

**AQUIFER HYDRAULIC CHARACTERISTICS AND VULNERABILITY
ESTIMATION FROM VERTICAL ELECTRICAL SOUNDING: CASE
STUDY OF ORU AND ENVIRONS, SOUTH-EASTERN, NIGERIA**

BY

IBEH-AMAJUOYI, LEONARD NWABUNWANNEM

(B.SC. GEOLOGY, UNN)

20124764148

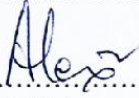
**A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL,
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CERTIFICATION

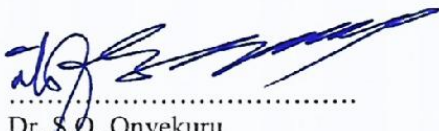
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.....
Prof. A.I. Selemo
Principal Supervisor

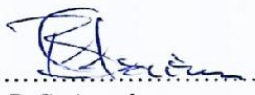
20-08-2018
.....
Date


.....
Dr. C.N. Okereke
Co-Supervisor

20-08-2018
.....
Date


.....
Dr. S.O. Onyekuru
Head of Dept., Geology

12/09/2018
.....
Date


.....
Prof. B.C. Anusionwu
Dean, School of Physical Science

13/09/2018
.....
Date

.....
Prof. N.N. Oti
Dean, Post-Graduate School

.....
Date


.....
Prof. C.S. Okereke
(External Supervisor)

11/8/18
.....
Date

DEDICATION

I am dedicating this piece of writing firstly to God Almighty because of His benevolence towards me; and to all my family members especially my beloved late mum: Late (Mrs.) Margaret Okwudima Ibeh-Amajuoyi; mama, you left positive imprints on sands of time.

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ABSTRACT

Aquifer Hydraulic Characteristics and Vulnerability Estimation from Vertical Electrical Sounding: A Case Study of Oru and its Environs, South-Eastern, Nigeria was carried out to delineate the different aquifer units with a view to determine the vulnerability of groundwater in the area. The study area is underlain by the Benin Formation which is within the Niger Delta Basin. Twenty-Seven (27) VES data were acquired using a Schlumberger array with a maximum electrode separation of $AB/2=500$ metres and interpreted using 2D-inverse interpretation resistivity software. The resistivities of the geoelectric layers vary between $1100\Omega\text{m}$ to $28200\Omega\text{m}$ which revealed that the lithology of the area is mainly composed of sands and alternating sequence of clays and silts. The thickness of sands increases from 22.2m to 42.7m at Awo-Omamma and from 32.1m to 258m at Ohakpu while it decreases towards Ura-Akatta community from 32m to greater than 60.3m and at Amagu community from 18m to greater than 50m. The aquifer hydraulic characteristics were estimated using the concept of Dar-Zarrock parameters while the aquifer vulnerability index assessment was determined using the DRASTIC model. Results show that the value of the apparent resistivity ranges from $2000\Omega\text{m}$ to $22,000\Omega\text{m}$. The aquifer conductivity ranges from 0.00020 Siemens per metre to 0.00052 Siemens per metre. For transverse resistance, it ranges from a low value of about $89175 \Omega/\text{m}^2$ to $3,000,000 \Omega/\text{m}^2$ as it occurs at Ibiasoegbe/Ofeahia, Otulu, Awo-Omamma to a much higher value of about $1,000,000 \Omega/\text{m}^2$ to $3,200,000 \Omega/\text{m}^2$ and it occurs as such at Umuokwe Awo-Omamma, Ubachima, Amaji, Akuma etc. The storativity of the area ranges from a moderate high value of about 0.0001 (1.0×10^{-4}) to 0.00025 (2.5×10^{-4}) at Akuma, Umuabiahu, Amadehi-Ubulu to a high value that ranges from 0.00025 (2.5×10^{-4}) to 0.0006 (6.0×10^{-4}) as it occurs at Awo-Omamma, Ibiasoegbe/Ofeahia. The aquifer thickness in the study area varies from one location to another. In terms of depth of occurrence of the aquiferous layer/medium, there are shallow aquifers at Amagu and Amiri at 16m and 15m respectively; while at Ura-Akatta, Akwada-Aji, Ubachima etc the aquifers occur at 32m, 39.9m and 38m respectively; but, at Umuokwe Awo-Omamma, Eziani-Mgbidi, Eziam-Ubulu, Umuezike Amadehi Oburu etc. the aquifers occur at 50.3m, 54m, 56.5m, and 63.5m respectively. Based on the information obtained from the iso-resistivity models, it showed that the groundwater potential in the study area is very promising and this was based on the fact that the study area has a lot of reservoir sands and sandy aquiferous units and that the depth to aquifer in both its thickness and lateral extent i.e. the volume is large. In terms of the aquifer vulnerability assessment, it was revealed that the study area is moderately high to high in vulnerability to groundwater contamination and pollution and based on this fact, it is very susceptible to contamination and pollution from the ground surface where infiltration and percolation often take place each time rain falls in the study area.

Keywords: Aquifer, Depth of Aquifer (Water Table), Aquifer Resistivity, Aquifer Conductivity, Aquifer Thickness, Transverse Resistance, Longitudinal Conductance, Transmissivity, Storativity.

CHAPTER ONE

INTRODUCTION

1.1 Introduction to Background

In the olden days, the only means through which people have access to water both the one they use as drinking water and the ones they use for their agricultural, domestic and other purposes was either through rainfall or surface waters such as rivers, streams, lakes, ponds etc. which they trek for a long distance to fetch; and this exercise was very difficult for them; for instance in my study area: Oru East and Oru West and environs, they trek as far as Njaba River and Ubana River, a very long distance that is more than one kilometer just to fetch water and that was against the World Health Organisation (W.H.O.) standard which states that no person should trek a distance up to one kilometer just to fetch water (W.H.O., 1982).

Between early 40's and 70's, to an extent till date, different arms of governments in the federation started helping the inhabitants of Oru East and West and its environs out in that direction when they started embarking on some regional and community water schemes. At this period, individuals couldn't provide water for themselves, they only depended on those different arms of government to do that for them; and still at that, getting access to water for the purposes mentioned above was still a herculean task for them.

But nowadays the trend has changed; individuals now drill boreholes indiscriminately without much monitoring to the extent that almost every household now has a borehole. But because of the indiscriminate drilling people now do without much monitoring or

supervision and because of the lack of expertise, those drilled boreholes might have the tendency to be contaminated and polluted.

The problem of potable water supply to the inhabitants of rural areas of Nigeria has persisted for quite a long time. Efforts made by previous governments (states and federal) did not yield much of the desired results. With the non-availability of potable water in these areas, environmental sanitation has degenerated to a level where water borne diseases are very rampant in many communities.

In determined efforts to alleviate the rural water supply problems, various regimes of governments and non governmental agencies have carried out baseline survey and geophysical investigations for ground water supply in some selected communities throughout South-Eastern Nigeria of which some of the communities including Oru East and Oru West of Imo State, South-Eastern, Nigeria are not exceptions.

1.2 Background of the Study

Although there are various methods in carrying out groundwater exploration and exploitation, Vertical Electrical Sounding (VES) is more convenient and reliable for such investigations. The most probable use of the electrical resistivity survey is in the hydro-geological investigation in relation to the aquifer delineations, lithologic boundaries and geological structures to provide subsurface information. This very method has been in use so extensively in the groundwater investigation in the basement complex terrains and also in the sedimentary basins. Hence, drilling programmes for groundwater development in areas of sedimentary terrain are generally preceded by detailed geophysical investigations.

Oru East and West are underlain by Benin Formation. These rocks are inherently characterized by high porosity and high permeability. The highest groundwater yield in sedimentary terrains is found in areas where thick sand/sandstone underlies the subsurface.

An important aquifer characteristic, transmissivity, significantly contributes to the development of local and regional groundwater resources and solute transport management. Estimation of this property allows quantitative prediction of the hydraulic response and solute transport of the aquifer to recharge and pumping.

Pre-drilling geophysical survey is a useful investigation, which must ordinarily be carried out at any borehole site before drilling operation starts. Some of the vital information that was obtained from the survey carried out in this research work includes the following: Viability of the project at the chosen site, estimated drill depth, type of geological formations to be encountered and correct drilling equipment to be employed

The problem of water supply to the inhabitants of both rural and urban centres in Nigeria has continued to be a source of concern to the governments and well meaning individuals which have tried to ameliorate this suffering by the poor rural Nigerian masses.

1.3 Statement of Problem

The importance of water resource cannot be over-emphasized, this is because from generation to generation, mankind has continued to bequeath to the upcoming generations with this very resource and has continued to make use of the resource that may be referred to as a scarce resource, due to the fact that most times, it is difficult to get water that may be completely free from impurities.

But harnessing this very important resource can sometimes be difficult and tasking and it requires an adequate knowledge, finance and manpower to get this our natural endowment for our very utilization. This process and even the product (water) are most times marred by pollution and contamination. This polluted when consumed by people most times result into sickness. The common diseases/pathogens associated with it include Escherichia coli, Salmonella typhi etc. therefore there is need to use geophysical method to investigate groundwater resource.

1.4 The Main Objective of the Study

The aim of this work is to determine how vulnerable the soils in the study area are towards rainwater, which will eventually turn out to become groundwater in the area of my research i.e. the vulnerability of groundwater in the study area; and hitherto make an attempt to delineate between the shallow aquifers and the deep aquifers (deep zones) in the study area.

1.5 The Specific Objectives of the Study

The Specific Objectives of the study include:

- (i) To obtain vertical electric soundings of the area and interpret them.
- (ii) To draw the geo-electric sections using the vertical electric soundings.
- (iii) To determine the depth to water table of the area.
- (iv) To compute the hydraulic characteristics of the study area.
- (v) To draw the vulnerability map of the area.

1.6 Research Work Justification

The inhabitants of Oru East and West and environs actually have ground water supply but they have health related challenges and complaints which hinge on the source of water. Some people attribute it to pollution of the source of water within the environment. This necessitated the need to investigate the ground water resource of this locality using the vertical electrical soundings to assess the aquifer parameters of the various locations to ascertain if actually the source of water is polluted.

1.7 The Geography of the Study Area

The Regional Geographic Setting gives us the insight of what the geography of the study area looks like and that of the geologic setting gives us the analysis of all the different series of successions and events that took place before and during the deposition of the layers.

1.7.1 The Physiography of the Study Area

By physiography of the study area, it means the nature or the physical structure of a particular region. Equally it has to do with the terrain or the natural appearance of the ground (land) surface. So, in this case, it has to do with the location, accessibility, climate, vegetation, drainage etc.

1.7.1.1 The Temperature, the Relative Humidity and the Visibility/Hazy Condition of the Study Area

Oru East and West and environs fall within the Tropical Rain Forest, the climate is hot and humid, with mean annual rainfall of 152.4mm to 203.2mm. The dry season is relatively short from November to March; while rainfall usually lasts in the study area from April to October with a break usually referred to as “August break”. Maximum

temperature is 34⁰C, while towards the end of the rains it is 18⁰C - 21⁰C. The vegetation is tropical rain forest with shrubs and elephant grasses, stunted trees.

1.7.1.1.1 The Temperature of the Study Area

The

study area has a temperature that ranges from 27⁰C to 34⁰C.

1.7.1.1.2 The Relative Humidity of the Study Area

Relative humidity is the amount of water in the atmosphere at any given time; moreover, it is a term that refers to dampness, especially that of the air. Relative humidity is a function of rainfall and temperature. The study area normally experiences a high amount of relative humidity which ranges from 35% to 60% during rainy season which is around April to October and harmattan season which starts from November through January; while it experiences a low relative humidity ranging from 0% to 35% during the hot (dry) season which occurs from January to April.

1.7.1.1.3 The Visibility/Hazy Condition of the Study Area

This on its own means the condition of the atmosphere where by the atmosphere is thick or clouded with haze. It can also be referred to as the condition in which the atmosphere is not clear or transparent, that is, being obscured. At this atmospheric condition, the visibility is somewhat reduced due to the presence of dust, mist, fog or smog in the atmosphere.

In the study area, during harmattan season, the condition of the atmosphere is hazy and visibility is reduced.

1.7.1.2 The Climate of the Study Area

The climatic conditions of Oru East and Oru West of Imo State and their environs fall within the warm-horrid tropical climate region where the wet and dry seasons are noticed prominently in the area.

The dry season is between November and April while the rainy seasons are mostly between May and October. Average rainfall is between 1000 mm and 1500 mm with temperature as high as 36.7°C (Udo, 1970).

The study area falls within the tropical rain forests of Nigeria and since the tropical rain forests occur in regions that lie between the equator and latitudes 5⁰ to 10⁰N and since also my study area has a latitude that falls between N05 39.623" to N05 48.154"; a longitude between E06 55.467 " to E06 57.463"; as well as a height between 263ft to 554ft which means that the tropical rain forest covers my study area (Oru East and Oru West Local Government Areas) or that my study area falls within the tropical rain forest of South-Eastern Nigeria.

The climate there is hot and wet throughout the year. The mean annual temperature is 27⁰C while the mean total annual rainfall is 2000mm. There are basically two broad seasons in the area: the rainy season and the dry season. The rainy season covers periods from March to October and dry from November to February; although, at times a third season called harmattan also occur but in most cases, it is referred together with the dry season as dry season. Two major air masses that control the climate of my study area are south-west (Tropical Maritime) air mass and the north-east (Tropical Continental) air mass, hence, the relative humidity there is a function of the prevalence of the either two and it is between 35 and 60% at 10:00 hours.

1.7.1.3 The Vegetation of the Study Area

The study area is blessed with abundant plants and trees. This shows that the area falls within the tropical rainforest of the south-eastern Nigeria, where different abundant and different classes of plants such as grasses, shrubs, trees, exist. The area is dense and made up of many types of broad-leaved trees that are mostly evergreen i.e. the trees drop their leaves gradually throughout the year and new leaves grow continuously to replace them. The trees form three layers. The tree tops form a thick canopy that prevents sunlight from reaching the forest floor. As a result, the vegetation on the forest floor is sparse. Epiphytic plants and woody climbers known as lianas are common features of these forests.

As stated above that the vegetation in the study area is a tropical rainforest type, it will be pertinent to note here that the study area has been altered by the constant clearing and fallowing systems from time to time. But on over much of the area, the retention of useful trees and the clearance of other trees have transformed the rainforest into a “palm-bush” where oil-palm trees are the predominant trees as well as a predominant factor.

1.7.1.4 The Drainage System of the Study Area

Drainage is the nature of the water system in an area. That is to say that it involves both the natural and artificial bodies of water like rivers, dams, streams, lakes, rivulets etc. and the pattern of rainfall that is associated in an area; which entails both the precipitation (rainfall), its percolation and infiltration into the land which eventually form the ground water in the area.

The area is being drained especially during the rainy season by the following rivers: Njaba River and Ubona River etc. These rivers from time to time most especially during the rainy season collect all the rain water that fall in the area especially the flooded

water. The rivers will eventually empty themselves to the Atlantic Ocean by the time it gets there.

However, the soils are deep and well drained. In these sandy soils, springs occur only at rare occasions and place, at points where impermeable layers of clay occur near the surface. Also very few streams originate in the coastal plain itself. Then within my research study area, it is drained mainly by the Njaba River and Ubona River etc.

1.7.1.5 The Location of the Study Area

The study area (Oru East and Oru West of Imo State and environs) are located within the latitude of $5^{\circ}39'N$ through $5^{\circ}50'N$ and longitude of $6^{\circ}50'E$ through $6^{\circ}59'E$.

Based on the topographic/location map of the study area (fig.1.1), the area has some L.G.As neighboring it. In the east side of the study area, it shares boundary with Njaba and Orlu L.G.As of Imo State; in the north side, the study area is sharing boundary with Ihiala L.G.A. of Anambra State; in the west side, Oru East and Oru West (the study area) shares boundary with Oguta L.G.A. of Imo State while in the south side, it shares boundary with Mbaitoli L.G.A. of Imo State.

Important Towns and Villages: The communities in Oru East where I carried out the research work are: Akatta, Akuma, Amagu, Amefuo, Amiri, Awo-Omamma, Isieke, Omuma, Ubahazu, Ubaheze, Ubuki, Umubochi, Umuezike, Umuezukwa, Umuokwu; while in the Oru West, the communities where I worked are: Ali, Eziala, Ibiasoegbe, Ofeahia, Mgbidi, Nempi, Ohakpu, Ozara, Umuabiahu, Uzinumu.

N/B: Oru has two recognised local government areas which are **Oru East and Oru West**. The **Headquarters** of Oru East is “**Omuma**” while the **Headquarters of Oru West** is “**Mgbidi**”.

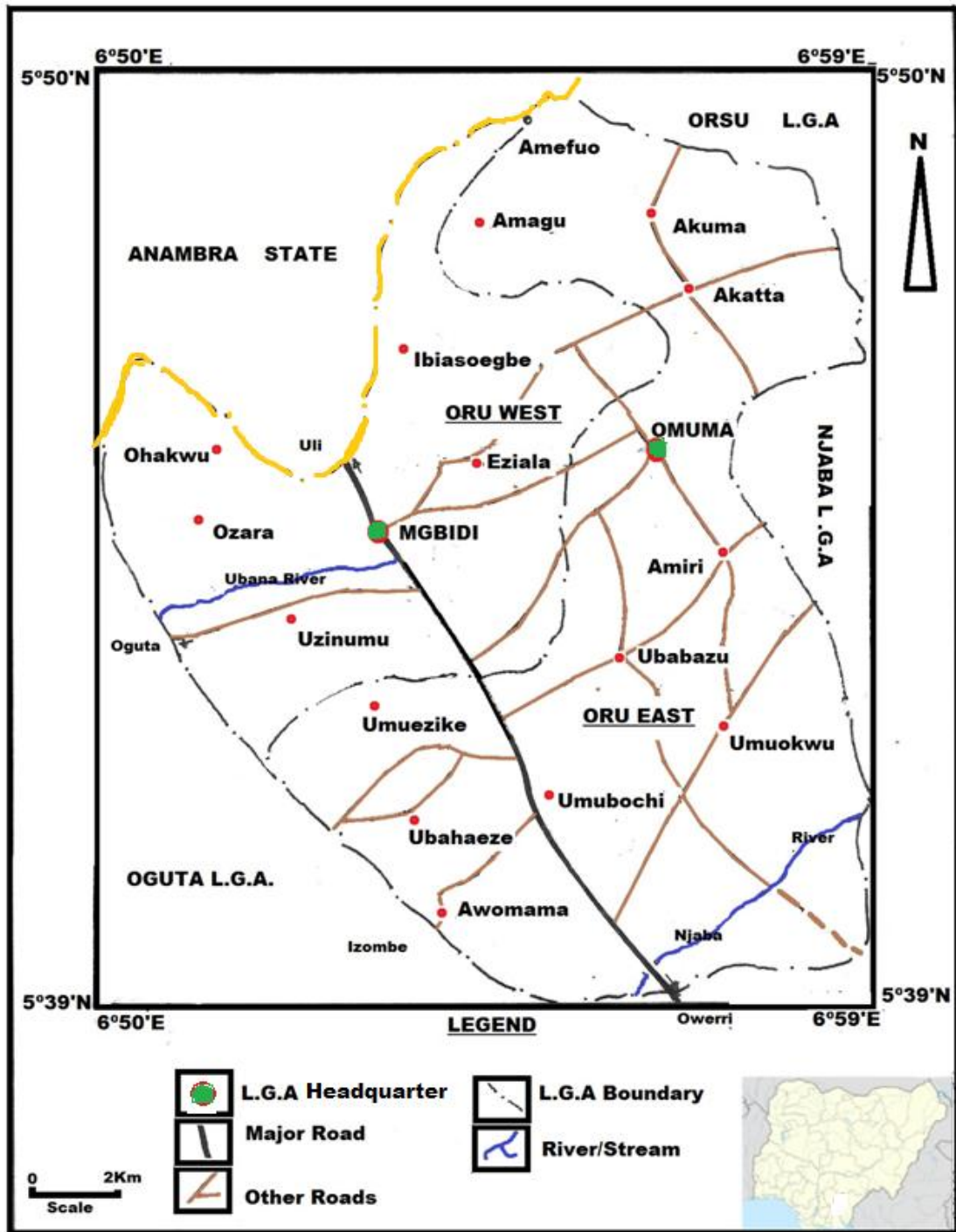


Figure 1.1: The Location Map of the Study Area (Edited from the Nigerian Geological Survey Agency Map of Old Imo State, 1991)

1.7.1.6 The Topography of the Study Area:

Topography is the nature of the land surface of an area i.e. the natural features of an area that make it appear unique or different from other ground surfaces. The topography of Oru East and Oru West is plain, though it has some other parts that have some kind of undulating features or appearance i.e. some areas are tilting while some others are laterally plain or level. The study area (**Oru East and Oru West**) has a very plain landform that is composed by basically sands; but in some places you see mud/clay. However, in some places, you might see undulating surfaces. These undulating land surfaces are valleys where some small water bodies like streams and rivulets exist or took their sources.

1.7.1.7 The Accessibility to the Study Area

The study area can be reached via a network of roads as there are some good and accessible roads that link to the area; as other means of transportation such as rail, air and water transportations are completely lacking in the study area.

Anybody trying to get to my study area (Oru East and Oru West), if he is coming from Owerri, can get through either Orlu road through Amaifeke Orlu-Mgbidi road or Onitsha-Owerri road.

Then if coming from Port-Harcourt, he follows through the Port-Harcourt-Owerri road, before getting to Owerri-Onitsha road and finally arrives at any part of Oru safely.

One can as well get to Oru East and West from Orlu by following the popular Amaifeke road and Mgbidi road that links to my study area.

Also coming from Onitsha to the study area, one can follow the express high way i.e. the popular Onitsha-Owerri express road before getting to the area (Oru East and Oru West and environs) safely.

N/B: The major means of transportation in the area is road transportation.

1.8 The Geology of the Study Area

The study area (Oru East and Oru West and their environs) is overlain by the Benin Formation which consists of lenticular, unconsolidated and sandy sediments. The Benin Formation has been described as “coastal plain sands”. The Benin Formation is continental in origin. The sediments of the Benin Formation were deposited during the Late Tertiary to Early Quaternary Period. The age of the Benin Formation is from Miocene to Recent and it consists of friable sands with intercalations of shale and clay lenses (Onyeagocha, 1980). It also contains some isolated units of gravels, conglomerates, very coarse-grained sands and sandstone in Owerri area in south-eastern Nigeria. The Formation has a thickness ranging from 0 – 2100 metres within Oru East and West and their environs close to Owerri. The sands and sandstones are commonly granular in texture and can be partly unconsolidated. The sediments represent upper deltaic plain deposits. The sands may represent braided bars and channel fills. The shales are few and thin and they may represent back swamp deposits. The shales are the locus of several river systems; these rivers are fed by small seasonal tributaries from the shales as well as by the perennial river fed by springs that issue from the margins of sand bodies.

The Benin Formation is underlain by the Ogwashi-Asaba Formation (Reyment, 1965). The Ogwashi-Asaba Formation (Oligocene-Miocene) is an extensive stratigraphic unit in the southern Nigeria sedimentary basins. The Formation starts with a thin edge at its

contact with the Benin Formation in the north of the Ogwashi-Asaba Formation and thickens seaward with lignite seams seen at various layers, mixed with unconsolidated sand. The Ogwashi-Asaba Formation was formally known as the “Lignite series” by Parkinson (1907) and Simpson (1948 and 1955).

Reyment, (1965) formalized it and described the lithology as consisting of alternation of seam and clays. The average thickness is 322ft, while Kogbe, (1976) suggested that part of the Formation may be of Oligocene age.

The Ogwashi-Asaba Formation is underlain by the Ameki Formation which is of Eocene-Oligocene age and consists of grey clayey sandstone and sandy claystone. The Formation also consists of bluish calcareous silt with mottled clay, thin limestone and abundant calcareous shale.

The litho-stratigraphy of the Oru East and Oru West and their environs is described as laterites-mudstone-lignite-clay-sand. The laterites overlie the mudstone which in turn overlies the lignite, which is the major reason for the name Ogwashi-Asaba Formation. The lignite overlies the clay which is an impermeable Formation. The clay overlies the sandstone. The mudstone is brownish in colour and is about 0.54m thick. The lignite is also brownish in colour and is about 1.2m thick. The clay is about 0.5m thick and is reddish-brown in colour. The sand is moderately indurated and is the source of some of the springs in the study area.

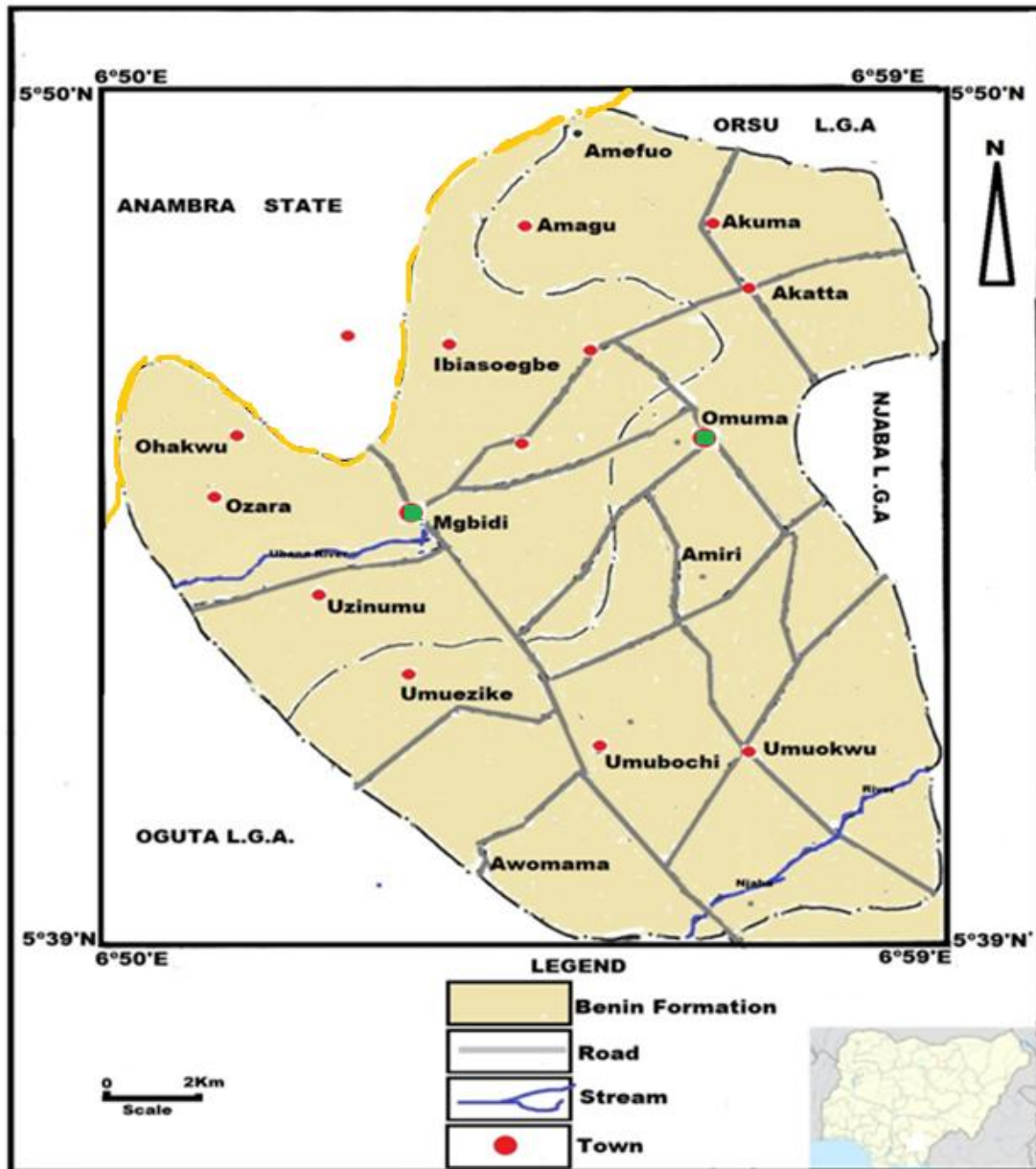


Figure 1.2: The Geologic Map of the Study Area (Edited from the Nigerian Geological Survey Agency Map of Old Imo State, 1991)

1.8.1 The Hydrogeology of the Study Area

The source of groundwater in the study area is from the underlying coastal plain sands. This Formation has good groundwater potentials being dominantly sandy with high permeability and porosity. A lot of boreholes have been drilled into the coastal plain sands. Data of an existing borehole drilled in the neighbouring villages and towns indicate that the depth to water table in the borehole is around 40.04m. The aquifer is quite prolific and groundwater exploitation in this community is very promising.

1.8.2 Regional Geologic Setting of Southern Nigeria

The oldest sedimentary rocks of southern Nigeria (the Asu River group) consist of non-fossiliferous, arkosic, gravelly, poorly sorted commonly cross bedded sandstones of probable Albian age, which is derived from the Basement Complex. These Albian deposits occur in the eastern and northern parts of the country, being exposed in Abakaliki and Calabar areas.

The Asu River Group is a major stratigraphic unit composed of dark micaceous sandy shale and fine grained sandstone with a rich ammonite fauna which indicate Albian age. Rocks of Cenomanian age occur only north of Calabar (Odukpani Formation) and consist of alternating sandstones, shale, sandy shale and fossiliferous limestone. It was deposited in a shallow water environment close to the Oban Massif.

The development of thick Eze-aku shale composed of grey flaggy calcareous shale with interbedded limestone lenses evidenced Turonian transgression. The formation grades laterally into the sandy and calcareous limestone (Amasiri Sandstone), and Awgu shale. The ammonite fauna indicate Coniacian age for the Eze-aku Shale.

Folding, Faulting and Uplifting in the earlier Santonian time signify the end of Aptian Santonian sedimentary phase. Erosion of the Coniacian, Turonian and in some places of the Albian deposits occurred with Uplifting of the Abakaliki Anticlinorium. Subsidence occurred after the folding initiated renewed marine transgression and hence the deposition of the Nkporo Shale of Campanian Maastrichtian age as well as their lateral equivalents, Owelli Sandstone and Enugu Shale.

East of the Niger, the Maastrichtian is represented by the deltaic Mamu Formation, Ajali Sandstone and Nsukka Formation containing Coal Seams at several levels. The marine influence becomes less positively identifiable from Mamu Formation upward giving way to regression in later Cretaceous time when the prodelta became initiated.

Marine transgression was wide spread in Southern Nigeria through-out the tertiary (Short & Stauble, 1967). The main stratigraphic unit of the Paleocene Imo Shale, outcrops as an arcuate belt from western Nigeria to the east. It is typically bluish grey, commonly fossiliferous, locally sandy and ranges into early Eocene. The onset of the regressive phase and the formation of the modern Niger Delta occurred with the deposition of Ameki Formation. It is predominantly shally, west of the Niger except north of Lagos where it grades into the sandy Ilaro Formation and the lagoonal clay Oshoshun Formation. East of the Niger it is heterogeneous, being composed of sandstone, shales, calcareous shale, marl and fossiliferous limestone. This heterogeneity is a positive proof of shallow water sedimentation.

Surface evidence of the Oligocene and Miocene units is limited and often questionable. The main units representing these ages are probably the Ogwashi-Asaba and Ijebu Formations, both of which are sandy with lignite seams (Reyment, 1965). The Benin Formation of Miocene-Recent age is the youngest stratigraphic unit and consists of

yellowish white continental sands with pebbly sands. Table 1.1: Shows the successions deposits in Southern Nigeria, the basins, stratigraphic units and their respective ages.

Table 1.1: The Stratigraphy of Southern Nigeria (After Uma, 1989)

Age	Basin	Stratigraphic Units						
Thanetian	Niger Delta	Imo Formation						
Danian								
Maastrichtian	Anambra Basin	Coal	Nsukka Fm					
			Ajelli Fm					
Measures		Mamu Fm						
		Nkporo Fm	Nkporo Shale	Enugu Fm	Owelli Ss	Afikpo Ss	Otobi Ss	Lafia Ss
Campanian								
Santonian	Southern Benue Trough	Awgu Fm						

1.9 The Scope of the Research Work

The research work centres on the Aquifer Hydraulic Characteristics and Vulnerability Estimation from Vertical Electrical Sounding: Case Study of Oru and Environs, South-Eastern, Nigeria. This is within the geographical locations of the communities in Oru East and Oru West L.G.A. of Imo State.

Geologically, the study area (Oru East and Oru West of Imo State and environs) is overlain by the Benin Formation of the Niger Delta Basin; the youngest sedimentary basin in Nigeria.

Geophysically, this research work is meant to estimate the aquifer and hydraulic parameters such as: Aquifer thickness, aquifer resistivity, aquifer conductivity, transverse resistance, longitudinal conductance, transmissivity, hydraulic conductivity and storativity of my study i.e. Oru East and Oru West of Imo State and environs as well as to ascertain the level of vulnerability the soils within Oru East and Oru West is towards pollution and contamination. Such can be done by employing several geophysical methods but the one so commonly use is the Vertical Electrical Sounding (VES) because of its simplicity, portability and reliability towards other geophysical methods and configurations. The estimation of aquifer vulnerability and hydraulic characteristics from Vertical Electrical Sounding as the topic suggests requires a sound knowledge of the subsurface environment which we cannot see from the surface where we reside, but such knowledge is what can be acquired by simply employing the various methods/tools of the following disciplines and sub-disciplines in the field of earth science (geosciences): Geology, Hydrogeology, Geochemistry, Geophysics.

Moreover, Geophysical investigation is very necessary in the acquisition of geophysical data on aquifer characteristics. This very geophysical approach will therefore be complemented with geochemistry as well as hydrogeology in order to obtain a sufficient knowledge of the subsurface in the study area. The reason is to be

able to assess the pollution status and vulnerability of water supply aquifers in parts of the Imo River Basin more especially in Oru East and Oru West, of Imo State (my study area).

CHAPTER TWO

LITERATURE REVIEW AND THE THEORETICAL FRAMEWORK

2.1 Review of Related Literature

Groundwater vulnerability estimation was conceptualized in France as far back as the 1960s, according to Margat (1968); and based on this some Mathematical models were developed in order to evaluate the vulnerability of groundwater resources. The Mathematical models help to describe the differences for the natural potential that exist in the geological formations, which overly the groundwater system in order to protect it from contamination. Geological formations have a property that is heterogeneous and this, as a result, shows that they are not equally sensitive to pollution related to the activities of man in his environment, thereby determining the different level/amount of vulnerability as a function of hydro-geological conditions and to determine the extent of protection that is needed by each area (Margat & Suais-Parascandola, 1987).

Albinet and Margat (1970) defined aquifer vulnerability, and they opined that it is the possibility of contaminants to percolate and diffuse from the ground surface into the natural water table reservoirs, under some natural conditions. Vulnerability as regards to groundwater has to do with the extent of endangering or polluting the groundwater which is determined by the natural conditions and independent of the source of pollution, this is according to Olmer and Rezac (1974). They are of the view and opinion that vulnerability is a function of vertical permeability in the unsaturated zone, and also on the hydraulic gradient and flow velocity in the aquifer.

According to Villumsen and Sonderskov (1982), they said that groundwater vulnerability is “the risk of chemical substances used or disposed on or near the ground-surface to influence the groundwater quality”. This they implied that groundwater vulnerability is dependent of series of parameters, which are grouped according to

experts into dynamic (land use, population density etc.) and of course the static intrinsic parameters of the soil-rock, groundwater system. Villumsen and Sonderskov (1982) also emphasized that the chemical composition of the groundwater system may be used as preliminary marker or indicator of vulnerability.

Aquifer vulnerability is divided into two: Firstly, by the degree of protection against contamination as a result of the overlying strata and secondly by the potential for the purification of contaminated water in the aquifer; Vierhuff *et al.* (1981). Vierhuff *et al.* (1981) assessed vulnerability on the basis of three (3) parameters: Type of aquifer, location of the aquifer in the hydrologic cycle, and the characteristics of the unsaturated zone or confining layers.

Bachmat and Collins (1987) on their own defined groundwater vulnerability as “the sensitivity of its quality to anthropogenic (human’s/man’s) activities, which may prove detrimental to the present and/or intended usage-value of the resource”. Bachmat and Collins (1987) expressed this vulnerability in terms of the change in concentration of a given substance per increment of a given human activity. Bachmat and Collins (1987) equally introduced the idea of using a vulnerability map to display results of vulnerability assessment or estimation in such a way that it will be useful and convenient for actual application in the decision-making process.

On his part, Forster (1987) defined this groundwater vulnerability being talked about as: “the intrinsic characteristics that will determine the sensitivity of various parts of an aquifer as it has been adversely affected by an imposed contaminant load”.

While Friesel in 1987 defined the groundwater vulnerability in his own terms as protectiveness or its associated openness to recharge, by this, he meant the permeability of the covering strata for water.

The U.S.A. National Research Council (1993) on their part has defined the groundwater vulnerability as “the tendency or likelihood for contaminants to reach a specified position in the groundwater system after the introduction at some locations above the very uppermost aquifer”.

All these different definitions by different authors target at assessing the natural protection capability of the geological formation to maintain the quality of any groundwater by a way of shielding it from the very adverse effects of human/anthropogenic activities. However, all these definitions are subjected to the basic principle that states that: “All groundwater is vulnerable” (Mato, 2002).

Then during the 1990s, groundwater vulnerability estimation had been conducted in many countries as part of comprehensive groundwater protection strategies (Breeuwsma & Duijvenbooden, 1987; Swanson, 1990; Richert *et al.*, 1992; Vrba & Zaporozec, 1994; Lindstrom and Scharp, 1995; Engel *et al.*, 1996; Navulur and Engel, 1997; Melloul & Azmon, 1997; Maxe & Johansson, 1998; Mato, 2002). Groundwater vulnerability estimation has been quite attractive to decision makers, physical planners, as well as land and groundwater managers (Maxe & Johansson, 1998).

So many approaches have been suggested as well implemented in the literature. In a general note, two types of vulnerability assessment and estimation can be defined. The first, specific vulnerability is used when vulnerability is referenced to a specific contaminant, contaminant class, or human activity (e.g. nutrient, pathogens, micro-organisms, heavy metals or poor sanitation, agricultural land-use practice, industrial effluent disposal, etc.); (Carter *et al.*, 1987). The second type, intrinsic vulnerability, refers to vulnerability that does not consider the attributes and behaviour of particular

contaminants. In practice, a clear difference between intrinsic and specific vulnerability cannot always be made (Mato, 2002).

There are some potential factors responsible for the contamination of groundwater by the following: Leach to groundwater depends mainly on unsaturated zone, the depth to the water table, the recharge rate, and environmental factors; all these influence the potential for biodegradation. The composition of the unsaturated zone can greatly influence transformation and reaction. For instance, a high organic matter or clay content increases sorption and thus lessens the potential for contamination. The depth to the water table can be an important factor because short flow paths decrease the opportunity for sorption and biodegradation, thus increasing the potential for many contaminants to reach the groundwater. Conversely, longer flow paths from land surface to the water table can reduce the potential for contamination by chemicals that sorbs or degrade along the flow path. Recharge rates affect the extent and rate of transport of contaminants through the saturated zone. Finally, environmental factors such as temperature as well as water content can significantly influence the degradation of contaminants by microbial transformation (Mato, 2002).

