsley Ozumba Mbadiwe University and its Environs and It is defined by the geographic coordinates given by Latitude $5^0$49.4'N to $5^0$50.5'N and Longitude $7^0$4.4'E to $7^0$5.5'E as shown in Figure 1. The study area shares boundary in the eastern part with Okigwe and Omuma Local Government Area (L.G.A), in the western part with Orlu L.G.A and in the southern part with Nkwere and Nwangele L.G.A's. The area is quite accessible with a network of tarred and untarred roads. There are topographic high and low areas observed across the study area.

The two main seasons in the rain forest climate region are the dry and the rainy (wet) seasons. With an average of over 2200 mm of rain each year, there is a lot of rainfall, and the relative humidity is typically over 70%. The study area's average yearly temperature is approximately 27 °C, and its average daily evaporation rate is 3.0mm. The research region has moderate to high topography, with an average elevation of roughly 152 metres above sea level and a general slope of about 0.0014 southward (Uma 1989).

The Imo River and its tributaries, including Otamiri and Oramurukwa, which flow southward before eventually draining into the Atlantic Ocean, are the study area's primary drainage system.

According to Uma 1989, the research area is situated inside the hydrological province of the Imo River. The Benin, Ameki, and Imo Shale Formations represent the geological underpinnings of the study area. Lenticular, unconsolidated, medium- to coarse-grained sands and clayey shales make up the Benin Formation (Miocene–Recent) (Uma 1989). Generally speaking, the sands are angular in shape, well-sorted, and poorly cemented (Onyeagocha 1980; Mbonu et al. 1991). Sandstone and clays make up the majority of the Benin Formation, with the thickness of the clays rising with depth. The sandstone is very ferruginous in certain areas, and the sands are often friable and varied in colour.

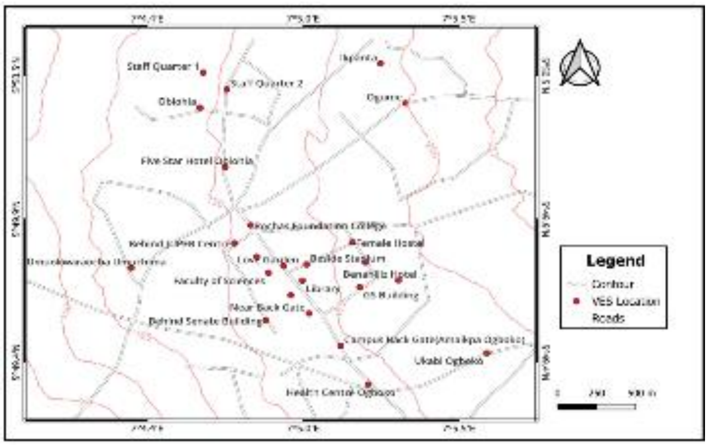


Figure 1 Location map of the study area showing VES points

The formation's thickness varies greatly, from roughly 200 metres at the margins to roughly 2000 metres in the centre. The Benin Formation is primarily composed of sand, which has strong permeability, transmissivity, and storativity. Accordingly, the Benin Formation has high porosity and permeability values, making it a good aquifer (Reyment 1965).

The Benin Formation sits atop the Ameki Formation. The Eocene–Oligocene Ameki Formation is composed of thin limestone units, bluish calcareous silt, white medium- to coarse-grained sand and sandstone, and clays with coloured patches or streaks. Throughout the research region, lateral alterations in lithological features have been noted (Uma 1989). The Ameki Formation is divided into two units lithologically (Whiteman 1982; Uma 1989). It is made up of a bottom unit of fine to coarse sand/sandstones, calcareous shales insertions, and thin layers of limestone made of broken shells, and a higher unit of grey-green sand-stones and sandy clay (Whiteman 1982; Uma1989). The Ameki Formation has a respectable aquifer potential overall.

