HYDROGEOPHYSICAL AND VULNERABILITY INDEX STUDIES OF PARTS OF UMUAHIA, SOUTHEASTERN NIGERIA

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CERTIFICATION

This is to certify that this work titled "Hydrogeophysical and Vunerability Index studies of parts of Umuahia, South-Eastern Nigeria"was carried out by IBENECHE WISDOM IYKE (20085632878) in partial fulfillment of the requirements for the award of the Degree of Master of Science (M.Sc) in Geophysics in the Department of Geology, School of Physical Sciences, Federal University of Technology Owerri

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DEDICATION

This work is dedicated to God Almighty for His faithfulness and to the memory of my beloved parents Chief Simeon Ihuoma Ibeneche and Lolo Ahuruchi Mgbeonyere Ibeneche who passed on while this study was on going.

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ABSTRACT

Groundwater potential, Contamination and vulnerability in urbanizing area are major concern and need attention. The present study involved the innovative methodology of integrating Electrical resistivity (Geophysical assessment) method using a Dar-Zarrouk parameter-Longitudinal unit conductance S which is directly related to the aquifer protective capacity in vulnerability assessment and the use of DRSATIC model in characterization of the groundwater quality and vulnerability of the study area. The results of the interpreted electrical resistivity data helped to delineate the aquiferous horizons within the study area. The aquifer protective capacity (APC) rating obtained from second order parameter of the VES revealed the rating less than 0.1Mhos across the study area; indicating aquiferous zone with poor protective capacity to contamination migration. The DRASTIC model of vulnerability assessment of the study area provided further insight by helping to delineate areas with Low, moderate and high vulnerability. The result obtained, revealed that about 63% of the study area are moderately vulnerable to pollution contamination, 35% of the area are within the range of high vulnerability and only 2% falls within the range of low vulnerability. Moderate to high vulnerability tendency revealed in DRASTIC model index constituting about 98% of the study area is agreement with the result obtained from the longitudinal conductance values with the rating denoting poor aquifer overburden protective capacity across the study area.

Keywords: *Hydrogeophysical, Vunerability Index studies, aquifer, Umuahia, South-Eastern Nigeria*

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Groundwater is a major source of clean drinking water all over the world. It has been an important resource especially in the dry part of the world.

Increased demands for water have stimulated development of underground water resources. As a result, techniques for investigating the occurrence and movement of groundwater have been improved; better equipment for extraction has been developed, concepts for resource management; quality assessment have been established, and the research has contributed to a better understanding of the subject.

Unsatisfactory water supplies and un-wholesome sanitation conditions can result in poor human health. This portends the fact that there are very strong links between water and health. Water is a natural resource whose scarcity or poor quality can cause a chain of unpleasant situations to mankind, especially in developing countries like Nigeria. There are many ways in which poor water quality and sanitary conditions can give rise to poor health. For instance classical water-borne diseases which include cholera and other diarrheal diseases as well as water – related parasitic diseases like schistosomiasis, guinea-worm, river blindness, hepatitis and malaria are very common (WHO, 1992 and WHO, 2017).

Nitrate compounds, heavy metals pesticides etc that are contained in our drinking water can also constitute undesirable pollutants when they are not within World Health Organization guidelines for drinking water (WHO, 2017).

The use of geophysics for groundwater resources detection and for water availability evaluation has increased dramatically over the last two decades. In geophysical investigation for water exploration, depth to bedrock determinations, sand gravel exploration and so on, the electrical resistivity method (ERM) can be used to obtain quickly and economically details about the location, depth and resistivity of subsurface formations. Accurate Electrical Resistivity method (ERM) is generally employed for groundwater studies such as quality, vulnerability, quantity, mapping fresh water lenses, investigation of salt water intrusion and determination of contaminants.

From literature, we understand that groundwater resource and stream water, follow the geology of the surrounding rocks. Hence, groundwater quality has direct link with the geology of the environment. The vertical electrical sounding (VES) as a geophysical tool has the capability to furnish information about the following; determination of depth, thickness and boundary of an aquifer, determination of interface, saline water and fresh water, porosity of aquifer, hydraulic conductivity of the aquifer, transmissivity of aquifer, specific yield of aquifer and electrical conductivity of the aquifer.

The electrical conductivity of an aquifer (Water bearing rock) is directly related to the quality of the groundwater resource. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulphate, phosphate ions (anions) or sodium, magnesium, calcium, iron and aluminum ions (cations).

The presence of theses dissolved minerals in water increase the conductivity due to presence of ions, the less the quality of the groundwater resource. Organic compounds like oil, phenol, alcohol and sugar do not conduct electricity and therefore have low conductivity in water.

The present study was undertaken in some parts of Umuahia South –Eastern Nigeria to enhance the knowledge of the groundwater vulnerability assessment of the area by applying a geophysical tool (VES).

The result of the interpreted VES data from the study area and the DRASTIC index model result obtained in the area were analyzed and used to classify the groundwater vulnerability assessment of the area.

From an environmental health stand-point, there is a need to ascertain the level of water quality of a locality to avoid or reduce prevalence health hazards.

Over decades, communities in Umuahia South have depended on surface water supplies, mainly rivers/streams, ponds and rainfall. The need and demand for better water quality has promoted the search for the best alternative (groundwater resource). The next is to ascertain the extent of the groundwater vulnerability and quality for human consumption.

The development in technology and improvement in interpretation techniques in time recent has helped in using vertical electrical sounding (Dar zurouk parameter) data to predict the groundwater vulnerability and qualityassessment of an area.

1.2 Problem Statement

There has been a continuous and steady increase in the demand for portable water due to rapid urbanization, population explosion as well as industrial activities within and around the study area. This has resulted to a large threat on the groundwater resources of the area. Similarly, too, information regarding hydraulic characteristics of the aquifer systems and quality of few groundwater bodies in the areas that will give rise to economic exploitation of the groundwater resources are scarce. Hence there exists a dire need to evaluate the aquifer vulnerability to pollution due to anthropogenic activities in the area.

1.3 Aim and Objectives of the Study

The aim of the work is to determine the groundwater of the study area using integrated result of VES and DRASTIC index model.

The specific objectives of this work include:

i. Determine the aquifer geometric parameters such as the depth, thickness and the electrical conductivity.
ii. Evaluate the parameters to generate the aquifer protective capacity (APC) mapwhich has relationship with the overburden protection of the aquifer system.
iii. To adopt the DRASTIC model assessment to ascertain the groundwater vulnerability potential of the study area.
iv. Present Lithology profiling maps and geoelectrical interpretation with reference to the geology of the area.
v. Present the result of geoelectric interpretation and the DRASTIC index model in the study area for clearer understanding of the groundwater vulnerability assessment of the area.

1.**4 Justification of the Study**

Access to portable water has been a major problem facing most communities around the study area. Most of the inhabitants of the area depend on rainwater harvesting, fetching of surface water and often times poorly drilled private boreholes to solve their daily water needs. This therefore calls for in-depth and accurate groundwater resources assessment and a quantitative description of aquifers so as to address several hydrological and hydrological problems posing a major hindrance to effective groundwater management in the study area.

1.**5 Scope of Study**

The study area covers parts of Umuahia South Eastern Nigeria. Twenty vertical electrical soundings conducted within selected towns and villages in thestudy area.

The DRASTIC model for vulnerability assessment using Arc GIS 10 software for computation of DRASTIC indices and the interpreted geoelectric parameters like aquifer electrical conductivitywere analyze.