Based on these factual factors, a configuration of methods for predicting groundwater vulnerability has been developed (Mato, 2002). These methods fall into three major classes, which include:

- (i) Overlay and index methods
- (ii) Process based methods
- (iii) Statistical methods

Overlay and index methods are based on combining maps of various physiographic attributes (e.g. geology, soils, depth to water table, etc.) of an area by assigning a numerical index or score to each attributes. In simplest form of this very method, all attributes are given equal weights, with no much effort being made on their relative importance. Thus, the areas where simple convergence of the specified attributes occur (e.g. sandy soil and less depth to groundwater-shallow aquifer) are deemed vulnerable. To be more quantitative, different range of scores and weights are assigned to the attributes in developing vulnerability classes. The vulnerability classes are displayed in a map as surface profiles.

Process-based methods employ process based simulation models and require analytical or numerical solutions to mathematical equations that represent coupled process controlling the contaminant transport. They range from indices that are based on simple transport models to analytical solutions for one dimensional transport of contaminants through unsaturated zone to coupled, unsaturated, multiple phase, 2D or 3D models.

Statistical methods incorporate data on known aerial contaminant distributions and provide characterization of contamination potential for the specific geographical area from which the data were drawn. Examples of the various methods developed to evaluate groundwater are shown in Table 2.1 (Mato, 2002).

Table 2.1: Selected Methods for Evaluating Groundwater Vulnerability (Mato, 2002)

Class	Method	Application Environment	Intrinsic/Specific	Reference
OVERLAY AND INDEX METHOD	DRASTIC	Groundwater	Intrinsic	Aller et al., 1985
	SEEPAGE	Groundwater	Intrinsic	Moore, 1988
	Groundwater Vulnerability	Groundwater	Intrinsic	Meinard et al. 1995
PROCESS BASED METHOD	BAM	Soil	Specific	Jury et al., 1983

	MOUSE	Groundwater	Specific	Steenhuis et al. 1987
	GLEAMS	Soil	Specific	Leonard et al., 1987
	CLASS	Soil	Specific	Kelly and Lunn 1999
STATISTICAL METHOD	Discriminant Analysis	Groundwater	Specific	Teso et al., 1988
	Regression Analysis	Groundwater	Specific	Chen and Druliner, 1988

Mato, 2002, classified the methods into five groups:

(i) Hydro-geological Complex and Setting (HCS) Methods;

(ii) Point Count System Models (PCSM);

(iii) Rating Systems (RS);

(iv) Analogical Relations (AR); and

(v) Matrix Systems (MS)

Such parameters as soil characteristics, hydrological features of the saturated and unsaturated zones, net recharge, depth to water table, and overburden/aquifer permeability are featured in table 2.1.

The workers outlined here used different parameters to explain groundwater vulnerability: Johnston (1988) used three parameters which are: groundwater flow system, the hydro-geological framework and climate to assess aquifer vulnerability; Pinnerker (1974) took into consideration both aridity and low temperature in assessing the vulnerability of the groundwater of Siberia.

Pinnerker (1974) found out that the permafrost regions were not as effective in their “self-cleaning” ability as the unfrozen regions, Vrba and Zaporozec (1994) considered the effect of rainfall on aquifer recharge; LeGrand (1964) developed an empirical point-count system which was based on five parameters for an unconfined aquifer. These include:

- (i) Depth to water table
- (ii) Sorption capability above the water table
- (iii) Aquifer permeability
- (iv) Gradient to water table
- (v) Horizontal distance from the source of pollution to water well or stream.

Pavoni *et al.* in 1973 applied a numerical evaluation of landfill sites using parameters such as soil, groundwater and air in order to arrive at a number which is inversely related to the pollution potential which is the vulnerability in focus of the sites. These parameters are:

- (i) Infiltration potential
- (ii) Bottom leakage potential
- (iii) Filtering capacity
- (iv) Adsorptive capacity
- (v) Potential travel distance of leachates
- (vi) Groundwater velocity i.e. groundwater parameter
- (vii) Prevailing wind direction
- (viii) Population factor i.e. air parameter

Forster (1987) developed a rating system based on three (3) parameters which include:

- (i) Groundwater occurrence
- (ii) Overlying lithology
- (iii) Depth to groundwater table

He equally considered the interaction between the natural vulnerability of the aquifer and the loading of contaminants in delineating or marking out the boundaries of groundwater contamination risks. Marcolongo and Pretto (1987) had introduced a rating system that was used in the Po valley in Veneto plain, in Italy, and this was taken into account the sum of rating points due to variations of four main parameters which are:

- (i) Soil characteristics
- (ii) Unsaturated zone thickness

(iii) Net recharge

(iv) Aquifer connections to the surface water through river beds.

Aller *et al.* (1985), on his part had developed a standardized system for evaluating vulnerability of groundwater to contamination for the United State Environmental Protection Agency. The Point Count System Model (PCSM) which is known as DRASTIC, uses a different seven parameters for the evaluation of groundwater vulnerability; and these parameters are enumerated below as:

(i) Depth to water table

(ii) Net recharge

(iii) Aquifer media

(iv) Soil media

(v) Topography

(vi) Impact of the vadose zone, and

(vi) Hydraulic conductivity of the aquifer.

The model has two parts and they are:

(i) The designation of mappable units, or hydrogeological settings; and

(ii) The superimposition of relative numerical rating system.

The DRASTIC model has been adopted for this research work.

Isabel *et al.* (1992) introduced a simple method of groundwater vulnerability estimation and assessment which was designed to accommodate the power lines right of way that

is similar to DRASTIC model that had earlier been mentioned. This Isabel method of assessing and estimating groundwater vulnerability is based on four (4) different parameters and they are as follows:

- (i) Soil type
- (ii) Intermediate zone material
- (iii) Groundwater surface slope
- (iv) Aquifer material

On their part, Unlu *et al.* (1985) in their comparison of uncertainty analysis method to assess impacts on groundwater of the constituents of the leachate leached from land disposed wastes, contrived a model in order to help in evaluating the uncertainties based on the constituents concentration in groundwater in focus due to the very fact of realizing the uncertainties in waste composition and the hydro-geological properties. Howard *et al.* of 1996 assessed the impact of land filling practices on groundwater resources in and around the municipal urban city of Toronto, Canada; by using a chemical unit of the municipal landfills, he demonstrated that the level of leachate that was generated in the urban city represents a quite significant amount of potential threat to groundwater and surface-water quality. Egboka *et al.* (1989) on his part addressed the effects these pollutions occasioned by the leachate seepage into the geologic and hydro-geologic cycles from both the point and distributed sources.

Groundwater vulnerability estimation (assessment) cannot be achieved without an adequate knowledge of the subsurface environment; such a knowledge which can be acquired by simply employing the methods in the fields of geochemistry, geology,

geophysics and hydrology. Geophysical investigation is very necessary in the acquisition of data on the aquifer characteristics.

Since the mid-1980s, some researchers from the academia both in Nigeria and in the Diaspora have continued to carry out the geological/geochemical investigations of the Imo River basin in the likes of Uma, 1984 and 1986; Okagbue, 1988; Ezeigbo, 1989; and also in the area of geophysical investigations in the likes of the people like Mbonu, *et al.*, 1991; Achilike, of 1991 and Onwuegbuche of 1993 on groundwater resources in the Imo River Basin. Works have also been carried out on determining the groundwater vulnerability assessment or estimation of Owerri (Imo State) as a part of the Imo River Basin, by Onyekuru, 1998; while the contributions made by these workers in different parts of the Imo River Basin are remarkable, more work is still needed to be done especially in those areas or parts that have not been mapped out or studied especially in the area of geophysics or geophysical studies, which up till now has covered only a small part (portion/fraction) of the area in the Imo River Basin, Onwuegbuche, 1993.

This research work is focused on and intended to use the geophysical approach to determine or find out the rate of the overburden conductivity which is required in the application of the DRASTIC model used in the study.

Niswas and Singhal (1981) had successfully established analytical relationships that exist between aquifer parameters and Dar-zarrouk parameters that were derived from the surface electrical resistivity data. Hence, using this analytical relationship, the transmissivity and hydraulic conductivity can be deduced.

Onu (1995) on his part carried out a hydro-geophysical study of the Njaba River sub-basin, using electrical resistivity method. He estimated aquifer hydraulic parameters

such as aquifer storage, transmissivity and hydraulic conductivity from surface geo-electrical data.

Moreover, studies within Oru area and environs have led to the underlying geology and geologic materials within the study area to be identified and recognized; and to help to determine the age of the formations that are encountered there.

Apakama (2010) studied the subsurface deposit of the Oru area and its environs by using vertical electrical sounding. He found out that the major lithologic units underlying the area are sand, sandstone, clay and a mixture of sand, silt and clay which occurs at varying depths and thicknesses.

Also, several studies have been carried out in order to assess the groundwater potential of the study area and most of the areas in question have been proven to be prolific. Some of the groundwater studies in the area include that done by Ukeche (2010). The study showed that most parts of the study area have prolific aquifers based on the analysis and interpretation of VES data. However, the study did not incorporate pumping tests to ascertain the fluid transmissivity and hydraulic conductivity variations of the area.

Some studies by (Iduma & Abam, 2010; Ahirakwem & Ejimadu, 2002; Ezeigbo, 1989; Uma, 1984; Etu-Efeotor & Odigi, 1983) have been carried out on some aspects of the hydrogeology of south-eastern, Nigeria of which the study area is a part although the flow potential of the groundwater resources in the area is yet to be studied.

The resistivity method has been recently used to study the geotechnical properties of soils and rocks in the study area. The electrical sounding method has been found to be very useful in the study area.

Onwuemesi *et al.* (2006) established a formula for the computation of hydraulic gradient using 2-D polynomial curve fitting technique.

Ekwe *et al.* (2006) estimated the geometry, hydraulic conductivity and transmissivity of the aquifers within the middle portion of the Imo River Basin using the electrical resistivity method. The investigation shows that the sedimentary sequence of south-eastern Nigeria contains several aquiferous units.

A number of authors have attempted the estimation of aquifer hydraulic properties from surface electrical sounding (Kelly, 1977; Niwas & Singh, 1981).

2.2 Conceptual Frameworks

Groundwater is an important resource that mankind from time immemorial has taken serious. This is basically because it offers the need of man's quest for water at least to solve his domestic water problem as well as his agricultural and industrial water problem. However, in order to obtain this groundwater, it often requires a more sophisticated means to get; and this has been the problem both the geologist and geophysicist especially the hydro-geologists have been facing and have been trying to solve.

Groundwater exploration and its management has been surrounded by a lot of uncertainties that ranges from insufficiency or even a total absence of the detailed description of the groundwater resources in an area with respect to geology of the area before the actual commencement of drilling. Even though, the drilling process was successful, the extent of vulnerability of the area as regards to its contamination may not easily be ascertained and hence, this offers a very great challenge to the groundwater management of an area.

Based on this, the quantitative assessment of groundwater resources in an area is necessary in order to minimize those uncertainties that are associated with the groundwater exploration and management.

In carrying out those quantitative assessments of groundwater resources in an area, there are three basic measurements that are required to be taken' they are:

- (i) The elevation i.e. the depth of the groundwater table (piezometric surface)
- (ii) The speed of groundwater movement and
- (iii) The specific yield of an aquifer

In delineating and demarcating the presence of an aquiferous layer during a hydro-geologic survey, some important fundamental exploratory techniques are adopted and they include the following:

- (i) Surface geological methods
- (ii) Sub-surface geological methods
- (iii) Surface geophysical methods
- (iv) Sub-surface geophysical methods

The integration of these methods highlighted above, when properly analysed, often give reliable information of the sub-surface structure and its heterogeneity. The heterogeneous nature of the sub-surface makes it very easy to find out the variations in the levels of responses of sub-surface materials and to the introduction of certain physical parameters. Geophysical investigations are centred on detecting and analysing these variations.

Moreover, geophysicists are interested in locating water bearing formations (aquifer) during the groundwater exploration. Aquifers are usually located in sedimentary rocks such as sandstones because of their permeable and porous nature.

In the search for this groundwater resource, often there are two main methods that are employed by geophysicists and they include: Seismic refraction method and Electrical resistivity method.

Any of these approaches, is targeted at identifying the water bearing formations which will show different properties from other formations anytime when elastic waves (seismic refraction) or electric current (electrical resistivity) is passed through them. Once an aquiferous medium is located, the approximate depth from the surface, its thickness and its lateral i.e. areal extent is determined. Based on this, the very end result is the selection of a drilling target of the greatest possible success in striking water for any location under investigation. It is also advisable that the results of the drilling operations and geophysical investigation are compared; this is in order to establish the extent of correlation between the actual exploration and estimated investigation. Based on the fore goings, it will lead to the appropriate management of the groundwater resource, reduce the chances of abortive boreholes, save cost and boost the confidence of the driller in the application of the geophysical survey for any borehole in the region.

2.3 Aquifer Hydraulic Characteristics from Vertical Electrical Sounding

In order 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 traverse resistance R is always given as below:

$$R = \sum_{i=1}^n h_i \rho_i \quad (\text{eq. 1})$$

But for a horizontal, homogeneous and isotropic medium

$$\rho = (R_1 - R_2)/(h_1 - h_2) \quad (\text{eq. 2})$$

where h_i and ρ_i are thickness and resistivity respectively of the i th layer in the section. The total longitudinal conductance S is:

$$R = \sum_{i=1}^n h_i / \rho_i \quad (\text{eq. 3})$$

The longitudinal layer conductance S_i can also be expressed by

$$S_i = \sigma_i h_i \quad (\text{eq. 4})$$

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

$$T = K_i h_i \quad (\text{eq. 5})$$

K is the hydraulic conductivity of the i th layer of thickness h_i . R and S of equation above 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

$$Q = K I A \quad (\text{eq. 6})$$

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:

$$J = \sigma E \quad (\text{eq. 7})$$

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 Niswas & Singhal (1981):

$$T = K \sigma R = K S / \sigma = K h \quad (\text{eq. 8})$$

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 Niswas 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 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.

2.4 The Electrode Configurations

It will be necessary that before discussing all the various electrode arrays available, that a necessary consideration will be made on what is being measured by either the current electrode or the potential electrode. The quantity that is being measured is known as the apparent resistivity of a zone in the neighbourhood of electrode array. It is only in the case of homogeneous ground that the apparent resistivity value will be equivalent to the actual resistivity.

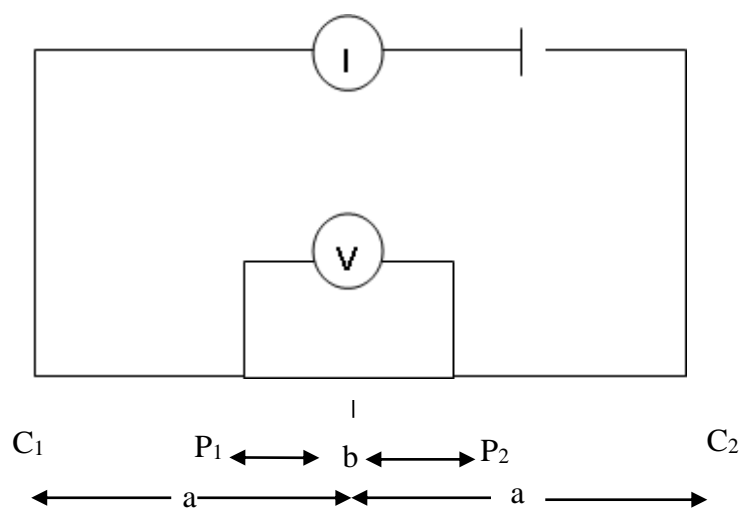


Figure 2.1: The General Electrode Configuration for Resistivity Measurement.

For quite some time, a good number of electrode spreads have been used in resistivity method. They are:

2.4.1 The Wenner Array

One of the electrode arrangements for measuring resistivity that are into existence is the Wenner array/arrangement. In the Wenner arrangement, the electrodes are spaced uniformly. The potential difference is measured normally from the separation between adjacent electrodes that are equally spaced.

From the normal equation for the apparent resistivity, the equation for Wenner configuration is obtained and is represented thus as:

$$\rho_a(w) = 2\pi aR. \quad (\text{eq. 9})$$

where $\rho_a(w)$ = The apparent resistivity of the Wenner array

a = Half current electrode spread ($AB/2$)

R = Resistivity

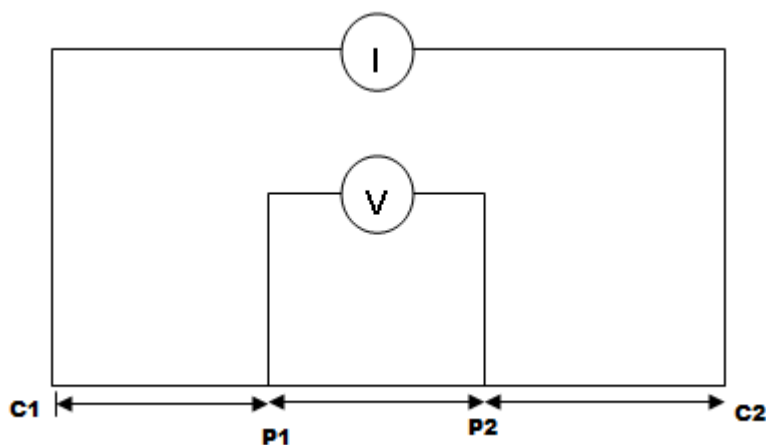


Figure 2.2: The Wenner Electrode Configuration.

2.4.2 The Schlumberger Array

The Schlumberger electrode configuration is normally employed for carrying out the Vertical Electrical Sounding (VES) at a place. This measures the potential gradient approximately. In the Schlumberger electrode configuration, the potential electrodes (P_1 and P_2) are placed so closely together in order to approximate a dipole.

$$P_1P_2 \ll C_1C_2$$

In actual fact, $C_1C_2 \geq 5P_1P_2$.

Using the equation for apparent resistivity,

$$\rho_a = \frac{2I\rho}{G} \quad (\text{eq. 10})$$

The apparent resistivity which is due to Schlumberger array is obtained as:

$$\rho_a(s) = \pi \left[\frac{a^2}{b} - \frac{b}{4} \right] R \quad (\text{eq. 11})$$

$$\text{Or } \rho_a(s) = KR$$

$$\text{where } K = \pi \left[\frac{a^2}{b} - \frac{b}{4} \right] \quad (\text{eq. 12})$$

a = half current electrode spread ($AB/2$)

b = potential electrode spread

$\rho_a(s)$ = Apparent resistivity of the Schlumberger array

R = Resistance of the Earth material

K = Geometric factor

The Schlumberger electrode configuration is represented diagrammatically as below:

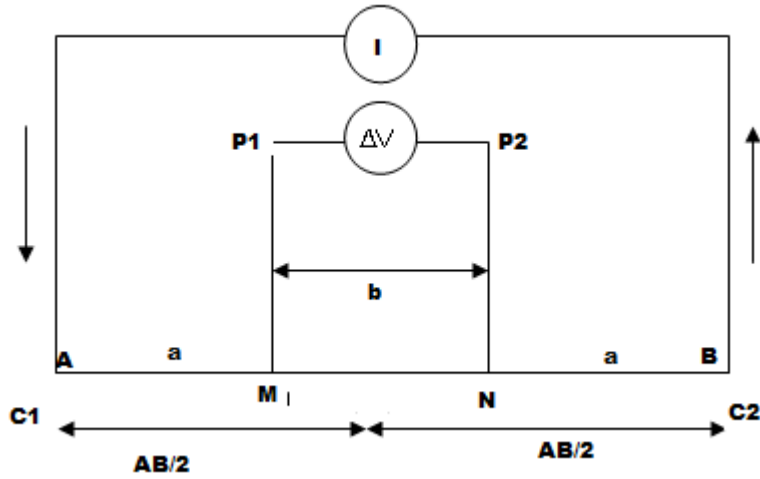


Figure 2.3: The Schlumberger Electrode Configuration

2.4.3 The Dipole-Dipole Array

The dipole-dipole configuration is the type of array that is being used for deep penetration. In the case of dipole-dipole arrangement, the current electrodes are usually well separated from the potential electrodes.

The apparent resistivity due to the dipole array is given below as:

$$\rho_a(d) = \pi R \frac{L(L^2 - a^2)}{a^2} \quad (\text{eq. 13})$$

a = Half electrode spacing between current electrode

$\rho_a(d)$ = Apparent resistivity of the dipole array

a = half current electrode spread

R = Resistance of the Earth material

L = Half of the electrode spacing

This type of expression holds true when the dipole array is collinear. In a situation where it is not, an expression that is more complicated is being used in order to obtain the apparent resistivity.

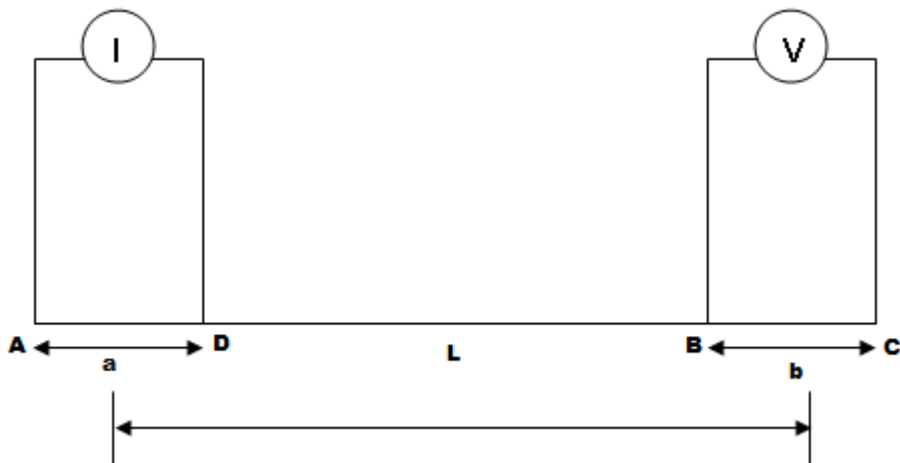


Figure 2.4: The Dipole-Dipole Electrode Configuration.

The different arrays have their advantages and disadvantages as shown in Table 2.2

Table 2.2 Summary of Advantages and Disadvantages of Different Arrays

Array	Advantages	Disadvantages
Wenner	Easy to calculate ρ_a in the field. Less demand on instrument sensitivity	All electrodes are moved during each sounding. Sensitive to local shallow variations. Long cables for large depths.
Schlumberger	Fewer electrodes to move at each sounding. Needs shorter potential cables.	Can be confusing in the field. Requires more sensitive equipment. Long current cables.
Dipole-dipole	Cables can be shorter for deep soundings.	Requires large current. Requires sensitive instruments.

2.5 Groundwater Vulnerability Assessment

Groundwater vulnerability assessment is increasingly applied in many parts of the world. It plays a very important role in making decision that relates to the way the groundwater resource can be managed and protected.

2.5.1 Groundwater Modeling

Since 1960's, observations of groundwater pollution and its vulnerability have been taken seriously, and this had led to the formulation of some mathematical models in order to evaluate groundwater resources (Gorelick, 1983). The mathematical models integrate process descriptions with pollutant properties and environmental characteristics in order to yield quantitative estimates of subsurface transport as well as knowing the fate of these substances in the soil mass. Modeling has in fact become an important tool in the very management of groundwater resources and is used to predict the effect of current and future conditions on groundwater and equally on contaminant movements and even assessing aquifer vulnerability (Getchell, 1996). Studies have

really shown that well calibrated models can provide a good estimate of the extent of the groundwater contamination (Wang, 1997).

A groundwater model may be defined as a simplified version of a real world groundwater system that approximately simulates the relative excitation-response relations of the real world systems (Bear & Verruijt, 1987; Getchell, 1996). Based on this premise, mathematical models can be classified as numerical, analytical or empirical. Among all, numerical models are the most sophisticated models, and it can be used to simulate the effects of either changing or steady state aquifer conditions (Getchell, 1996). Models are built from a series of mathematical equations that simulate a groundwater situation in a real world aquifer system. Mathematical equations describing groundwater flow in aquifers are based on Darcy's law. According to Darcy's law, the average flow velocity is a function of the hydraulic head gradient and the effective porosity (Freeze & Cherry, 1979). The flow rate Q , is given by:

$$Q = n V A \quad (\text{eq. 14})$$

where Q is the flow rate in m^3/s , V is the velocity of flow in m/s , n is the effective porosity of the porous medium and A is the cross-sectional area. The Darcy's law is given by:

$$V = - \frac{K}{n} \frac{dh}{dx} \quad (\text{eq. 15})$$

where K is the hydraulic conductivity in m/s ; h is the hydraulic head in m and n is the effective porosity; x is the distance of flow, in the x direction say; and dh/dx is the hydraulic gradient in the same direction. Combining equations 14 and 15, Darcy's law can be expressed as:

$$Q = -K A \frac{dh}{dx} \quad (\text{eq. 16})$$

For a 3-D groundwater flow equation through a saturated anisotropic heterogeneous porous medium, Darcy's law is expressed as:

$$\frac{\partial}{\partial x} \left[K_{xx} \frac{\partial h}{\partial x} \right] + \frac{\partial}{\partial y} \left[K_{yy} \frac{\partial h}{\partial y} \right] + \frac{\partial}{\partial z} \left[K_{zz} \frac{\partial h}{\partial z} \right] + R = S_s \frac{\partial h}{\partial t} \quad (\text{eq. 17})$$

where K_{xx} , K_{yy} , K_{zz} , are principal components of hydraulic conductivity tensor in x, y and z – directions, respectively. R represents sources/sinks in the system, and S_s is the specific storage. This is also called the diffusion equation.

For many problems, the velocity distribution, and hence the hydraulic head distribution, does not change with time (implying a steady state) (Mercer & Faust, 1980). Many regional groundwater flow systems can be represented as steady – state boundary value problems.

Thus for steady state flow,

$$\frac{\partial h}{\partial t} = 0, \quad (\text{eq. 18})$$

Hence, eq. 17 becomes: Type equation here.

$$\frac{\partial}{\partial x} \left[K_{xx} \frac{\partial h}{\partial x} \right] + \frac{\partial}{\partial y} \left[K_{yy} \frac{\partial h}{\partial y} \right] + \frac{\partial}{\partial z} \left[K_{zz} \frac{\partial h}{\partial z} \right] + R = 0 \quad (\text{eq. 19})$$

For a closed homogeneous medium in which sources and sinks are negligible, eq. 19 reduces to:

$$K_{xx} \frac{\partial^2 h}{\partial x^2} + K_{yy} \frac{\partial^2 h}{\partial y^2} + K_{zz} \frac{\partial^2 h}{\partial z^2} = 0 \quad (\text{eq.20})$$

For an isotropic medium, $K_{xx} = K_{yy} = K_{zz} = K$, equation 20 reduces to:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = 0 \quad (\text{eq. 21})$$

where there are sources of recharge, such as precipitation, the 3-D steady state equation becomes:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = \frac{-R(x,y,z)}{T} \quad (\text{eq. 22})$$

where $R(x, y, z)$ is the volume of water added per unit time per unit aquifer area, and T is the transmissivity of the aquifer (i.e. hydraulic conductivity times the saturated thickness, Kh). Transmissivity is defined as the rate at which water can pass through the thickness of saturated aquifer of unit width under a unit hydraulic gradient (Clark, 1988).

2.5.2 The Vulnerability of Aquifer Systems

The DRASTIC model was developed in USA in order to protect groundwater resources (Aller *et al.*, 1985; Aller, 1987). DRASTIC is an empirical groundwater model that estimates aquifer groundwater vulnerability of aquifer systems based on the hydrogeological settings of the area. A hydrogeological setting is defined as mappable unit with common hydrogeological characteristics (Engel *et al.*, 1996). The model employs a numerical ranking system that assigns relative weights to various parameters. The acronym DRASTIC is derived from the seven factors considered in the method, which are Depth to water table [D], net Recharge [R], Aquifer media [A], Soil media [S], Topography [T], Impact of the vadose [I], and hydraulic Conductivity [C]. Each DRASTIC factor is assigned a weight based on its relative significance in affecting pollution potential. The ratings range from 1 – 10 and weights from 1 – 5 (Tables 2.3 – 2.9). The DRASTIC Index [DI], a measure of pollution potential, is computed by summation of the products of ratings and weights of each factor. The final result for each hydrogeological setting is a numerical value, called DRASTIC Index. The higher

the value is, the more susceptible the area is to groundwater pollution. The DRASTIC model is designed to evaluate the vulnerability of groundwater in regions greater than 40 hectares of land (100 acres).

$$DI = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w \quad (\text{eq. 23})$$

where the subscripts r and w denote the rating and the weight of the factor being considered, respectively. The higher the value of DI the greater the vulnerability or relative pollution potential of the aquifer. Navulur *et al.*, (1996) converted the computed DRASTIC indices into qualitative risk categories of low, moderate, high and very high.

2.5.3 Weights and Ratings for the Drastic Parameters

Tables 2.3–2.9 show the weights and ratings assigned to various DRASTIC parameters (after Aller *et al.*, 1987). Table 2.10 shows the qualitative risk categories of low, moderate, high and very high vulnerabilities, respectively (after Navulur *et al.*, 1996).

Table 2.3: Depth to Water Table

FACTOR WEIGHT = 5

DEPTH (ft)	RATING
100+	1
75 – 100	2
50 – 75	3
30 – 50	5
15 – 30	7
5 – 15	9
0 – 5	10

Table 2.4: Net Recharge Rating

FACTOR WEIGHT = 4

RECHARGE (inches)	RATING
0 – 2	1

2 – 4	3
4 – 7	6
7 – 10	8
> 10	9

Table 2.5: Aquifer Media Characteristics

FACTOR WEIGHT = 3

AQUIFER MATERIAL	RATING
SHALE	1
TILL	3
SILT	3
SCHIST	4
SANDSTONE	5
LIMESTONE	6
GREEN ROCKS	6
SAND	8
SAND AND GRAVEL	9
GRAVEL	10

Table 2.6: Soil Media

FACTOR WEIGHT = 2

SOIL TYPE	RATING
CLAY/ORGANIC SOIL	1
LOAMY CLAY	4
CLAYEY LOAM	5
LOAM	7
SANDY LOAM	8
LOAMY SAND	9
SAND/GRAVEL	10

Table 2.7: Topography

FACTOR WEIGHT = 1

SLOPE (%)	RATING
>18	1
16 – 18	2
14 – 16	3
12 – 14	4
10 – 12	5
8 – 10	6
6 – 8	7
4 – 6	8
2 – 4	9
0 – 2	10

Table 2.8: Impact of the Vadose Zone

FACTOR WEIGHT = 5

UNSATURATED MATERIAL	RATING
CLAY	1
SHALE	2
SILT	3
SCHIST	4
TILL	4
GREEN ROCKS	5
SANDSTONE	5
LIMESTONE	6
SAND	8
SAND AND GRAVEL	9
GRAVEL	10

Table 2.9: Net Recharge Showing the Rating Based on the Hydraulic Conductivity

FACTOR WEIGHT = 3

HYDRAULIC CONDUCTIVITY RATING

(gpd/ft²)

1 – 100	1
100 – 300	2

300 – 700	4
700 – 1000	6
1000 – 2000	8
2000+	10

Table 2.10: Showing the DRASTIC Index Ranges for Qualitative Risk Categories
(After Navulur et al., 1996)

	DRASTIC QUALITATIVE CATEGORY			
	LOW	MODERATE	HIGH	VERY HIGH
DRASTIC Index [DI]	1 – 100	101 – 140	141 - 200	>200

CHAPTER THREE

METHODOLOGY

3.1 The Preliminary

The method of research involved desk studies and field work. The desk studies encompasses planning and designs including map production, consultations with some materials relating to my research topic (including theories) that are relevant to the prospect in view, data computation, data reduction, data processing, data presentation and data interpretation. The field work is concerned with feasibility cum reconnaissance studies which includes scouting of the area of study, noting down important locations, hazardous spots that could constitute obstacles during field operations, settlements, roads, rivers, relief, power equipment, flow stations, outcrops, lithologic units, altitude and the real time data acquisition

3.2 Instrumentation

3.2.1 Instruments

The instruments employed for the research work include: ABEM Terrameter SAS1000, Etrex GPS, Compass, Two 500m Current Cable reels, Two 70m Potential cable reels, Electrodes, four hammers, two measuring tapes, etc.

3.2.2 Materials

Log-log graph sheets, Computer modeling using resistivity software by Henker (1985), Sufer 10 software.

3.2.3 Functions of the instrument and its accessories

The functions of the instruments and materials used for the resistivity data acquisition are as follows:

ABEM Terrameter SAS 300B:- This instrument is capable of measuring the resistance on the various rock units in a formation when current is introduced to them through current electrodes. The terrameter has a liquid crystal digital read-out and automatic signal averaging microprocessors. SAS stands for Signal Averaging System whereby consecutive readings are taken automatically and the results are averaged continuously. The continuously updated running average is presented automatically on the display. SAS results are more reliable than those obtained using single-shot systems.

Electrodes (two current and two potential electrodes): These are steel rods used to pass the artificial current into the ground.

Global Positioning System (GPS) – It detects the coordinates of points, which is the longitude and latitude. It is also used to determine elevation at a place.

Ranging poles – They are used to align the profile into a straight line.

Reel of cables – These are coils of current – carrying cables that connect the potential and current electrodes to the terrameter.

Graduated rope – This rope is often graduated in meters to enhance quick detection of potential or current electrodes spacing at a point of measurement.

Geologic hammers – They are required to send the electrodes into the ground.

Umbrella- This provides shade and covering for the terrameter against sunshine, dews or rain.

Field note and log – log graph – field note is used to take records of the measurement.

Log – log graph is used to make a quick/trial plot of the field data.

Protective clothing – These are necessary to protect crew members from injury. They include safety boots, helmet, hand gloves etc.

3.3 Data Acquisition

A total of twenty-seven soundings were carried out within the study area. The maximum spread was $AB/2=500\text{m}$. The data were acquired under favourable weather conditions using the Schlumberger array. The array has been found to be convenient and reliable in most terrains.

3.4 Precautions

Some necessary precautionary measures were taken in order to obtain fairly accurate results. They include:

Equal spacing (or spread) of the electrodes (current and potential) on both sides of the profile was ensured.

About 50% of the electrodes were driven into the earth to guarantee firm contact with the earth. Sometimes, water was poured at the base of the electrode to enhance contact with the earth.

The sounding was avoided around buried electric cables and other metallic conductors to avoid erratic readings. Usually, enquiries are made before the start of VES in any location. Also, sometimes electrodes are used to penetrate the ground up to 2ft to ascertain if there are any buried objects on the surface or near surface; even sometimes

along the traverse, any time obstacles are met, about half a metre or one metre deviations were made in order to avoid it.

The ranging poles were used to ensure that the lines of spread are along a straight line.

The cables were checked properly to make sure that there were no indiscriminate leakages of current into the earth. Any exposed wire was cello-taped to prevent leakages.

All connections were correctly done before the terrameter was switched on.

For long spread array, communication methods were devised between the terrameter operator and the electrode handlers.

3.5 Data Processing and Interpretation

All raw field data were processed by using the appropriate constants and analysed using a FORTRAN Resistivity 2D Inverse Computer Program which is an iterative inversion-modeling program. The VES data are then presented as sounding curves which are obtained by plotting graphs of apparent resistivity versus half-current electrode spacing on double logarithmic graph sheets yielding layered earth models composed of individual layers of specified thickness and apparent resistivity. All the sounding curves are displayed on the appendix. It is from these computer-modeled curves that the geoelectric sections are generated. The direction of the different VES points was noted and the base map was used to generate a map showing the VES profiles. The geoelectric sections were then combined according to those lying along the same profile.

Aquifer resistivities and other hydraulic characteristics gotten from the interpretations were modeled using surfer 13 produces contour maps and 3D maps.

3.6 Limitations of the Resistivity Method

Resistivity surveying is an efficient method for delineating shallow layered sequences or vertical discontinuities involving changes of resistivity. It does, however, suffer from a number of limitations:

1. Interpretations are ambiguous - Consequently, independent geophysical and geological controls are necessary to discriminate between valid alternative interpretations of the resistivity data.
2. Interpretation is limited to simple structural configurations. Any deviations from these simple situations may be impossible to interpret.
3. Topography and the effects of near-surface resistivity variations can mask the effects of deeper variations.
4. The depth of penetration of the method is limited by the maximum electrical power that can be introduced into the ground and by the physical difficulties of laying out long lengths of cable. The practical depth limit for most surveys is about 1 kilometre (Telford et al, 1976).

3.7 The Application of the Drastic Model to the Study Area

The DRASTIC model was used to develop the groundwater vulnerability map of the study area. The generic model was used to determine such parameters as the depth to the water table, the aquifer media, the soil media as well as the impact of the vadose zone. The hydraulic conductivities were derived from the Dar Zarrouk parameters which was obtained from the VES conducted in the study area as well as its corresponding data. The recharge rate was as estimated from the annual rainfall records from Oru, Owerri and Umuahia, and extrapolated for the rest of the study area

3.7.1 Depth to the Water Table

The depth to the water table is the distance from the ground to the water table. This determines the depth of material through which a contaminant must travel before reaching the aquifer. The presence of low permeability layers, which confine aquifers, limits the travel time of the contaminants into an aquifer. There is a greater chance for attenuation to occur as the depth to water increases because, deeper water levels imply longer travel distances. The depth to the water table was obtained from Table 4.1 and converted to feet to determine the DRASTIC rating.

3.7.2 Net Recharge

Net recharge can be said to be a representation of the amount of water per unit area of land, which penetrates the land and reaches the water table. Recharge water is the means by which leaching and contaminants activities are transported vertically into the water table and horizontally or laterally within the aquifer zone. The greater the recharge rate, the greater the potential for groundwater to pollution. The net recharge was taken to be about 12% of the average annual rainfall; this is in accordance to what Navulur, in 1996 pinpointed. The annual rainfall for Owerri is 2482.6mm in 2007 (shown in Table B-2 in Appendix B) which is still applicable to my study area (Oru East and Oru West L.G.As, Imo State). The 12% of this is 11.6in. This was assumed as the recharge rate for all the locations in the study area.

3.7.3 Aquifer Media

An aquifer is defined as a permeable geologic unit that will yield useful quantities of water. The aquifer medium influences the amount of effective surface area of materials with which contaminants may come in contact. The larger the size of the particles of the grain, and the more the fractures or openings within the aquifer, the higher the permeability and as the lower the attenuation capacity of pollutants in the aquifer media

i.e. the rate of reducing the effect of the contaminants becomes lower. In this case, only the unconfined aquifer is considered, for which the DRASTIC model earlier talked about is valid according to Aller *et al.*, 1987. The aquifer media in question was gotten by taking into account, the depth at which water was struck and correlating those depths with the lithological description of the VES results obtained or even the strata description to identify the aquifer media.