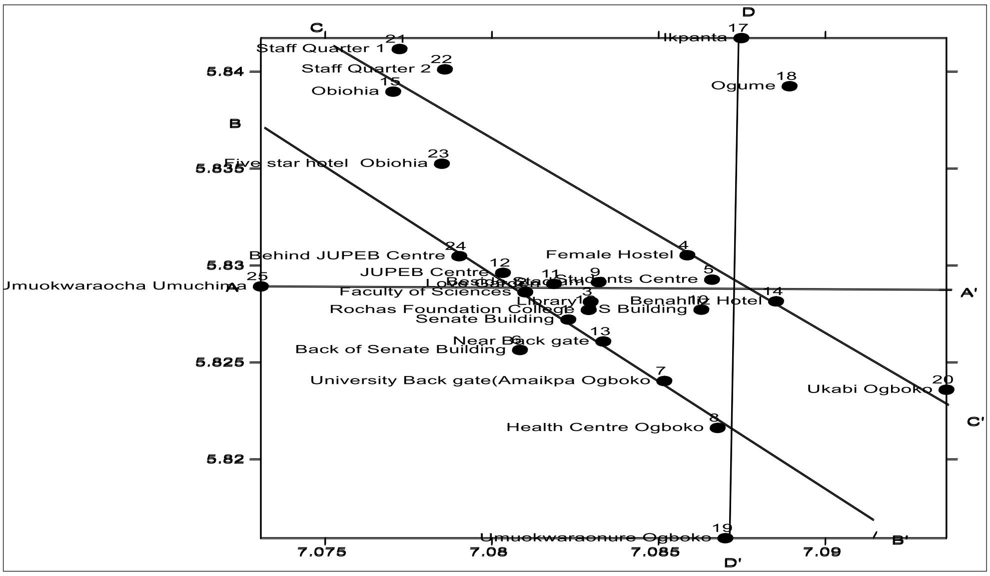


Figure 2 Geology Map of the study area.

Lastly, well-laminated blue and dark grey clayey shales with sporadic bands of calcareous sandstones, marls, and lime stone define the Imo Shale Formation. The shales are impermeable, fragmented, and extremely compressed. The Umunna and Ebenebe sandstones are examples of sand members that are typically represented by large ventricular sands, which are common in certain locations (Reyment 1965; Uma 1989). The Ebenebe sand units, which are interbedded within the Imo Formation, and the gravelly Umunna sandstones feature silty sands and typically have poor coverage and lateral continuity (Reyment 1965; Uma 1989). At the top, though, the formation gets sandier and typically consists of a shale and sandstone mixture.

The younger Ameki Formation (Eocene) succeeds the Imo Shale Formation vertically. The Ameki Formation and the interbedded formation's lithostratigraphic borders are not yet clearly defined, though. According to Frank and Cordry (1967) and Amadi(2008), a portion of the subsurface Akata Formation can be found in the Imo shale, which is its up-dip equivalent. The formation reaches a thickness of around 1200 m near the contact with the Akata Formation, however it is only about 480 m thick at the type locality (Whiteman 1982). On the Nsukka Formation, it lays conformably. The Imo Shale Formation's hydro-geological potential is generally quite low, with the exception of locations where the sand members are locally distributed.

1.2. Problem statement

Within the study area, real-time field measurements of the Aquifer parameters and aquiferous zones are not always available because of the prohibitive cost of standard measurements of these parameters in the study area. Because of this problem, therefore, important baseline data required for more robust and sustainable management of the groundwater resources are usually insufficient or unavailable thereby leading to inefficient exploitation of the groundwater system of the study area.

2. Materials and methods

2.1. Materials

The materials that were used for this research are highlighted below.

- ABEM Terrameter SAS 1000
- External Battery Connector
- deep penetration resistivity meter.
- Two potential electrodes
- Two current electrodes
- A 12-volt car battery (power source).
- Four electrical cable rims, two each for the potential and current electrodes.