CHAPTER TWO

2.0 LITERATURE REVIEW

Geophysical techniques, especially gravity, magnetic, seismic and electrical methods, detect difference or anomalies of physical properties within the earth's crust. Density, magnetism, elasticity and electrical resistivity are properties most common measured.

The increased interest in recent years in underground sources of water has led to a need for more intensive studies of the geometry and properties of aquifers.

Geophysics has played a useful part in such investigation for many years and improvements in instruments and the development of better methods is resulting in a widening of its applications. It is still used mainly to determine structure but there is a considerable interest in the possibilities of estimating aquifer properties such as permeability and porosity from the measurements of geophysical properties.

Recently, resistivity imaging surveys have been used to map groundwater contamination and it is widely used for environmental surveys (Griffiths and Baker, 1993). It has also been successfully used in Engineering and hydrogeological applications.

Baker (1996) carried out mapping of groundwater contamination using DC resistivity. Smith and Raines (1988), Olayinka and Baker (1990) and ACworth and Griffiths (1985) demonstrated that resistivity imaging has application in hydrogeology in basement areas and mapping of strong faulted areas even where the weathered layer is so deep and laterally variable such that other electrical and electromagnetic methods prove ineffective. It has been proved to be useful for mapping saline intrusion into aquifer (Baker, 1990; Mooney, 1980; and Patra and Bhattacharya, 1967). It can be used to map rock quality for quarrying purpose and where tunneling is required (Dahlia, et al, 1996).

2.1Roles of Geophysics in Groundwater Prospecting and Hydrogeology

The demand for groundwater is increasing very fast the rapid urbanization and industrialization programs of the developing and the developed countries and the urgency to increase food production. Finding potential sources of groundwater by wildcat drilling is proving to be very expensive when the cost benefit ratio is taken into account.

Many geophysical methods (i.e magnetic, gravity, seismic and electrical methods) have been used to locate and delineate subsurface water resources. They are inexpensive and can rapidly provide information about the geological structure and lithology's of a large region under investigation compared to an extensive drilling program.

The most important objective of any geophysical survey for groundwater prospecting and study is to translate the result of geophysical interpretation in terms of the subsurface hydrogeology. For this purpose of fence diagram, a water table map, geological cross-section, geological correlation and location map of potential sites for drilling to groundwater are prepared.

Petroleum, mineral exploration and geotechnical and groundwater geophysicists have routinely used geophysical reconnaissance surveys. Further detailed geophysical survey can in many cases accurately identify geological structures or environments suitable for a particular target of interest. In this way the geological survey results are used to determine the locations of the minimum number of exploratory boreholes required for both selecting potential sites of groundwater aquifer and to provide controls for the geophysical interpretation.

Exploration geophysics is primarily concerned with mineral and petroleum exploration. Its importance in geotechnical engineering and groundwater exploration has been recognized later. Geophysical surveys can be used to determine hydrogeological parameters such as aquifer thickness, its boundaries, and transmissivity and storage coefficient. The values of the parameters determined from the geological methods can be considered fairly accurate in many cases when measurements are made between dump sites. Geophysical methods also play in important role in protecting the groundwater resources from being contaminated by toxic and other hazardous wastes.

Geophysical investigations are essential to determine the following;

1. Subsurface layering i.edepths, thickness and fluid saturation
2. Aquifer parameters like resistivity and conductivity.
3. Structural complications such as faults, voids or karstic features.
4. Presence of subsurface water as a potential water source and potential sources of contamination.

2.2 The use of the Resistivity Method in Groundwater Prospecting and Studies

Both one dimensional (1-D) and two dimensional (2-D) techniques have received a great deal of attention in direct current exploration techniques used in groundwater investigations, mineral resources exploration, archaeology and civil engineering studies.

Resistivity sounding (1-D) is the best common technique used to investigate changes of resistivity in the vertical direction. Lateral variation such as faults or dykes in subsurface resistivity is, however, best studied using 2-D or 3-D imaging survey methods. When the lateral variation in the electrical properties of subsurface geological structures is gradual, one-dimensional sequence of horizontal layers can be reasonably assumed.

The resistivity method is the most popular of all the geophysical methods as far as groundwater study is concerned. The fundamental physical parameter used in the exploration and description of subsurface rock by the resistivity method is RESISTIVITY. The wide range of values in the resistivities of rocks is sometimes misleading and difficult to utilize. The resistivity of subsurface materials depends more on the pore volume including fractures, degree of saturation, weathering, and conductivity of the saturant than on the rock type. In groundwater exploration the resistivity method is capable and can determine thickness of an aquifer overlying resistive bedrock. The method is capable of determining even the quality of groundwater i.e whether the water is saline, brackish, and fresh or contaminated with toxic wastes (Zohdy, 1976; Stellar and Roger and Keen, 1980; Urish, 1983; Arafin and Lee, 1988, Baselli et al, 1990 and ZohdyBisdorf, 1990).

The geophysical literature contains papers (Flathe, 1954; Meidav, 1960; Van Dam and Meuleukamp, 1967; Vincenz, 1968; Zohdy,1988; Van Overmeeren, 1989) showing ample evidence for the successful use of the method in groundwater prospecting in alluvial deposits. However, there is only few literatures regarding successful application of the direct current (DC) resistivity method in the exploration of groundwater in karstic areas.

Hallenbach (1952) studied the hydrology of the areas in west Germany employing the geoelectrical method. He was able to identify areas with salty groundwater, and suitable places for the establishment of new gravels and the relief of the underlying impervious layer.

Bristow (1966) employed a pole –dipole array to detect air filled subsurface cavities comprising cavern systems. However, this array is very sensitive to near surface lateral changes in resistivity. It has been reported (Vincenz, 1968) that a few authors (Zagorae,1954; Seldar,1954) have attained some degree of success in the exploration of groundwater in limestone aquifer using resistivity techniques. However, it is usually very difficult to detect a narrow water bearing zone in the surrounding massive rock. The presence of an unconsolidated overburden, and of interbedded clay layers, makes it complicated so that in general it becomes almost impossible to get a hydrogeologically meaningful interpretation of resistivity data. Vincenz, 1968 and Militzer et al, 1979 conducted both theoretical and experiment work on caving research using the resistivity method. Serres (1969) carried out resistivity survey in Tulim valley, western Argentina to find groundwater in alluvial deposits where the bedrock consists of limestone. The vertical electrical sounding (VES) curves are mostly bowl-shaped.

Setpathy and Kanugo (1976) used electrical resistivity measurements very extensively to delineate potential water bearing areas and also to estimate the thickness and quality of the water – bearing layer in hard rock terrains.

Bugg and Lloyd (1976) have used the resistivity method for the quantitative delineation of fresh water lenses in Cayman Islands. In many oceanic islands such lenses constitute the main source of potable water. Due to their relatively low density, fresh water lenses rest on top of the saline water that penetrates the subsurface of the islands from the sea. Fresh water lenses are subject to the dynamic effects of tides so that significant saline transition zones develop along their boundaries. Resistivity methods were used to solve this problem. All the information obtained from resistivity technique was integrated to provide a rapid and inexpensive method of mapping the base of fresh water lenses. The large resistivity contrast between fresh and saline water causes a distinctive decrease of apparent resistivity with depth, thus base of the fresh lens is easily defined. Therefore, the surface resistivity method appears to be suitable technique for locating the transition zone (interface), between fresh and saline or brackish groundwater in coastal areas.