3.7.4 Soil Media

Soil media refers to the uppermost portion of the vadose zone which characterized the significance of the biological activity. It was considered as the upper weathered zone of the earth, which averages a depth of one metre or less from the ground surface. Soil has a significant impact on the amount of recharge which can infiltrate into the ground and hence on the ability of contaminant to move vertically into the vadose zone; the smaller the grain size, the less the pollution potential.

3.7.5 Topography

Topography which is referred to as the variability of slope of the land surface helps to control the likelihood that a pollutant will run off or pool and remain on the surface in one area long enough to infiltrate. The study area is relatively flat; and moreover, a flat topography is a topography that has a range between 0% - 3%.

3.7.6 Impact of the Vadose Zone

The vadose zone is defined as the zone above the water table that is unsaturated or even discontinuously saturated. This zone determines the attenuation characteristics of the material that is below any typical soil horizon and equally above the water table. The

impact of the vadose zone was obtained by using the strata description or better still the lithological description that came as a result obtained from the VES data analysis.

3.7.7 Hydraulic Conductivity

Hydraulic conductivity means the ability or the capacity of the aquifer material to transmit water, when afterwards, controls the rate at which groundwater will flow under a given gradient or slope. The values of this hydraulic conductivity are shown in Table 4.4 in Chapter 4. The hydraulic conductivity was converted from m/day to gpd/ft^2 before application in finding the DRASTIC Index.

N/B: $1 \text{ gal/day/ft}^2 = 0.0408 \text{ m/day}$.

CHAPTER FOUR

DATA PRESENTATION, ANALYSIS AND RESULTS

4.1 Field Work Data

The results of the geophysical data acquired from the field are presented using the apparent resistivity values got from various locations visited within the study area. Each of these data was manually plotted on a log-log graph sheet, curve-matched and modeled. The curve types, true geoelectric layer resistivities, depth, and other aquifer parameters were determined and analysed.

4.2 Geophysical Field Data Results

The results of the curve matching and computer modeling of the field data (appendix I; VES 1 - 27) have shown that the character of each of the VES curve would be determined through the shape of the curve of each of the soundings. By implication, both the features of each of the layers and their maximum depth of penetration would easily be ascertained by simply observing each of the VES curves. The reason is because the shape of a VES curve depends on the number of layers encountered in the subsurface; its thickness and the ratio of the resistivity of the layers as well (Osemeikhian et al, 1982).

The quantitative description of the curve types identified as the simple A, K, H, Q, the compound AK, HA, HK, KH and to the more complex ones like HKH and KHK.

Predominantly among them are the curve types A, K and HK. The A curve type constitutes about 29.63%, K gives 22.22% while the HK has the highest number of 33.33% of the total curve types. Others are: KH, H, Q, and KHK each has a total of 3.7% of occurrence of all the curve types that were obtained/identified in the study area, Table 4.1 and appendix 1; VES 1 - 27. The general sequence of the entire curve types indicates a sequence that alternates between resistive and conductive layers. Also Table 4.2 shows the number of geoelectric layers with the corresponding resistivities and depths for each location.

Table 4.1: VES Numbers, Curve Type and Curve Characteristics

S/N	VES No.	Curve Type	Curve Characteristics	Percentage (%)
1	1,5,6,7,8,12,26,27	A	$l_1 < l_2 < l_3$	29.6296
2	2,11,16,17,18,22	K	$l_1 < l_2 > l_3$	22.2222
3	10,13,14,15,19,20,21,23,25	HK	$l_1 > l_2 < l_3 > l_4$	33.3333
4	4	KHK	$l_1 < l_2 > l_3 < l_4 > l_5$	3.7037
5	9	KH	$l_1 < l_2 > l_3 < l_4$	3.7037
6	3	H	$l_1 > l_2 < l_3$	3.7037
7	24	Q	$l_1 > l_2 > l_3$	3.7037

4.3 Iso-Resistivity Results

Iso- resistivity shows variation of apparent resistivity for different locations within a specified environment at a particular depth. The variations may be a good indicator of areas of low or high resistivities which may help to evaluate locations that have aquifers or not. The apparent resistivity values at specified spread of $AB/2 = 1\text{m}, 15\text{m}, 30\text{m}, 50\text{m}, 80\text{m}, 100\text{m}, 150\text{m}, 200\text{m},$ and 300m of all the locations were collated and contoured as shown in Table 4.2 and Figures 4.1(a) to 4.9(b). The importance of these spacings is to enable the electric current to penetrate deeper into the sub-surface in order to hit the aquiferous unit or layer. The values obtained range from $240.1\Omega\text{m}$ at Uzinaumu to $83314\Omega\text{m}$ at Eziani. The data of the geoelectric sounding was used for the preparation of the iso-resistivity map of the area. Resistivity contour maps display the lateral variation in the surface geology of the area. The areas with low resistivity value indicate the occurrence of relatively good conductors and the lowest resistivity value obtained was $240.1\Omega\text{m}$ while those with high value indicate poor conductors and the highest resistivity value obtained was $83314\Omega\text{m}$. The resistivity values at the different VES depths are tabulated and given below.

Table 4.2: Apparent Resistivity Values of the Locations from AB/2=1m to AB/2=300m

VES	LOCATION	LONG (°E)	LAT (°N)	HEIGHT (ft)	APPARENT RESISTIVITY , (Ω m)								
					AB/2(m)								
					1m	15m	30m	50m	80m	100m	150m	200m	300m
1	AKUMA 1	6.9511	5.7169	459	1164	5118	5000	7130	6600	7510	11670	13950	11700
2	AKUMA 2	6.9520	5.7167	459	1478	3330	2960	3550	4350	4720	5040	4560	4210
3	AMAGU 1	7.0389	5.6933	511	713	794	1209	3180	3830	3840	4618	6710	7060
4	AMAGU 2	7.0386	5.6929	531	814	1103	1506	1896	2690	3090	3650	4040	
5	OMUMA 1	6.9726	5.5590	262	532	865	1287	1795	2640	2750	3060	3430	3060
6	OMUMA 2	6.9704	5.5577	269	444	2060	3230	2920	4980	4470	8570	8970	8470
7	AMIRI 1	6.9585	5.7241	454	873	1137	1512	3060	4230	4980	6040	5370	6620
8	AMIRI 2	6.9599	5.7228	453	767	1824	3030	4290	7010	8680	15680	12750	11620
9	URA	6.8473	5.7471	451	2500	3210	1620	3600	1170	1000	1840	1840	3840
10	AKWADA	6.8562	5.7475	217	2500	1600	1400	2050	2620	3000	3000	2800	1460
11	EZIAMA	6.9207	5.7944	478	1880	1400	1250	2000	2300	2400	2500	2350	2050
12	UMUEJIKE	6.9333	5.6495	90	401.2	426	899	1377	1973	2380	3192	3880	5000

13	UZINAUMU	6.8833	5.7351	249	240.1	1322	1520	1702	1645	1417	1097	903	839.3
14	AMADIHE	6.9363	5.7638	451	2129	2893	3686	5395	6133	6589	7418	7554	6632
15	EZIANI	6.9113	5.7487	488	2773	3080	3512	5735	7043	8128	83314	6284	4265
16	UBACHIMA	6.9413	5.6792	497	617.1	2333	4144	4085	4930	4931	7030	7431	8434
17	CHC	6.8918	5.7338	341	230.1	779.5	923.3	1363	1802	2200	2130	1605	998.2
18	UBULU	6.8921	5.8117	499	303.3	1183	1611	2478	3202	4030	4897	4586	2083
19	UMUEJIKEA	6.9839	5.6950	529	570.5	2299	2610	1975	2776	3872	5277	5957	7430
20	UMUOKWE	6.9573	5.6924	494	616	1954	2208	2937	4791	5421	5520	5691	6532
21	OHAKPU	6.8514	5.7488	225	2567	4976	5408	5658	5118	5369	5000	4483	4200
22	OTULU	6.9156	5.7036	310	534	1777	2304	3745	4411	5000	5511	5611	4900
23	IBIASOEGBE	7.0965	5.6335	543	2100	2739	2937	4118	6584	6929	8609	7329	6040
24	UMUABIAH	6.8919	5.7161	264	7637	5568	5702	5877	5608	2169	2610	2422	1726
25	LH,OW/ONT	6.9245	5.6604	263	2292	1756	4348	6457	8201	9029	8142	6575	3814
26	AMAEGBU	6.9507	5.8026	554	999.1	1062	1449	1870	2264	2692	2943	3687	4594
27	AFOR,URU	6.9577	5.7866	509	479.9	936.4	1491	2384	2233	2269	2446	2661	3423

Table 4.3: Interpreted Layer Parameters from Geo-electric Resistivity Sounding.

VES NO	Layer resistivity(Ωm)										Layer depth (m)								
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	d1	d2	d3	d4	d5	d6	d7	d8	d9
1	940	5520	5648	2658	8526						0.8	8.0	46	125					
2	1185	4528	2462	9886	358						0.8	6.0	32	135					
3	850	250	1784	9862	2123						0.8	3.5	18	50					
4	768	1654	774	5466	3055						0.8	3.0	14	145					
5	540	606	2658	9886	1002						1.2	8.5	48	109					
6	352	2869	2689	2568	1582						0.8	9.0	32	138					
7	855	1120	1025	1652	1125						0.8	6.0	16	108					
8	682	2150	1425	3652	2536						1.0	5.0	14	115					
9	2260	11300	288	1330	1800	8100					6.9	14.0	33	46	60.3				
10	2560	528	10500	4580	3920						8.1	17.0	39	50.5	65.6	92.2			
11	1510	4210	4210	2440	3220	1250					33.0	56.0	78	88	110				
12	245	3630	13400	6870	1090						7.4	17.0	50	70	108				
13	202	3760	1060	2530	1870	587	295	634	1270	6930	1.1	3.5	9.8	29.8	50.5	76.8	123	161	201
14	2260	1240	4360	2240	1600	5610	6010	5810			1.4	3.4	7.2	17.1	63.5	107	149	193	
15	2510	5310	1340	2630	1320	4460	9100	3240	2130	308	0.8	4.1	9.3	14.7	20.7	40.1	54	72.4	93.4
16	375	1670	11500	2430	1250	2510	1390	9900	6500	2360	0.4	6.3	15	38.6	66.2	113	156	201	247
17	209	1010	529	2490	9200	870	462	395	375	126	1.1	5.2	13	21.7	44.9	63.2	85.9	111	138
18	199	3070	518	2390	1060	1940	1290	1080	980	195	0.6	3.1	9.5	29.3	48.1	69.1	93.4	118	143

19	276	2620	3610	722	1310	4300	1220	8500	5080		0.4	3.6	12	26.7	42.9	93.1	135	182	231
20	287	7670	608	2280	7170	3180	3040	3330	3810	1930	0.4	2.4	9.4	40.1	69.8	113	157	202	244
21	2010	9300	4130	7700	4600	4460	4420	3920	2610		0.7	2.8	13	32	97.8	152	205	258	
22	307	6570	601	1320	1070	1130	5990	3500	860		0.5	2.3	7.4	24.8	40.5	71.5	106	144	
23	1500	3280	1060	3800	1360	5620	3070	714			0.3	7.4	15	39.9	59.3	82.6	112		
24	8200	3100	16000	1330	4380	553					5.1	11.0	22	62.9	131				
25	2490	490	61200	4350	187						2.0	4.9	22	42.7					
26	1370	393	1650	4820	5880	3730					1.0	3.2	34	105	196				
27	403	651	4550	970	5100	3780					0.6	8.7	35	64.6					

4.4 The Explanation of the Iso-Resistivity Results

4.4.1 The Explanation of the Iso-Resistivity of the Study Area at AB/2=1m

The values of apparent resistivities at AB/2=1m are from values 240.1 Ω m at Uzinaumu to 1478 Ω m at Umuabiahu, Akuma, Akwada, Eziama, Ibiasoegbe and Umuabiahu have high resistivities greater than 1000 Ω m while others have low resistivities less than 1000 Ω m. These values are interpreted as clayey and sandy top soils respectively.

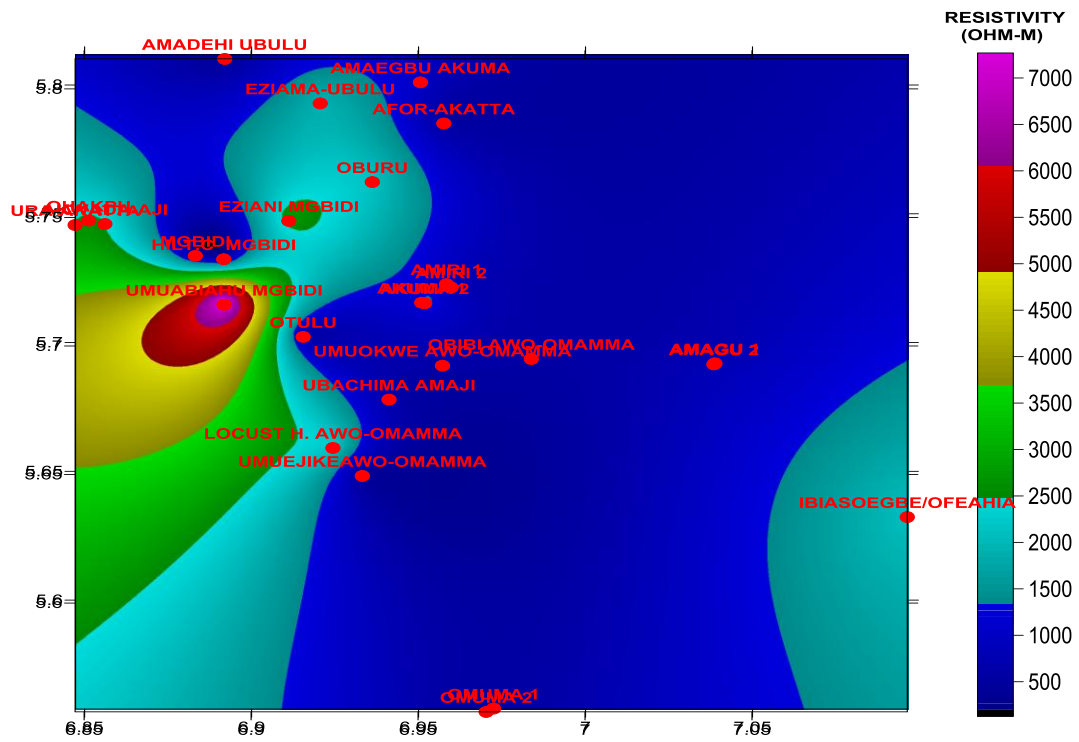


Figure 4.1(a): The Spatial Variation Map of Iso-Resistivity of the Study Area at $AB/2 = 1m$

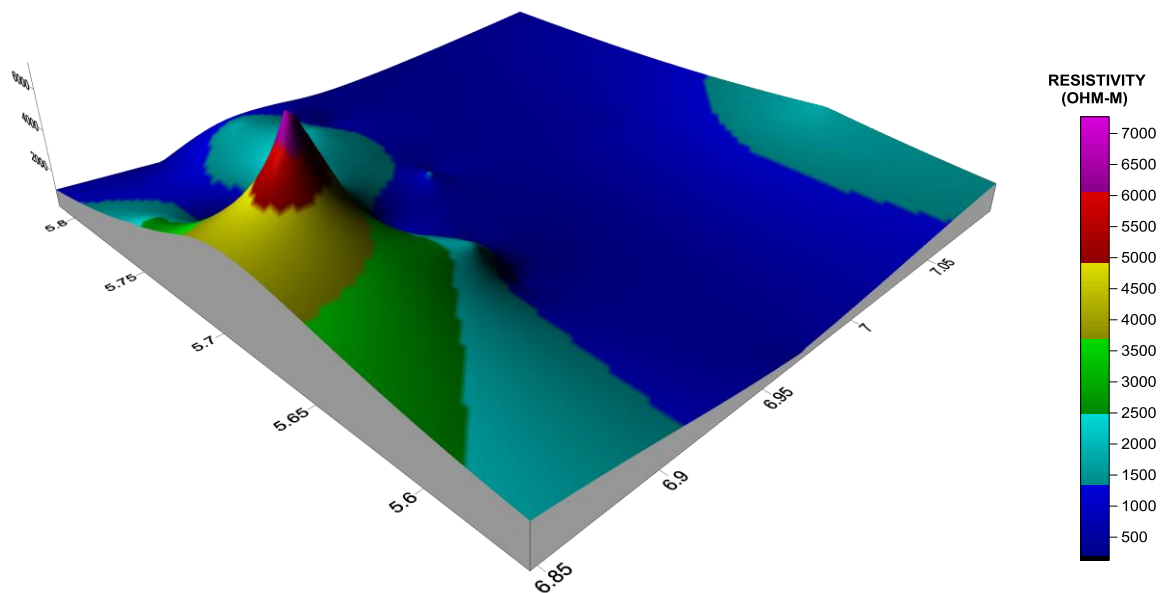


Figure 4.1(b): The 3D Model of Iso-Resistivity of the Study Area at 1m

4.4.2 The Explanation of the Iso-Resistivity of the Study Area at AB/2=15m

At AB/2=15m, except at Amagu, Omuma 1 and Umuejike where the resistivities are 428 Ωm , 794 Ωm and 865 Ωm , other locations have resistivity values ranging between 1000 Ωm and 5200 Ωm . The horizons of sand units increased at this depth except few dark blue spots around Omuma with low resistivity values.

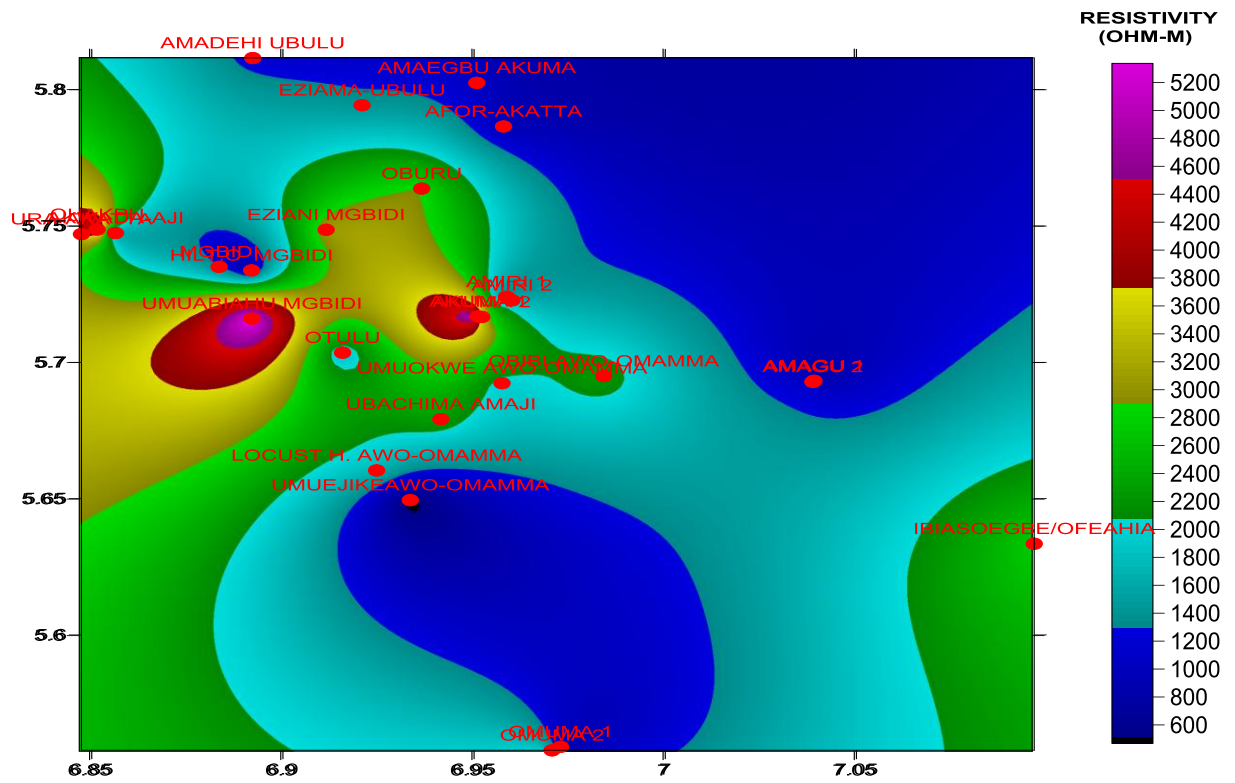


Figure 4.2(a): The Spatial Variation Map of Iso-Resistivity of the Study Area at $AB/2 = 15m$

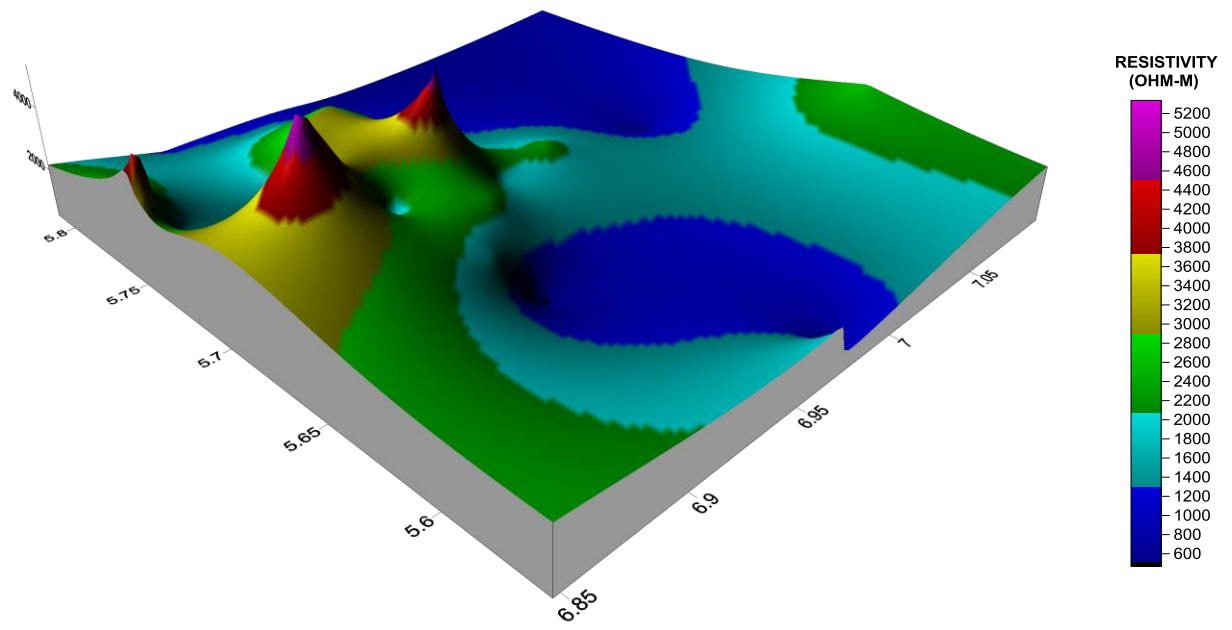


Figure 4.2(b): The 3D Model of Iso-Resistivity of the Study Area at 15m

4.4.3 The Explanation of the Iso-Resistivity of the Study Area at AB/2=30m

Figure 4.3(a) as displayed, all have high resistivities in the range of 1000 Ω m to 5400 Ω m. they are all interpreted as sand units with highest values around Awo-ommama, Mgbidi, Oburu. Figure 4.3(b) shows a 3-D model of area indicating points as sandstone or dry sand units

In the same AB/2=30.00m (fig. 4.3 a and b), it will be seen that the same eastern, north-eastern and south-eastern axis (parts) with similar colour indications of dark blue and light blue is made up of material of relatively low resistivity while the western part with colour indices of green and yellow have a relatively moderate resistivity. On the other hand, still on the western part, the parts shaded red and purple have a relatively high resistivity values. The communities where the low resistivity values material fall under are: Amagu, Eziamma-Ubulu, Afor-Akatta, Umuejike Awo-Omamma, Amaegbu Akuma, Amadehi Ubulu, Ibiasoegbe, Otulu while the area with a relatively moderate resistivity values include: Omuma, Obibi Awo-Omamma, Amiri, Ura-Akatta, Akwada-Aji, Eziani Mgbidi, Oburu. Then the communities where the relatively high values occur include Umuabiahu-Mgbidi, Ubachima Amaji, Akuma, Locust Hotel Awo-Omamma, etc.

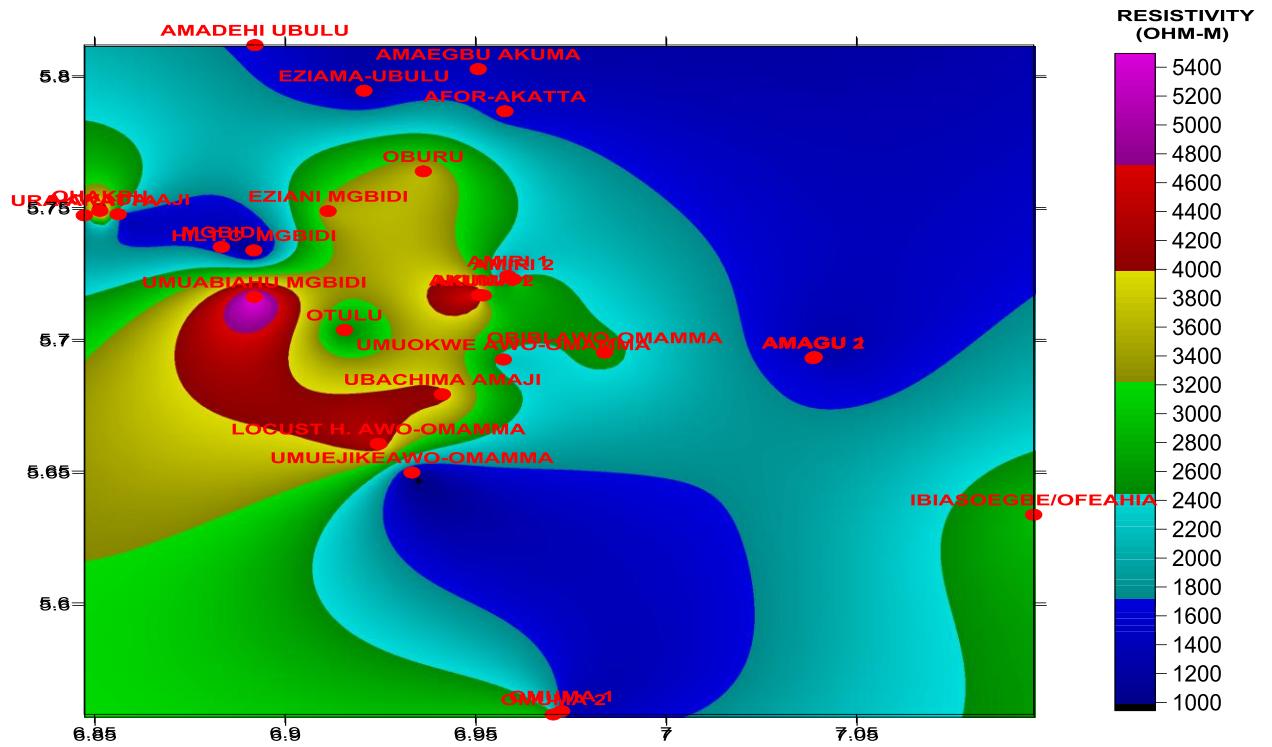


Figure 4.3(a): The Spatial Variation Map of Iso-Resistivity of the Study Area

at $AB/2 = 30m$

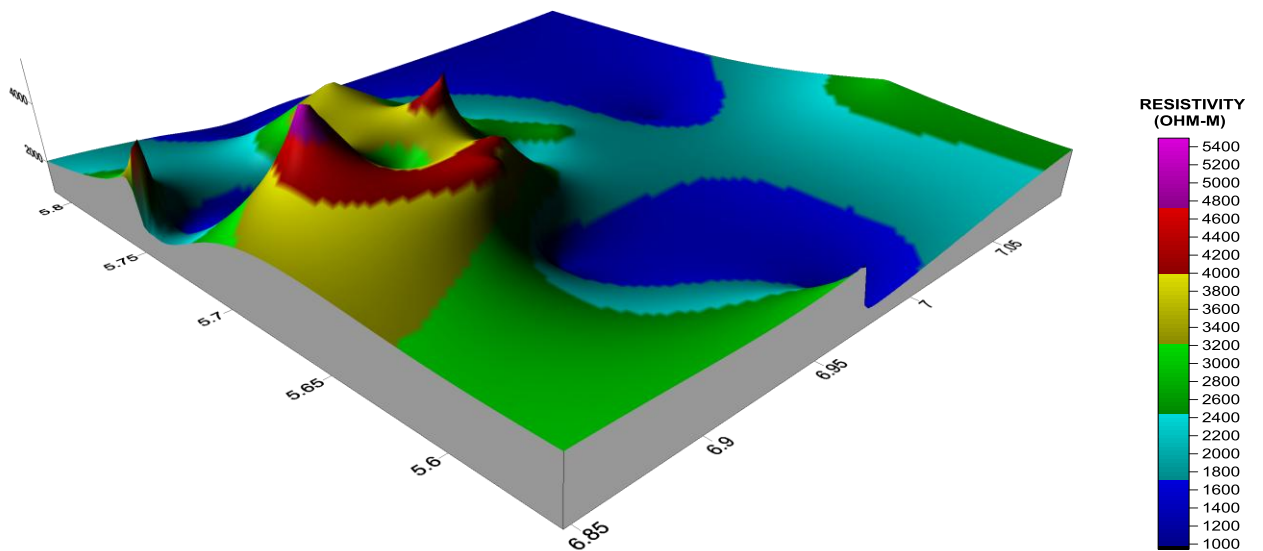


Figure 4.3(b): The 3D Model of Iso-Resistivity of the Study Area at $AB/2 = 30m$

4.4.4 The Explanation of the Iso-Resistivity of the Study Area at AB/2=50m

At the depth or spread of AB/2=50.00m figures 4.4(a) and 4.4(b), shows marked low resistivity values materials underlying the eastern part and the topmost northern part of the iso-resistivity maps above with the same colour indices of dark blue and light blue while on the contrary, the western part, the farthest eastern part and the north-western part of the iso-resistivity map which have colour indices of yellow, red and purple indicate areas that are underlain by high resistivity materials.

The towns that fall under the low (moderate) resistivity are: Amaebu-Akuma, Eziani-Ubulu, Afor-Akatta, Omuma, Obibi Awo-Omamma etc. while those that fall under the high resistivity are: Locust Hotel Awo-Omamma, Ubachima, Amaji, Umuokwe Awo-Omamma, Otulu, Umuabiahu Mgbidi, Eziani Mgbidi, Mgbidi, Oburu etc.

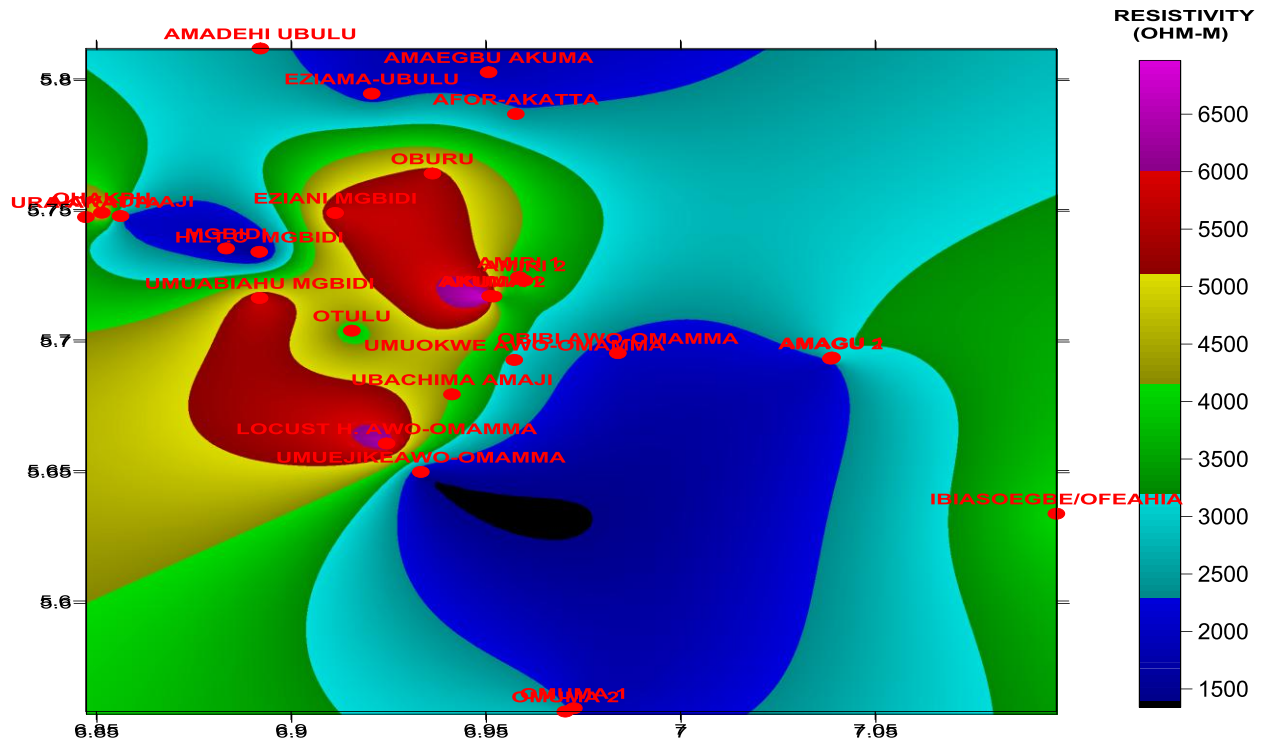


Figure 4.4(a): The Spatial Variation Map of Iso-Resistivity of the Study Area at $AB/2 = 50m$

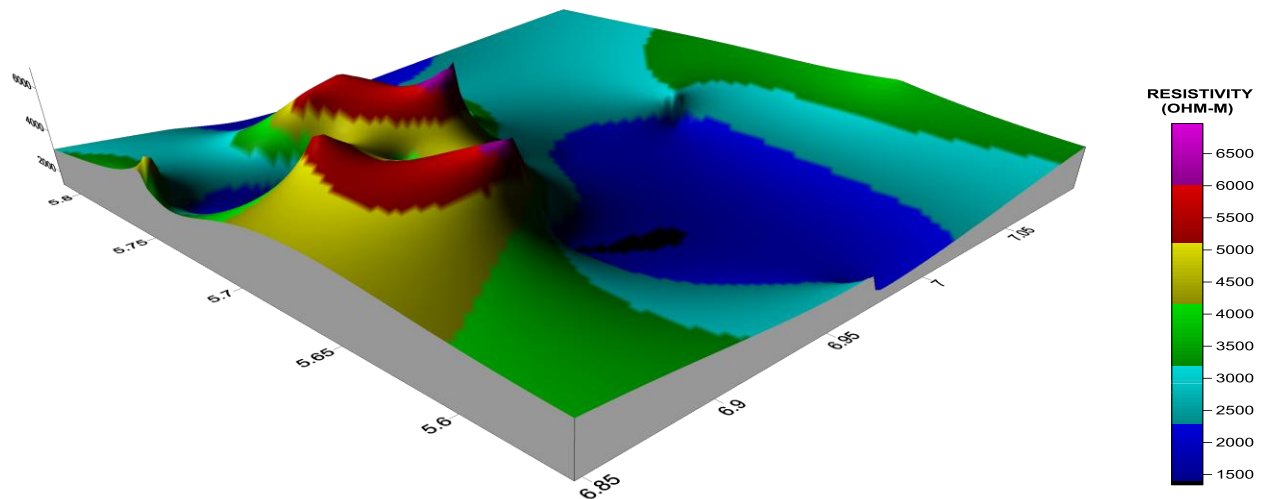


Figure 4.4(b): The 3D Model of Iso-Resistivity of the Study Area at $AB/2 = 50m$

4.4.5 The Explanation of the Iso-Resistivity of the Study Area at AB/2=80m

In the iso-resistivity map of AB/2=80m, Figures 4.5(a) and 4.5(b), blue colour which are observed both at the northern and some parts of the south of the iso-resistivity map are underlain with low resistivity materials of clays, while the parts marked by the yellow and green colour have a relatively moderate values; then on the other hand, the areas shaded red and purple colours are underlain by high resistivity materials and they are sands.

The towns that fall under the low resistivity values are: Amaebu-Akuma, Eziana-Ubulu, Afor Akatta, Ura Akatta, Akwada Aji. The communities where the moderate resistivity values occur are Amagu, Omuma, Umuokwe, Ubachima Amaji, Umuabiahu Mgbidi, etc. while those that fall under the high resistivity are: Locust Hotel Awo-Omamma, Amiri, Oburu, Eziani-Mgbidi, Ibiasoegbe/Ofeahia etc.