- Two 100m tapes
- Four geological hammers.
- GPS for measuring Co-ordinates and Altitude

2.2. Methods

The method adopted in this study involved the hydrogeophysical techniques. The electrical resistivity survey was carried out in the study area and Vertical Electrical Sounding (VES) technique was applied. The Schlumberger configuration was chosen over Wenner configuration for this study. This is because the Schlumberger array of electrodes provides high signal-to-noise ratios, good resolution of horizontal layers and good depth sensitivity (Ward 1990). A total of twenty-five (25) VES data with a maximum half current electrode separation (AB/2) of 500 m were acquired from the study area using the ABEM Terrameter SAS 1000. Current was injected into the earth through a pair of current electrodes and the potential difference was measured between a pair of potential electrodes. The current and potential electrodes are normally arranged in a linear array. However, electrode spacing varies for each measurement and the center of the electrode array where the electrical potential is measured remains constant. (Reynolds, 2011).

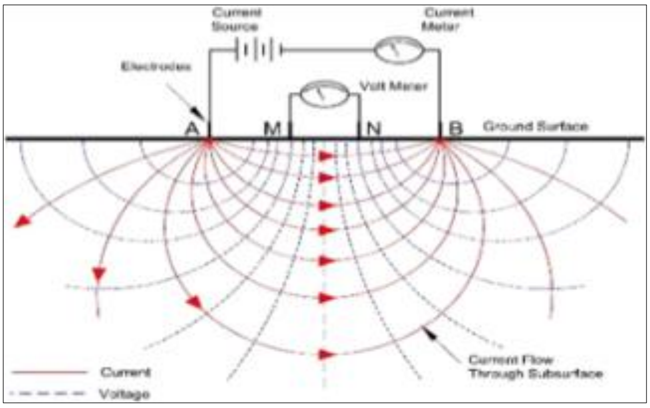


Figure 3 Schlumberger Array

2.2.1. Collection and Process of resistivity survey data.

Data Acquisition

A variety of pre-selected places were used to collect the data. The system was configured on both sides of the instrument. After that, the results were examined on a simple data entry sheet using IPISW, a resistivity data analysis programme. Quantitative data interpretation was done using computer iterative approaches and curve matching. The resistivities and corresponding electrode spacing data were entered into an automated computer programme that was designed using the Schlumberger theory. Based on computer data, logarithmic-scale graphs showing apparent resistivity against depth were plotted for every station.

2.2.2. Data Analysis

The data that were gathered were examined using the previously indicated model. Its main working theory is the conventional theory of curve matching. The depth to the water table was computed using the data that was gathered. The readings obtained from a resistivity survey were cross-checked in several places with the water table depths previously noted from nearby wells. IPI2WIN was the iteration programme used to iterate the VES curves. The set of smooth curves that were drawn through the data points was quantitatively interpreted using the partial curve matching technique. Resistivity and layer thickness were calculated. By analyzing these curves with the aid of the auxiliary curves that matched them, the resistivity, thickness, and depth of the water table of each of the demarcated strata were ascertained.

Electrical Resistivity Profiling

Electrical resistivity is the subject of interest. Performing a linear grid survey provides detailed analysis of lateral alterations and, frequently, provides only a limited understanding of vertical variations. The process of data profiling entails the methodical gathering of data recordings at regular intervals along a chosen profile. The profile is often marked at specified periods of predetermined distances. We consider a current between two electrodes with different potentials that is flowing through a homogeneous medium inside a well-defined uniform cross section in the context of a geometrically ideal scenario.

$\boldsymbol{R} = {}^{\boldsymbol{V}}/_{\boldsymbol{I}}$ .... Equation 1

Where R is the resistance of the current carrying conductor, V is the voltage of the battery and I is current passing through conductor. The offered resistance is also affected by the electrode distance L and the cross-sectional area of the conductor. The apparent resistivities were computed as the initial stage of data processing since the values obtained from field measurements correlate to potentials or resistances. These were computed using the electrode configuration-specific formula.