Henriet (1976) conducted resistivity surveys in karsticlimestones and determined the storage coefficient for aquifer protection from bacteriological contamination. The area of surveys appears to be ideal in the sense that it is a 4-layer model where the fracture zone is sandwiched between unsaturated bedrock and the compact limestone basement. In a situation the vertical electrical sounding (VES) curves show a sigmoid bend framed between two steep segments. By drawing two 45 asymptotes on the two ascending portions of the curves, two conductivities were determined. The difference of the two quantities was then used to calculate the storage coefficient using the planimeter method.

Heigold (1979) found an inverse empirical relationship between aquifer resistivity determined from surface electrical measurements and the hydraulic conductivity of a granular aquifer. The author claimed that such a relationship is the result of difference in sorting of the outwash sediments.

Rogers and Keen (1980) reported the successful monitoring at a fly ash disposal site using surface resistivity methods. While the VES method in conjunction with laboratory studies showed the vertical and horizontal profiling, done on a monthly basis, was able to monitor the changing concentration of leachate after, the profile was corrected to a common groundwater temperature.

Roy and Elliott (1980) carried out a combination of resistivity and induced polarization (IP) sounding near Frederiction junction, New Bronswick, Canada, in order to delineate saline water and fresh water zones. They found that combined resistivity and IP survey could give better resolution of the surface than do resistivity alone. Integrated borehole lithologs, geophysical logs and water analyses data indicate that deeper aquifer are more saline.'

The results of several sounding curves may be combined to be presented as a geoelectrical section (a very common form of electrical image). Zafraan (1981) used this method to study the sandstone aquifer of the North Yorkshire area.

Fretwell and Stewart (1981) evaluated the resistivity method for locating the fresh –water /saline-water interface in the karstic Florida aquifer. The study showed that the resistivity method is a powerful tool for locating this interface and that the method can provide hydrologic information between wells and used for control.

Kosinski and Kelly (1981) established useful relationship between hydraulic and electrical properties for unconfined aquifers by using VES method. They explained the cause of the apparent discrepancy between the empirical relationship (between normalized resistivity and permeability) established in the study and earlier laboratory studies as partly due to the high resistivity of the ground.

Palacky (1981) used various electromagnetic and electrical techniques to locate fracture zones beneath the saprolite in the basement complex. They presented three types of aquifers, alluvial, transition zone and fracture zone. Based on the result they have successfully located the area for drilling.

Stewart (1983) used geoelectrical section method, which is very common form of electrical image to outline major hydrogeological features as a part of a regional hydrogeological investigation. Two hydrogeological features were mapped on a regional scale, i.e presence of shallow high resistivity limestone associated with late tertiary reef complexes and the approximate depth to waters with total dissolved solids (TDS) concentration well above the potable water limits.

The application of electrical resistivity surveys to geothermal exploration has been established in various geothermal fields of the world that Singh et al (1983) carried out DC resistivity survey in the puga valley, India Geothermal field have been delineated an elongated narrow low resistivity structure partly underlain by a gas –vapor zone. The resistivity sounding, profile and traverse data together suggest the channeled flow of hot fluids. The data further show that the eastern and western parts of the valley are devoid of subsurface formations saturated with hot waters.

Kessels (1985) used resistivity measurements to drive the order of magnitude of the water content using Archie's formula. Also he showed that from his experimental results, the determination of the water content is possible even for highly resistive salt formations.

Van Kuijk (1985) used DC resistivity in west Sudan, where the water is scarce and groundwater is found in small shallow alluvial deposits lying on the basement complex. He used conventional VES data with two different but valid interpretations. In the first one a 13m, 33^m clayey-sand layer overlies resistive basement, whereas in the other a 30m, 92^m saturated sand layer form the cover and the agreement is closest with subsequent drilling confirmed bedrock at 13m.

Smith (1986) used electrical survey to detect cavities in soft porous lime stones, using a specially designed cable and switching mechanism, reconnaissance surveys conducted with a minimum of manpower and expanded time. Thus, large segments of highways can be routinely investigated to identify potentially damaging cavities. The Karst terrain in North central Florida is essentially geoelectrially uniform, and subsurface solution cavities, whether air filled or water filled, exhibit detectable resistivity anomalies, which were interpreted as indicative of voids and lithology changes.

Al-Rumaih and Ali (1986) applied VES in relation to exploration and evaluated of water resources in Kuwait, with special emphasis on demarcation of water –quality interfaces. Generalized graphical empirical relation has been established between aquifer resistivity and water salinity (TDS) which can be used in other areas in Kuwait.

Van Lissa (1987) employed electromagnetic ground conductivity and conventional resistivity measurements to locate well sites in Nyansa Province, Kenya. Vertical electrical sounding (VES), resistivity profiling and electromagnetic ground conductivity meter profiling were then calmed out to precisely locate the structure for accurate drilling. VES soundings were used first to determine weathered zone thickness resistivity.

Seara and Granda (1987) using of combined inter pretention of the vertical electrical sounding (VES) and the induced polarization sounding (IPS) allowed them to correlate the salinity and the mean chargeability of formations mainly composed of clays with intercalation of sands and gravels. Meanwhile, the interpretation of (IP) and (VES) in other areas gives an idea of the different regional hydrogeological models to assist further exploration in the region.

An integrated approach in interpreting the resistivity and induced polarization (IP) Sounding data was presented by Arafia and Lee (1987) to show the effectiveness of the resistivity and IP in identifying the karstic limestone aquifers in Perlis to find areas of potential groundwater. Resistivity data have been interpreted quantitatively, where a qualitative interpretation for IP sounding data was presented, because of the lack of smoothness in most of the IP sounding curves. Resistivity data are however; smooth enough to be interpreted in terms of horizontally layered earth models.

Resistivity depth soundings utilizing the schlumberger electrode array have been very successful in locating areas of good groundwater potential. By using landsat image and aerial photography techniques it is possible to identify geomorphologic features such as palechannels in which the shallow aquifer is often found. Apparent resistivity measurements are made by Charukalas and Tamblyn (1987) in Chacphraya aquifer in Thailand to determine optimum bore locations. Aquifers found in shallow alluvial sediments are major source of good quality groundwater for irrigation in the Northern Thailand.

In the application of electrical resistivity survey in the groundwater development project at Mardi Bertam station and the usefulness of the of the results of this surface investigation for the subsequent subsurface (drilling) investigation for groundwater, ten resistivity profiles were carried out by Mohamed (1987) using a wenner configuration, to look for high resistivity gravel/sand anomalies since the alluvium was thought to be a better aquifer than the Sungai Petani formation. However, the slight resistivity contrast between the weathered shales, siltstone and sands of the alluvium makes the separation of bedrocks and alluvium difficult. It was concluded that, electrical resistivity survey finds its best application in preliminary exploration of a large area where a substantial groundwater development is desired. The objective is to permit exploration of a large area with fewer test holes than would be needed if a program of random drilling only were followed i.e resistivity survey is both time and cost effective.

A somewhat different approach, using resistivity and electromagnetic ground conductivity meters, has been adopted by Beeson and Jones (1988), in Kano state, Nigeria, where the objective was to construct, in selected villages, successful boreholes fitted with hand pumps. They employed the two complementary geophysical techniques to identify those sites with sufficient thickness of saturated weathered material where furthermore, bulk electrical in

Baker (1988) used the geoelectrical section technique to study the nature and thickness of the overburden in an area of few miles North of Birmingham.

Van Overmeeren (1989) used schlumberger soundings to provide information on the distribution of aquifers, aquitards and impermeable rocks and the salinity of the groundwater. Quantitative interpretation shows that no single resistivity model completely satisfies all the hydrogeological and geologic facts and theories. Basically, two different models were possible in one the thickness of the other its salinity is fixed, both models supported by data. However, geophysical well logging in two exploratory bore holes provided conclusive evidence for the model in which the thickness of the aquifer is fixed.