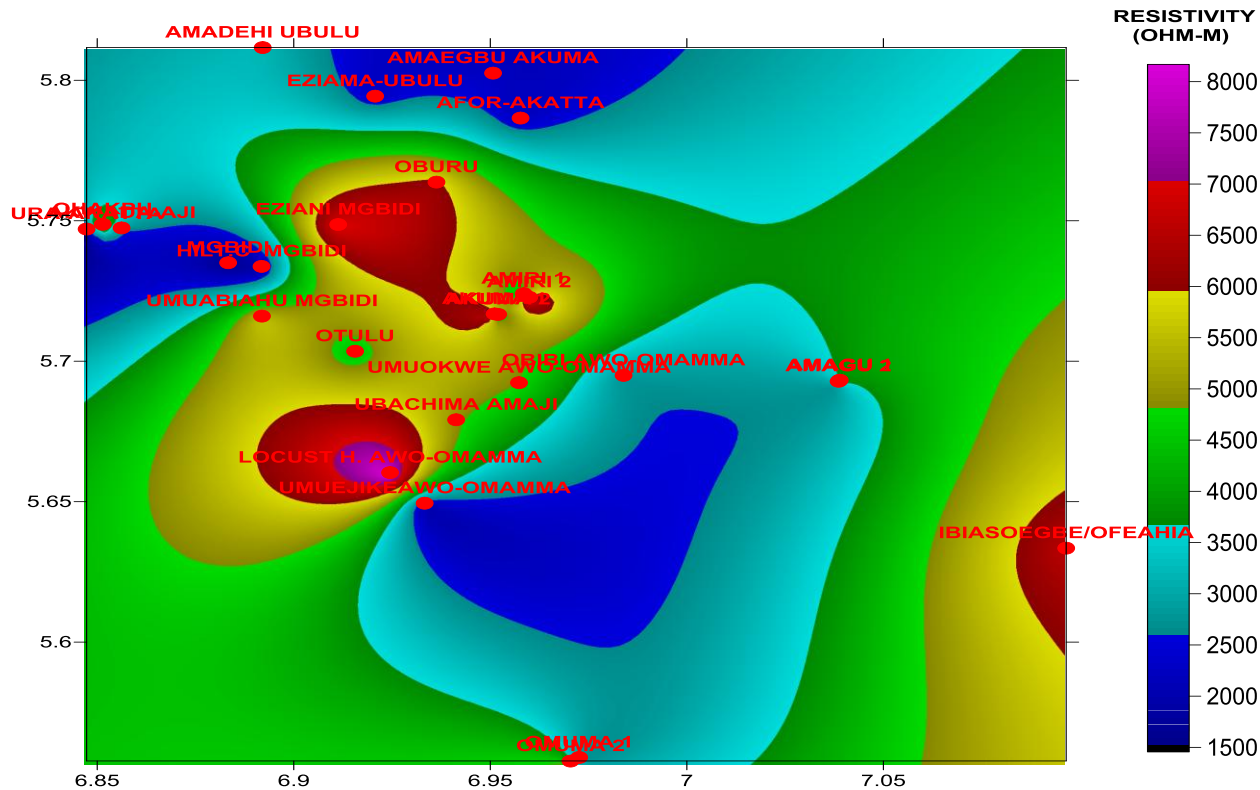


Figure 4.5(a): The Spatial Variation Map of Iso-Resistivity of the Study Area at $AB/2 = 80m$

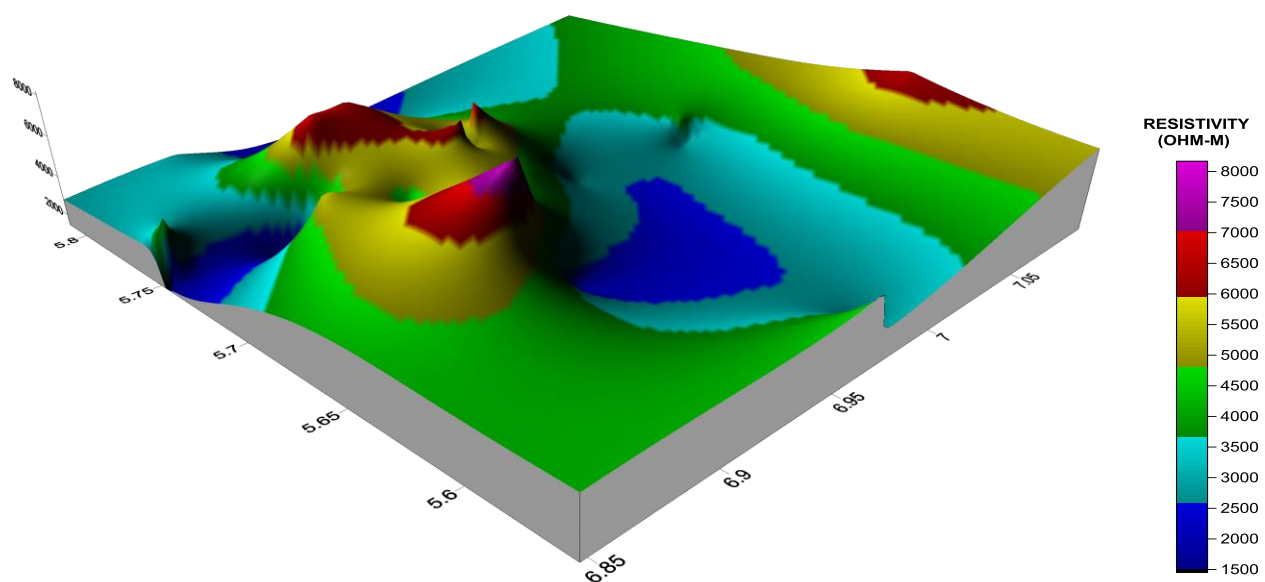


Figure 4.5(b): The 3D Model of Iso-Resistivity of the Study Area at $AB/2 = 80m$

4.4.6 The Explanation of the Iso-Resistivity of the Study Area at AB/2=100m

In the 2D and 3D iso-resistivity map AB/2=100.00m above figures 4.6(a) and 4.6(b) show some areas that have both low and moderately high resistivity values and they are found at mostly the northern, western, central to partly southern parts and some prominent towns within the area are: Afor-Akatta, Eziama-Ubulu, Amaebu Akuma, Amaji, Umuabiahu Mgbidi, Mgbidi, Umuejike Awo-Omamma etc while on the contrary, the areas that have high resistivity include the following towns with the study area: Oburu, Eziani Mgbidi, Amiri, Akuma, Umuokwe Awo-Omamma, Obibi Awo-Omamma etc and it is located at the central towards the western part as well as the eastern part of the iso-resistivity map.

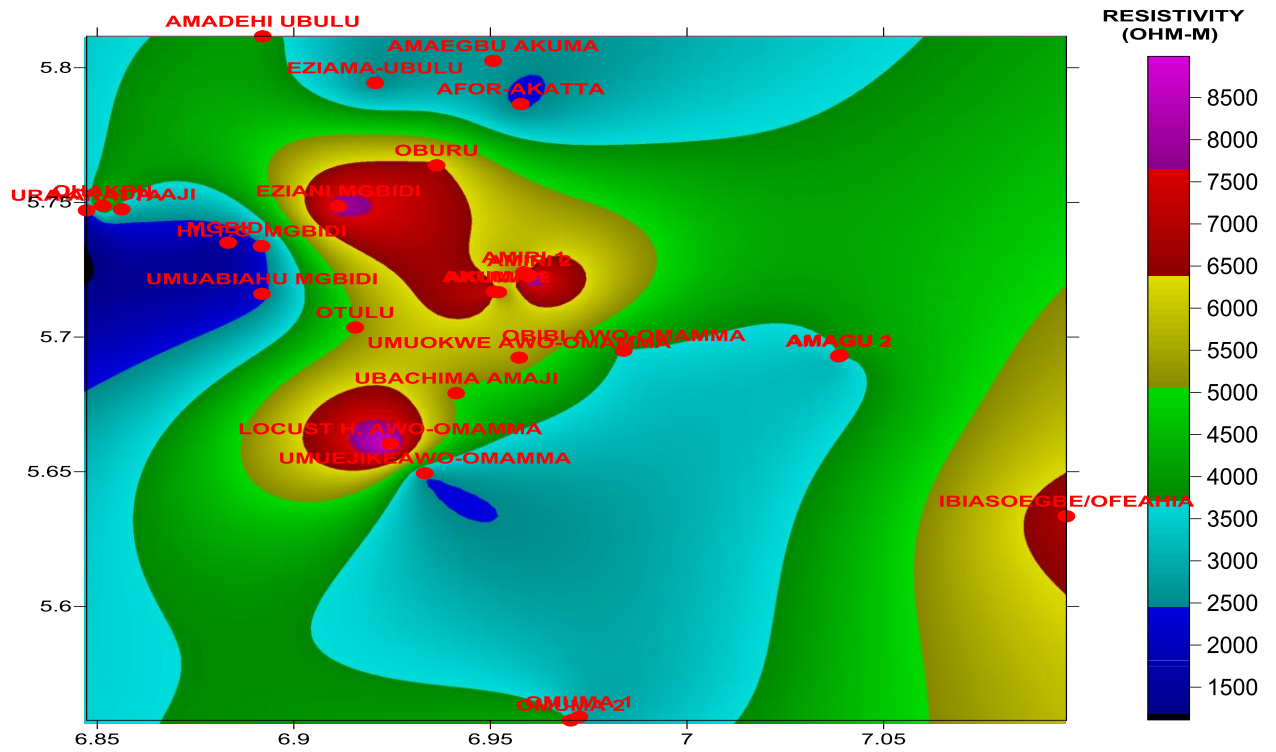


Figure 4.6(a): The Spatial Variation Map of Iso-Resistivity of the Study Area at $AB/2 = 100m$

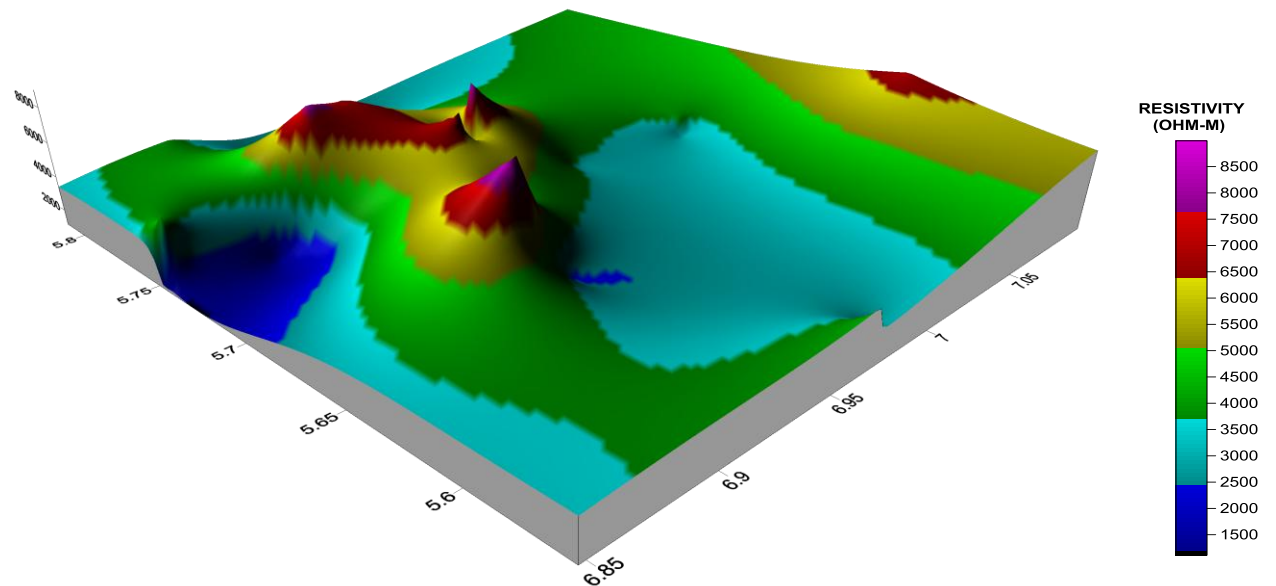


Figure 4.6(b): The 3D Model of Iso-Resistivity of the Study Area at $AB/2 = 100m$

4.4.7 The Explanation of the Iso-Resistivity of the Study Area at AB/2=150m

The iso-resistivity map AB/2=150.00m above Figures 4.7 (a) and 4.7 (b) show the areas that have both the low and moderately high resistivity values and they occur at Amaji, Amaebu-Akuma, Eziana-Ubulu, Afor-Akatta, Mgbidi, Umuabihu Mgbidi and it occurs at the northern, western southern and partly central parts of the iso-resistivity map above with their colour indices as light and dark blues . Then on the contrary, the areas within the map that have high resistivity are Amiri, Akuma, Eziani-Mgbidi etc and it occurs mostly at the central part of the iso-resistivity map above and their own colour indices are mostly yellow, red and purple colours as it can be observed in the iso-resistivity map above.

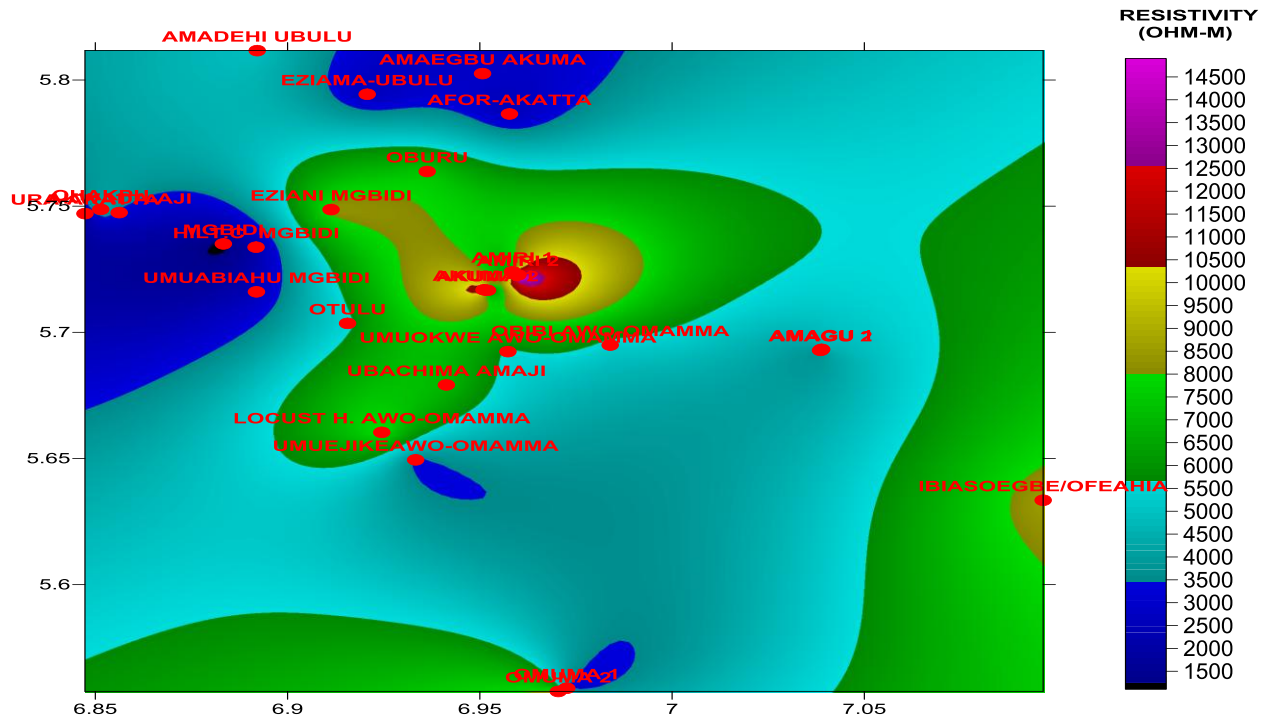


Figure 4.7(a): The Spatial Variation Map of Iso-Resistivity of the Study Area at $AB/2 = 150m$

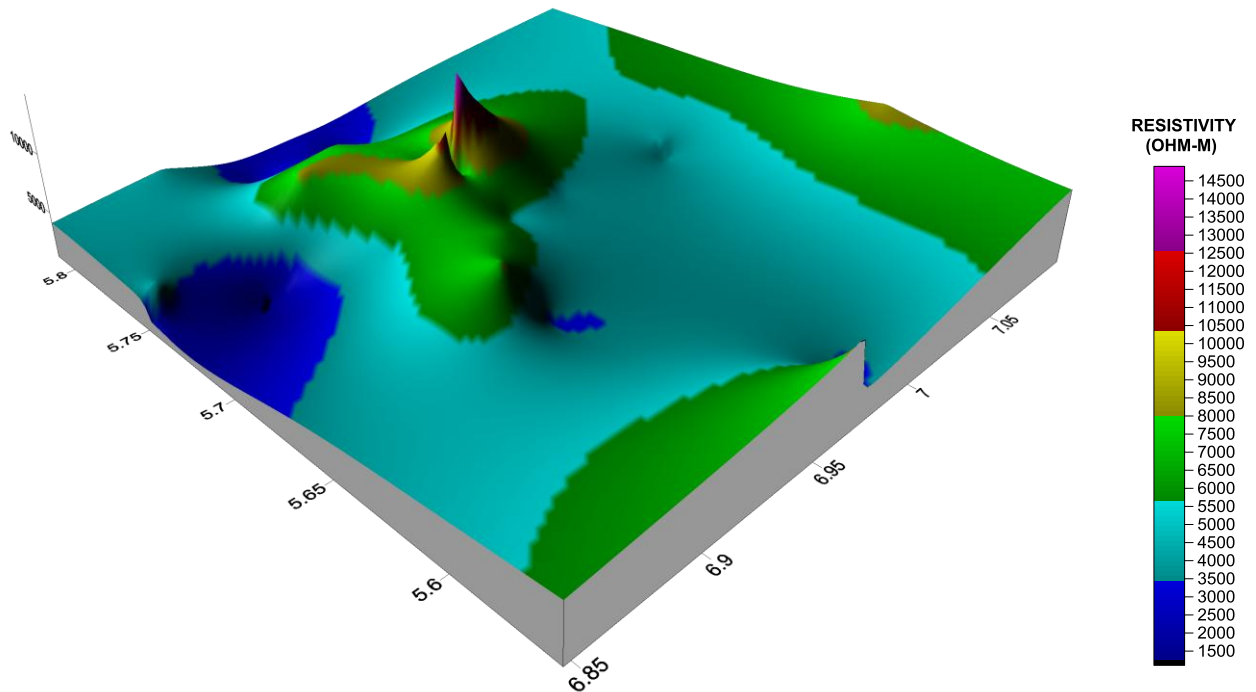


Figure 4.7(b): The 3D Model of Iso-Resistivity of the Study Area at $AB/2 = 150m$

4.4.8 The Explanation of the Iso-Resistivity of the Study Area at AB/2=200m

In the iso-resistivity of AB/2=200m above Figures 4.8(a) and 4.8(b), the towns and villages that make it up are: Amaji, Afor-Akatta, Mgbidi, Amaebu Akuma, Eziam-Ubulu, Mgbidi, Umuabiahu Mgbidi etc. the parts of the study area where both the low resistivity values and moderately high resistivity values can be found within the iso-resistivity map as indicated above, and it can be found more especially at the northern, western, and southern parts in the iso-resistivity map above but on the contrary, the areas that have high resistivity values are areas like: Omuma, Ibiasoegbe/Ofeahia, Amagu, Obibi-Awo-Omamma, Umuokwe Awo-Omamma, Ubachima, Amaji, Locust Hostel Amo-Omamma, Umuejike Awo-Omamma, Oburu, Amiri, Otulu etc and they appear mostly at the central part of the iso-resistivity map.

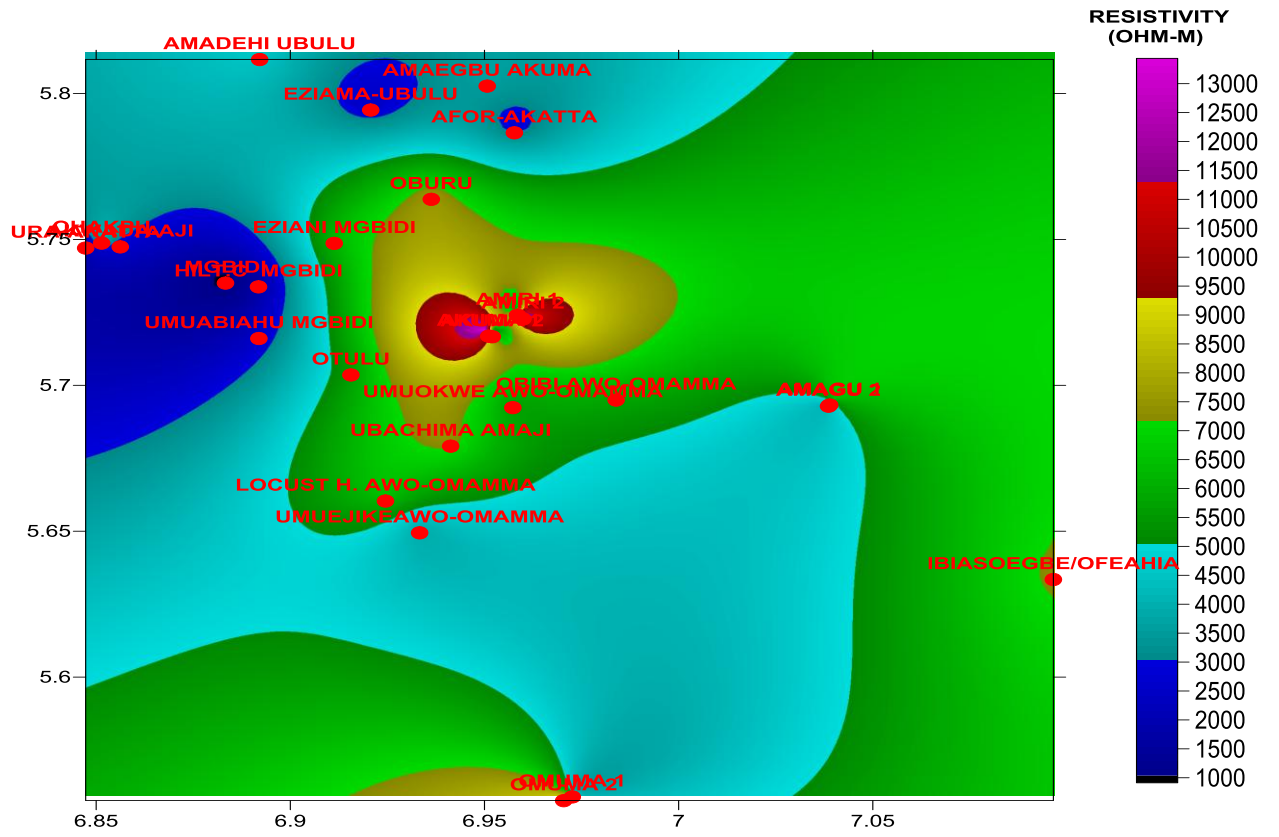


Figure 4.8(a): The Spatial Variation Map of Iso-Resistivity of the Study Area at

AB/2

=

200m

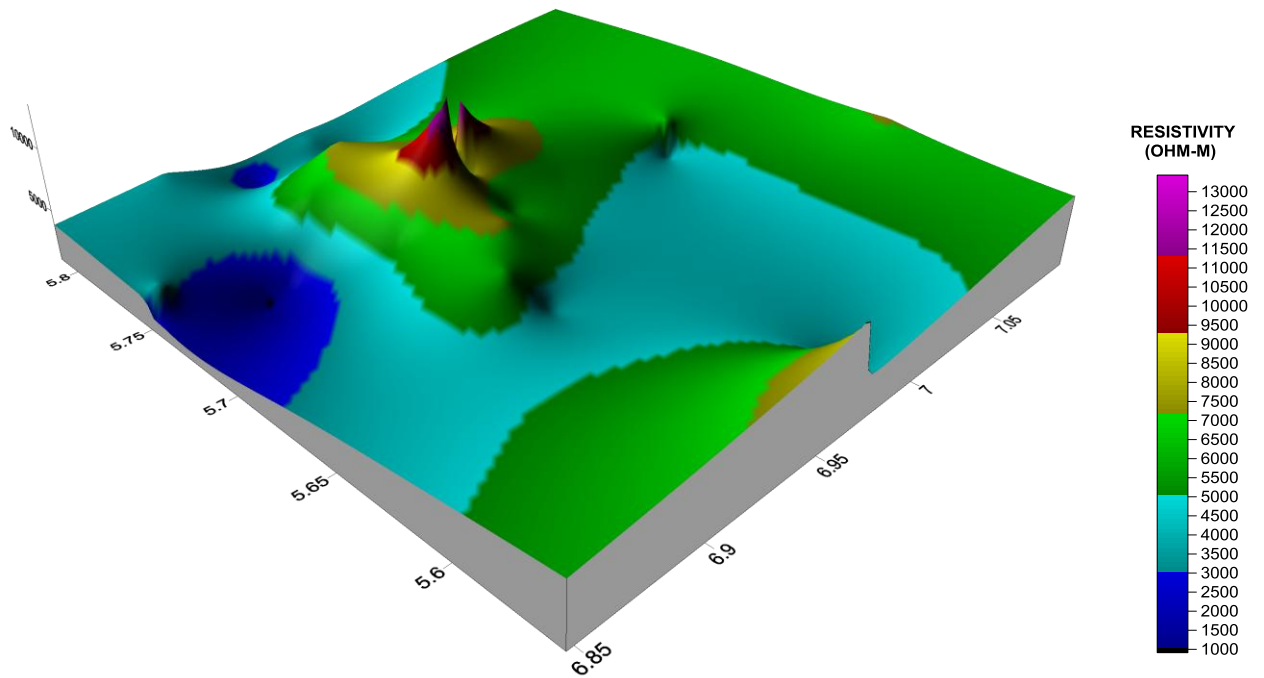


Figure 4.8(b): The 3D Model of Iso-Resistivity of the Study Area at AB/2 = 200m

4.4.9 The Explanation of the Iso-Resistivity of the Study Area at AB/2=300m

In the iso-resistivity AB/2=300.00m above figures 4.9(a) and 4.9(b), the parts dominated by the low values of resistivity and moderately high values of resistivity and it occurs in the areas like Akuma, Ezianya-Ubulu, Eziani-Mgbidi, Umuabiahu Mgbidi, Locust Hotel Mgbidi etc and it is found at the north-western, western and some southern parts of the iso resistivity map above, its colour indices are mostly light and dark blue colours. While places such as Amiri, Akuma, Amagu, Amaji, Ubachima, Ibiasoegbe/Ofeahia, Omuma, Umuokwe Awo-Omamma, Umuejike Awo-Omamma are areas characterized by the high resistivity values interpreted as sands/ sandstones and are underlain around the central, eastern, southern parts of the iso-resistivity map above. They are denoted yellow, red and purple colours.

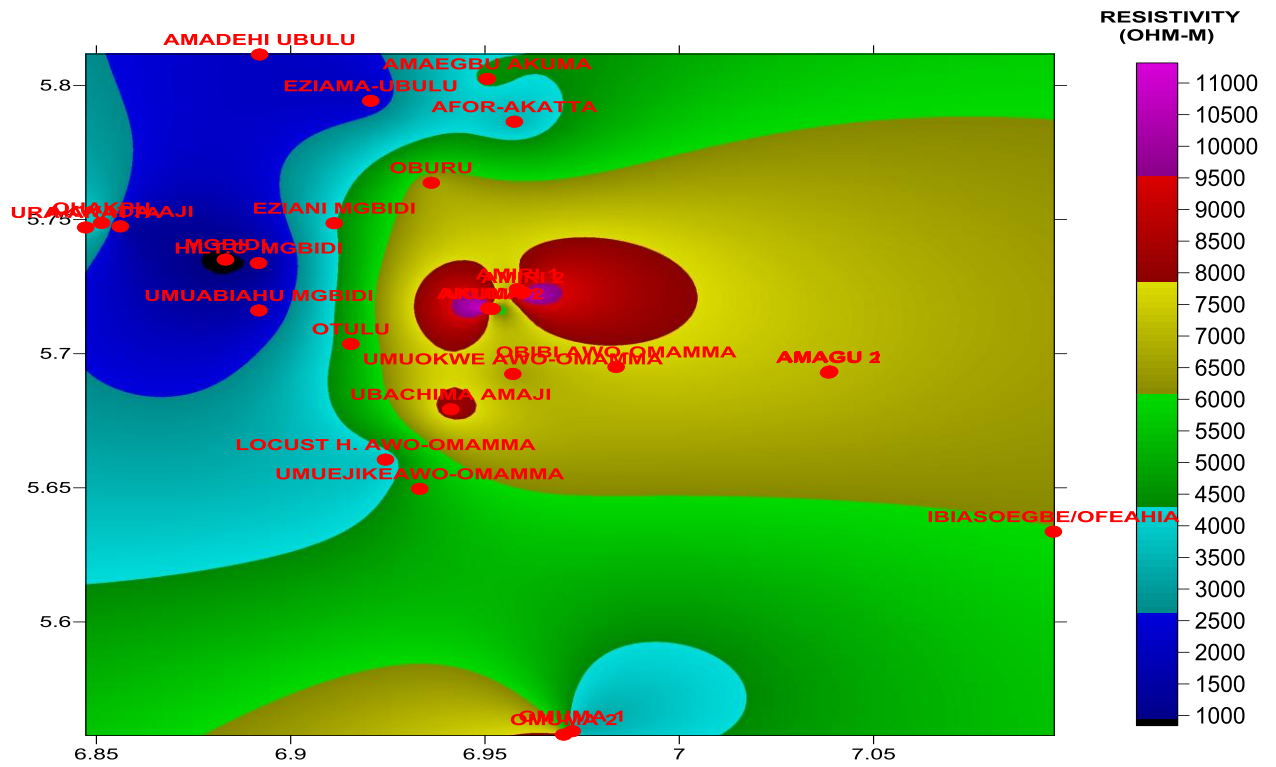


Figure 4.9(a): The Spatial Variation Map of Iso-Resistivity of the Study Area at $AB/2 = 300m$

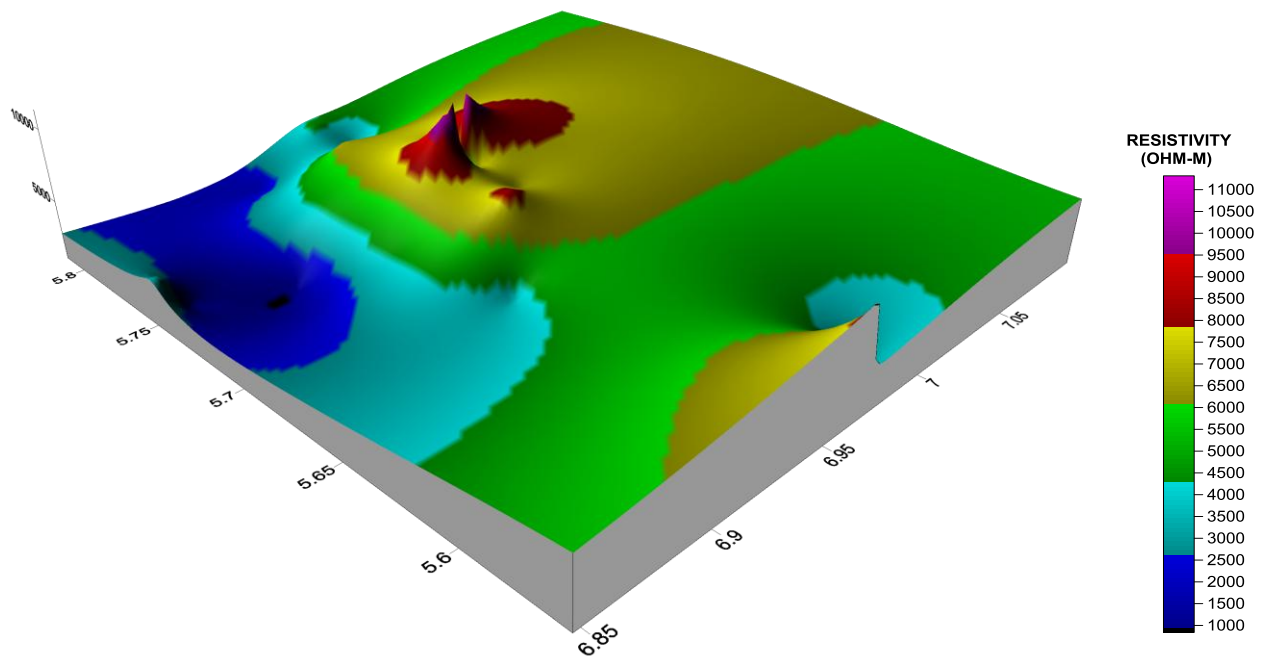


Figure 4.9(b): The 3D Model of Iso-Resistivity of the Study Area at $AB/2 = 300\text{m}$

4.5 Interpretative Cross-Section

Three (3) profile sections A-A^I, B-B^I and C-C^I were generated from the interpretations of the twenty-seven (27) electrical resistivity soundings (VES) that were carried out in the study area as shown in figure 4.10.

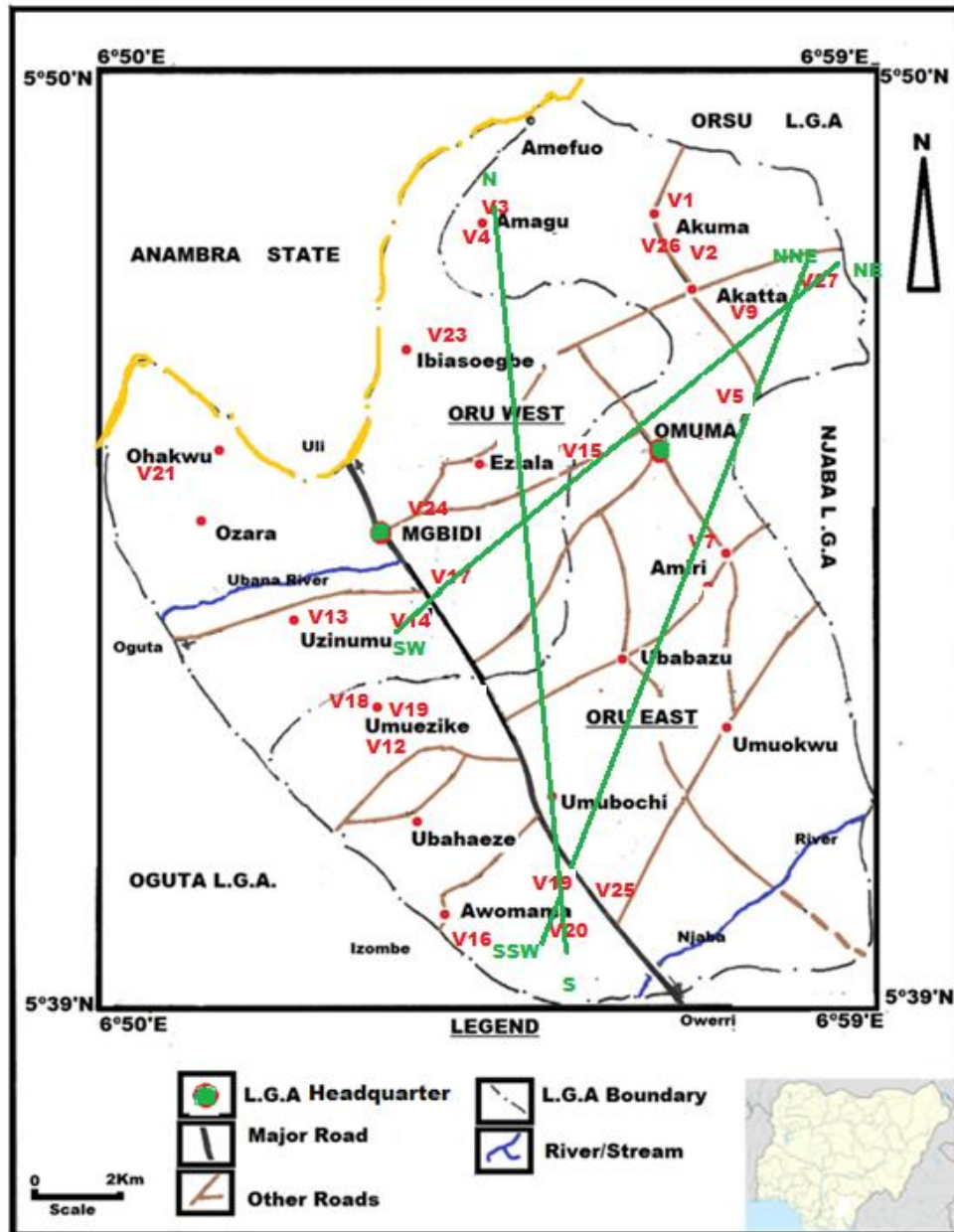


Figure 4.10: The Location Map of the Study Area Showing the Cross Sectional Profiles along N-S, NE-SW and NNE – SSW directions

The profile A-A^I in the North-South direction can be called North-South (N-S) Profile. The profile B-B^I in the North East-South West direction can be referred to as North East-South West (NE-SW) Profile while the profile C-C^I is a profile that runs in the North North East-South South West direction and it can be called a North North East-South South West (NNE-SSW) Profile. All the profiles can be observed in figure 4.10. The probable lithology of each profile is drawn as shown in figures 4.11(a), 4.11(b) and 4.11(c).

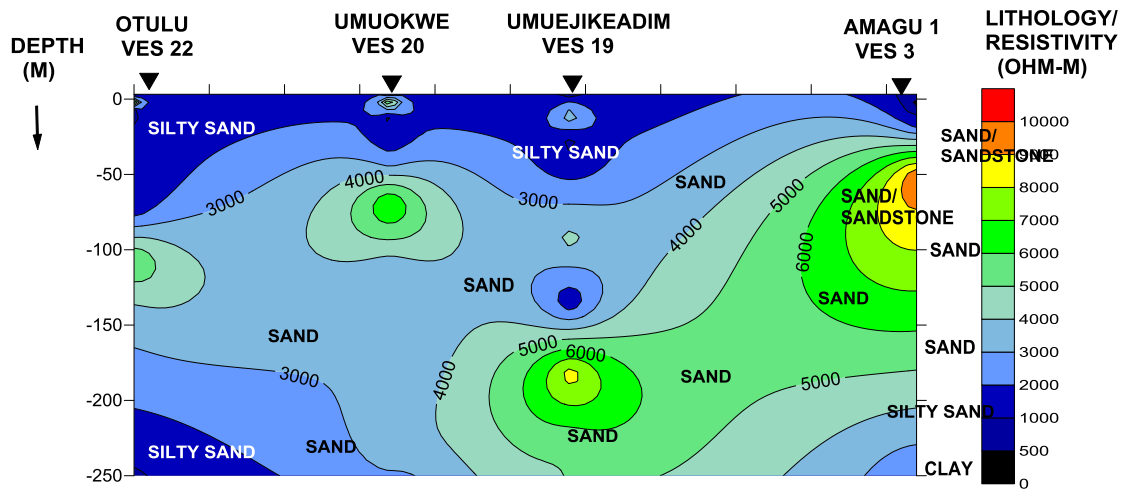


Figure 4.11(a): The Profile of the Study Area in the N-S Direction Showing the Lithology

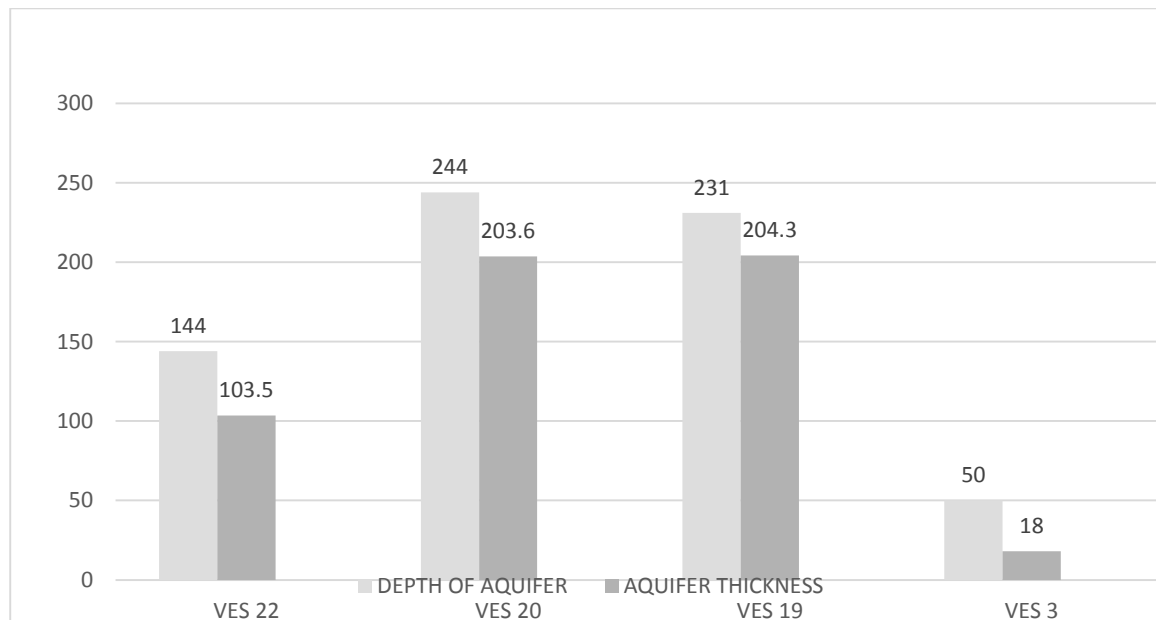


Figure 4.11(b): The Bar Chart Representation of the Profile N-S Direction

The profile A-A^I which runs through the East-West Direction traverses Amagu, Umuokwe, Obibi, Otulu, Awo-Omamma etc.; and the VES Numbers of those places (areas/communities) where it cut across are: VES 3, VES 4, VES 19, VES 20, VES 22. The lithology of the areas is mostly sand, silty-sand, clay; the resistivity of the sands and sandy units. The resistivities range from 20,000 Ω m to 60,000 Ω m for the sand units, 5,000 Ω m to 20,000 Ω m for silty-sand while 0 Ω m to less than 1000 Ω m represents clay. A trend of high resistivity can be observed in the NW-SE direction which increases in thickness towards the southeast.