2.2.3. Subsurface Geologic and Hydrogeologic Characteristics of the Aquifer in the Study Area using Resistivity Survey.

The Study Area was thoroughly assessed to identify the unique features and characteristics that affect the area's ground level before the in-depth data was collected. The profiles were carefully selected with consideration for accessibility and all conceivable modes of mobility in order to conduct a practical resistivity survey. The main goal of the feasibility survey was to prevent problems with data collection. The data were collated using the standard Schlumberger configuration, which states that the current electrodes vary in both directions in a straight line. However, in the event of weak signals, the potential electrodes are moved when better subsurface start results are required.

Hydraulic Conductivity

According to Amadi (2008), the hydraulic conductivity K is directly proportional to the layer resistivity. Hydraulic conductivity is inversely correlated with permeability. According to Younger (2007), the following equation describes the relationship between hydraulic conductivity and layer resistivity in a porous aquifer medium:

$K(m/s) = 10^{-5} \times 97.5^{-1} \times \rho^{1.195}$ .... Equation 2

$K(m/day) = 60 \times 60 \times 24 \times K(m/s)$ ....Equation 3

2.2.4. Transmissivity of the aquifer

Transmissivity is a major property of an aquifer which helps in the characterization of rocks as water conducting media.

$T = Kh$ .... Equation 4

Where T is the aquifer transmissivity, K is aquifer hydraulic conductivity and h is the aquifer thickness.

2.2.5. Protective Capacity

The values of the total longitudinal conductance of the overburden layers of an aquifer were used in evaluation of the protective capacity of the aquifer.

$\boldsymbol{PC} = \Sigma \boldsymbol{LC} = \Sigma \boldsymbol{h}_i/\boldsymbol{\rho}_I$ .... Equation 5

Where PC is protective capacity, LC is longitudinal conductance, hi is thickness of the layer and ρi is resistivity of the layer (Oladapo and Akintorinwa, 2007).

3. Results and discussion

The results of some selected computer- modeled curve types are presented in Figures 4.1 to 4.25. This was determined by inserting a model that was represented by the thickness of each curve layer and apparent resistivity.

3.1. Interpreted layer parameters

The results of the study showing layer parameters are presented in Table 1. Figures 4.1 to 4.25 displays representative geo-electrical curves that have been interpreted from the study area. The geo-electric curves quantitative curve description revealed the identification of multiple curve kinds, ranging from simple to complex. Curve types identified include K, KQ, AQ, QH, KQH, KHQ, etc. with the KH type curve been predominant.

Table 1 Summary of the aquifer hydraulic parameters interpreted from the geo-electric section

VES NO.	No of Layers	Town	Resistivity of Layers	Thickness of Layers	Depth from Top	Aquiferous Zones	Aquifer Thickness	Depth of Water table	Aquifer Resistivity	Lat.	Long.	Elevation above Sea Level
	9	Senate Building K.OMU. Ogboko, Ideato South LGA, Imo State	6214 148 7274 338 72236 2.6E+5 90646 72920 3.5+5	0.227 0.508 1.58 7.67 18.3 30.8 35.5 85.5	0.227 0.735 2.31 9.98 28.3 59 94.5 180	4th Layer	7.67m	2.31Ω m	338Ωm	5⁰49.632' N	7⁰04.937' E	164m
	10	Faculty of Sciences KOMU	1191 218 4278 156 3773 3.0E+6 31528 5720 17760 1139	0.428 1.18 1.57 6.57 8.03 3.53 61.4 67.3 30	0.428 1.61 3.12 9.69 17.7 21.2 82.7 150 180	8th Layer	67.3m	82.4Ω m	5720Ωm	5⁰49.717' N	7⁰04.860' E	159m
	8	Library KOMU	264 4382 351 1422 30809 428 3442	0.74 2.21 2.61 20.9 44.2 31.8 77.5	0.74 2.95 5.56 26.5 70.7 102 180	6th Layer	31.8m	70.7Ω m	428Ωm	5⁰49.687' N	7⁰04.977' E	164