Zohdy (1989) developed a fully automatic method for the interpretation of wenner and schlumberger sounding curves, which produces a model with a multilayered variation of the resistivity with depth. The model consists of a horizontal layer where the number of data points on the sounding is measured; the resulting models can be combined to produce a contoured section of the subsurface.

Zohdy and Bisdorf (1990) used schlumberger soundings to explore the geothermal potential of medicine lake area near California, which is proved to be challenging because of high contact resistance which were caused by the presence of the loose and dry pumice deposits. Computer animation of 42 resistivity maps revealed that there are three areas near Medicine Lake which may form geothermal targets.

Because of its potential to detect changes in pore-water salinity, the surface electrical resistivity method can become a valuable aid in coastal groundwater exploration and investigations. With such concern Urish and Frohlich (1990) used electrical resistivity method to determine the freshwater layer. It was recognized that the lower boundary of the unsaturated zone corresponds to the top of the capillary zone, not to the water, and that the lower boundary of the freshwater layer corresponds only approximately to the top of the fresh- water –salt-water transition zone. The existence of fresh-water layer can be ascertained qualitatively by visual inspection of electrical sounding curves, provided there is a fresh-water/unsaturated layer thickness ratio of at least 4.

Mbonu, Ebeniro, Ofoegbu and Ekine (1991) used schlumberger vertical electrical soundings (VES) to determine aquifer characteristics, in Umuahia, Nigeria. Aquifer hydraulic conductivity and transmissivity are obtained from pumping tests and also calculated from the models. Three distinct geoelectric layers overlaying a conductive geoelectric basement are indicated, and the area divided into two zones, homogeneous in hydraulic properties, but distinct in changes in either subsurface geology or water quality.

Yaramanci and Flach (1992) found that the resistivity of the rocks salt is related to the amount of freely adhesive water in the pores. To describe the relationship, he used Archie's equation by also including the dependence on saturation.

A resistivity survey was carried out by EL-Waheidi et al (1992) in the Azraq basin, Jordan in order to study the groundwater conditions in the shallow aquifer complex including depth and thickness of the aquifer, type of water and the interface between saline and freshwater. The resistivity data confirmed that the shallow aquifer complex of the area consists mainly of an alluvial aquifer, a basaltic aquifer and a chert- limestone aquifer. The presence of good resistivity contrasts between saline water- bearing sediments and fresh water bearing sediments allows the determination of the boundary between saline and fresh water zones with a reasonable accuracy.

Quarto and Schiavone (1994) used electrical and magnetotelluric surveys on the Apulian carbonate platform to study the deep coastal karst aquifer. He indicated that a complete knowledge of aquifer geometry and hydraulic properties is a necessary condition for the formulation of a regional hydrogeological model of karst aquifers. He used Archie's law to estimate groundwater reserve.

Sapari (1994) did geophysical investigation by electrical resistivity trenching and vertical electrical soundings (VES) to identify the soil stratification of deeper aquifers. The hydraulic conductivity (k) was determined. Water movement through the soil was calculated based on the k values and hydraulic gradient obtained from measurements.

Metias (1994) have studied the effect of the leachate emanating from landfills which contaminates nearby aquifers. The groundwater contaminated by a landfill, located on very porous and permeable formations, is assessed by both geophysical and hydrogeological techniques. The contamination plume was determined by electromagnetic method and ground conductivity survey. Several resistivity soundings were proposed and two resistivity pseudo-sections were obtained. Based on the geophysical data, boreholes were drilled a strategic place, water samples obtained and chemical analyses carried out.

Meheni (1995) used resistivity prospecting to investigate the shallow structure of the ground. He used Wenner prospecting techniques for mapping lateral variations in resistivity. He found that electrical resistivity is very sensitive a granularity and porosity changes.

A multi-electrode resistivity data acquisition system was by Dahlm (1996) which shows that 2D resistivity surveying can form a powerful geological mapping tool, for use in engineering and environmental applications, including hydrogeological mapping. He found that pseudo section plotting provides control over data quality, and thus is presented along with depth sections as a quality indicator pseudo section can also be used in qualitative interpretation.

Ritz et al (1999) used electrical resistivity tomography (ERT) to investigate the electrical properties of a lateritic weathering mantle. The field survey was conducted along two profilesgeological mapping. He found that pseudo section plotting provides control over data quality, and thus is presented along with depth sections as a quality indicator pseudo section can also be used in qualitative interpretation.

Ritz (1999) used electrical resistivity tomography (ERT) to investigate the electrical properties of a lateritic weathering mantle. The field survey was conducted along two profiles providing continuous coverage. Color modulated sections of resistivity versus depth were plotted, giving an approximate image of the subsurface structure. Three layers were investigated. The near-surface topsoil comprising unsaturated lateritic material is highly resistive. The intermediate layer with low resistivities contains including small quantities of water. The third, highly resistive layer reflects the granitic basement. The results show and suggest that ERT can be used as a fast and efficient exploration tool to map the lateritic weathering mantle in tropical basement areas with hard rock geology.

Osella (1999) used electrical resistivity imaging to describe the investigation of an alluvial aquifer. Vertical electrical soundings were carried out to obtain information about the electrical structure of the alluvial cover. A geological model is proposed taking into account complementary hydrogeological and geophysical information. In this model the various layer layers which could contain fresh water are identified and the level of the water table inferred from the model is almost coincident with that observed from existing wells in the surveyed zone.

Akaolisa (2006) has it that computation of aquifer transmissivity value based on the resistivity sounding results makes it possible to demarcate region with good groundwater potential in an area. In this work he puts forward that through resistivity sounding the determination of the depth of water table, aquifer thickness and subsurface geology are made possible thus revealing its groundwater distribution and potential.

2.3 Review of Geology

It is generally not possible to make a meaningful interpretation of the hydrogeological-petrophysical aspects of an area without having first examined the geological framework.

Geologically, Umuahia South L.G.A is within the Imo River basin.

2.3.1 Review of the Geology of Imo River Basin

The Imo River basin covers an area of approximately 9100km. It includes two main sub-basins; the Oramiriukwu-Otamiri sub-basin and the Aba River sub-basin (Uma, 1989).

The basin is bounded in the North East by the Udi-Okigwe-Arochukwu cuesta and in the North West by the Awka-Umuchu-Umuduru cuesta. The Southward boundary of the basin is the estuary of the Imo River at the Atlantic Ocean.

The bedrock of the Imo River basin consists of a sequence of sedimentary rocks of about 5480m thick and ranging in age from upper cretaceous to recent. A summarized regional stratigraphy of the Imo River Basin is shown in table 1.1

Table 2.1: Geology of the Imo River Basin (Uma, 1989).

Age	Formation	Maximum Appropriate Thickness (m)	Character
Miocen-recent	Benin	2000	Unconsolidated yellow & white sands, occasionally pebbly with lenses of gray sandy clay.
Oligocene-miocene	Ogwashi/Asaba	500	Unconsolidated Sandstones with carbonaceous mudstones, sand clays and lignite seams
Eocene	Ameki	1460	Sandstones grey to green argillaceous sandstones, shales and thin limestone.
Paleocene	Imo	1200	Blue to dark grey shales and subordinate sandstone members; the Umuna and Ebenebe sandstones
Upper Maestrichtian	Nsukka	350	White to grey coarse-to-medium grained sandstones; carbonaceous shales, sandy shales; subordinate coals and thin lime stones.
Lower Maestrichtian	Ajali Sandstone	350+	Medium-to-coarse grained sandstones; poorly consolidated with subordinate white and pale grey shale bands.