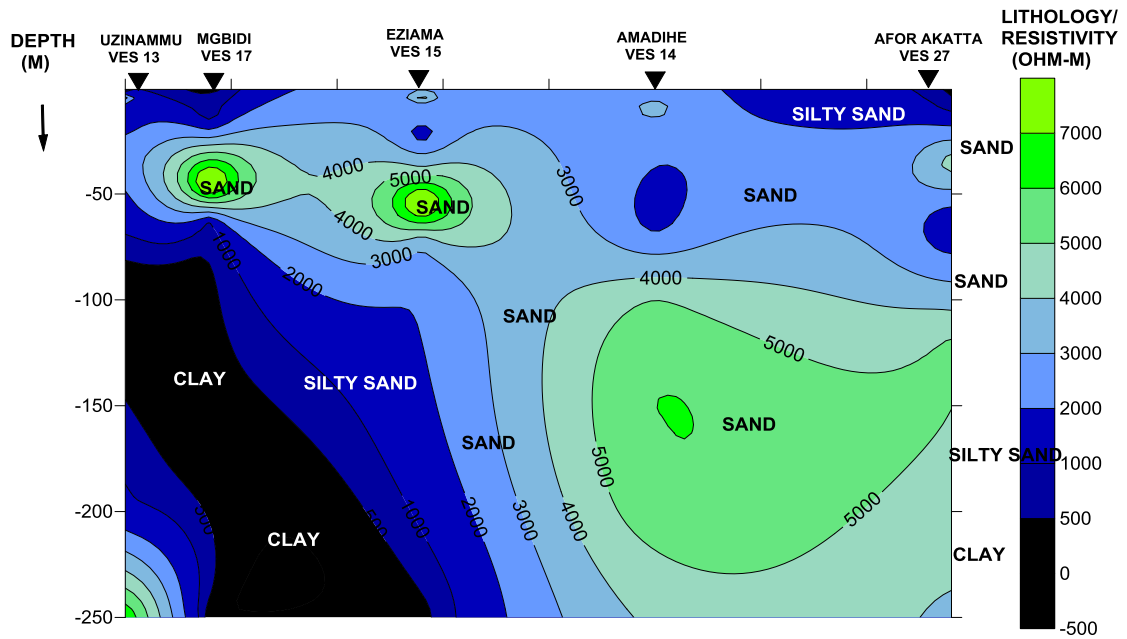


Figure 4.12(a): The Profile of the Study Area in the NE – SW Direction Showing the Lithology

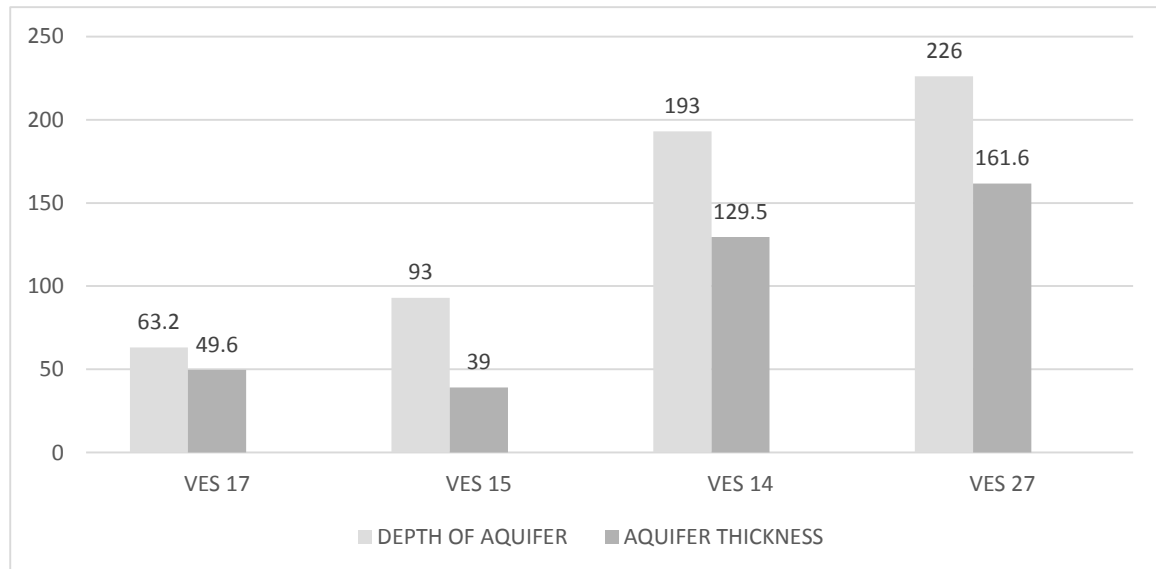


Figure 4.12(b): The Bar Chart Representation of the Study Area along the NE – SW Direction

The profile B-B^I which runs through Akuma, Akwada-Aji, Eziama-Ubulu, Amaebu, Eziani-Mgbidi, Umuabiahu, Mgbidi, Afor Akatta, etc, with corresponding VES Numbers: VES 11, VES 12, VES 13, VES 14, VES 15, VES 16, VES 17, VES 24, VES 25, VES 26 and VES 27. The resistivity values are between <1000 Ω m and >44000 Ω m which are interpreted as sand/sandstone for values from 26000 Ω m to 44,000 Ω m, sand, ranges from 1,000 Ω m to 26,000 Ω m and clay/sandyclay as 0 Ω m to <1,000 Ω m. There is a prominent high resistivity range of values from 6000 Ω m to 26000 Ω m, sand/sandstone units occurring between 10m and 100m. Locations in the middle of the profile have higher resistivity than other places along the profile.

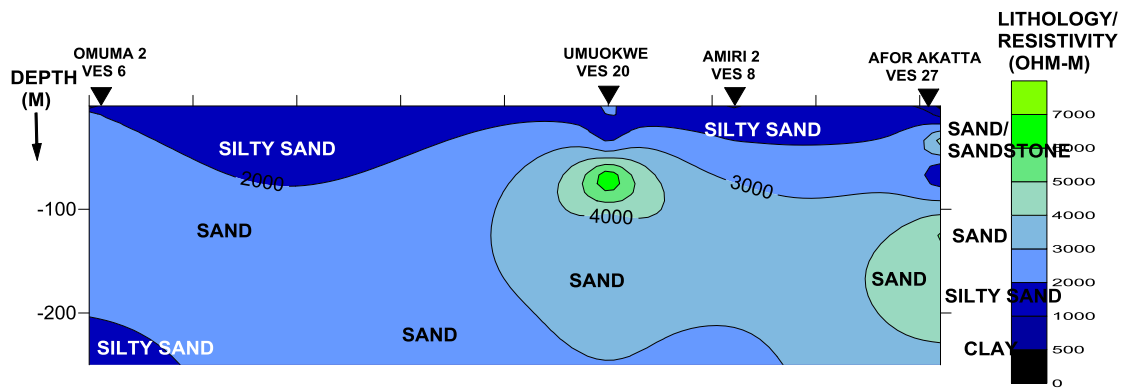


Figure 4.13(a): The Profile of the Study Area in the NNE – SSW Direction Showing the Lithology

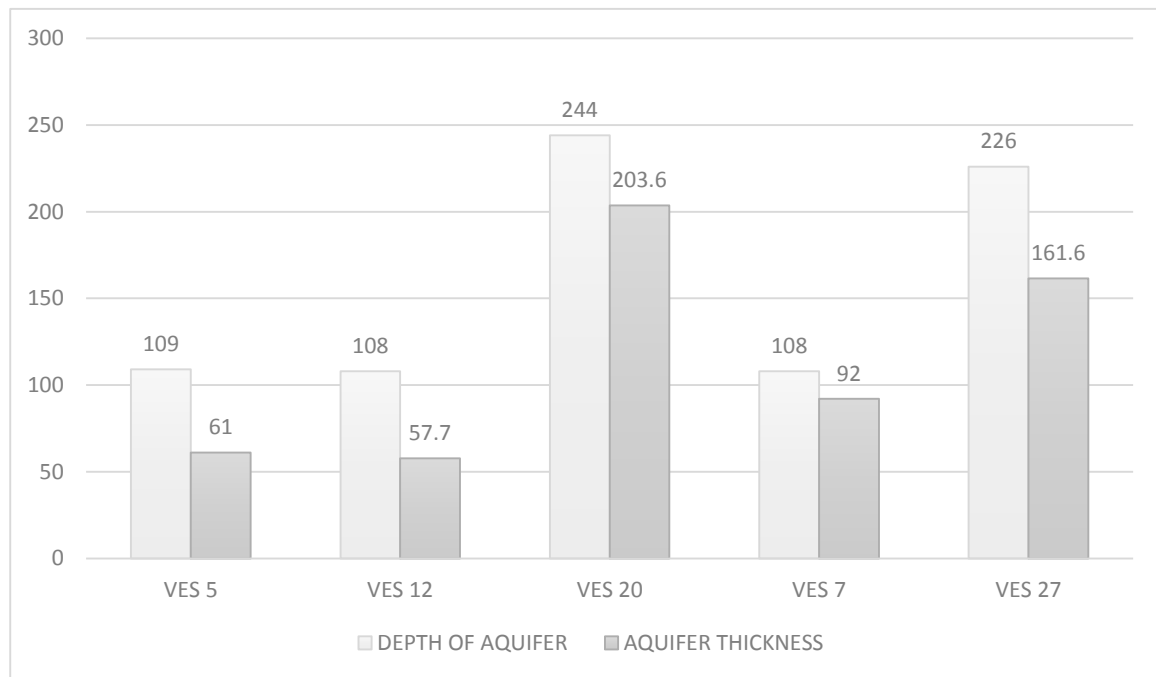


Figure 4.13(b): The Bar Chart Representation of the Study Area along the NNE – SSW Direction

Omuma, Umuejike, Oburu, Ubachima, Afor Akatta are locations situated along profile C-C^I. Their corresponding VES Numbers are: VES 5, VES 12, VES 20, VES 7, and VES 27. The lithology of the area is mainly sandstone, sand and clay; and their resistivities are as follows: sandstone has resistivity ranging from 8,000Ωm to 22,000Ωm; sand ranges from 1,000Ωm to 8,000Ωm and the clay has resistivity that ranges from <10Ωm to <1000Ωm.

4.6 Results of Aquifer Parameters from VES across the Study Area

The results obtained are based on values of modeled VES data (Appendix I; VES 1 - 27) and Da-Zarrock parameters (Table 4.4), were applied to estimate aquifer parameters such as: Depth to water table, aquifer thickness, aquifer conductivity, transverse resistance, longitudinal conductance, storativity as displayed in Table 4.4. and Figure 4.14.

Table 4.4: Result of Aquifer Characteristics/ Parameters

VES No.	Top of Aquifer h ₁ (m)	Bottom of Aquifer h ₂ (m)	Aquifer Thickness h ₁ -h ₂ h(m)	Aquifer Resistivity P(Ωm)	Aquifer Conductivity δ(S) Or(Ωm) ⁻¹	Transverse Resistance R(Ωm ²)	Longitudinal Conductance S=h/p(δ ⁻¹) x10 ⁻²	Storativity, S=3x10 ⁻⁶ h(m) x10 ⁻⁴
1	46	>125	79	17554	5.6967x10-5	1386766	0.45004	2.37
2	32	135	103	9886	1.0115x10-4	1018258	1.0419x10-2	3.09
3	18	>50	32	15548	6.4317x10-5	497536	2.0581x10-3	0.96
4	14	>145	131	4260.8	2.3471x10-4	558125.5	3.0748x10-2	3.93
5	48	>109	61	5484	1.8235x10-4	334524	1.1123x10-2	1.83
6	32	>138	106	13632	7.3357x10-5	1444992	7.7758x10-3	3.18
7	16	>108	92	8822.5	1.1335x10-4	811670	1.0428x10-2	2.76
8	14	>115	101	19532	5.1198x10-5	1972732	5.1710x10-3	3.03
9	32	>60.3	28.3	28210	3.5448x10-5	798343	1.0032x10-3	0.0849
10	39.9	95	55.1	3373.3	2.9645x10-4	185868.83	1.6334x10-2	1.653
11	56.5	>110	53.5	2780	3.5971x10-4	148730	1.9245x10-2	1.605
12	50.3	>108	57.7	8885	1.1255x10-4	512664.5	6.4941x10-3	1.731
13	161	>201	40	4100	2.4390x10-4	164000	9.7561x10-3	1.2
14	63.5	>193	129.5	5810	1.7212x10-4	752395	2.2289x10-2	3.885
15	54	93	39	4823.3	2.0733x10-4	188108.7	8.0858x10-3	1.17
16	38	>247	209	11710	8.5397x10-5	2447390	1.7848x10-2	9.27
17	13.6	63.2	49.6	4186.7	2.3885x10-4	207660.32	1.1847x10-2	1.488
18	29.3	145	115.7	3178	3.1466x10-4	367694.6	3.6407x10-2	3.471
19	26.7	>231	204.3	16376	6.1065x10-4	3345616.8	1.2476x10-2	6.129

20	40.4	>244	203.6	3743.3	2.6714x10-5	762135.88	5.4391x10-2	6.108
21	32.1	>258	225.9	4002	2.4988x10-4	904051.8	5.6447x10-2	6.777
22	40.5	144	103.5	8645	1.1567x10-4	894757.5	1.1972x10-2	3.105
23	39.9	112	72.1	7430	1.3459x10-4	535703	9.7039x10-3	2.163
24	22.3	>131	108.7	2855	3.5026x10-4	310338.5	3.8074x10-2	3.261
25	22.2	42.7	20.5	4350	2.2989x10-4	89175	4.7126x10-3	0.615
26	34.5	>196	161.5	4810	2.0790x10-4	776815	3.3576x10-2	4.845
27	64.4	>226	161.6	4440	2.2523x10-4	717504	3.6396x10-2	2.37

4.6.1 Depth to Water Table

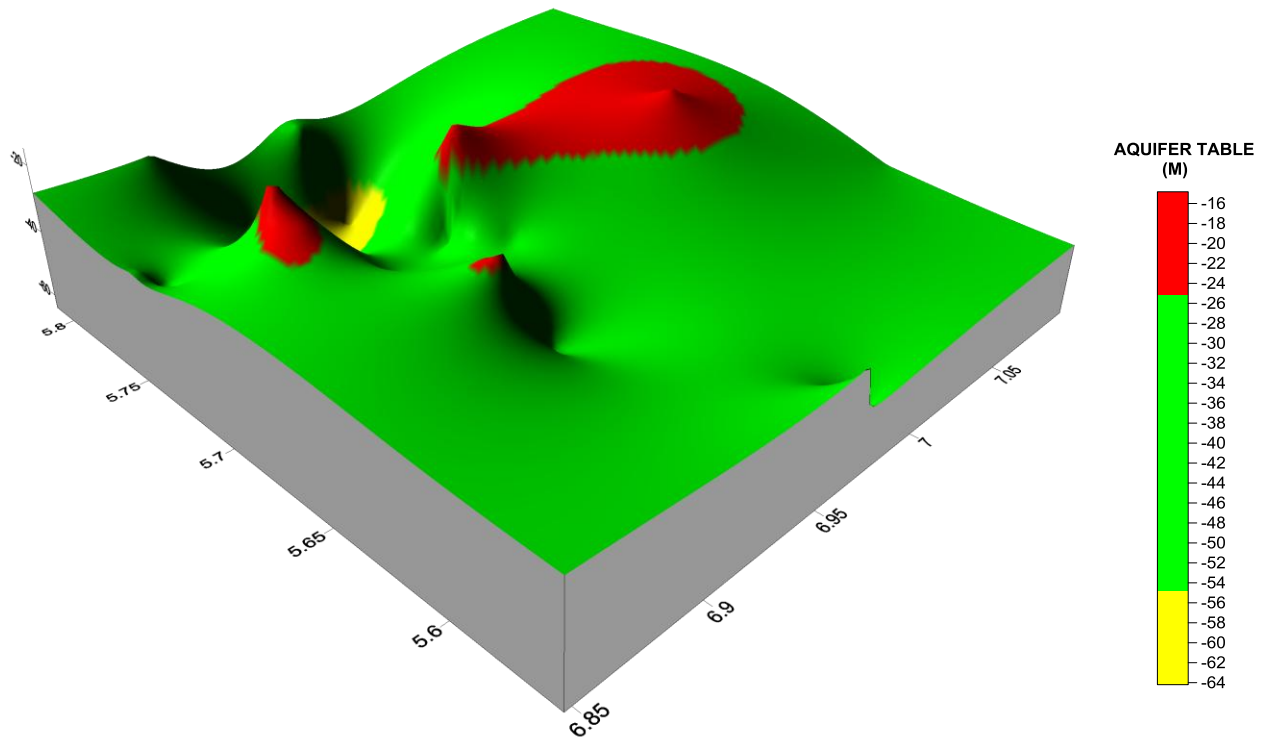


Figure 4.14: Showing the 3D Model of the Depth to Water Table (m) of the Study Area (Based on VES data)

From the map of Depth to water table in Figure 4.12 obtained from Table 4.4, it shows a varying distribution of aquifer depth in various parts of the study area. The area that is represented with red colour has a shallow aquifer from 15m to 25m and it trends to the North-East axis of the study area. The following towns and villages: Amagu, Ura-Akatta, Umuehi-Uzinaumu-Mgbidi etc. fall within it. Places such as Eziaji Village, Akwada Aji Oru, Eziamu Ubulu, Umuejike Umuokwe, etc have their water table within 25m to 55m and they are represented with green colour have moderately deep aquifer; however, the areas that are represented with yellow colour have a relatively deeper aquifer and they are located at places like: Ohakpu, Umudoji-Umuokwe-Awo-Omamma, Umuejikeadim-Obibi Awo-Omamma etc.

4.6.2 Aquifer Thickness

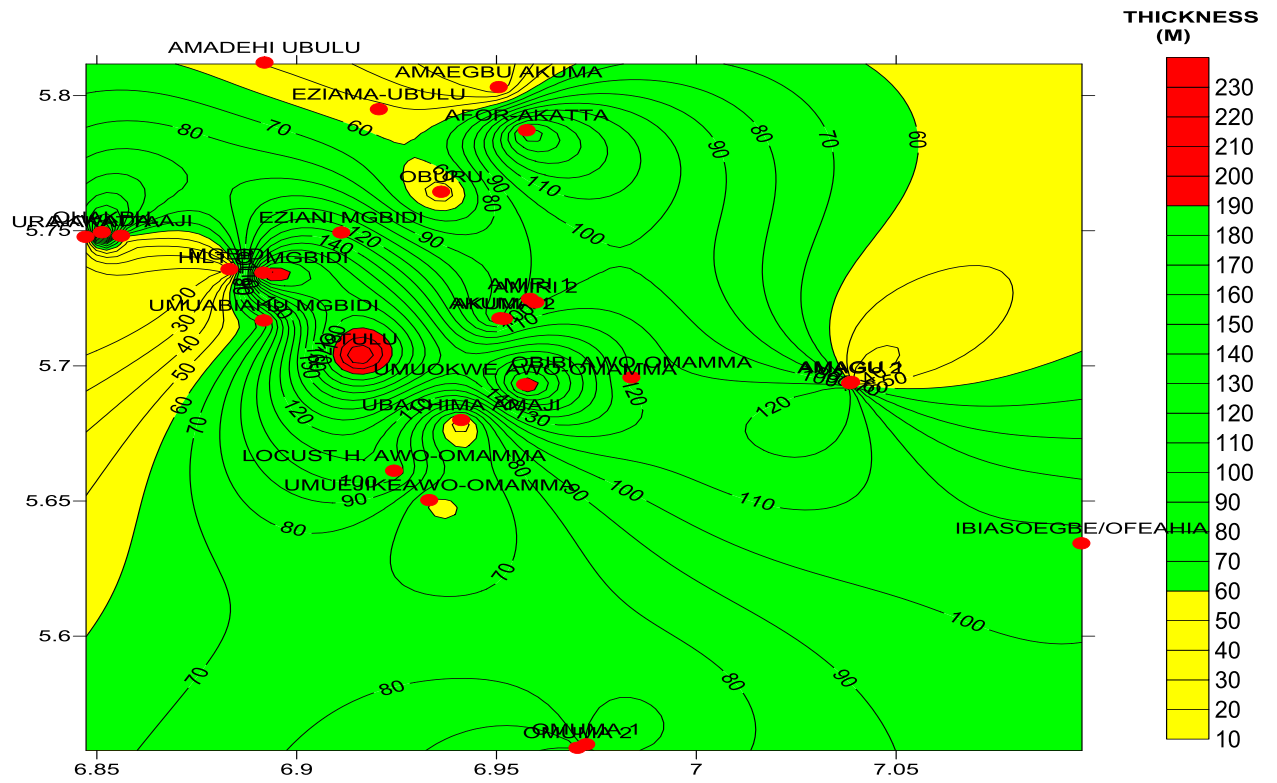


Figure 4.15(a): The Spatial Variation Map of Aquifer Thickness (m) of the Study Area

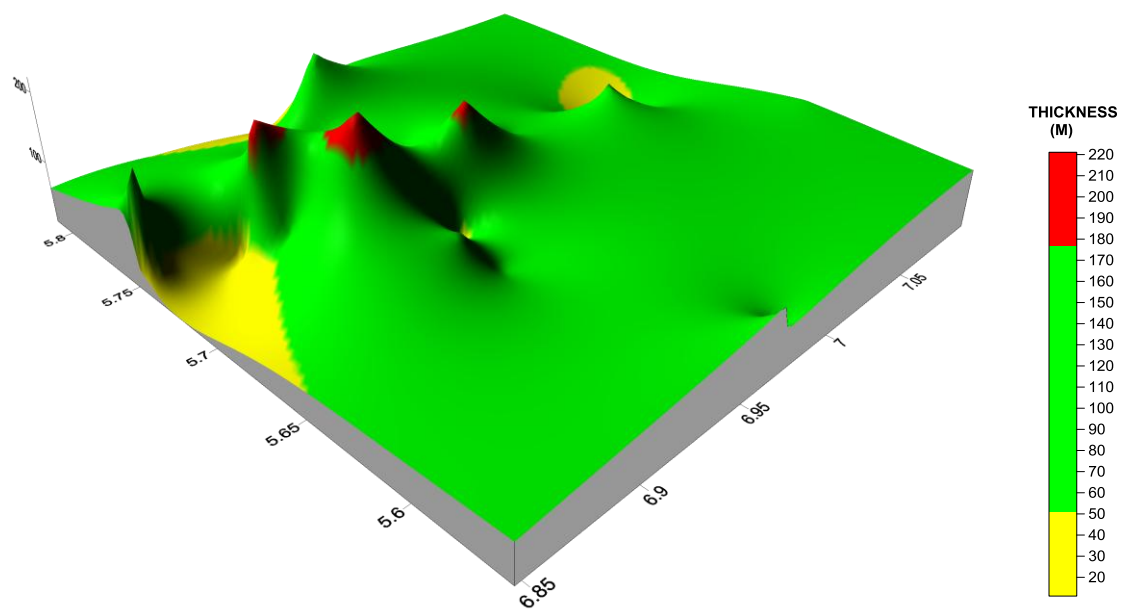


Figure 4.15(b): The 3D Model of the Aquifer Thickness (m) of the Study Area

From the isopach map in Figures 4.13(a) and 4.13(b), it shows how the various aquifers in the study area vary in thickness. Almost the whole parts marked with green colour have a thick aquifer range of about 50m to 130m except few places like Umuabahu Mgbidi, Akwada Aji, Amagu etc. In the north-western part and partly northern part that is marked with yellow colour have a relatively thinner aquifer of about 10m to 50m. Also red colour denotes a range of 180m to 220m and it is inundated along a NW-SE trend around Otulu Umuokwe.

4.6.3 Aquifer Resistivity

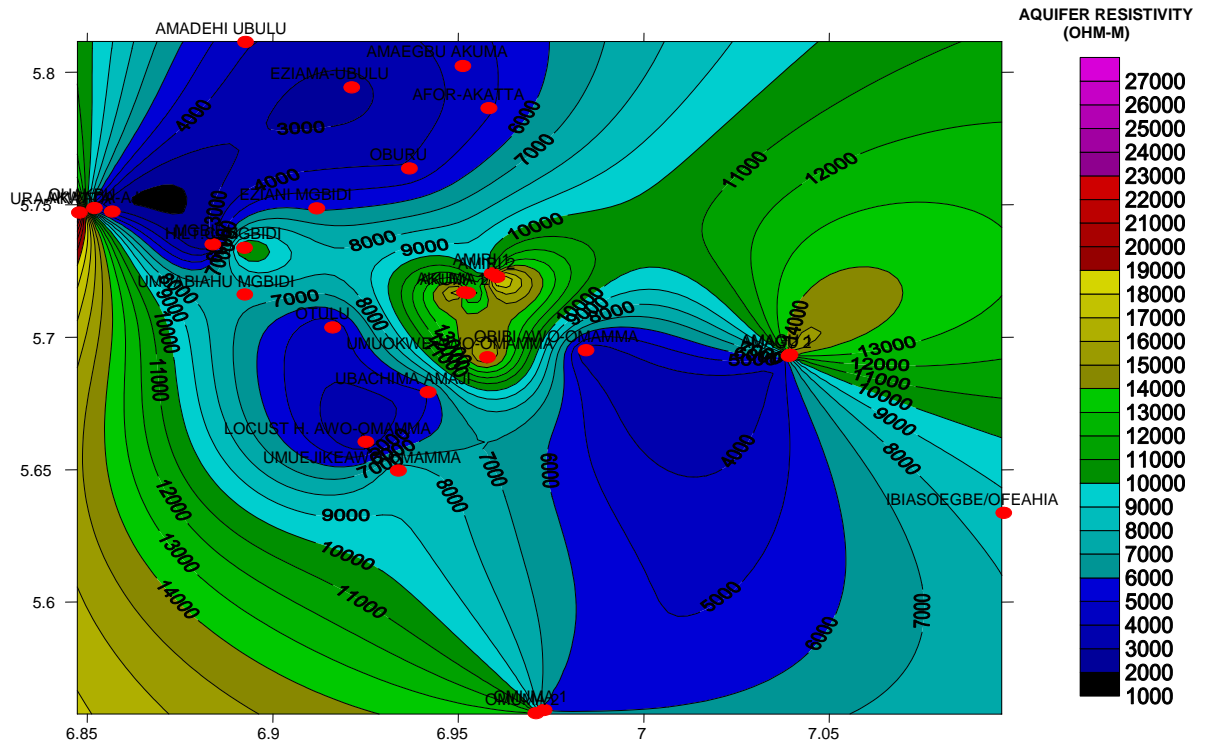


Figure 4.16(a): The Spatial Variation Map of the Aquifer Resistivity (Ωm) of the Study Area

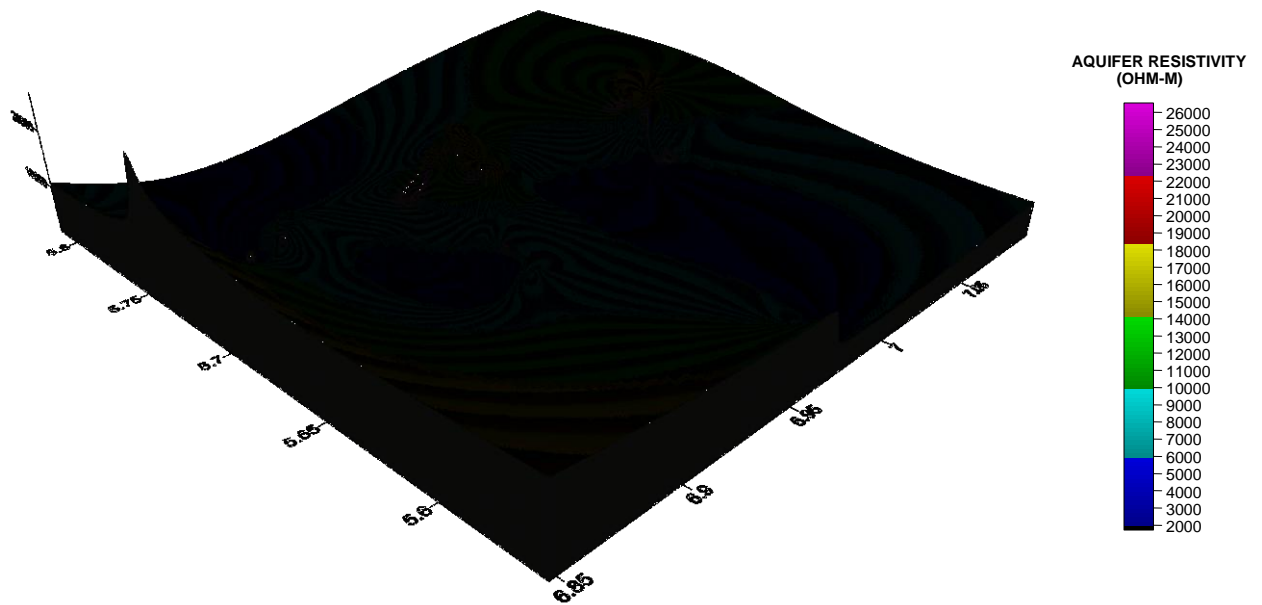


Figure 4.16(b): The 3D Model of Aquifer Resistivity (Ωm) of the Study Area

The resistivity of an aquifer serves as a yardstick or the basics for inferring or determining the aquiferous unit or the water bearing unit of any place. By implication, places that have a lower resistivity cannot be the aquiferous unit; but places which have a much higher resistivity when compared to others, will be the aquiferous unit. In Figures 4.14(a) and 4.14(b) most parts have high aquifer resistivity, but there are some areas that have higher aquifer resistivity than others. Locations such as Ibiasoegbe/Ofeahia, Omuma, Awo Omamma, Locust hotel, Umuabiahu Mgbidi, Eziana Ubulu, Afor Akatta, Amaebu Akuma have resistivity values of about 2,000 Ωm to 10,000 Ωm with colour indications of black, navy blue, and blue colours, while places like Amagu, Akuma, Amaji, Amiri, Ura Akatta, Umuokwe Awo Omamma have a relatively higher resistivity of about 10,000 Ωm to 18,000 Ωm ; and they are indicated by green, yellow, and orange colours. The highest resistivity in the range of 19000 Ωm to 27000 Ωm occurred around Amiri

places are overlain by clay, mud, shale, somewhat silt and siltyclay Whereas places like Akuma, Amiri, Omuma, Ibiasoegbe and Ofeahia etc. contain a thick/thicker volume of sand and sandstones lithologies.

4.6.5 Transverse Resistance

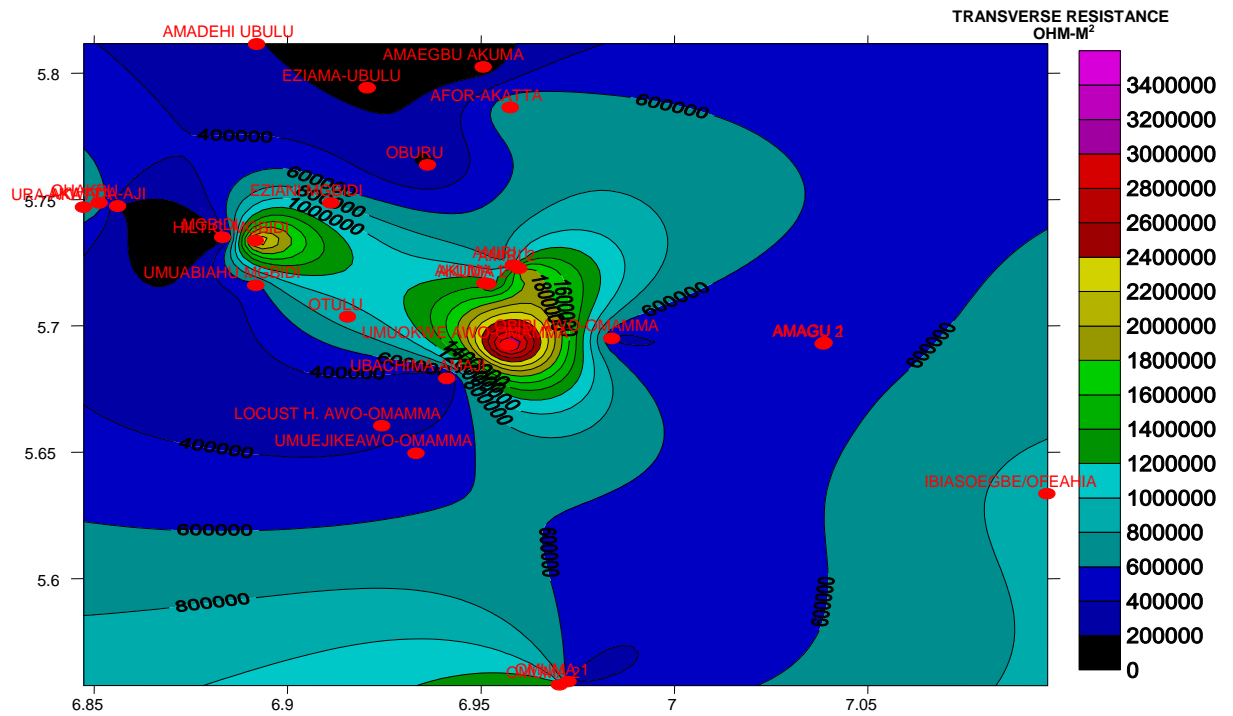


Figure 4.18(a): The Spatial Variation Map of Transverse Resistance ($\text{ohm}\cdot\text{m}^2$) of the Study Area

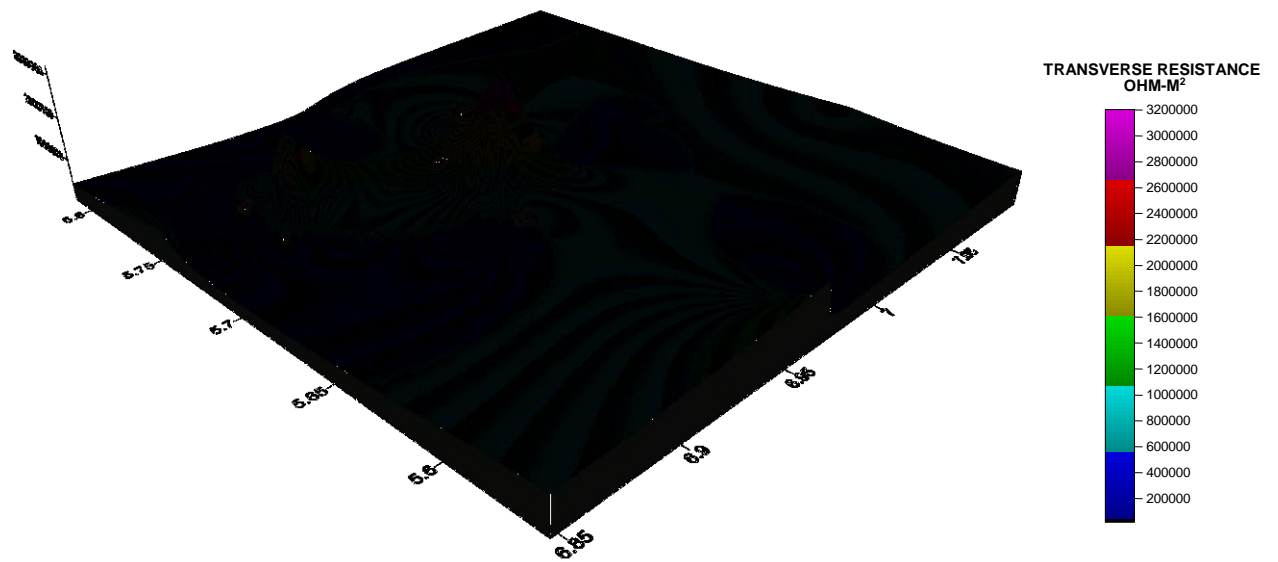


Figure 4.18(b): The 3D Model of the Transverse Resistance ($\text{ohm}\cdot\text{m}^2$) of the Study Area

Transverse resistance is the measured resistance along the horizontal profiling of an area of study. What that means is to determine how the resistance of an area or a ground surface varies from place to place as one moves/pulls away from his original position. Transverse resistance within and across the study area was estimated by simply taking into account the products of both the aquifer resistivity and aquifer thickness, Figures 4.16(a) and 4.16(b). The distribution of this transverse resistance shows that low transverse resistance values of about $0\Omega\text{m}^2$ to $1,000,000\Omega\text{m}^2$ as shown with the light and dark blue colours above is found at the south-eastern and far north-western parts of the maps above and it can be found in such towns as Ibiasoegbe/Ofeahia, Otulu, Umuejike Awo-Omamma etc. but it began to increase towards the central and near north-western parts as indicated by the green, yellow, red and purple colours in the maps above from about $1,000,000\Omega\text{m}^2$ to $3,200,000\Omega\text{m}^2$ and some towns within the area are: Umuokwe Awo-Omamma, Ubachima, Amaji, Akuma, Amiri, Mgbidi etc.

The longitudinal conductance was estimated on the division of aquifer thickness and the aquifer apparent resistivity, Table 4.4 and the distribution of it across the study area indicates that an upward maximum values are found towards the central part of the maps and that the minimum values are scattered around the outermost parts as shown in Figure 4.19.