			9028									
	9	Female Hostel KOMU	3483 14292 220 62787 27159 6.1E+6 11867 734 1561	0.355 0.721 2.28 8.49 0.218 1.11 57.5 109	0.355 1.08 3.36 11.8 12.1 13.2 70.7 180	8th Layer	109m	70.7Ω m	734Ωm	5^{0}49.831’ N	7^{0}05.151’ E	183m
	9	Students Centre KOMU	676 2726 264 2.5E+5 1092 3445 14564 30372 2.3E+5	0.282 0.577 2.14 6.21 34.6 22.1 84.1 30	0.282 0.859 3 9.21 43.8 65.9 150 180	5th & 6th Layer	34.6m 22.1m	9.21Ω m	1092Ωm 3445m	5^{0}49.756’ N	7^{0}05.196’ E	187m
	9	Back of Senate Building behind BH1 KOMU	524 31305 1.3E+6 536’77 4493 33775 7.6E+5 52997 7509	1.35 0.489 3.85 5.59 23 20.3 79.8 45.7	1.35 1.84 5.68 11.3 34.3 54.6 134 180	5th Layer	23m	11.3Ω m	4493Ωm	5^{0}49.538’ N	7^{0}04.850’ E	162m

	9	University Back Gate (Amaikpa Ogboko)	226 1946 222 14117 1234 3.5E+5 34688 9840 1850	0.373 0.304 1.91 1.09 15 22.8 70.8 37.8	0.373 0.677 2.59 3.68 18.6 41.4 112 150	5th Layer	15m	3.68Ωm	1234Ωm	$5^0$44.442' N	$7^0$05.110' E	173m
	10	Health Centre Ogboko Near KOMU	273 38483 171 2582 17952 2910 29409 1.0E+5 44037 1.5E+5	0.351 1.18 3.27 2.95 10.7 43.7 31.9 70.4 45.6	0.351 1.53 4.8 7.75 18.5 62.1 94 164 210	6th Layer	43.7m	18.5Ωm	2910Ωm	$5^0$49.297' N	$7^0$05.206' E	175m
	9	Beside Stadium KOMU	1752 243 922 81.9 5872 1.0E+5 21957 1.4E+5 71572	0.535 0.379 1.22 2.61 3.31 78.9 3 60	0.535 0.915 2.14 4.75 8.06 87 90 150	5th Layer	3.31m	4.75Ωm	5872Ωm	$5^0$82359' N	7.09363'N	151m
	8	GS Building KOMU	5116 28241 499	0.421 1.12 3.12	0.421 1.54 4.66							

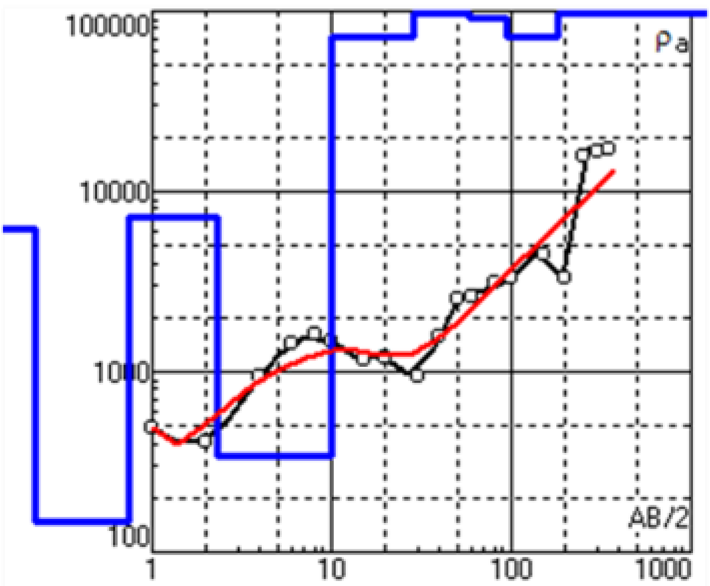
			3.1E+5 2917 19421 63294 3.2E+5	5.15 49.8 29.7 75.1	9.82 59.6 89.4 164	5th Layer	49.8m	9.82Ω m	2917Ωm	5.82772^{0}N	7.08628^{0}E	186m
	9	Love Garden KOMU	338 2405 846 2192 24144 497 2242 1.4E+5 1.5E+5	0.789 1.82 4.72 1.83 10.9 29.1 13.8 117	0.789 2.61 7.33 9.15 20 49.2 63 180	6th 7th Layer	29.1m 13.8m	20Ωm	497Ωm 2242Ωm	5.82905^{0}N	7.08186^{0}E	164m
	8	JUPEB Centre KOMU	490 11215 177 1079 66109 5.0E+6 1.8E+5 3824	0.717 1.97 1.98 9.21 38.7 56.4 53	0.717 2.69 4.68 13.9 52.6 109 162	4th Layer	9.21m	4.68Ω m	1079Ωm	5.82962^{o}N	7.08033^{o}E	163m
	9	Medical Centre KOMU	232 18435 481 3606 83057 2.3E+5 6.1E+5 7.4E+5	0.476 0.958 7.39 5.14 11.2 22.4 60.4 56	0.476 1.43 8.82 14 25.2 47.6 108 164	3rd 4th Layers	7.39m 5.14m	1.43Ω m	481Ωm 3606Ωm	5.82608^{o}N	7.08334^{0}E	167m