The stratigraphic succession of the Imo river basin after Uma (1989) is given below:

2.3.1.1 Ajali Formation

The Ajali Sandstone (Maestrichtian) is the oldest exposed geologic formation in the River Basin. It outcrops along a NW-SE (2km-4km wide) bound at the North Eastern margin of the basin. The Ajali sandstone consists of thick friable poorly consolidated sandstones typically white in colour but sometimes iron stained.

There is a marked banding of coarse and fine-grained layers and the sand grains and larger fragments are sub-angular with a sparse cement of white clay (Reyment, 1965). Units of the Ajali Sandstones are typically cross bedded and both the major bedding planes and foreset bedding planes are frequently lined with very thin (Sometimes less than 1mm) white clay streaks. The maximum thickness of the formation within the Imo River Basin is about 300m

2.3.1.2 Nsukka Formation

The Nsukka formation conformably overlies the Ajali sandstone and occupies a trelatively broader stretch of land west of the area underline by the Ajali sandstones. The Average dip is 6^{o}southwest ward but may decrease to about 1^{o} or 2^{o} especially in areas north of the Imo River Basin.

The rock units consist of an alternating succession of sandstones, dark shales and sandy shales within coal seams at various horizons. However, examination of cuttings recovered from boreholes penetrating the Nsukka formation did not reveal any coal seam. The basal units of the formation consist of fine to medium grained loosely consolidated sandstones which dip at 3^o to 4^o towards the west and southwest and from a broken line of dissected ridges and hills at the eastern boundaries of the formation.

2.3.1.3 Imo Formation

The Imo Formation (Paleocene) unconformably overlies the Nsukka Formation between the two formations is angular, while the Nsukka formation dips at relatively higher angles of 17^o to 25^o to the southwest and south. The Imo Formation consists of a thick sequence of blue and dark grey shales with occasional bands of clay-ironstone and subordinate thin standstone (Swardt& Casey, 1961). It includes three sandstone members; the Igbadu, Ebenebe and Umuna sandstones with the last two outcropping at the Imo River Basin.

The Umuna sandstone generally consists of relatively thick sandstone units and minor shales and is commonly less than 70m thick within the Imo Rivers Basin. The Ebenebe sandstone occurs as a lens in the northwestern extremity of the Imo River Basin. It is similar in lithology to the Umuna sandstone but is relatively thickner with a maximum thickness of 130m.

2.3.1.4 Ameki Formation

The Ameki Formation (Eocene) vertically overlies the formation. However, the lithostratigraphic boundaries between the Ameki formation and the inter-bedded formations are not yet precisely located. Lithologic units of the Ameki formation fall into two general groups (Reyment, 1965; Whiteman, 1962; andArua, (1986), an upper grey-green sandstones and sandy clay; and a lower unit with fine to coarse sandstones and intercalations of calcareous shales and thin shelly limestone.

2.3.1.5 Ogwashi/Asaba Formation

TheOgwashi/Asaba formation (Oligocene-Miocene vertically succeeds the Ameki formation). The formation is generally made up clays, sands, grits and seams of lignite alternating with gritty clay (Dessauvagie, 1974). The dominance of thick sandy units in the Ogwashi/Asaba formation (as revealed by the stata and geophysical logs of boreholes penetrating its outcrop area) appear to contrast the known lithostratigraphy of the formation (Uma, 1989). A charateristics feature of the formation within the Imo River Basin is the up dip and down dip pinch outs.

2.3.1.6 Benin Formation

The Ogwashi/Asaba formation is overlain by the Benin formation which is the youngest formation (Miecene-Recent) in the Imo River Basin. The formation occupies the middle to lower region and directly overlies more than half of the Basin. The Benin formation is made up of very friable sands with minor intercalations of clays. It is mostly coarse-grained, pebbly poorly sorted and contains pods and lenses of fine grained sands, sandy-clays and clays (Whiteman, 1982; Uma and Egboka, 1985). The formation is in part cross-stratified and the foreset beds alternate between coarse and fine–grained sands. Petrographic study on several thin sections (Onyeagocha, 1980) show that quartz makes up more than 95% of all grains but Asseez (1976) and Avbovbo(1987) indicated a possible presence of more percentage to other skeletal materials including feldspar. The dominance of sandy horizon in the Benin formation is also indicated by the logs of boreholes drilled through the formation. The strata log of more than 85% of the sandy clays making up the rest. The Benin formation and the other formations are covered (at their exposed areas) to varied depths by red acid sandy soils and mangrove soils.

2.4 Location and Physiography of the Study Area

Geographically, the study area is located within Lat. $5^0$34' - $5^0$38'and Long. $7^0$22' – 733'E within the rain forest belt. The area is characterized by high temperatures of about 29^0-31^0C and has double maxima rainfall peaks in July and September. The location map and the topographical map of the study area are shown in Fig 2.1 and Fig 2.2 respectively.

Geologically, the area is underlain by the Benin Formation (Miocene-Recent), Ogwashi-Asaba (Oligocene-Miocene) formation and the Ameki formation (Eocene-Oligocene) as shown in Fig 2.3. The sediments of the Benin formation consist of lenticular, unconsolidated coarse-grained sands and clayey shales. The sands are generally moderately sorted, poorly cemented and angular to sub-angular in shape. The Benin formation overlies the Ogwashi-Asaba formation and the youngest in the area. The Ogwashi-Asaba formation overlies the Ameki formation,It is mostly coarse-grained, pebbly poorly sorted and contains pods and lenses of fine grained sands, sandy-clays and clays (Whiteman, 1982; Uma and Egboka. The Ameki formation consists of medium to coarse grained white sandstone, bluish calcerous silt with mottled clay, thin limestone beds and abundant calcareous shale.