4.6.7 Transmissivity

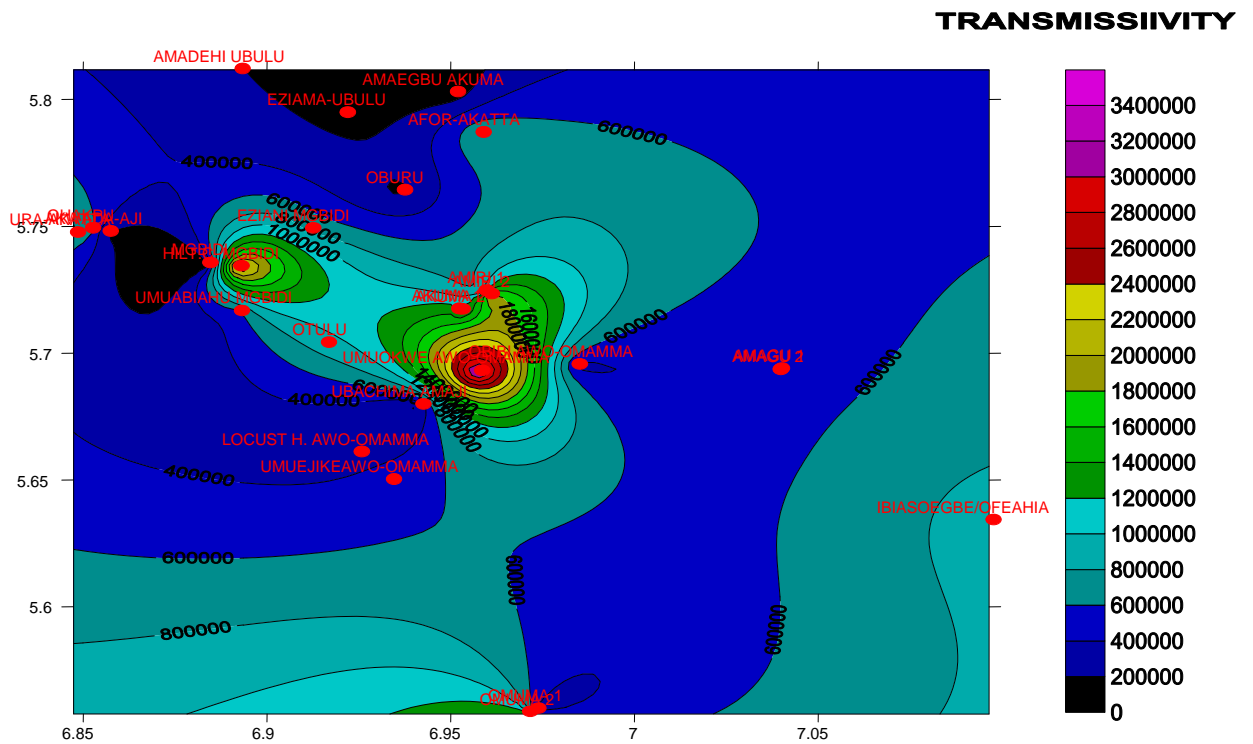


Figure 4.20 (a): The Spatial Variation Map of Transmissivity (M^2/Day) of the Study Area

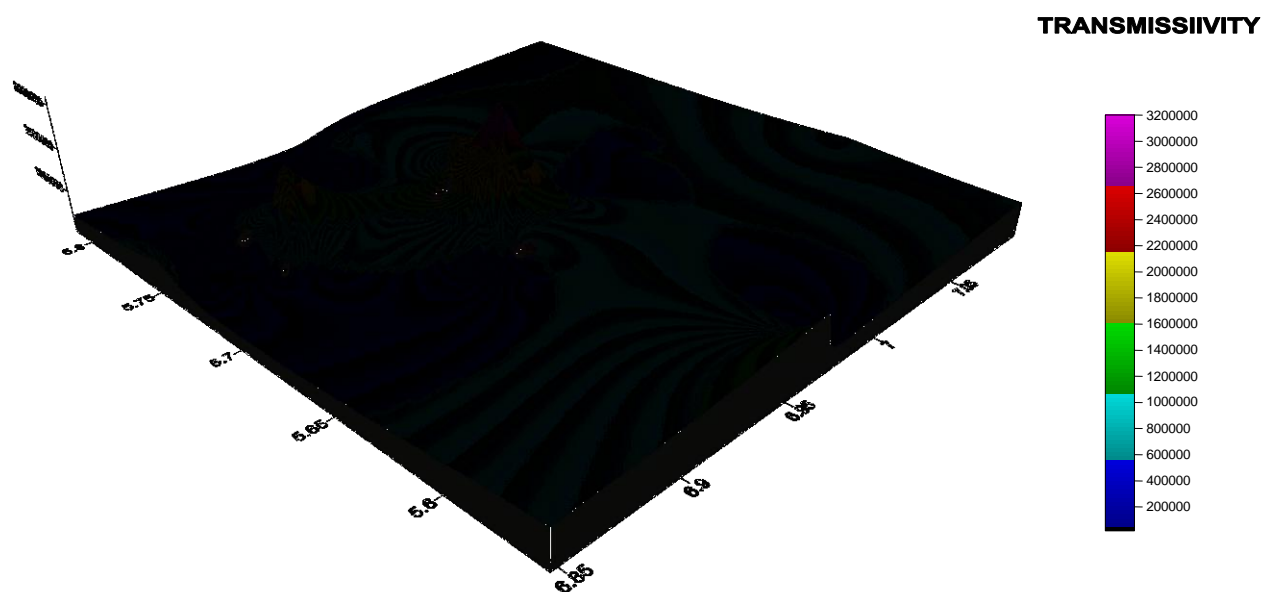


Figure 4.20 (b): The 3D Model of Transmissivity (M^2/Day) of the Study Area

The central part: Amiri, Akuma, Umuokwe-Awo-Omamma, Ubachima, Umuabiahu Mgbidi which has a very high rate of transmissivity that ranges from 1200000 m²/day to 3400000 m²/day is marked with green, yellow, red and purple colours. Omuma which occurs at the tail end of the southern part also has a very high transmissivity. On the other hand, places like Amagu, Ibiasoegbe/Ofeahia, Locust Hotel Awo-Omamma, Umuejike Awo-Omamma with a colour indication of light blue and dark blue colours, also have a high transmissivity but not as high as the ones above; their values is within the range of 0m²/day to 120000m²/day.

4.6.8 Hydraulic Conductivity

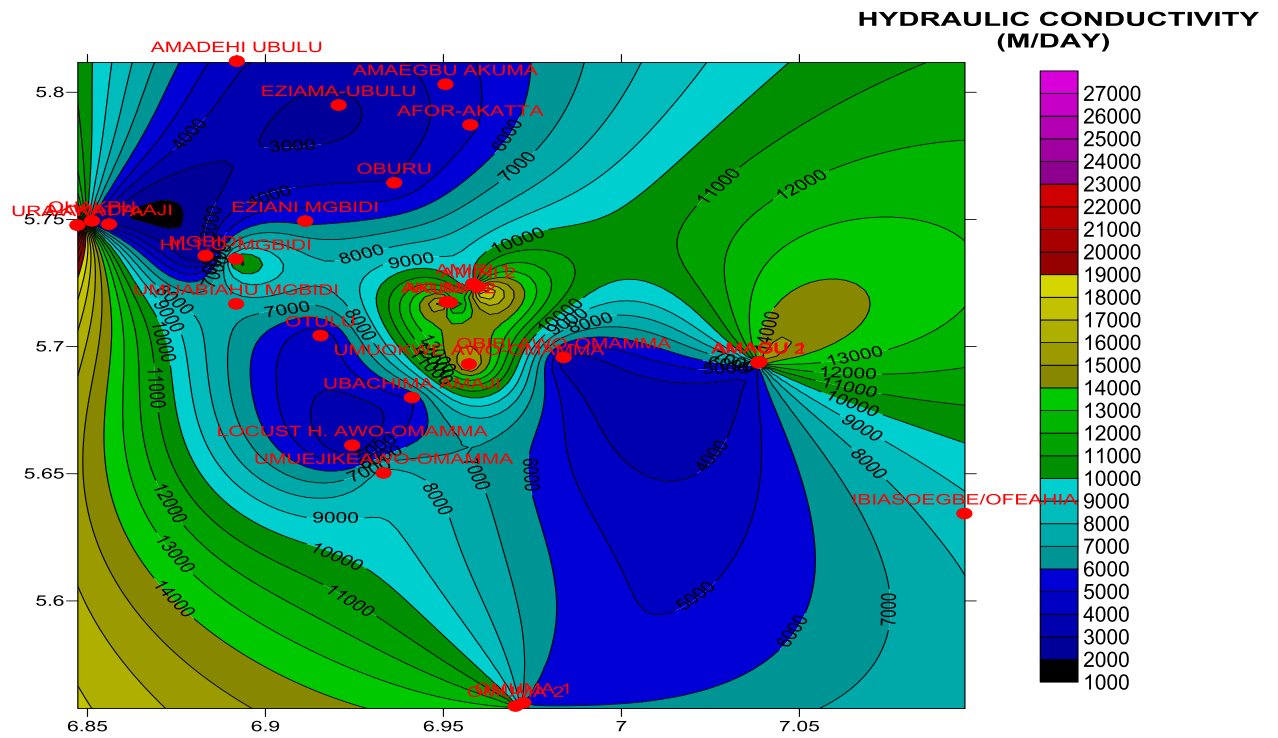


Figure 4.21 (a): The Spatial Variation Map of Hydraulic Conductivity (m/day) of the Study Area

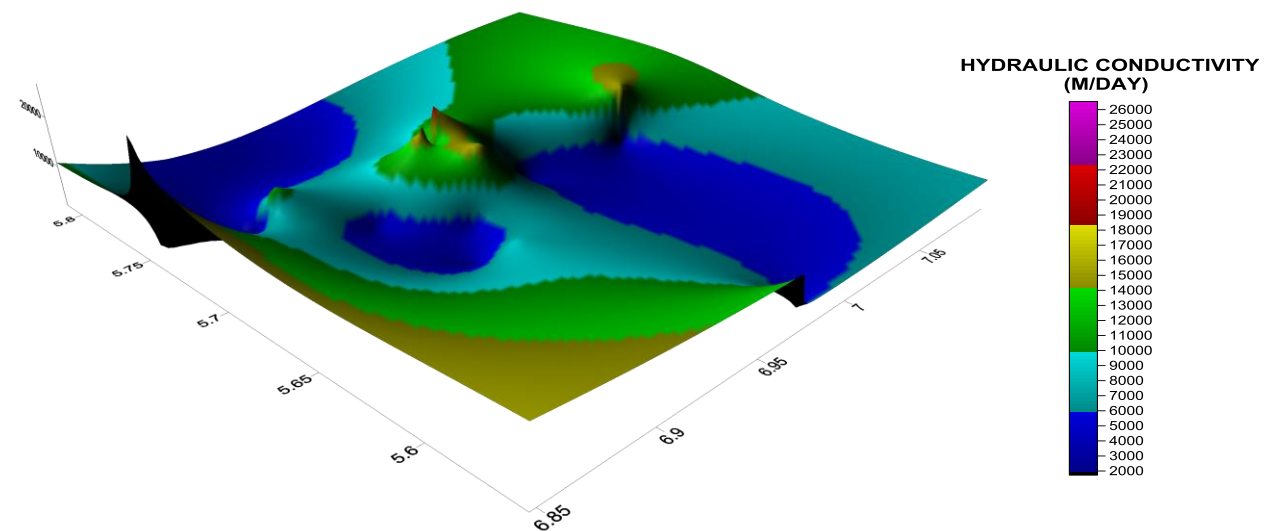


Figure 4.21 (b): The 3D Model of Hydraulic Conductivity (m/day) of the Study Area

Hydraulic conductivity, K , is used to describe the ability of a material to conduct fluids under a unit hydraulic gradient (Fetter, 1994). In this research, the hydraulic conductivity was estimated from the product of the diagnostic constant and the aquifer conductivity. The hydraulic conductivity range within the study area ranges from 2000 m/day-5000 m/day at Amagu, Ubulu, Awo-Ommama, etc; 6000 m/day -10000 m/day in Mgbidi, Ibiasoegbe and some parts of Awo-Ommama; 14000 m/day – 19000 m/day Amiri, Amagu, Amaebu.

From the map, and from all indications, it is observed that the study area is basically underlain by the Benin formation, a formation that is widely known to have the ability to contain a large volume of fluid including groundwater. From the results, it shows that some towns like: Ibiasoegbe/Ofeahia have a low value of hydraulic conductivity of about 1000 m/day and they are those areas marked with light and dark blue colours occurring at the north-western, central and south-eastern parts of the map.

However, other communities occurring at the north-eastern and south-western parts of the map, within the study area like: Mgbidi, Akuma, Amagu, Omuma have a very high hydraulic conductivity and this indicates that the area has the proficiency of yielding from 10,000 m/day up to 27,000 m/day and it has such colour variance as green, yellow, red and purple colours.

4.6.9 Aquifer Storativity

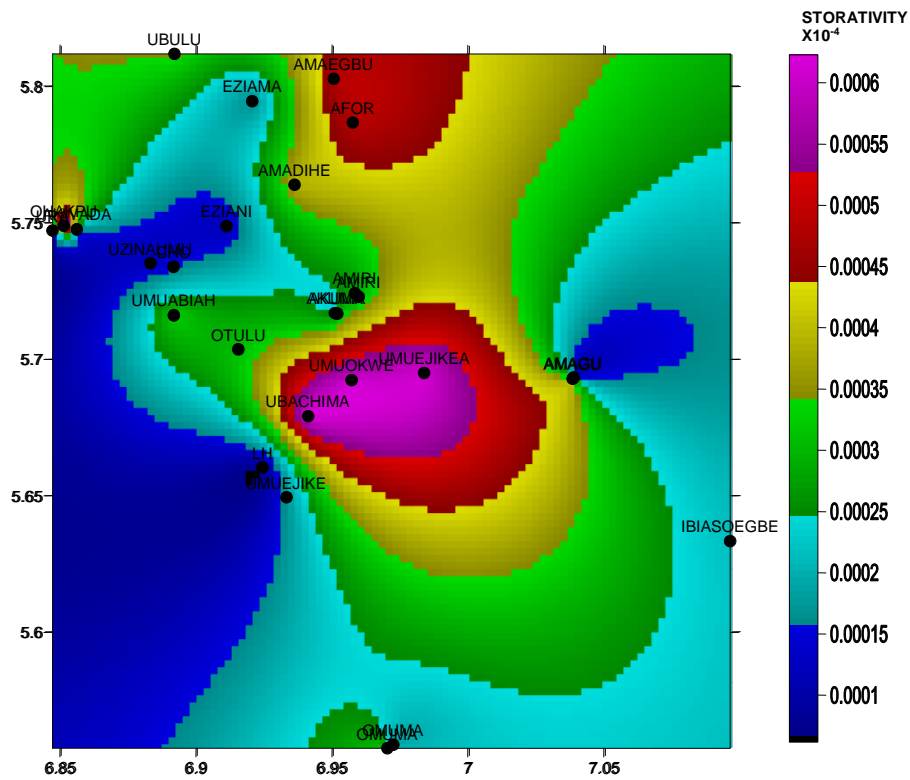


Figure 4.22 (a): The Spatial Variation Map of Storativity of the Study Area

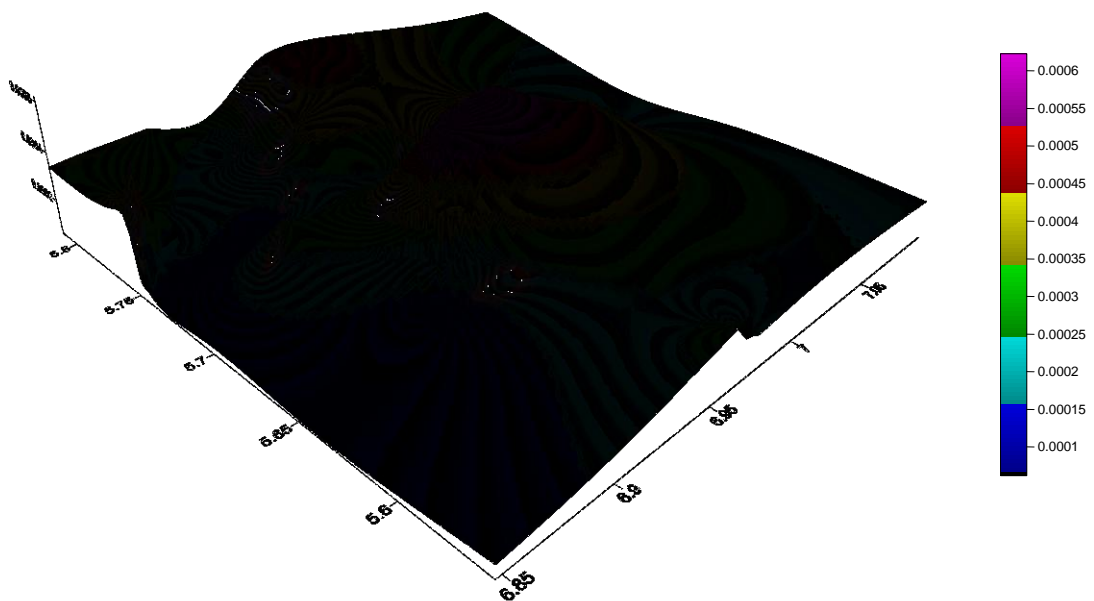


Figure 4.22 (b): The 3D Model of Storativity of the Study Area

Aquifer Storativity coefficient is the amount of water an aquifer releases or takes into storage. The numerical value that is assigned to an aquifer is its storativity; and it is a dimensionless value. Storativity was determined from the rule of thumb according to Lohman (1972): $S = 3 \times 10^{-6}h$. The distribution of the aquifer storativity within the study area indicates that the area is characterized with very high storativity values; while some areas have a moderately high storativity values. Communities like: Afor-Akatta, Eziani-Mgbidi, Ubachima, Umuejike Awo-Omamma, Ibiasoegbe and Ofeahia are those areas that have a relatively higher storativity values ranging within the neighbourhood of 0.00025 (2.5×10^{-4}) to 0.0006 (6.0×10^{-4}) with colour indications of green, yellow, red and purple as can be seen in Figures 4.22(a) and 4.22(b). Then towns like: Eziana-Ubulu, Amaebu, Akuma, Oburu, Amadehi Ubulu, Umuabiahu, Akuma etc are those places that have a relatively moderately high storativity values that fall within the neighbourhood of 0 – 0.0001 (1.0×10^{-4}) to 0.00025 (2.5×10^{-4}) and they are marked with such colours like black, dark blue and light blue.

4.7 Aquifer Vulnerability Assessment

The determination of the groundwater vulnerability index of the study area was determined using the DRASTIC model as shown in Table 4.5.

Table 4.5: Summary of Aquifer DRASTIC Vulnerability Ratings

VES NO	D		R		A		S		T		I		C		DRASTIC Index	Vulnerability Ratings
	R	W	R	W	R	W	R	W	R	W	R	W	R	W		
1.	1	5	9	4	9	3	8	2	10	1	8	5	8	3	158	HIGH
2.	1	5	9	4	8	3	9	2	10	1	8	5	8	3	157	HIGH
3	3	5	9	4	9	3	8	2	10	1	1	5	8	3	133	MODERATE
4	3	5	9	4	8	3	8	2	10	1	3	5	8	3	140	MODERATE
5	1	5	9	4	8	3	7	2	9	1	1	5	8	3	117	MODERATE
6	1	5	9	4	9	3	4	2	9	1	8	5	8	3	149	HIGH
7	3	5	9	4	8	3	8	2	10	1	8	5	8	3	165	HIGH
8	3	5	9	4	9	3	8	2	10	1	8	5	8	3	168	HIGH
9	1	5	9	4	5	3	10	2	10	1	8	5	8	3	150	HIGH
10	1	5	9	4	8	3	10	2	9	1	8	5	8	3	158	HIGH
11	1	5	9	4	3	3	10	2	10	1	8	5	8	3	144	HIGH
12	1	5	9	4	8	3	4	2	8	1	8	5	8	3	145	HIGH
13	2	5	9	4	8	3	4	2	9	1	8	5	8	3	151	HIGH
14	1	5	9	4	8	3	10	2	10	1	8	5	8	3	159	HIGH
15	1	5	9	4	8	3	10	2	10	1	8	5	8	3	159	HIGH

16	1	5	9	4	9	3	4	2	10	1	9	5	8	3	155	HIGH
17	5	5	9	4	8	3	4	2	10	1	8	5	8	3	167	HIGH
18	2	5	9	4	8	3	1	2	10	1	8	5	8	3	146	HIGH
19	2	5	9	4	9	3	8	2	10	1	8	5	8	3	155	HIGH
20	1	5	9	4	8	3	8	2	10	1	8	5	8	3	147	HIGH
21	1	5	9	4	8	3	10	2	9	1	8	5	8	3	158	HIGH
22	1	5	9	4	8	3	4	2	10	1	8	5	8	3	147	HIGH
23	1	5	9	4	8	3	10	2	10	1	3	5	8	3	134	HIGH
24	2	5	9	4	8	3	10	2	9	1	8	5	8	3	163	HIGH
25	2	5	9	4	8	3	10	2	9	1	1	5	8	3	128	MODERATE
26	1	5	9	4	8	3	10	2	10	1	8	5	8	3	159	HIGH
27	1	5	9	4	8	3	4	2	10	1	1	5	8	3	112	MODERATE

$$\text{DRASTIC Index (DI)} = \text{DrDw} + \text{RrRw} + \text{ArAw} + \text{SrSw} + \text{TrTw} + \text{IrIw} + \text{CrCw}$$

The vulnerability ratings are grouped into moderate and high within the study area. There are few locations that fall under moderate vulnerability namely: VES 3, VES 4, VES 5, VES 25 and VES 27 and their respective drastic index are 133, 140, 117, 128, and 112. The drastic index range for moderate is 112 to 140 while 141 to 168 are for high, Figure 4.23(a). The moderate vulnerability area constitutes about 18.52% and the high vulnerability area form 81.48% of the total area. Towns located within the moderate rating are Omuma, Ibiasoegbe, Amagu and Akatta while towns such as Otulu, Awo-Omamma, Mgbidi, Ubulu, Akuma, etc, are rated as high vulnerability areas. This can be observed clearly in figure 4.23 (a) and 4.23 (b) where peaks indicate high vulnerability areas and they are in violet, red and yellow colours whereas dark blue, light blue and green colours lie on a plain and low landscape forms describe the moderate vulnerability rated areas.

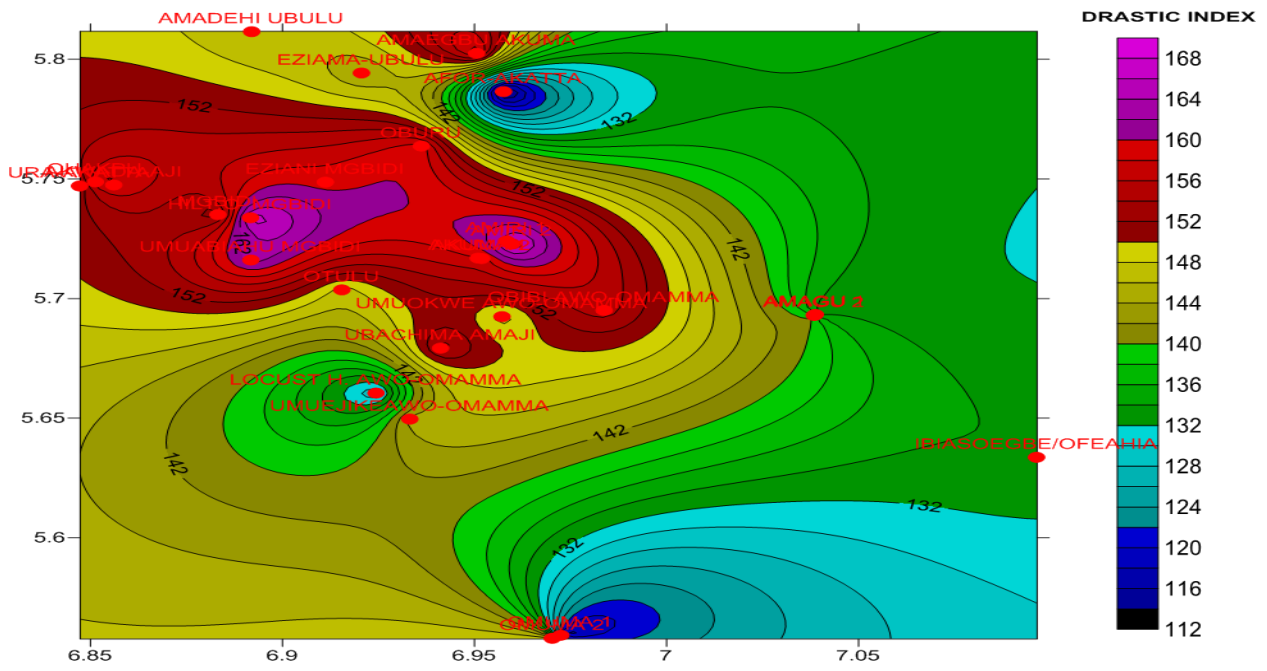


Figure 4.23 (a): The Spatial Variation Map of the DRASTIC Index of the Study Area

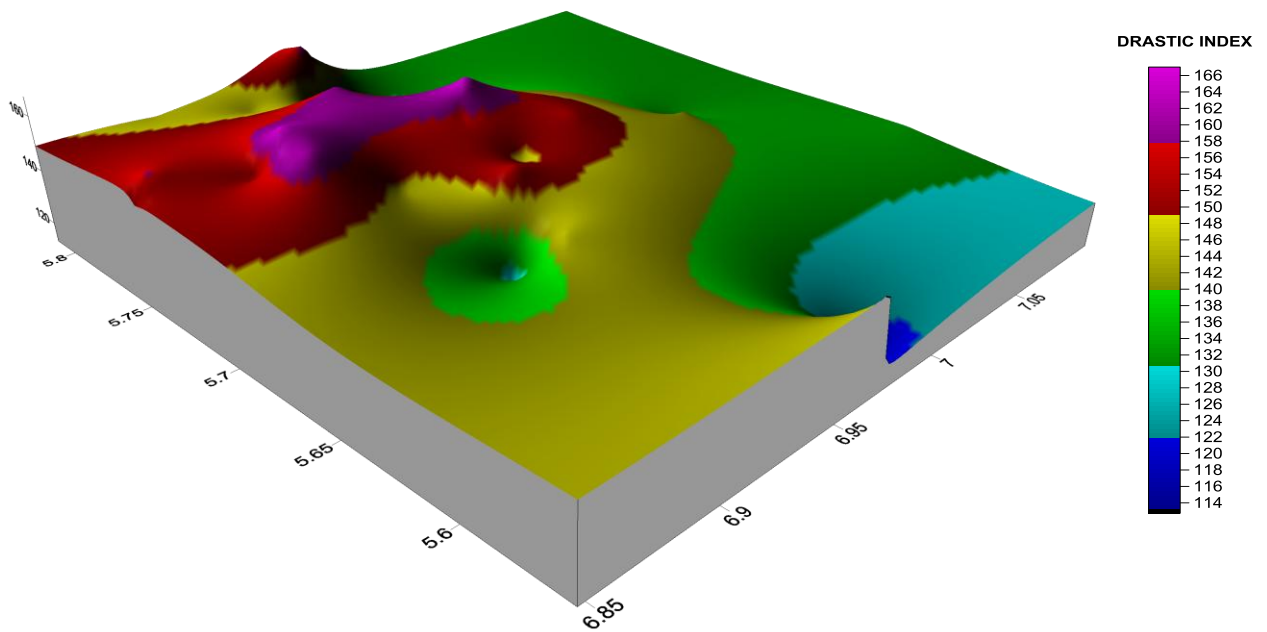


Figure 4.23 (b): The 3D Model of the DRASTIC Index of the Study Area

CHAPTER FIVE

DISCUSSION, CONCLUSION, RECOMMENDATIONS AND CONTRIBUTION TO KNOWLEDGE

5.1 Discussion

The geoelectric layers show that the study area is predominantly composed of sand units (Appendix II). Starting from Akuma, Amagu, Omuma, Amiri down to Ohakpu, Otulu, Uzinaumu, Amadihe, Ubachima, Awo-Omamma, Mgbidi, Ibiasoegbe and Ofeahia communities, it is observed that the areas which made up of mainly sands and sandy units, in some occasions would have intercalations of clay, and sandy clay or clayey sand units as the case would be is overlain by the Benin Formation. Based on the literature, it has been revealed that the geology of the Benin Formation is the type that has mostly of sandy units with clay/shale at the basal part of the Formation, Uma, 1989; Mbonu, 1991.

In the study area: Oru East and Oru West L.G.As. of Imo State, south-eastern, Nigeria, the area falls within the Benin Formation of the Niger Delta Basin which is the youngest formation of the whole three formations within the basin, others being Akata Formation and Agbada Formation. The Benin Formation has been adjudged to be made up of coastal plain sands and to be highly prolific in groundwater potential and supply (yield) by the several authors and workers in southern Nigeria based on the literature review.

This research work was intended to obtain vertical electrical soundings of the area and interpret them; to draw the geo-electric sections using the vertical electrical soundings; to determine the depth to water table of the area; to compute the hydraulic characteristics of the study area; to draw the vulnerability map of the area.

The quantitative description of the curves types identified are HK, A and K (the major ones), others are KHK, KH, H and Q (the minor ones). The predominantly curve types HK, A and K constitute about 33.3%, 29.6%, 22.2% respectively each of the total curve types. Others like: KHK, KH, H and Q constitute about 3.7% each of the total curve types. The general sequence of the entire curve types indicates a sequence that alternates between resistive to conductive layers. There are eleven lithologs that were used in this analytical comparison between lithological logs and geoelectric layers (sections). Meanwhile, there are three profiles that were drawn across the study area i.e. they are Profile A-A^I or Profile that traverse in the east-west direction, Profile B-B^I or the profile that traverse the north-east and south-west directions, and Profile C-C^I or the profile that traverse in the north-south direction. But, for easy comparisons, in each of these profiles, a total of two lithologs were used to make the comparison i.e. the comparison between the geoelectric section (layers/stratum/body/medium) and the lithological logs (lithologs). In the case of profile A-A^I or Profile that traverse in the North-South direction, the Vertical Electrical Sounding (VES) numbers 3, 19 and 20 were used, In the case of Profile B-B^I or the profile that traverse the North-East and South-West directions, the Vertical Electrical Sounding (VES) numbers 17, 14, 15 and 27 were used and in the case of Profile C-C^I or the profile that traverse in the North North East – South South West direction, the Vertical Electrical Sounding (VES) numbers 5, 20, 7 and 27 were used for this purpose. It is a general rule in the Vertical Electrical Sounding experiment of the Electrical resistivity method of the geophysical prospecting that the effective depth of penetration is two-third, $\frac{2}{3}$ of half of the current electrode, i.e. $\frac{AB}{2}$, the downward continuation of the resistivity value of the VES points across the study area gave rise to the iso-resistivity map which shows variations of resistivity at specified intervals at $\frac{AB}{2}=1.00\text{m}$ to $\frac{AB}{2}=300.00\text{m}$. In terms of topography, the study area has an even surface (flat surface) or topography due to the outward almost flat terrain but due to the fact that the earth is not flat naturally but spherical

in shape and due to the fact that some areas especially those areas surrounded by rivers and some other small water bodies i.e. the land adjoining rivers and water bodies in the area are lower in elevation while those areas that are farther from the water bodies are higher in elevation; and due to the fact also that the mean sea level has 0m elevation using it as a reference point, the areas towards the land will naturally begin to have an increasing elevation. The areas with a shallow aquifer are places like: Amagu, Ura-Akatta, Umuehi-Uzinaumu-Mgbidi etc; the areas with a moderate aquifer are places like: Eziaji Village Akwada Aji Oru, Eziana Ubulu, Umuejike Umuokwe etc. while the areas with a deep aquifer are places like: Ohakpu, Umudoji-Umuokwe-Awo-Omamma, Umuejikeadim-Obibi Awo-Omamma etc. The apparent resistivity in the area ranges from around $2000\Omega m$ to far above $22,000\Omega m$. In terms of aquifer conductivity, the values obtained in the study area ranges from $6E.005 (\Omega m)^{-1}$ – $0.00020 (\Omega m)^{-1}$ to $0.00020 (\Omega m)^{-1}$ - $0.00052 (\Omega m)^{-1}$. The transverse resistance within and across the study area was estimated by simply taking into account the products of both the Aquifer Resistivity and Aquifer Thickness. The distribution of this transverse resistance shows that low transverse resistance values of about $0 \Omega/m^2$ to $1,000,000 \Omega/m^2$ found at Ibiasoegbe/Ofeahia, Otulu, Umuejike Awo-Omamma and environs etc. while on the contrary, a high transverse resistance values of about $1,000,000 \Omega/m^2$ to $3,200,000 \Omega/m^2$ are found at Umuokwe Awo-Omamma, Ubachima, Amaji, Akuma, Amiri, Mgbidi etc. all within the study area. The longitudinal conductance of the study area ranges from $1.0032 \cdot 10^{-3}$ at Ura-Akatta to 0.45004 at Akuma 1. Other areas that have relatively low longitudinal conductance include: Amagu 1, Omuma 2, Amiri 2, Umuejike, Eziani, Ibiasoegbe, Locust Hotel Awo-Omamma while the town that have relatively high longitudinal conductance are Ohakpu, Umuokwe Awo-Omamma, Umuabiahu etc. The distribution of aquifer transmissivity within the study area shows that towns like: Amiri, Akuma, Umuokwe-Awo-Omamma, Ubachima, Umuabiahu Mgbidi have a very high rate transmissivity that ranges from $1200000 m^2/day$ to

3400000 m²/day. However, Omuma area has a high transmissivity; while places like Amagu, Ibiasoegbe/Ofeahia, Locust Hotel Awo-Omamma, Umuejike Awo-Omamma have a moderate high transmissivity with values that ranges from 0m²/day to 120000m²/day. In terms of the hydraulic conductivity, the results obtained showed that towns like: Ibiasoegbe/Ofeahia have a low value of hydraulic conductivity of about 1000m/day; but Mgbidi, Akuma, Amagu, Omuma areas have a very high hydraulic conductivity and this indicates that the area has the proficiency of yielding from 10,000 m/day up to 27,000m/day of groundwater supply. The vulnerability ratings showed that the area is generally vulnerable to pollution or contaminations as a result of high resistivity values of the geoelectric layers across the study area.

5.2 Conclusion

The inferred lithology obtained shows a dominant sand unit profiles. The average water level for the various locations is 40.04m. The aquifer depth of the various locations studied were obtained, which varies between 50m (157ft) at a place like Amagu and 258m (811ft) at Ohakpu. Aquifer parameters determined were: Aquifer resistivity ranges from 2780m at Eziama Ubulu to 28210m at Ura-Akata; aquifer conductivity ranges from $8.5397 \times 10^{-5} \Omega m^{-1}$ at Ubachima to $1.0115 \times 10^{-4} \Omega m^{-1}$ at Akuma 2; transverse resistance ranges from 89175m² Locust Hotel, Awo-Omamma to 1972732m² Amiri 2; longitudinal conductance ranges from 9.7561×10^{-5} at Uzinaumu to 0.45004×10^{-2} at Akuma 1 and the storativity of my study area ranges from 0.0849×10^{-4} Ura-Akata to 9.27×10^{-4} at Ubachima. The vulnerability of these locations using DRASTIC method gave ratings between moderate to high which shows that on the average, the area has high vulnerability tendency. Out of the the total number of 27 locations, only 5 have moderate values and they occur at locations like Amagu 1, Amagu 2, Omuma 1, Locust Hotel Awo-Omamma and Afor Uru while the 22 others have a high

vulnerability at places like Akuma 1, Akuma 2, Omuma 2, Amiri 1, Amiri 2, Akwada Aji, Ubachima, Umuokwe, Ohakpu etc. which implies that the place is vulnerable.

5.3 Recommendations

The followings recommendations are made based on the results obtained from the available geological and geophysical data:

A detailed geophysical data of the area should be carried out to enable the relevant authorities enforce drill depth that will assure potable water for the area.

The relevant authorities should monitor the manner in which industrial and domestic wastes are disposed in the study area.

Down the hole geophysical log should be carried out to facilitate screening and pump installation.

A thorough hydro-chemical evaluation should be carried out to ascertain the water quality of the aquifer systems of the study area.

There is need for pumping test to be conducted to characterize the well before choice of pump size and to ascertain the area that can sustain large scale and continuous abstractions.

Government should establish regional water schemes to facilitate a sustainable portable water supply.

5.4 Contribution to Knowledge

In this research work, I have been able to get the hydraulic parameters of the study area, and based on this, it will be a sort of guide to any driller that would like to drill a borehole in the study area (Oru East and Oru West L.G.As. of Imo State and Environs, South-Eastern, Nigeria) in the future.