	8	Benahillis Hotel KOMU	1082 54.3 2022 572 39115 2.3E+5 2201 2017	0.448 0.649 1.46 5.15 10 6.19 126	0.448 1.1 2.56 7.71 17.7 23.9 150	7th Layer	126m	23.9Ω m	2201Ωm	5.82615^{0}N	7.08852^{0}E	195m
	8	Umuduru-Anyanwu Obioha KOMU	694 208 3883 280 4963 29.4 6581 24947	0.268 0.797 4.42 3.41 30.4 42.2 117	0.268 1.07 5.48 8.9 39.3 81.6 199	5th Layer	30.4m	8.9Ωm	4963Ωm	5^{0}50338' N	7^{0}04.617' E	135m
	9	Rochas Foundation Colege Ogboko Near KOMU	998 6193 555 46933 1909 27155 5.4E+5 18620 6.1E+5	0.83 0.796 2.97 1.78 20.1 14.9 117 21.7	0.83 1.63 4.6 6.37 26.4 41.4 158 180	5th Layer	20.1m	6.37Ω m	1909Ωm	5.82771^{0}N	7.0829^{0}E	193m
	9	Ikpanta Ozuakoli Urualla, Ideato	122 82745 15573 17747 2321 5306	1.66 5.89 4.66 40.1 59 91	1.66 5.89 4.66 27.9 18.9 32	5th 6th Layer	18.9m 32m	40.1Ω m	2321Ωm 5306Ωm	5^{0}50.949' N	7^{0}05.055' E	40ft

			12493 14159 3209	138 172	47 34							
	9	Umuokwaraonure Ogboko Ideato	132 2113 209 65544 4144 599 91.6 818 141	0.94 1.53 4.6 14.5 11.8 37.8 78.9 30	0.94 2.47 7.06 21.5 33.4 71.1 150 180	6th Layer	37.8m	33.4Ωm	599Ωm	5^{0}48.956' N	$7^{005.220'E}$	179m
	9	Obingwu Ogboko Ideato	3908 85.1 494 80.2 4.47 31.2 0.584 67.2	0.431 1.09 1.79 3.21 4.65 17.2 28.3 88.8	0.431 1.52 3.31 6.52 11.2 28.4 36.7 146	NILL	-	-	-	5^{0}48.479' N	7^{0}04.093' E	221ft
	9	Ukabi Ogboko Ideato	71873 43.1 10806 2.3E+6 21312 508 2375 2028 618	0.149 0.559 0.427 1.54 15.3 58.6 73.4 30	0.149 0.708 1.14 2.67 18 76.6 150 180	6th 7th 8th Layer	58.6m 73.4m 30m	18Ωm	508Ωm 237Ωm 2028Ωm	5.82359^{0}N	7.09363^{0}E	193m
	9	Behind Jopeb KOMU	27420 87.9	0.17 1.66	0.17 1.83							