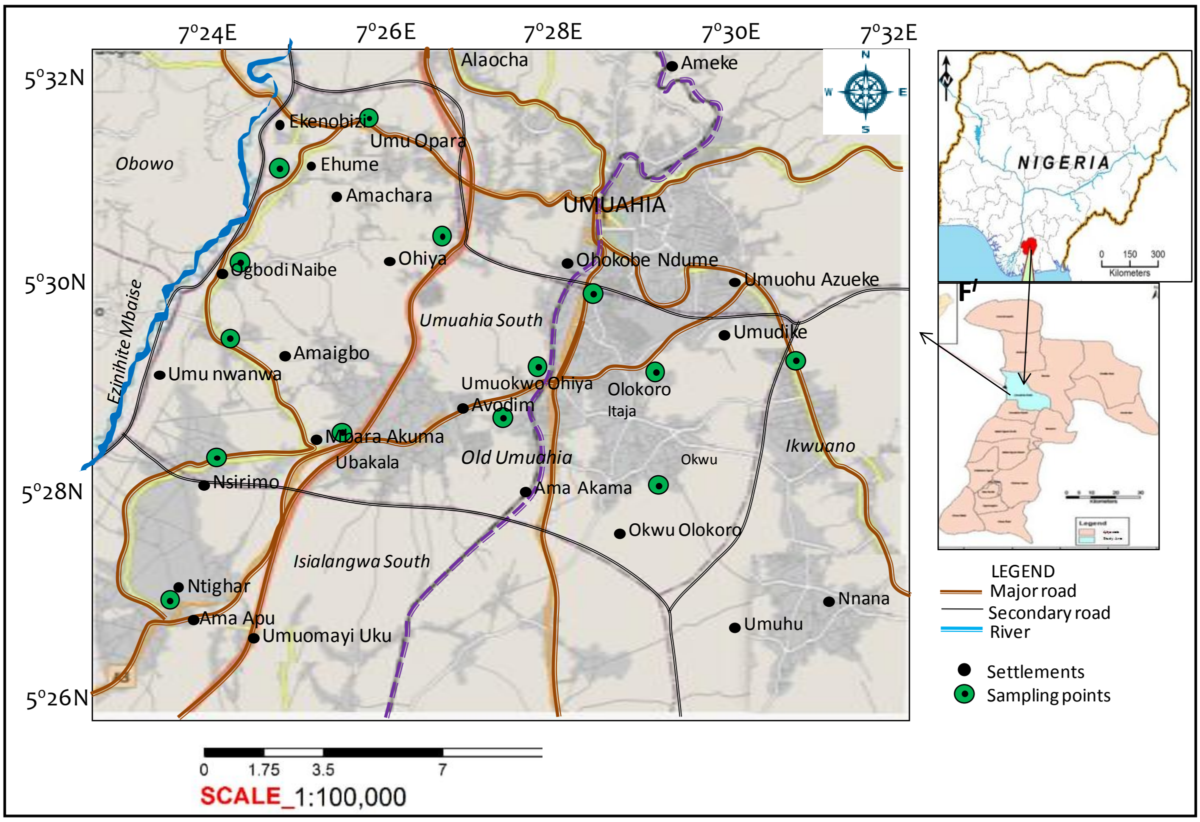

Fig. 2.1 Location Map of the study area

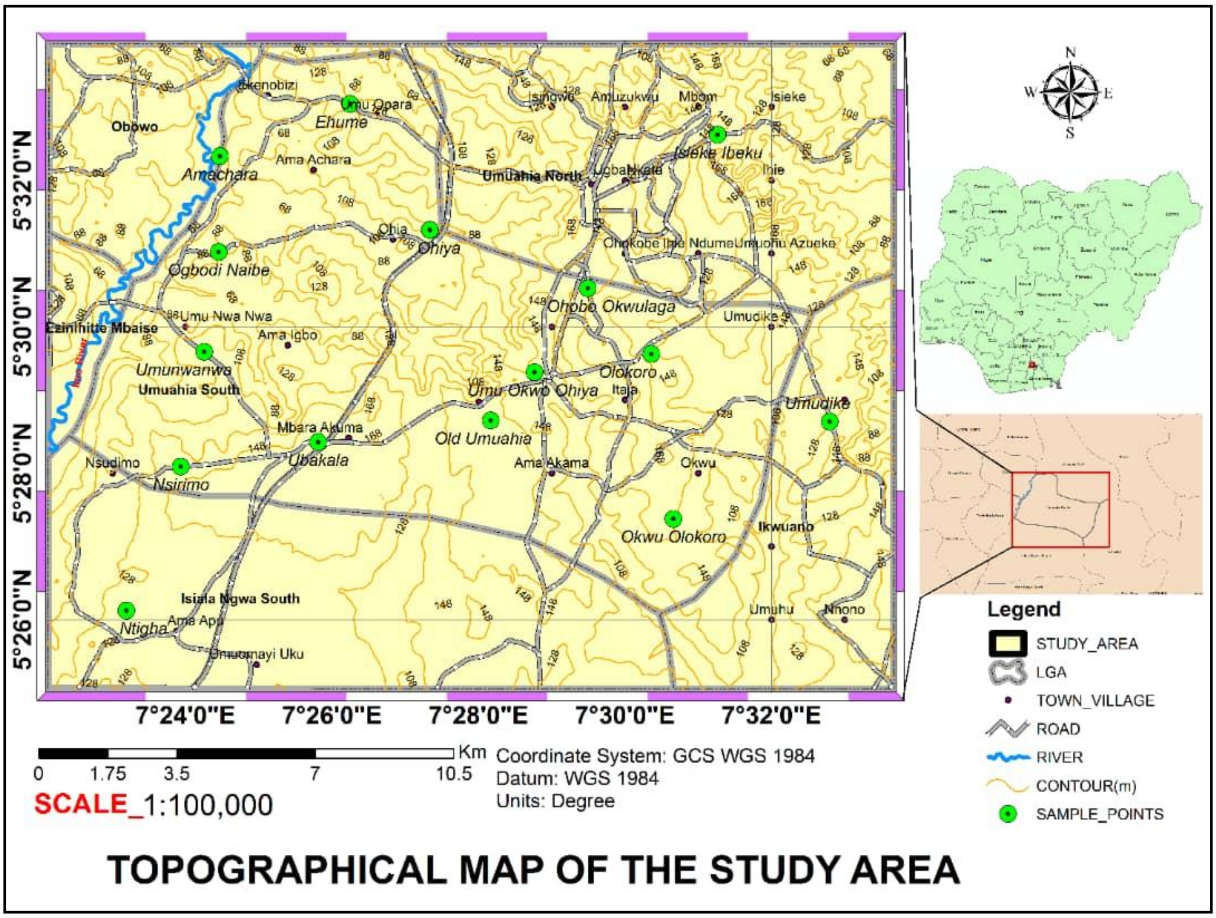

Fig. 2.2. Topographical map of the study area

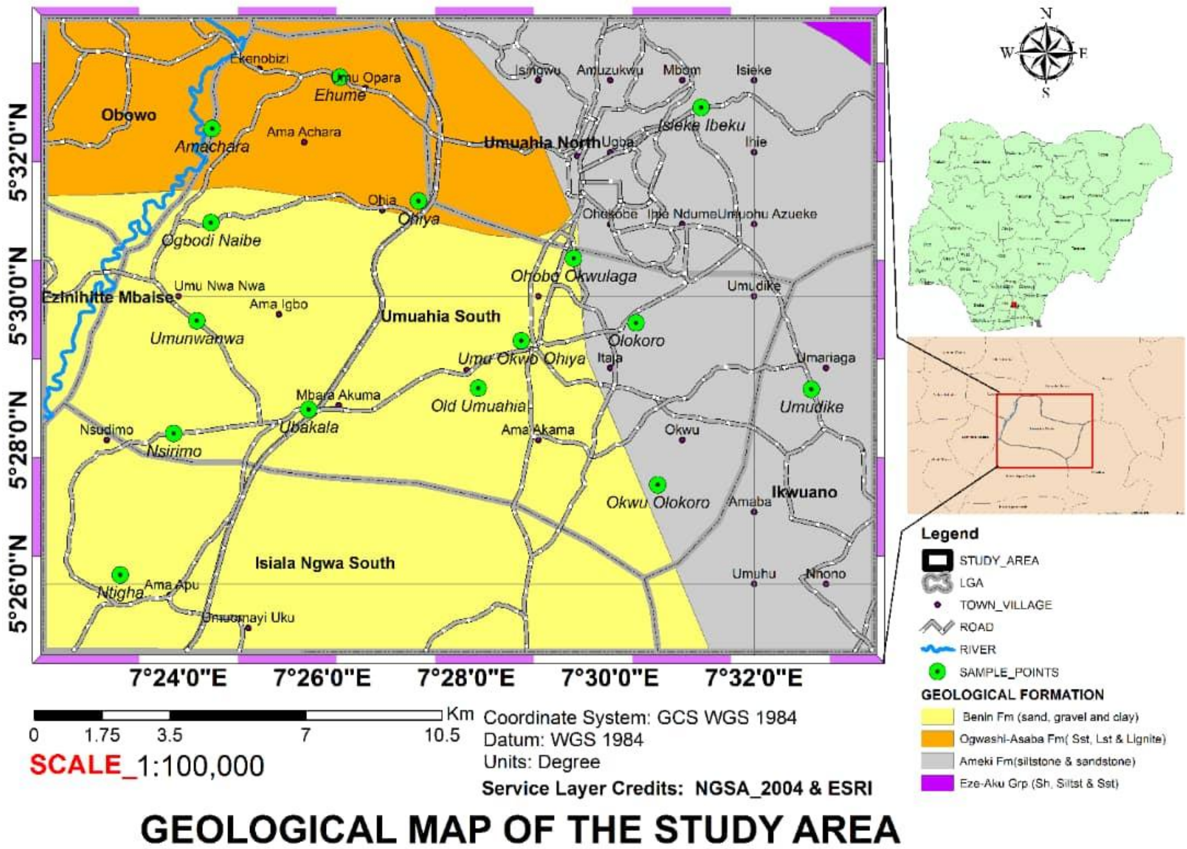

Fig 2.3: The Geological Map of the Study Area

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Conceptual Framework

Groundwater exploration and management is surrounded by so many uncertainties. These uncertainties can be attributed to insufficient or total absence of detailed description of the groundwater resources of an area with respect to geology prior to drilling. More-so even when the drilling is successful, the level of vulnerability of an area to contamination may not be readily ascertained, thus posing serious challenges to groundwater management of the area.

Qualitative assessment of groundwater of an area is therefore necessary in order to minimize the uncertainty associated with groundwater exploration and management of a given area.

In carrying out quantitative and qualitative assessment of groundwater resources in an area,

Three fundamental measurements are required. They are;

i. The elevation of the water table (piezometric surface)
ii. The speed of groundwater movement
iii. The specific yield of Aquifer and
iv. Aquifer conductivity

In delineating the presence of an aquiferous layer during a hydrogeologic survey, some basic exploration techniques are adopted, they include:

i. Surface geological methods
ii. Sub-surface geological methods
iii. Surface geophysical methods and

iv. Sub-surface geophysical methods.

The integration of these methods when properly analyzed, provide veritable information of the subsurface structure & heterogeneity. The heterogeneous nature of the subsurface makes it easy to detect variations in levels of responses of subsurface materials to the introduction of certain physical parameters. Geophysical investigations are centered on detecting and analyzing these variations.

The Geophysicist is interested in locating water bearing formations (Aquifer) during groundwater exploration. Aquifer is usually located in sedimentary rocks such as sandstones because of their porous and permeable nature.

Two principal methods are employed by Geophysicists in the search for groundwater. They are seismic refraction and the electrical resistivity methods.

These approaches are aimed at identifying water bearing formations which contrast to other formations when elastic waves (seismic refraction) or electric current (electrical resistivity) is passed through them. Once an aquiferous medium is identified, the approximate depth from the subsurface, its thickness and aerial extent are delineated. The end result is the selection of a drilling target of greatest possibility of success in striking water for each selected site. The comparison of results of drilling operation and geophysical investigation are advisable in other to establish the degree of correlation between the actual exploration and the estimated investigation. This leads to effective groundwater resource management, reduced incidence of abortive boreholes, cost advantage and improved confidence in the application of the geophysical survey for borehole exploration in the region.