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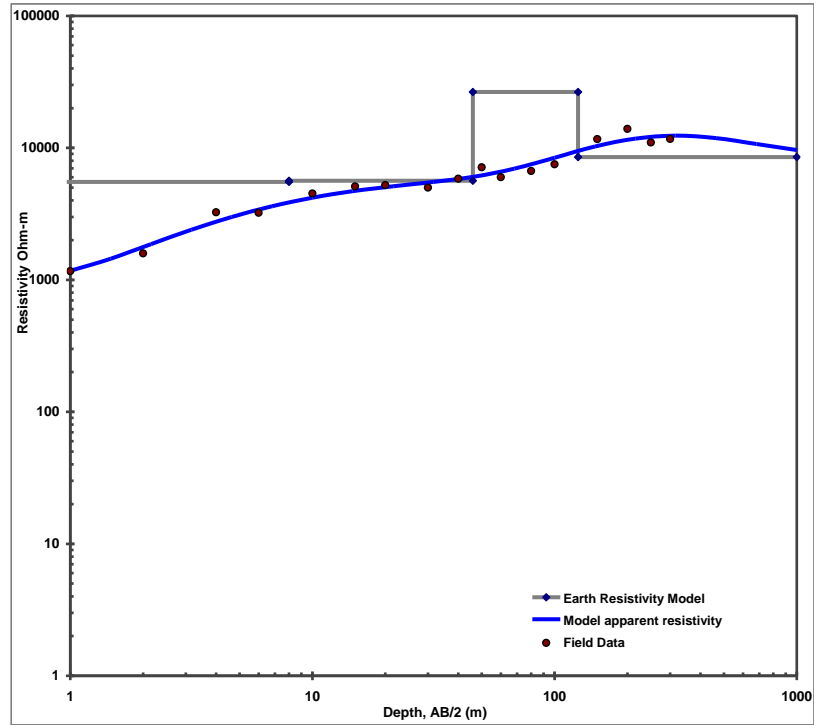
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APPENDIX I

Number of Layers			
5			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	0.80	0.80	940.00
2	7.20	8.00	5520.00
3	38.00	46.00	5648.00
4	79.00	125.00	26582.00
5	-	-	8526.00
-	-	-	-
-	-	-	-
-	-	-	-

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.0	1164.0
2.0	1589.0
4.0	3250.0
6.0	3220.0
10.0	4520.0
15.0	5110.0
20.0	5230.0
30.0	5000.0
40.0	5850.0
50.0	7130.0
60.0	5990.0
80.0	6680.0
100.0	7510.0
150.0	11670.0
200.0	13950.0
250.0	10980.0
300.0	11700.0



VES NUMBER: 1 DIRECTION LAYOUT: N-S DATE: 2017

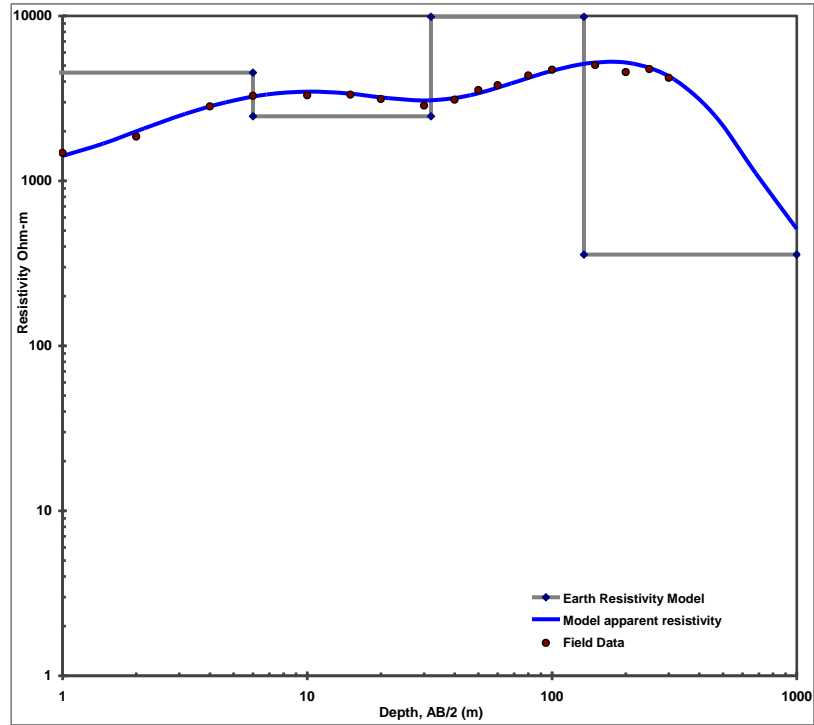
LOCATION: AKUMA, ORU EAST LGA, IMO STATE

COORDINATES: N 5.7169 E 6.9511 ELEVATION : 459FT

PROJECT STUDENT THESIS

Number of Layers			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	0.80	0.80	1185.00
2	5.20	6.00	4528.00
3	26.00	32.00	2462.00
4	103.00	135.00	9886.00
5	-	-	358.00
-	-	-	-
-	-	-	-
-	-	-	-

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.0	1478.0
2.0	1855.0
4.0	2830.0
6.0	3280.0
10.0	3300.0
15.0	3330.0
20.0	3140.0
30.0	2860.0
40.0	3110.0
50.0	3550.0
60.0	3800.0
80.0	4350.0
100.0	4720.0
150.0	5040.0
200.0	4560.0
250.0	4760.0
300.0	4210.0



VES NUMBER: 2 DIRECTION LAYOUT: N-S DATE: 2017

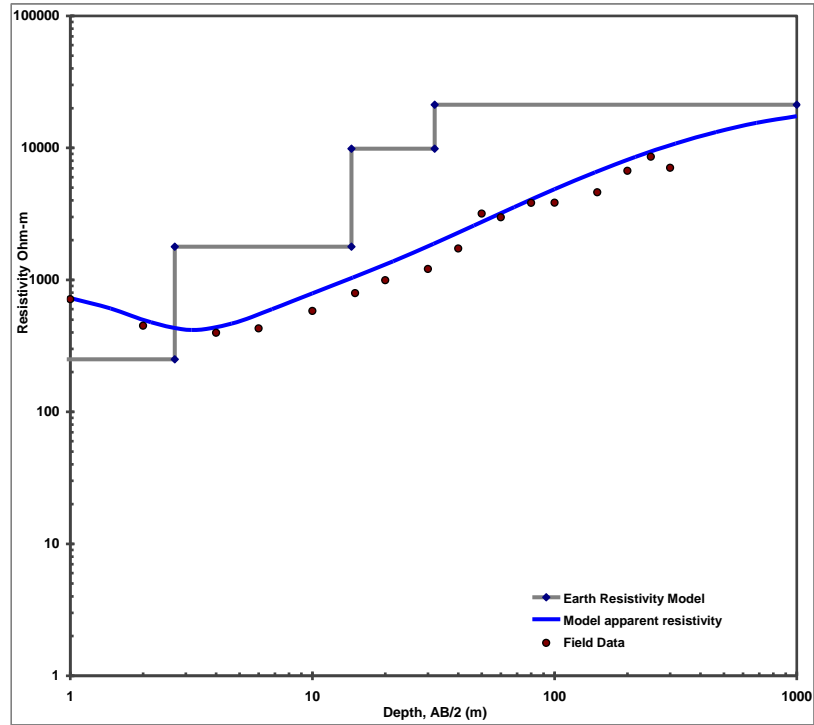
LOCATION: EZI AKUMA, ORU EAST LGA, IMO STATE

COORDINATES: N 5.7167 E 6.9520 ELEVATION : 459FT

PROJECT STUDENT THESIS

Number of Layers			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	0.80	0.80	850.00
2	1.90	2.70	250.00
3	11.80	14.50	1784.00
4	17.50	32.00	9862.00
5	-	-	21234.00
-	-	-	-
-	-	-	-
-	-	-	-

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.0	713.0
2.0	449.0
4.0	397.0
6.0	429.0
10.0	582.0
15.0	794.0
20.0	993.0
30.0	1209.0
40.0	1730.0
50.0	3180.0
60.0	2980.0
80.0	3830.0
100.0	3840.0
150.0	4610.0
200.0	6710.0
250.0	8570.0
300.0	7060.0



VES NUMBER: 3 DIRECTION LAYOUT: N-S DATE: 2017

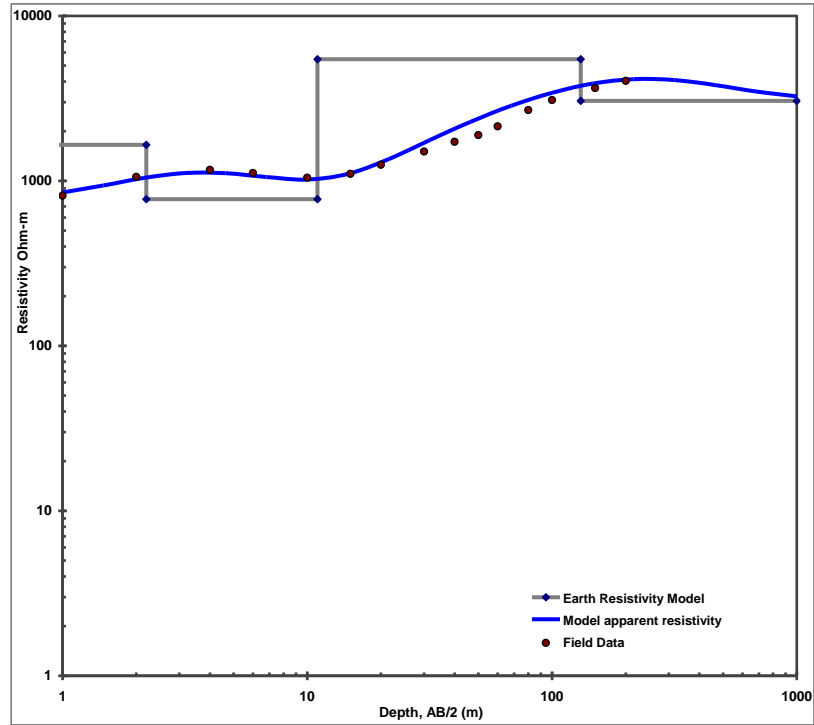
LOCATION: AMAGU, ORU EAST LGA, IMO STATE

COORDINATES: N 5.6933 E7.0389 ELEVATION : 511FT

PROJECT STUDENT THESIS

Number of Layers			
5			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	0.80	0.80	768.00
2	1.40	2.20	1654.00
3	8.80	11.00	774.00
4	120.00	131.00	5466.00
5	-	-	3055.00
-	-	-	-
-	-	-	-
-	-	-	-

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.0	814.0
2.0	1057.0
4.0	1168.0
6.0	1116.0
10.0	1045.0
15.0	1103.0
20.0	1251.0
30.0	1506.0
40.0	1726.0
50.0	1896.0
60.0	2140.0
80.0	2690.0
100.0	3090.0
150.0	3650.0
200.0	4040.0



VES NUMBER: 4 DIRECTION LAYOUT: N-S DATE: 2017

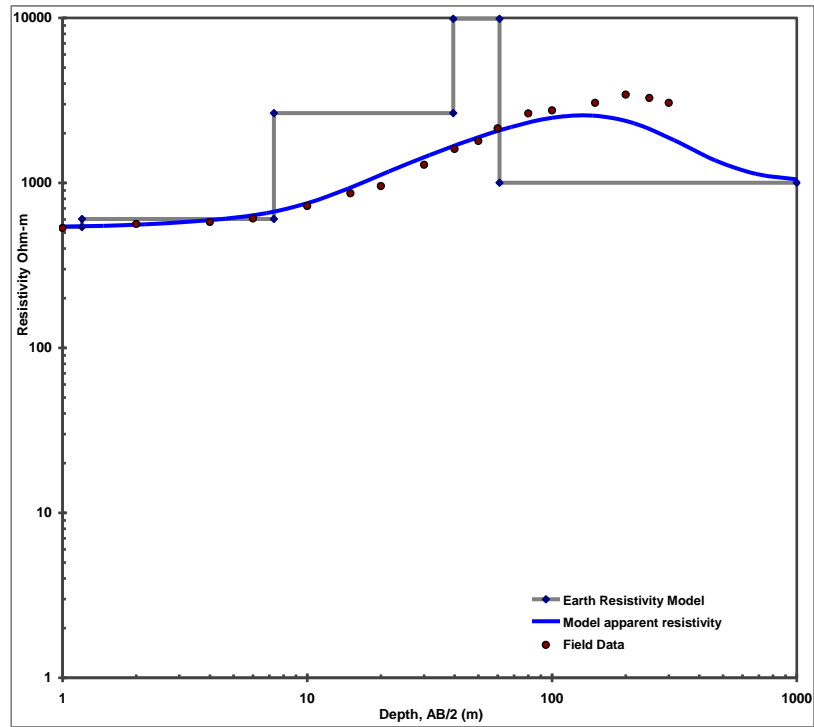
LOCATION: AMAGU, ORU EAST LGA, IMO STATE

COORDINATES: N 5.6929 E 7.0386 ELEVATION : 531FT

PROJECT STUDENT THESIS

Number of Layers			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	1.20	1.20	540.00
2	6.10	7.30	605.00
3	32.20	39.50	2650.00
4	21.50	61.00	9886.00
5	-	-	1002.00
-	-	-	-
-	-	-	-
-	-	-	-

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.0	532.0
2.0	563.0
4.0	579.0
6.0	608.0
10.0	723.0
15.0	865.0
20.0	957.0
30.0	1287.0
40.0	1605.0
50.0	1795.0
60.0	2140.0
80.0	2640.0
100.0	2750.0
150.0	3060.0
200.0	3430.0
250.0	3270.0
300.0	3060.0



VES NUMBER: 5 DIRECTION LAYOUT: N-S DATE: 2017

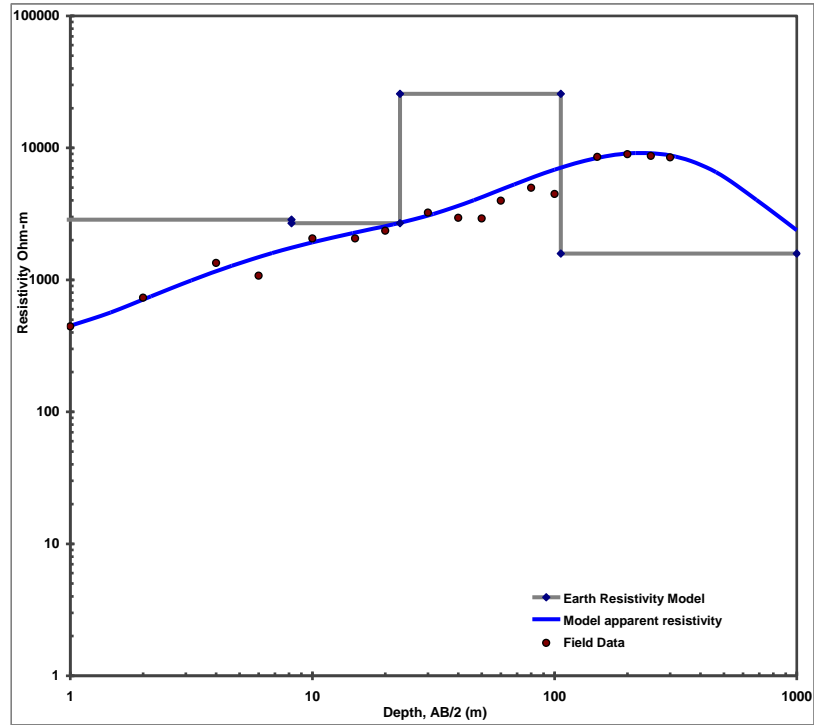
LOCATION: OMUMA, ORU EAST LGA, IMO STATE

COORDINATES: N 5.5590 E 6.9726 ELEVATION: 262FT

PROJECT STUDENT THESIS

Number of Layers			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	0.80	0.80	352.00
2	7.40	8.20	2859.00
3	14.80	23.00	2689.00
4	83.00	106.00	25682.00
5	-	-	1582.00
-	-	-	-
-	-	-	-
-	-	-	-

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.0	444.0
2.0	733.0
4.0	1344.0
6.0	1075.0
10.0	2060.0
15.0	2060.0
20.0	2360.0
30.0	3230.0
40.0	2950.0
50.0	2920.0
60.0	3980.0
80.0	4980.0
100.0	4470.0
150.0	8540.0
200.0	8970.0
250.0	8690.0
300.0	8470.0



VES NUMBER: 6 DIRECTION LAYOUT: N-S DATE: 2017

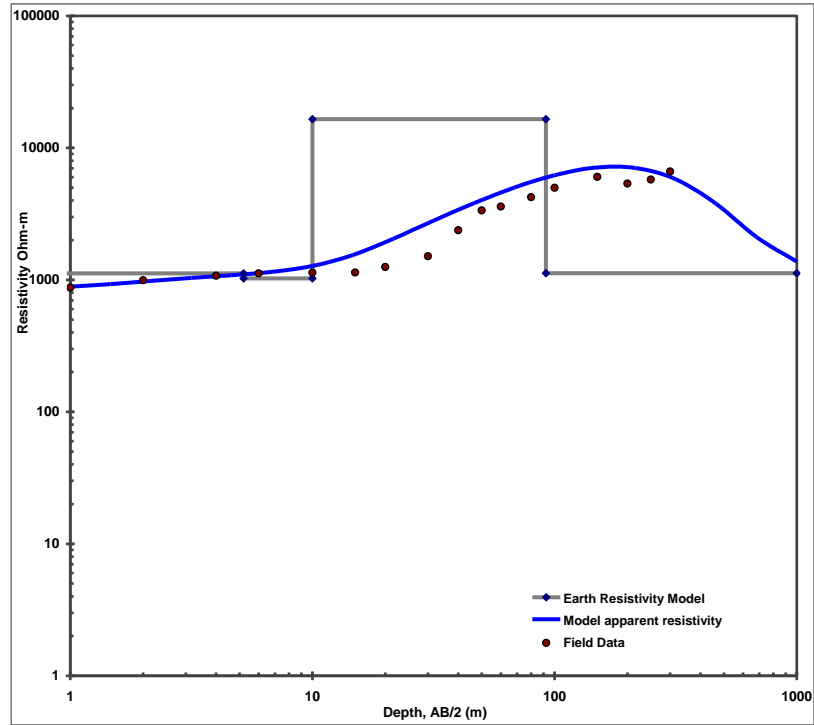
LOCATION: OMUMA, ORU EAST LGA, IMO STATE

COORDINATES: N 5.5577 E 6.9704 ELEVATION: 269FT

PROJECT STUDENT THESIS

Number of Layers			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	0.80	0.80	855.00
2	4.40	5.20	1120.00
3	4.80	10.00	1025.00
4	82.00	92.00	16520.00
5	-	-	1125.00
-	-	-	-
-	-	-	-
-	-	-	-

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.0	873.0
2.0	995.0
4.0	1074.0
6.0	1120.0
10.0	1133.0
15.0	1137.0
20.0	1253.0
30.0	1512.0
40.0	2380.0
50.0	3360.0
60.0	3590.0
80.0	4230.0
100.0	4980.0
150.0	6040.0
200.0	5370.0
250.0	5760.0
300.0	6620.0



VES NUMBER: 7 DIRECTION LAYOUT: N-S DATE: 2017

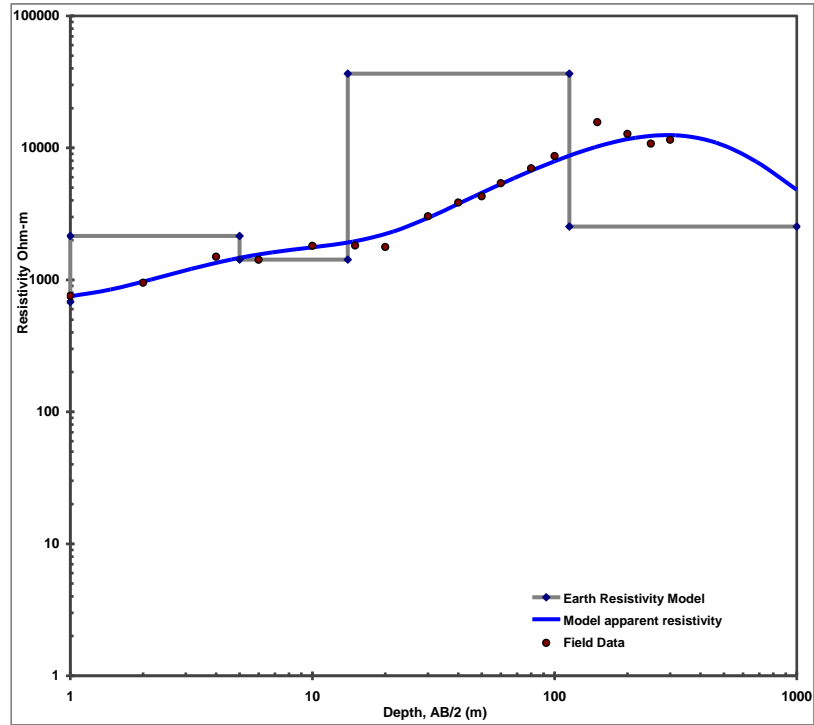
LOCATION: AMIRI, ORU EAST LGA, IMO STATE

COORDINATES: N 5.7241 E 6.9585 ELEVATION: 454FT

PROJECT STUDENT THESIS

Number of Layers			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	1.00	1.00	682.00
2	4.00	5.00	2150.00
3	9.00	14.00	1425.00
4	101.00	115.00	36528.00
5	-	-	2536.00
-	-	-	-
-	-	-	-
-	-	-	-

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.0	757.0
2.0	951.0
4.0	1495.0
6.0	1420.0
10.0	1809.0
15.0	1824.0
20.0	1776.0
30.0	3030.0
40.0	3860.0
50.0	4290.0
60.0	5390.0
80.0	7010.0
100.0	8680.0
150.0	15680.0
200.0	12750.0
250.0	10780.0
300.0	11530.0



VES NUMBER: 8 DIRECTION LAYOUT: N-S DATE: 2017

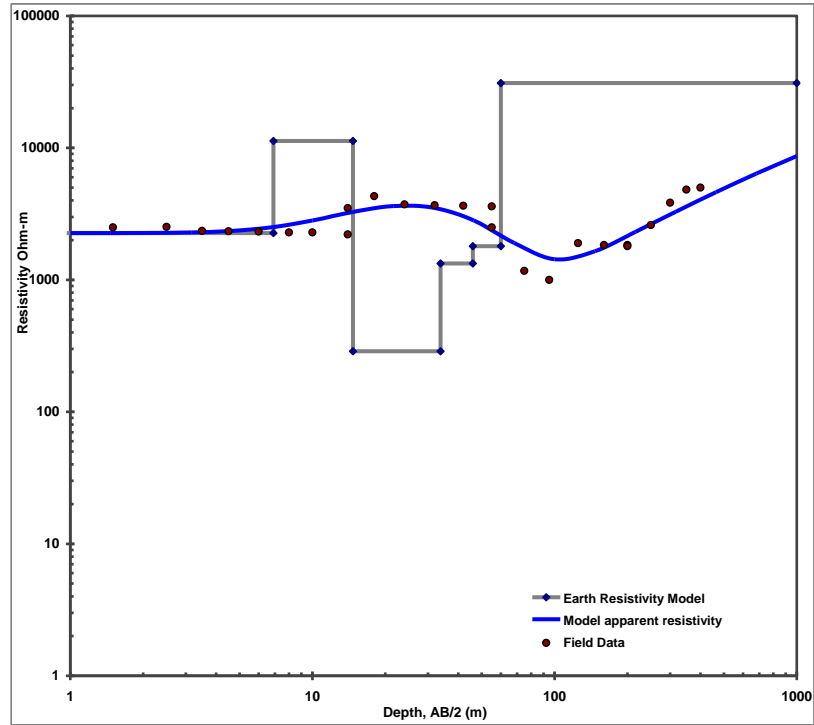
LOCATION: AMIRI, ORU EAST LGA, IMO STATE

COORDINATES: N 5.7228 E 6.9599 ELEVATION: 453FT

PROJECT STUDENT THESIS

Number of Layers			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	6.90	6.90	2260.00
2	7.80	14.70	11300.00
3	19.10	33.80	288.00
4	12.20	46.00	1330.00
5	14.00	60.00	1800.00
6	-	-	31000.00
-	-	-	-
-	-	-	-

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.5	2500.0
2.5	2520.0
3.5	2350.0
4.5	2335.0
6.0	2320.0
8.0	2290.0
10.0	2290.0
14.0	2210.0
14.0	3500.0
18.0	4310.0
24.0	3730.0
32.0	3680.0
42.0	3650.0
55.0	3600.0
55.0	2500.0
75.0	1170.0
95.0	1000.0
125.0	1900.0
160.0	1840.0
200.0	1840.0
200.0	1800.0
250.0	2600.0
300.0	3840.0
350.0	4830.0
400.0	5000.0



VES NUMBER: 9 DIRECTION LAYOUT: N-S DATE: 2017

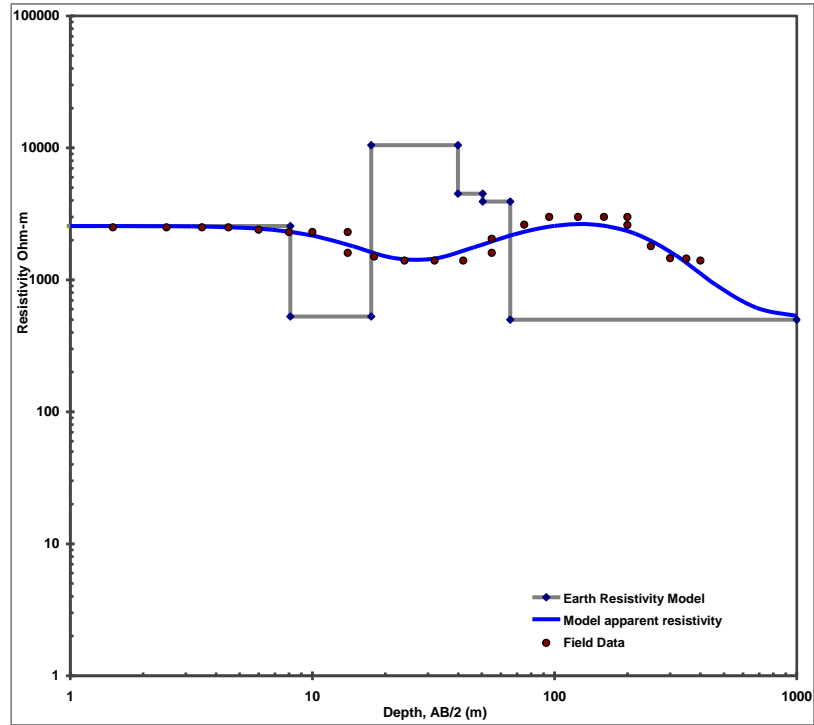
LOCATION: URA, AKATA, ORU EAST LGA, IMO STATE

COORDINATES: N 5.7471 E 6.8473 ELEVATION: 451FT

PROJECT STUDENT THESIS

Number of Layers			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	8.10	8.10	2560.00
2	9.40	17.50	528.00
3	22.40	39.90	10500.00
4	10.60	50.50	4500.00
5	15.10	65.60	3920.00
6	-	-	500.00
-	-	-	-
-	-	-	-

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.5	2500.0
2.5	2500.0
3.5	2500.0
4.5	2500.0
6.0	2400.0
8.0	2300.0
10.0	2300.0
14.0	2300.0
14.0	1600.0
18.0	1500.0
24.0	1400.0
32.0	1400.0
42.0	1400.0
55.0	1600.0
55.0	2050.0
75.0	2620.0
95.0	3000.0
125.0	3000.0
160.0	3000.0
200.0	3000.0
200.0	2600.0
250.0	1800.0
300.0	1460.0
350.0	1450.0
400.0	1400.0



VES NUMBER: 10 DIRECTION LAYOUT: N-S DATE: 2017

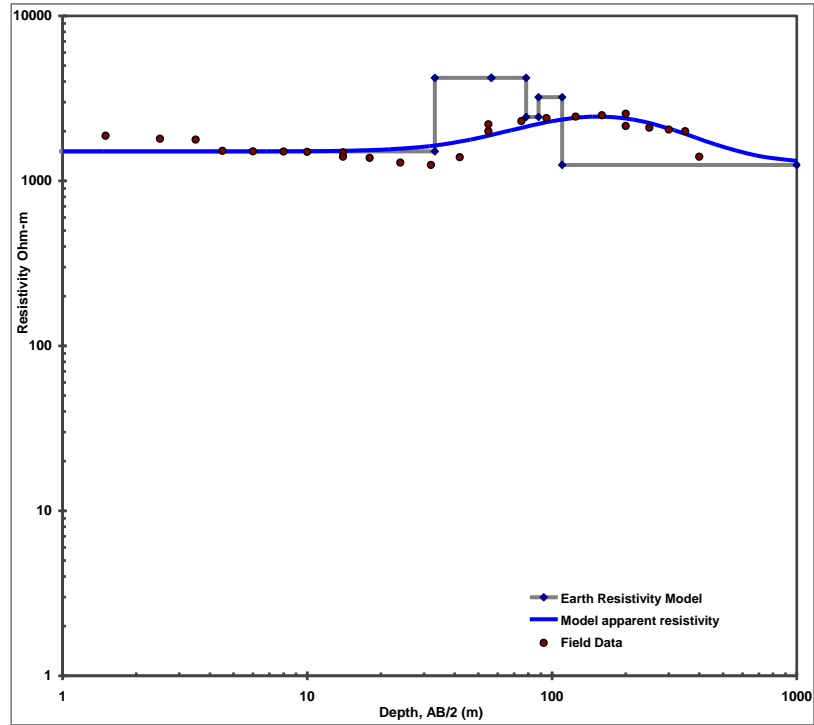
LOCATION: AKWADA AJI, ORU EAST LGA, IMO STATE

COORDINATES: N 5.7475 E 6.8562 ELEVATION: 217FT

PROJECT STUDENT THESIS

Number of Layers			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	33.20	33.20	1510.00
2	23.30	56.50	4210.00
3	21.90	78.40	4210.00
4	9.60	88.00	2440.00
5	22.00	110.00	3220.00
6	-	-	1250.00
-	-	-	-
-	-	-	-

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.5	1880.0
2.5	1800.0
3.5	1780.0
4.5	1520.0
6.0	1510.0
8.0	1508.0
10.0	1500.0
14.0	1490.0
14.0	1400.0
18.0	1378.0
24.0	1290.0
32.0	1250.0
42.0	1390.0
55.0	2000.0
55.0	2200.0
75.0	2300.0
95.0	2400.0
125.0	2450.0
160.0	2500.0
200.0	2550.0
200.0	2150.0
250.0	2100.0
300.0	2050.0
350.0	2000.0
400.0	1400.0



VES NUMBER: 11 DIRECTION LAYOUT: N-S DATE: 2017

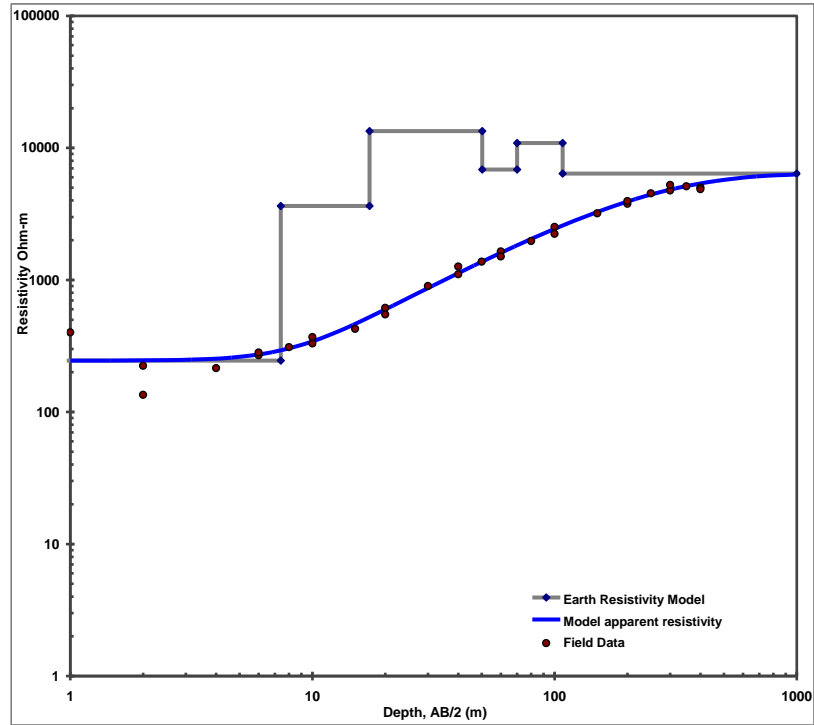
LOCATION: EZIAMA OBULU, ORU WEST LGA, IMO STATE

COORDINATES: N 5.7944 E 6.9207 ELEVATION: 478FT

PROJECT STUDENT THESIS

Number of Layers 6			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	7.40	7.40	245.00
2	9.80	17.20	3630.00
3	33.10	50.30	13400.00
4	19.70	70.00	6870.00
5	38.00	108.00	10900.00
6	-	-	6400.00
-	-	-	-
-	-	-	-

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.0	401.2
2.0	224.0
2.0	135.0
4.0	215.0
6.0	268.8
6.0	282.0
8.0	310.0
10.0	330.0
10.0	369.0
15.0	426.0
20.0	615.0
20.0	548.0
30.0	899.0
40.0	1262.0
40.0	1103.0
50.0	1377.0
60.0	1645.0
60.0	1506.0
80.0	1973.0
100.0	2519.0
100.0	2239.0
150.0	3192.0
200.0	3775.0
200.0	3953.0
250.0	4531.0
300.0	4753.0
300.0	5241.0
350.0	5126.0
400.0	5012.0
400.0	4875.0



VES NUMBER: 12 DIRECTION LAYOUT: N-S DATE: 2017

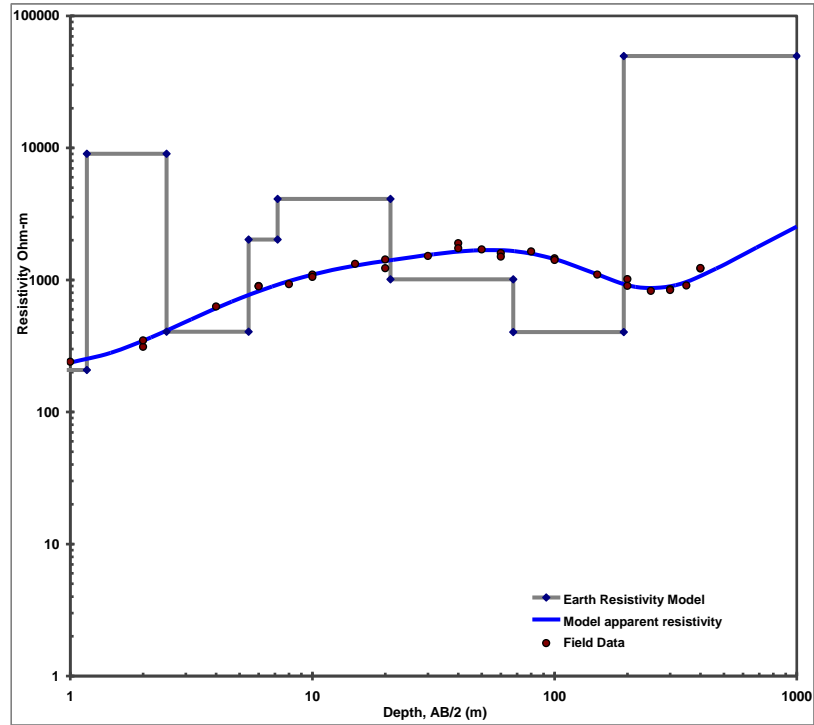
LOCATION: UMUEJIKE UMUOLEWE, ORU EAST LGA, IMO STATE

COORDINATES: N 5.6495 E 6.9333 ELEVATION: 90FT

PROJECT STUDENT THESIS

Number of Layers			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	1.17	1.17	208.00
2	1.33	2.50	9034.00
3	2.95	5.45	406.00
4	1.73	7.18	2022.00
5	13.82	21.00	4112.00
6	46.50	67.50	1012.00
7	125.50	193.00	403.00
8	-	-	49716.00

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.0	240.1
2.0	312.0
2.0	348.7
4.0	629.6
6.0	898.2
6.0	894.9
8.0	929.6
10.0	1098.2
10.0	1054.2
15.0	1322.4
20.0	1430.6
20.0	1226.0
30.0	1520.3
40.0	1897.2
40.0	1737.2
50.0	1702.0
60.0	1596.9
60.0	1502.0
80.0	1646.0
100.0	1457.8
100.0	1416.8
150.0	1097.6
200.0	1013.9
200.0	902.0
250.0	825.7
300.0	850.1
300.0	839.3
350.0	906.7
400.0	1219.1
400.0	1232.1



VES NUMBER: 13 DIRECTION LAYOUT: N-S DATE: 2017

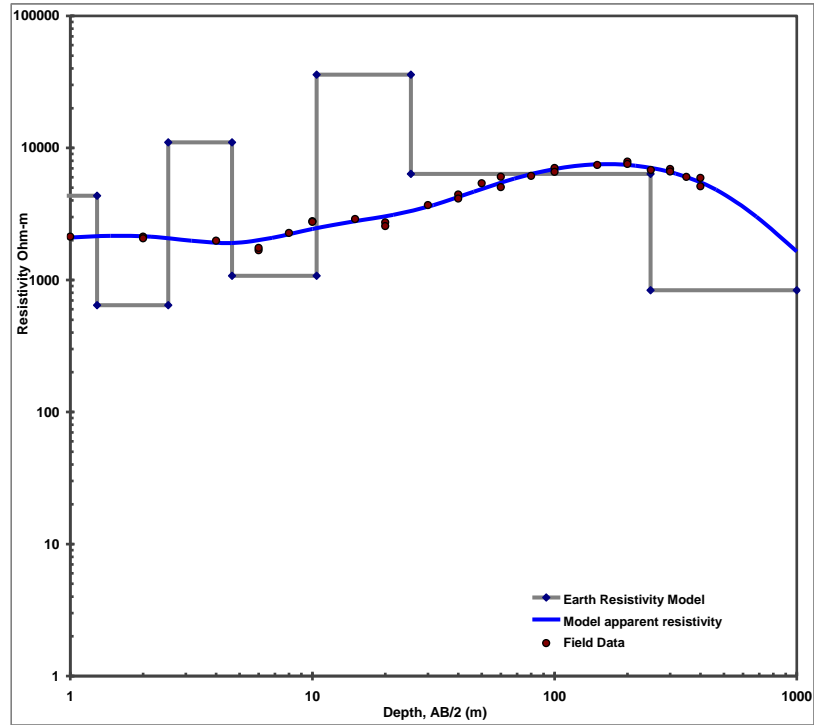
LOCATION: UMUEHI-UZINAUMU MGBIDI, ORU WEST LGA, IMO STATE

COORDINATES: N 5.7351 E 6.8833 ELEVATION : 249FT

PROJECT STUDENT THESIS

Number of Layers 8			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	0.79	0.79	1982.00
2	0.51	1.29	4345.00
3	1.25	2.54	645.00
4	2.12	4.66	11024.00
5	5.74	10.40	1076.00
6	15.10	25.50	35920.00
7	223.50	249.00	6368.00
8	-	-	835.00

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.0	2129.0
2.0	2130.0
2.0	2068.0
4.0	1984.0
6.0	1680.0
6.0	1747.0
8.0	2267.0
10.0	2783.0
10.0	2756.0
15.0	2893.0
20.0	2725.0
20.0	2556.0
30.0	3686.0
40.0	4441.0
40.0	4135.0
50.0	5395.0
60.0	6054.0
60.0	5044.0
80.0	6133.0
100.0	7037.0
100.0	6585.0
150.0	7418.0
200.0	7868.0
200.0	7554.0
250.0	6805.0
300.0	6913.0
300.0	6632.0
350.0	6035.0
400.0	5926.0
400.0	5124.0