			12394 358 35392 4109 56.8 667 69.8	2.99 6.25 30.8 8.25 99.8 30	4.83 11.1 50.2 150 180	4th 6th Layers	6.25m 8.25m	4.83Ω m	358Ωm 4109Ωm	5.83048^{0}N	7.07902^{0}E `	160m
	9	Staff Quarters KOMU	710 56.2 611 30245 383 5268 67042 5.9E+5 11063	0.341 0.353 0.346 7.05 30.2 19.5 60 75	0.341 0.694 4.16 11.2 41.4 60.9 121 196	5th 6th Layer	30.2m 19.5m	11.2Ω m	383 Ωm 5268 Ωm	5.84117^{0}N	7.07723^{0}E	152m
	9	Staff Quarters 2 KOMU	21648 120 31588 3611 430 6125 43646 11742 53950	0.319 0.919 2.56 1.38 30 55.8 57 33	0.319 1.24 3.8 5.17 35.2 91 148 181	5th Layer	30m	5.17Ω m	430Ωm	5.84012^{0}N	7.07859^{0E}	157m
	8	5 Star hotel Obiohia KOMU	219 444 90 868 13751 1.2E+6	0.891 0.811 2.18 11.1 4.67 112	0.891 1.7 3.88 15 19.7 132	3rd Layer	2.18m	1.7Ωm	90Ωm	5.83525^{0}N	7.07850^{0}E	165m

			11814 2155	68.8	201							
	9	Umuokwaraocha Umuchima KOMU	27420 87.9 12394 358 25392 4109 56.8 667 69.8	0.17 1.66 2.99 6.25 30.8 8.25 99.8 30	0.17 1.83 4.83 11.1 41.9 50.2 150 180	4^{th} 6^{th} Layer	6.25m 8.25m	4.83Ω m	358Ωm	5.82892^0E	7.07307^0E	126m



Location: **SENATE BUILDING K.O.M. UNIVERSITY OGBOKO, IDEATO SOUTH L.G.A. IMO STATE**
Direction Layout: **NW-SE (330°- 150°)** *Coordinates*: **5°49.632' N, 7°04.937E.** *Height*: **538ft (164m)**
Code Name: **VES 1**

AB/2 (m)	Resistivity (Ωm)	AB/2 (m)	Resistivity (Ωm)	AB/2 (m)	Resistivity (Ωm)
1	486.2	20	1558.1	100	2412.8
2	390.1	20	924.4	150	4512.8
2	427.6	30	951.1	200	4976.2
4	943.5	40	1318.6	200	2251.9
6	1717.0	40	1869.9	250	15513.7
6	1177.0	50	2558.9	300	15831.0
8	1626.6	60	3089.6	300	17567.2
10	3021.7	60	2194.1	350	17369.0
10	741.3	80	3070.9		
15	1157.1	100	4450.8		

N	ρ	h	d	Alt
1	6214	0.227	0.227	-0.227
2	148	0.508	0.735	-0.735
3	7274	1.58	2.31	-2.315
4	338	7.67	9.98	-9.983
5	72236	18.3	28.3	-28.26
6	2.6E+5	30.8	59	-59.01
7	90646	35.5	94.5	-94.5
8	72920	85.5	180	-180
9	3.5E+5			

Figure 4 Computer modeled curve at Senate Building KOMU

3.2. Aquifer Resistivity of the study area

The aquifer resistivity across the study area varies from 90 Ωm at 5 Star Hotel Obiohia, KOMU (VES 24) to 5872 Ωm beside the Stadium KOMU (VES 9). The aquifer resistivity values across the study area thus indicate that the aquifer geo-materials are more resistive in areas underlain by the Benin Formation than the areas underlain by the Ameki Formation indicating that the aquifer materials within the Benin Formation are sandier.