3.1.1 Electrical Resistivity Method

Earth materials respond differently to the passage of electric current through them. While some are very conductive in nature, others show high level of resistance to the passage of electric current.

Resistivity is a fundamental property of rock materials that is closely related to their lithology and fluid content. Resistivity of rock formations vary over a wide range depending on the rock texture, density, porosity, pore size and shape, fluid content and temperature. A water bearing strata conducts electricity more readily than similar strata that are dry. With the exception of clays and some metallic minerals, the passage of electricity through rocks takes place by way of the groundwater contained in the pores and fissures as the rocks are non-conducting.

Electrical resistivity is based on the fact that when electric current is passed into the ground through the current electrodes, any subsurface variation in conductivity alters the current flow within the earth and this affect the distribution of the electric potentials. The degree to which the potential at the surface is affected depending on the resistivity of the formation generally depends on the resistivity of the contained electrolyte and inversely related to the effective porosity and degree of saturation and salinity.

There is no general correlation of lithology with resistivity since the later may range widely even within a particular formation. Nevertheless, in a sedimentary terrain, some generalization is possible, for example in order of increasing resistivity is clay, sand, gravel and limestone.

Field data acquisition, using electrical resistivity method; four electrodes are employed a pair of current electrodes for passing current into the earth; and a pair of potential electrode for measuring potential difference. The surface arrangements of these electrodes depend on the particular configuration to be adopted. Some widely used configurations include:

i. Schlumberger array

ii. Wenner array

iii. Dipole-dipole spread

iv. Three-point spread

v. Lee-partition spread

For this work the Schlumberger electrode configuration was used.

In Schlumberger array (Fig 3.1) the current and potential pairs of

Electrodes have a common midpoint but the distances between adjacent electrodes differ so that a≠b.

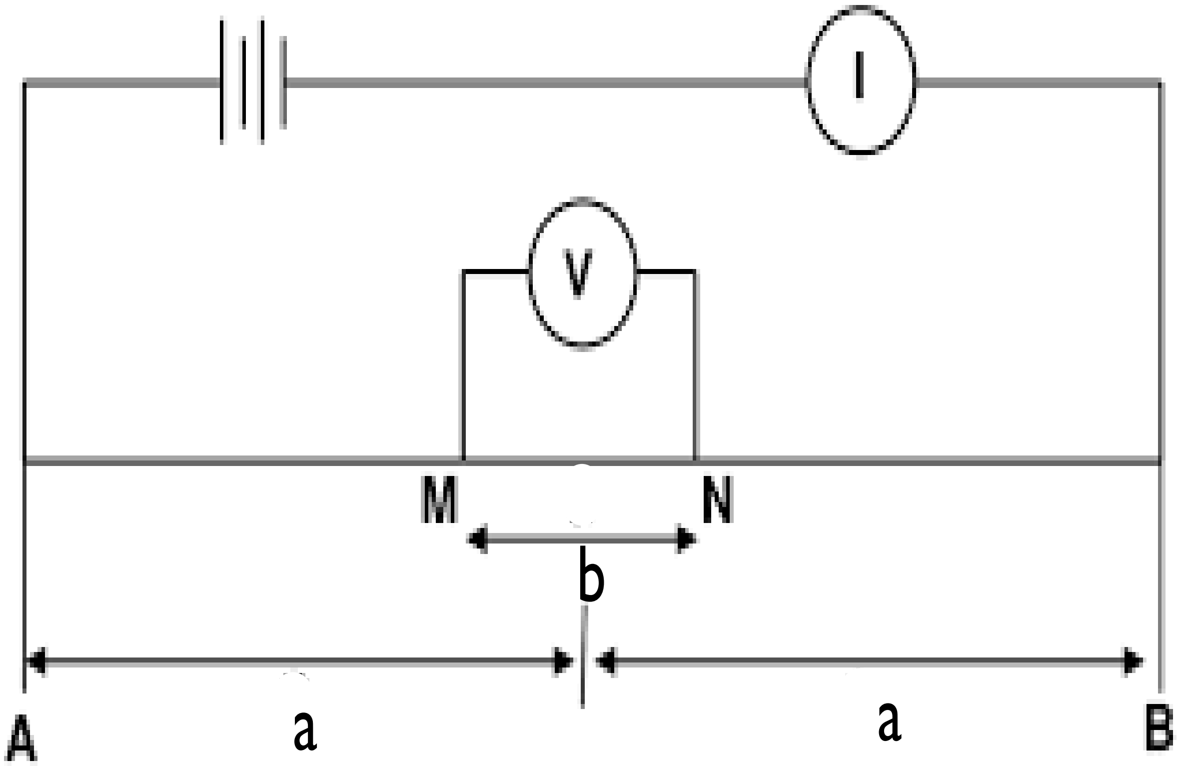

Fig 3.1: Schlumberger electrode arrangement for resistivity survey

Theoretically, the resistivity (ρ) of a material is directly proportional to the potential difference (V) and inversely proportional to the induced current (I)

$$\rho \propto \frac{v}{I} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

$$\rho = K\left(\frac{v}{I}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.2)$$