VES NUMBER: 14 DIRECTION LAYOUT: NE-WS DATE: 2017

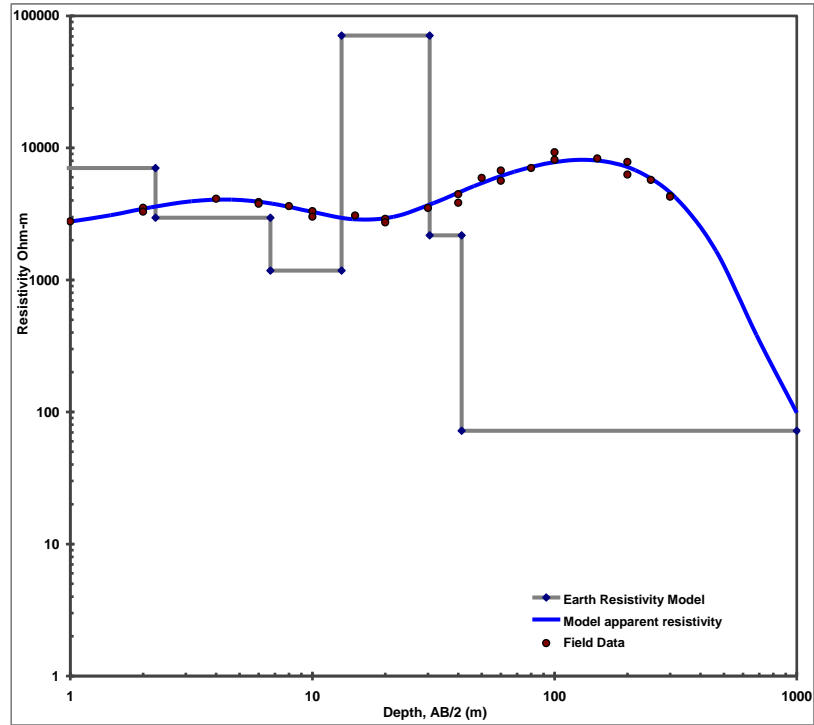
LOCATION: UMUEZIKE AMADIHE-OBURU, ORU EAST LGA, IMO STATE

COORDINATES: N 5.7638 E 6.9363 ELEVATION : 451FT

PROJECT STUDENT THESIS

Number of Layers			
8			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	0.85	0.85	2497.00
2	0.08	0.93	3352.00
3	1.32	2.25	7053.00
4	4.46	6.71	2960.00
5	6.49	13.20	1178.00
6	17.30	30.50	70963.00
7	10.80	41.30	2176.00
8	-	-	72.10

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.0	2773.0
2.0	3523.0
2.0	3286.6
4.0	4123.4
6.0	3886.4
6.0	3778.5
8.0	3623.4
10.0	3322.8
10.0	3009.8
15.0	3079.8
20.0	2901.6
20.0	2728.0
30.0	3512.9
40.0	3844.0
40.0	4466.7
50.0	5934.8
60.0	6734.7
60.0	5641.9
80.0	7042.5
100.0	9275.8
100.0	8128.1
150.0	8331.4
200.0	7837.5
200.0	6284.5
250.0	5731.4
300.0	4318.2
300.0	4265.3



VES NUMBER: 15 DIRECTION LAYOUT: E-W DATE: 2017

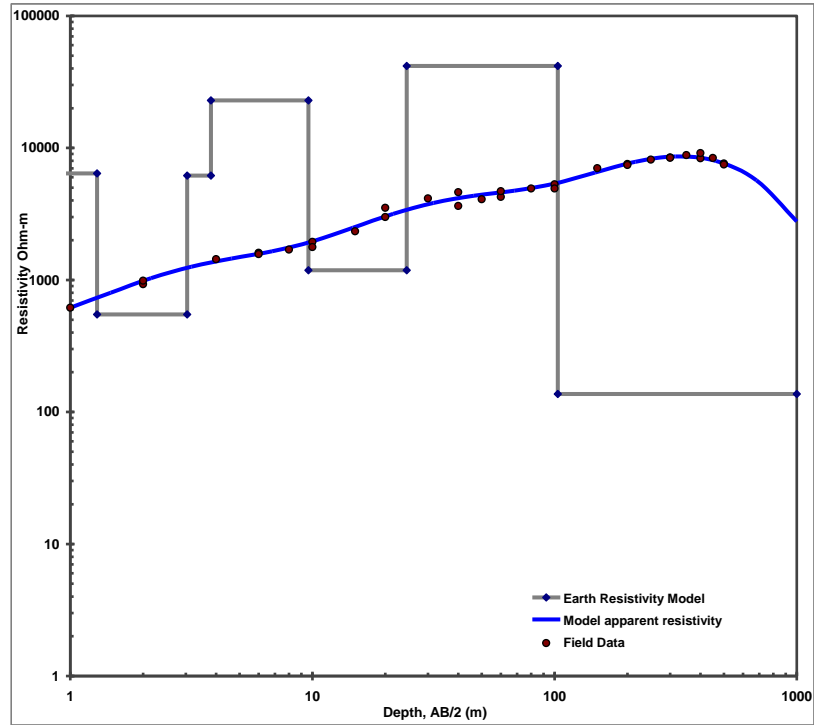
LOCATION: UMUCHUKWU EZIANI-MBGIDI, ORU EAST LGA, IMO STATE

COORDINATES: N 5.7487 E 6.9113 ELEVATION : 488FT

PROJECT STUDENT THESIS

Number of Layers 8			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	0.63	0.63	415.00
2	0.66	1.29	6409.00
3	1.75	3.04	549.00
4	0.77	3.81	6169.00
5	5.82	9.63	22932.00
6	14.87	24.50	1183.00
7	78.50	103.00	41748.00
8	-	-	137.00

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.0	617.1
2.0	928.3
2.0	987.2
4.0	1435.5
6.0	1606.1
6.0	1567.6
8.0	1695.9
10.0	1940.6
10.0	1773.1
15.0	2333.3
20.0	3523.6
20.0	2999.4
30.0	4144.4
40.0	4627.7
40.0	3640.3
50.0	4084.7
60.0	4263.0
60.0	4709.7
80.0	4929.8
100.0	5302.3
100.0	4931.2
150.0	7029.6
200.0	7557.5
200.0	7431.3
250.0	8160.0
300.0	8476.5
300.0	8434.4
350.0	8838.9
400.0	8344.4
400.0	9148.9
450.0	8410.3
500.0	7614.9
500.0	7495.2



VES NUMBER: 16 DIRECTION LAYOUT: E-W DATE: 2017

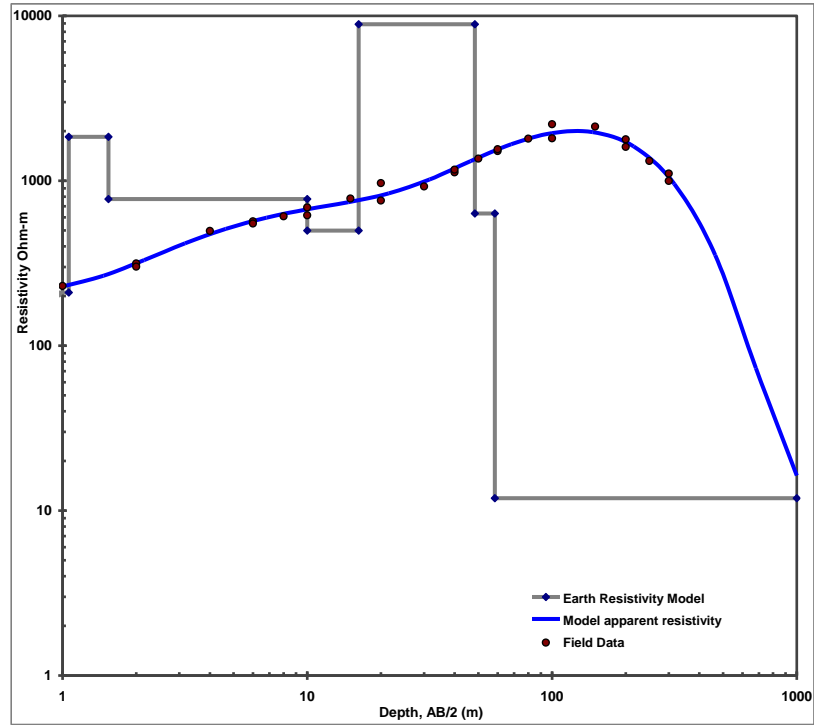
LOCATION: UMUONWUNA UBACHIMA AMAJI AWO-OMAMMA, ORU EAST LGA, IMO STATE

COORDINATES: N 5.6972 E 6.9413 ELEVATION : 497FT

PROJECT STUDENT THESIS

Number of Layers			
8			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	0.97	0.97	202.00
2	0.09	1.06	210.00
3	0.48	1.54	1847.00
4	8.46	10.00	774.00
5	6.20	16.20	499.00
6	32.20	48.40	8891.00
7	10.00	58.40	634.00
8	-	-	11.90

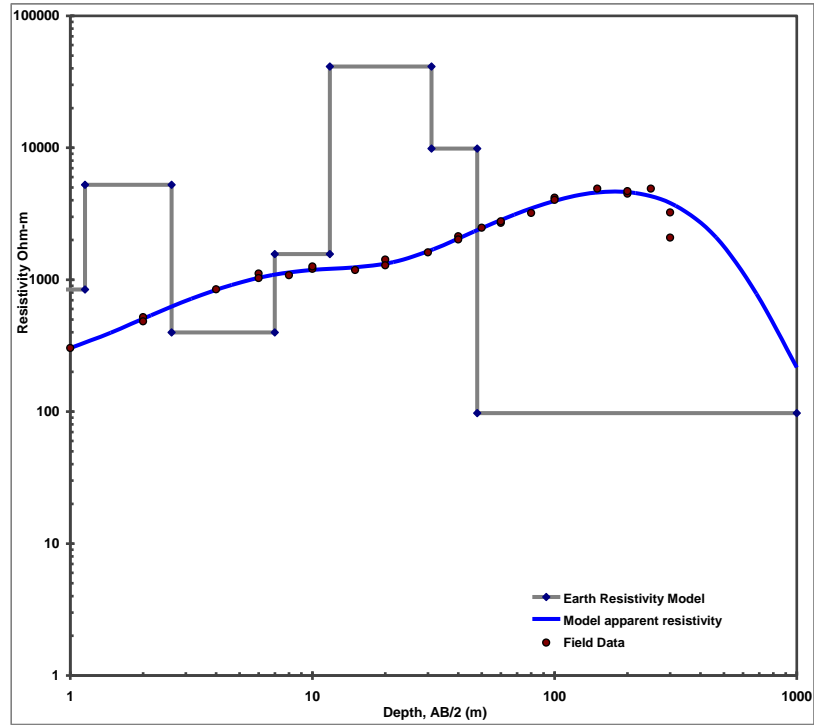
FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.0	230.1
2.0	315.2
2.0	301.6
4.0	496.0
6.0	566.7
6.0	550.0
8.0	608.9
10.0	617.8
10.0	689.1
15.0	779.5
20.0	967.2
20.0	758.5
30.0	923.3
40.0	1125.2
40.0	1167.2
50.0	1363.2
60.0	1513.6
60.0	1551.7
80.0	1801.6
100.0	1808.7
100.0	2200.0
150.0	2129.7
200.0	1782.1
200.0	1605.0
250.0	1319.2
300.0	1105.8
300.0	998.2



VES NUMBER: 17 DIRECTION LAYOUT: NE-SW DATE: 2017
 LOCATION: MGBIDI HEALTH CENTRE, ORU EAST LGA, IMO STATE
 COORDINATES: N 5.7338 E 6.8918 ELEVATION : 341FT
 PROJECT STUDENT THESIS

Number of Layers 8			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	0.63	0.63	215.00
2	0.52	1.15	843.00
3	1.47	2.62	5249.00
4	4.37	6.99	399.00
5	4.81	11.80	1563.00
6	19.20	31.00	41276.00
7	16.90	47.90	9877.00
8	-	-	97.50

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.0	303.3
2.0	519.5
2.0	483.0
4.0	845.0
6.0	1112.2
6.0	1028.5
8.0	1081.1
10.0	1207.4
10.0	1260.5
15.0	1183.2
20.0	1418.6
20.0	1286.3
30.0	1610.5
40.0	2133.5
40.0	2020.7
50.0	2477.6
60.0	2696.2
60.0	2766.1
80.0	3201.9
100.0	4179.9
100.0	4029.5
150.0	4894.7
200.0	4494.1
200.0	4685.7
250.0	4905.7
300.0	3232.9
300.0	2082.5



VES NUMBER: 18 DIRECTION LAYOUT: E-W DATE: 2017

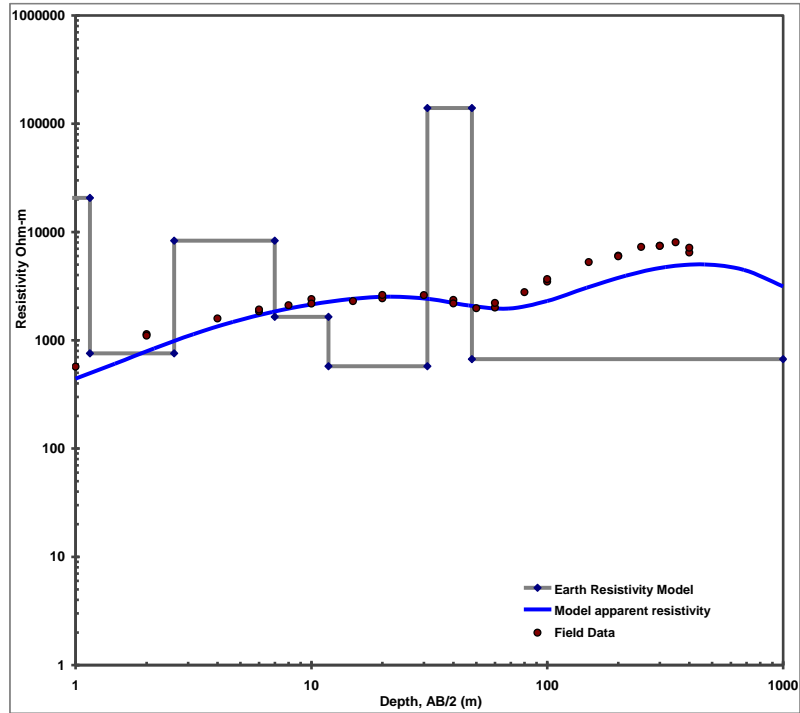
LOCATION: UMUEZIKE AMADEHI UBULU, ORU WEST LGA, IMO STATE

COORDINATES: N 5.8117 E 6.8921 ELEVATION : 499FT

PROJECT STUDENT THESIS

Number of Layers			
8			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	0.63	0.63	278.00
2	0.52	1.15	20668.00
3	1.47	2.62	758.00
4	4.37	6.99	8326.00
5	4.81	11.80	1645.00
6	19.20	31.00	577.00
7	16.90	47.90	140000.00
8	-	-	671.00

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.0	570.5
2.0	1140.5
2.0	1105.0
4.0	1589.0
6.0	1852.5
6.0	1919.5
8.0	2108.7
10.0	2402.4
10.0	2182.9
15.0	2298.5
20.0	2444.5
20.0	2614.9
30.0	2610.2
40.0	2357.4
40.0	2189.6
50.0	1975.4
60.0	2006.5
60.0	2212.2
80.0	2776.1
100.0	3483.3
100.0	3672.0
150.0	5276.5
200.0	6036.7
200.0	5957.4
250.0	7289.2
300.0	7459.5
300.0	7429.9
350	8041.4
400	6468.8
400	7149.9



VES NUMBER: 19 DIRECTION LAYOUT: E-W DATE: 2017

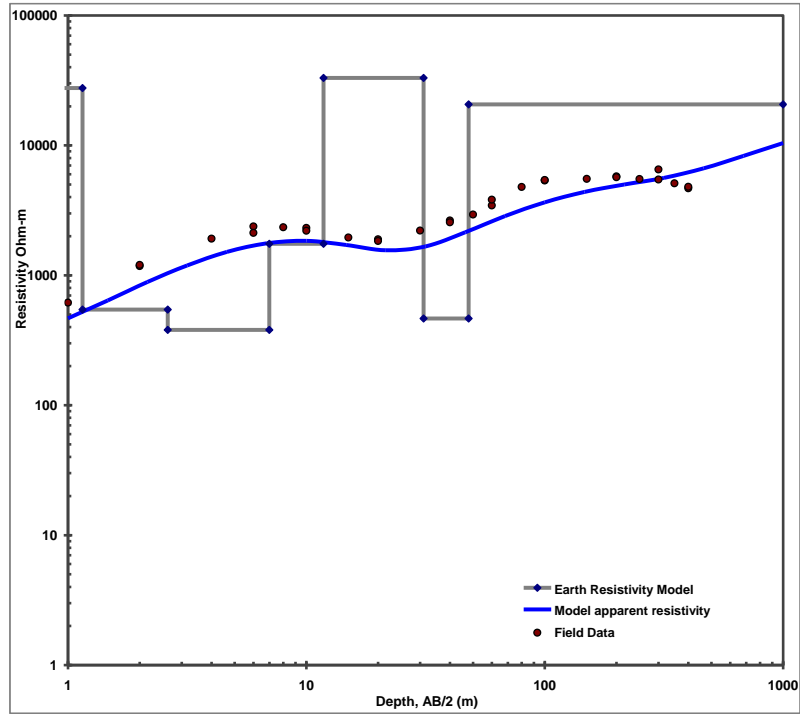
LOCATION: UMUEJIKEADIM UBIBI AWO-OMAMMA, ORU EAST LGA, IMO STATE

COORDINATES: N 5.6950 E 6.9839 ELEVATION : 529FT

PROJECT STUDENT THESIS

Number of Layers		8	
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	0.63	0.63	292.00
2	0.52	1.15	27692.00
3	1.47	2.62	545.00
4	4.37	6.99	380.00
5	4.81	11.80	1749.00
6	19.20	31.00	33082.00
7	16.90	47.90	466.00
8	-	-	20693.00

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.0	616.0
2.0	1177.6
2.0	1202.7
4.0	1915.7
6.0	2374.4
6.0	2123.0
8.0	2346.3
10.0	2316.6
10.0	2205.5
15.0	1954.0
20.0	1890.9
20.0	1835.2
30.0	2207.6
40.0	2643.5
40.0	2554.6
50.0	2936.8
60.0	3443.7
60.0	3822.8
80.0	4790.6
100.0	5366.8
100.0	5421.3
150.0	5519.5
200.0	5778.6
200.0	5691.2
250.0	5508.8
300.0	5458.2
300.0	6532.4
350.0	5100.0
400.0	4670.0
400.0	4800.0



VES NUMBER: 20 DIRECTION LAYOUT: NE-SW DATE: 2017

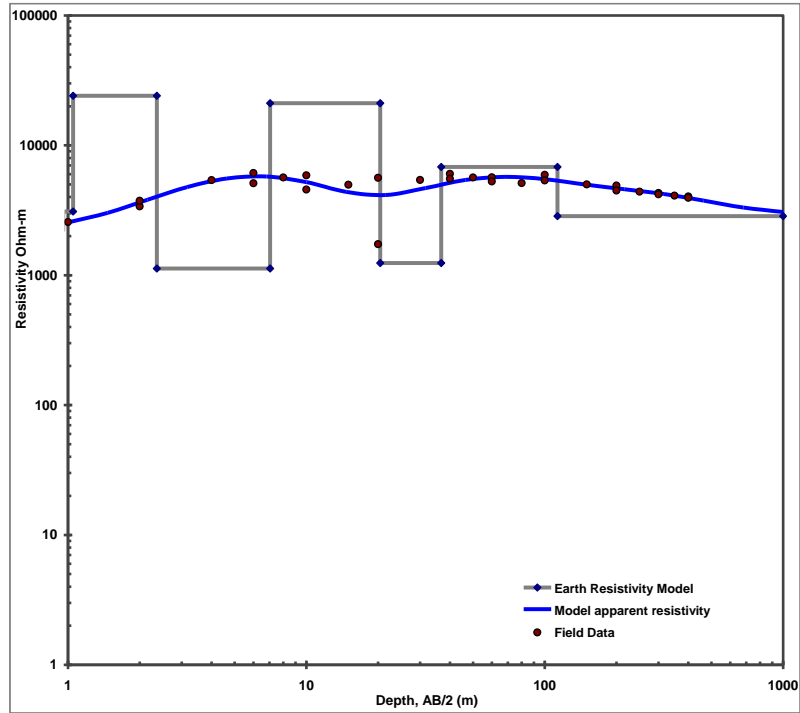
LOCATION: UMUOKWE AWO-OMAMMA, ORU EAST LGA, IMO STATE

COORDINATES: N 5.6924 E 6.9573 ELEVATION : 494FT

PROJECT STUDENT THESIS

Number of Layers		8	
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	0.96	0.96	2214.00
2	0.10	1.05	3092.00
3	1.31	2.36	24068.00
4	4.69	7.05	1126.00
5	13.35	20.40	21119.00
6	16.40	36.80	1240.00
7	76.20	113.00	6814.00
8	-	-	2852.00

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.0	2566.5
2.0	3389.4
2.0	3746.0
4.0	5400.5
6.0	6115.2
6.0	5098.5
8.0	5652.9
10.0	5881.2
10.0	4566.9
15.0	4976.4
20.0	5629.1
20.0	1735.1
30.0	5407.8
40.0	6039.6
40.0	5522.3
50.0	5658.3
60.0	5679.4
60.0	5270.5
80.0	5118.1
100.0	5921.6
100.0	5368.5
150.0	5000.0
200.0	4900.0
200.0	4483.4
250.0	4400.0
300.0	4300.0
300.0	4200.0
350.0	4100.0
400.0	4043.0
400.0	3941.5



VES NUMBER: 21 DIRECTION LAYOUT: NE-SW DATE: 2017

LOCATION: OHAKPU

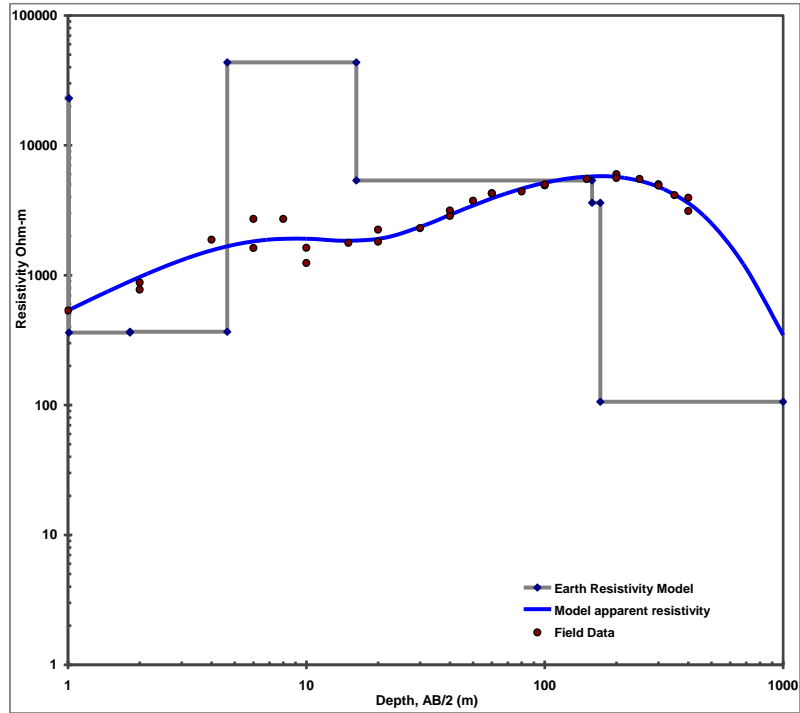
COORDINATES: N 5.7488 E 6.8514 ELEVATION : 225FT

PROJECT STUDENT THESIS

Number of Layers			
8			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	0.47	0.47	262.00
2	0.54	1.01	23091.00
3	0.81	1.82	362.00
4	2.84	4.66	367.00
5	11.54	16.20	43550.00
6	141.80	158.00	5364.00
7	13.00	171.00	3610.00
8	-	-	106.00

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)

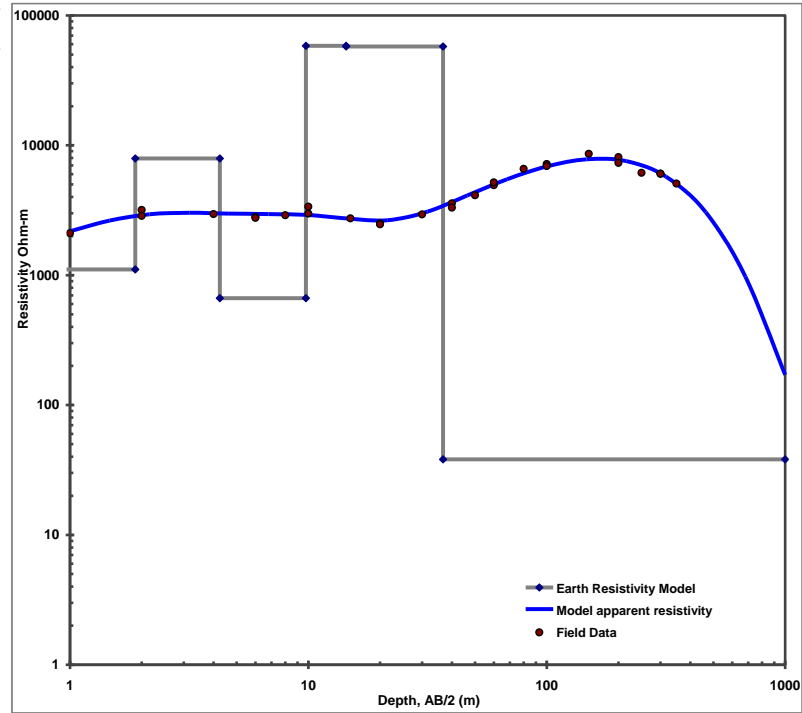
1.0	534.0
2.0	878.3
2.0	775.1
4.0	1876.1
6.0	2716.0
6.0	1622.5
8.0	2712.6
10.0	1623.0
10.0	1239.7
15.0	1776.5
20.0	2241.0
20.0	1812.0
30.0	2304.0
40.0	3153.5
40.0	2862.2
50.0	3745.0
60.0	4276.9
60.0	4257.0
80.0	4411.0
100.0	4911.0
100.0	5000.0
150.0	5511.0
200.0	6000.0
200.0	5611.0
250.0	5510.0
300.0	5010.0
300.0	4900.0
350.0	4129.9
400.0	3121.0
400.0	3941.5



VES NUMBER: 22 DIRECTION LAYOUT: NE-SW DATE: 2017
 LOCATION: UMUEZEM - OTULU
 COORDINATES: N 5.7036 E 6.9156 ELEVATION : 310FT
 PROJECT STUDENT THESIS

Number of Layers			
8			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	0.39	0.39	1141.00
2	0.40	0.79	11967.00
3	1.09	1.88	1108.00
4	2.37	4.25	7920.00
5	5.51	9.76	666.00
6	4.64	14.40	58340.00
7	22.30	36.70	57728.00
8	-	-	38.20

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.0	2100.4
2.0	3174.1
2.0	2862.5
4.0	2955.2
6.0	2811.2
6.0	2761.0
8.0	2890.8
10.0	3369.6
10.0	2980.0
15.0	2738.8
20.0	2500.0
20.0	2465.6
30.0	2936.5
40.0	3576.5
40.0	3314.6
50.0	4118.2
60.0	4922.6
60.0	5175.5
80.0	6584.0
100.0	7160.1
100.0	6929.3
150.0	8609.1
200.0	8117.4
200.0	7329.0
250.0	6134.5
300.0	6046.0
300.0	6039.5
350.0	5069.8



VES NUMBER: 23 DIRECTION LAYOUT: E-W DATE: 2017

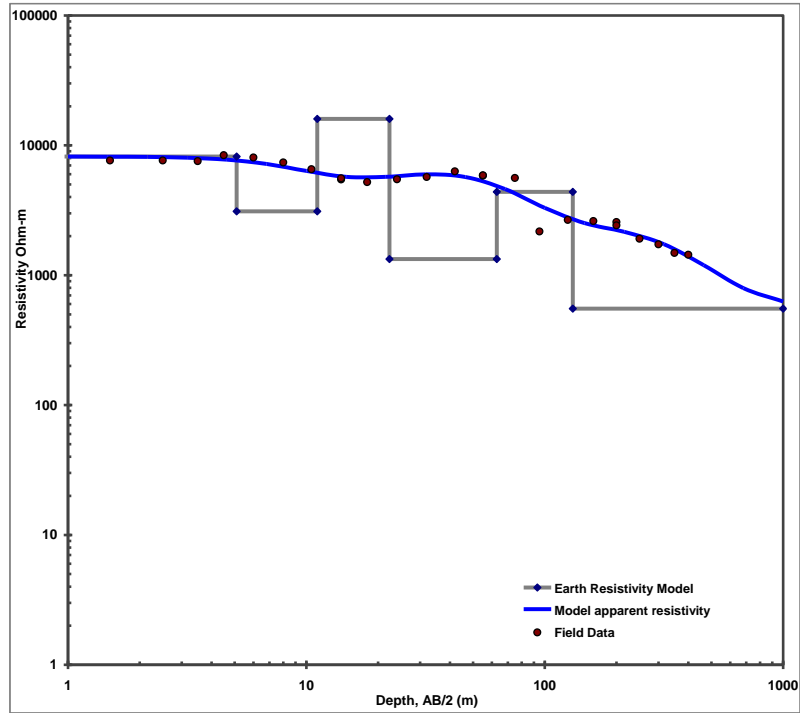
LOCATION: IBIASOEGBE & OFEAHIA COMMUNITIES

COORDINATES: N 5.6335 E 7.0965 ELEVATION : 543FT

PROJECT STUDENT THESIS

Number of Layers			
6			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	5.10	5.10	8200.00
2	6.00	11.10	3100.00
3	11.20	22.30	16000.00
4	40.60	62.90	1330.00
5	68.10	131.00	4380.00
6	-	-	553.00
-	-	-	-
-	-	-	-

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.5	7636.5
2.5	7637.7
3.5	7558.6
4.5	8396.4
6.0	8057.5
8.0	7378.0
10.5	6545.3
14.0	5460.0
14.0	5567.9
18.0	5206.6
24.0	5485.0
32.0	5702.2
42.0	6300.6
55.0	5850.1
55.0	5877.2
75.0	5608.4
95.0	2169.3
125.0	2664.2
160.0	2610.2
200.0	2569.3
200.0	2422.1
250.0	1908.5
300.0	1726.3
350.0	1485.3
400.0	1438.2



VES NUMBER: 24 DIRECTION LAYOUT: E-W DATE: 2017

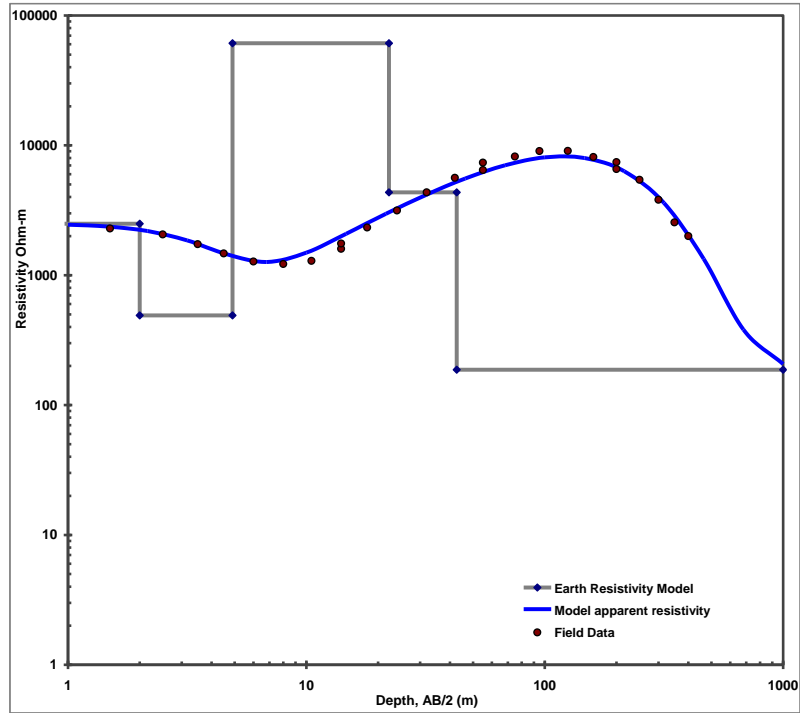
LOCATION: UMUABIAHU MGBIDI

COORDINATES: N 5.7161 E 6.8919 ELEVATION : 264FT

PROJECT STUDENT THESIS

Number of Layers			
5			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	2.00	2.00	2490.00
2	2.90	4.90	490.00
3	17.30	22.20	61200.00
4	20.50	42.70	4350.00
5	-	-	187.00
-	-	-	-
-	-	-	-
-	-	-	-

FIELD DATA	
AB/2 (m)	ρ_a (Ω -m)
1.5	2291.6
2.5	2061.1
3.5	1733.7
4.5	1470.1
6.0	1274.6
8.0	1218.2
10.5	1288.0
14.0	1595.3
14.0	1755.6
18.0	2326.8
24.0	3152.4
32.0	4348.0
42.0	5623.8
55.0	7371.3
55.0	6457.3
75.0	8200.8
95.0	9029.0
125.0	9063.5
160.0	8142.2
200.0	7418.7
200.0	6575.2
250.0	5422.2
300.0	3813.5
350.0	2547.2
400.0	1999.5



VES NUMBER: 25 DIRECTION LAYOUT: E-W DATE: 2017

LOCATION: OWERRI/ONITSHA RD, AWO OMAMMA

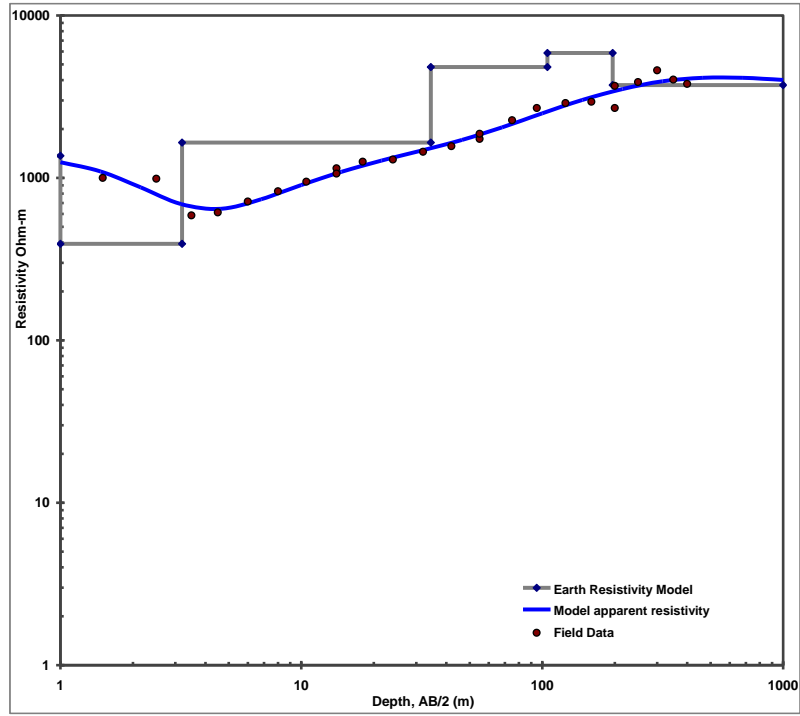
COORDINATES: N 5.6604 E 6.9245 ELEVATION : 263FT

PROJECT STUDENT THESIS

Number of Layers			
6			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	1.00	1.00	1370.00
2	2.20	3.20	393.00
3	31.30	34.50	1650.00
4	70.50	105.00	4820.00
5	91.00	196.00	5880.00
6	-	-	3730.00
-	-	-	-
-	-	-	-

FIELD DATA

AB/2 (m)	ρ_a (Ω -m)
1.5	999.1
2.5	988.9
3.5	587.8
4.5	612.2
6.0	714.7
8.0	827.0
10.5	948.5
14.0	1146.4
14.0	1061.8
18.0	1257.1
24.0	1297.4
32.0	1449.2
42.0	1568.9
55.0	1740.0
55.0	1869.7
75.0	2264.2
95.0	2691.6
125.0	2892.6
160.0	2942.9
200.0	2696.1
200.0	3686.8
250.0	3894.2
300.0	4593.8
350.0	4025.4
400.0	3789.2



VES NUMBER: 26 DIRECTION LAYOUT: E-W DATE: 2017

LOCATION: AMAEBU ORU AFOR AKUMA, ORU EAST LGA

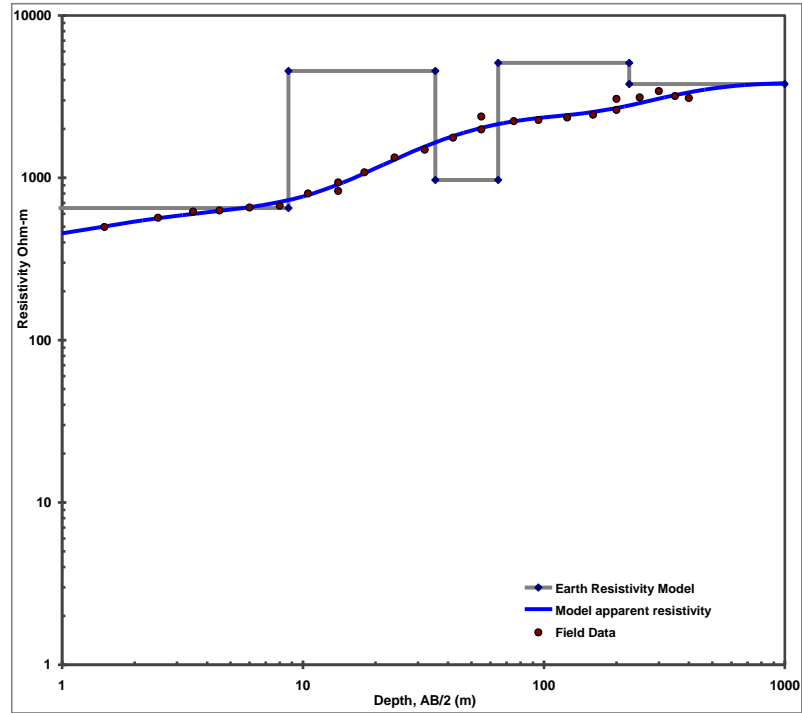
COORDINATES: N 5.8026 E 6.9507 ELEVATION : 554FT

PROJECT STUDENT THESIS

Number of Layers			
Layer NO	Thickness (m)	Depth (m)	ρ (Ω -m)
1	0.60	0.60	403.00
2	8.10	8.70	651.00
3	26.70	35.40	4550.00
4	29.20	64.60	970.00
5	161.40	226.00	5100.00
6	-	-	3780.00
-	-	-	-
-	-	-	-

FIELD DATA

AB/2 (m)	ρ_a (Ω -m)
1.5	497.9
2.5	567.1
3.5	618.3
4.5	629.3
6.0	656.6
8.0	672.8
10.5	801.3
14.0	828.4
14.0	936.4
18.0	1079.7
24.0	1333.3
32.0	1490.5
42.0	1767.7
55.0	1986.1
55.0	2383.8
75.0	2233.2
95.0	2269.4
125.0	2349.3
160.0	2445.5
200.0	2619.3
200.0	3061.2
250.0	3131.2
300.0	3423.4
350.0	3188.5
400.0	3097.4



VES NUMBER: 27 DIRECTION LAYOUT: E-W DATE: 2017

LOCATION: AFOR AKATTA - URU AKATTA, ORU EAST LGA

COORDINATES: N 5.7866 E 6.9577 ELEVATION : 509FT

PROJECT STUDENT THESIS

APPENDIX II