3.3. Aquifer depth and thickness of the study area

The depth to the water table across the study area varies from 1.43 m at Medical Centre KOMU (VES 13) to as high as 82.7m at Faculty of Sciences KOMU (VES 2). Shallower depths to the water table were recorded within the northeastern and southeastern parts of the study area. The aquifer thickness across the study area varies from 2.18m at 5 Star Hotel Obiohia, KOMU Environs (VES 24) to 126m at Benahllis Hotel, KOMU Environs (VES 14).

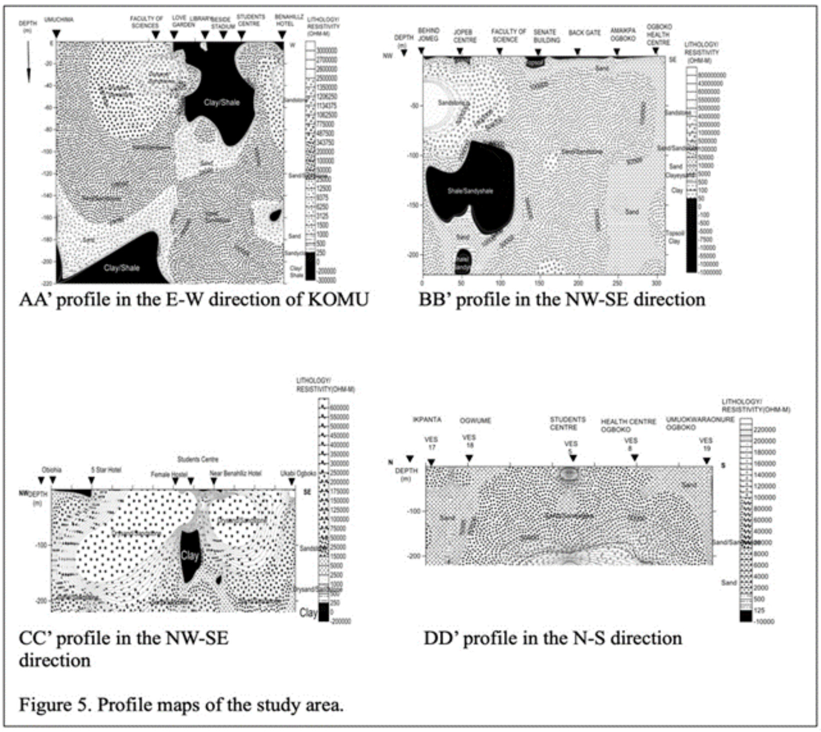


Figure 5 Profile Map of study area

4. Conclusion

The research work has provided information on the depth and the thickness of the aquifer units in the study area. This information will greatly assist in the development of an effective water scheme for the area. The findings of the present study revealed spatial variation of aquifer depth and thickness values across the study area. Partial curve matching was used to statistically evaluate the VES data. The aquifers are much thicker in the areas around Benahllis hotel, Female hostel, Ukabi Ogboko and Faculty of sciences and very thin around 5 Star hotel Obiohia, beside stadium and Senate building areas. Generally, the aquifers are thicker within the areas underlain by the Benin Formation. Estimates of the aquifer geo-hydraulic parameters across the study area also revealed that the aquifer hydraulic parameters are higher in the areas underlain by the Benin Formation than the other areas. The areas with low aquifer transmissivity values are mainly underlain by the Ameki Formation. These findings therefore indicate that the areas underlain by the Benin Formation hold more potential for groundwater than the other areas. Finally, the findings of this study have shown that geologically calibrated Dar-Zarrouk parameters are effective for estimating aquifer hydraulic parameters from surficial resistivity data. It is therefore recommended that any regional water scheme within the area should be sited within the area underlain by the Benin Formation, since their geo-hydraulic attributes can support huge groundwater abstraction usually required in regional water schemes.

4.1. Recommendations

Following careful research, the following recommendations are possible:

- The public should be educated about the negative health effects of poor groundwater management and the necessary laws should be enforced to manage the quality of the groundwater.
- Engineers should investigate the theory and application of the resistivity method in depth to obtain more trustworthy data.

Compliance with ethical standards

Disclosure of conflict of interest

The authors have declared that no conflicting interest exists.

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