Where K is the geometric factor and can be obtained thus:

$$K = \pi\left\{\frac{\left[\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2\right]}{MN}\right\} = \pi\left(\frac{a}{b}^2 - \frac{b}{4}\right) \ldots\ldots\ldots\ldots(3.3)$$

Hence,

$$\rho = \pi\left(\frac{a}{I}^2 - \frac{b}{4}\right)\left(\frac{v}{I}\right) \text{Or } \rho = \pi\left(\frac{a}{I}^2 - \frac{b}{4}\right) R \ldots\ldots\ldots\ldots\ldots. (3.4)$$

Recall ρ = KR

Where R is the resistance

The geometric factor K depends on the electrode separation. R responds to the resistance of the volume of ground between the potential electrodes. If V and I are measured in millivolts and mill amperes respectively and the distance of separations in meters, then the resistivity ρ is expressed in ohm-meter.

It should be noted that in resistivity survey the parameter measured is called the apparent resistivity ρ_a. The apparent resistivity is the resistivity which the ground would have if it were homogenous. This implies that in an isotropic medium, the apparent resistivity equals the true resistivity. In practice, this is difficult to obtain.

However, the subsurface is assumed to be divided into thin strata with each stratum regarded as completed homogenous and isotropic. This is a convenient way to represent a response of the actual distribution of lateral resistivities in the subsurface on the basis of surface measurement in vertical electric sounding; the charge in the value of resistivity with the electrode spacing makes it possible in most cases to determine the variation of resistivity with depth. The apparentResistivity data are interpreted in terms of layer resistivities and depth to the bedrock or other interfaces across which a strong electrical contrast exists. Depth sounding curves are then interpreted on the assumption that the earth is made up of different resistivity by a plane interface.

3.1.2 Aquifer Hydraulic Characteristics from Surface Electrical Resistivity Data

The determination of aquifer hydraulic characteristics can be achieved using the Dar-Zarrock parameters of transverse resistance and longitudinal conductance.

Niwas and Singhal(1981) established an analytical relationship between transmissivity and transverse resistance on one hand and transmissivity and longitudinal conductance on the other hand.

From Darcy’s law, the fluid discharge Q is given by

Q=kia………………………………. (3.5)

Andfromohm’s law

J=σE…………………………………. (3.6)

Where K= hydraulic conductivity, I= hydraulic gradient, A= cross sectional area

Perpendicular to the direction of flow, J= current density, E=electric field intensity and σ= electrical conductivity (inverse of resistivity).

Considering a prism of aquifer material having a unit cross-sectional area and thickness h, Niwas&Singal (1981) combined equations (5) & (6) to get

T= $K\delta R = \frac{KS}{\delta}$……………………………….. (3.7)

Where T= Aquifer transmissivity, R= Transverse resistance and S=Longitudinal conductance, K=hydraulic conductivity.

Quantitative interpretations of vertical electrical sounding data often lead to the generation of geoelectric layers. The information from those geoelectric layers enhances the identification of layer parameters which include aquifer depth and thickness. These layer parameters thus obtained will be used to evaluate the Dar-Zarrock parameters. The transverse resistance (R) is the product of the aquifer resistivity (ρ) and the aquifer thickness (h) while the longitudinal conductance(S) is obtained by dividing the aquifer thickness (h) by the resistivity (ρ) of the aquifer.

$R = h\rho$……………………………………… (3.8)

$S = \frac{h}{\rho}$ ……………………………………….. (3.9)

In areas of similar geologic setting and water quality the product Kσ remains fairlyConstant (Niwas&Singhal, 1981); (Mbazi&Onuoha, 1988); (Onu&Ibezim, 2004). Thus, knowing the K values for existing boreholes and σ values extracted from the sounding interpretation for the aquifer at borehole locations, the determination of transmissivity and its variation from place to place is made possible, including those areas without boreholes.

The storability S of the confined aquifer system and the deep and thick unconfined aquifer which may be hydraulically similar to it may be estimated from the rule of thumbs equation given by Lohman (1972) & Todd (1980) as

$$S = 3\text{x } 10^{-6}\text{b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.10)$$

Where b is the saturated thickness of the aquifer.

Dar-Zarrouk Parameters

Dar-Zarrouk (D-Z) parameters were defined by Maillet (1947). T is the resistance normal to the face and S is the conductance parallel to the face for a unit cross section area, which plays an important role in resistivity soundings. D-Z parameters are sufficient for computing the distribution of surface potential and hence electrical resistivities graph (Henriet 1976).

Suppose that a section consists of N fine layers with thickness h_1, h_2, ..., $h_n$and resistivity ρ_1, ρ_2, ρ_3,....,$\rho_n$for a block of unit square area and thickness

$$H = \sum_{i=1}^{N} hi$$

These values of S and T are set equal to those for an anisotropic block with unit square area.

So that: Longitudinal Unit Conductance S,

$$S = \frac{h1}{p1} + \frac{h2}{p2} + \frac{h3}{p3} + \dots \dots + \frac{hn}{pn} = \sum_{i=1}^{N} \frac{hi}{pi} \dots (3.11)$$

Transverse Unit Resistance T,

$T = p_1h_1 + p_2h_2 + p_3h_3 + \cdots \dots + p_nh_n =$

$= \sum_{i=1}^{N} p1h1 \dots$ (3.12)

Longitudinal Resistivity R_S, =

$$R_s = \frac{H}{S} \dots \dots \dots \dots \dots (3.13)$$

Transverse Resistivity, R_T =

$$R_T = \frac{T}{H} \dots \dots \dots \dots \dots (3.14)$$

In this study however, only the Longitudinal Unit Conductance S in mhos (Equation 3.9 and 3.11) was considered as it is found to be proportional to the protective capacity of the overburden (Olorunfemi et al., 1998; Oladapo et al., 2004. Ayolabi, 2005 and Atakpo and Ayolabi, 2009).

3.1.3 Groundwater Vulnerability Assessment Using Drastic Model

3.1.3.1 Theoretical Background

Groundwater has been considered as an important source of water supply due to its relatively low susceptibility to pollution in comparison to surface water and its large storage capacity (US EPA, 1985). However, there are significant sources of diffuse and point pollution of groundwater from land use activities particularly agricultural practices. The intrusion of these pollutants to groundwater makes remediation activities expensive and often impracticable.

Vulnerability assessment to delineate areas that are more susceptible to contamination from anthropogenic sources has become an important element for sensible resource management and land use planning. This concept was first introduced in France by the end of the 1960s to create awareness to groundwater contamination (Vrba&Zoporozec, 1994).

Groundwater vulnerability can be defined as the tendency and likelihood for contamination to reach the water table after introduction at the ground surface.

This is a function of the intrinsic properties of aquifer system and their sensitivity to human and natural activities.

Vulnerability mapping is defined as a function not only of the properties of the groundwater flow system (intrinsic vulnerability) but also of the proximity of contaminant sources, characteristics of the contaminant, and other factors that could potentially increase load of specified contaminants to the aquifer and/ or their eventual delivery to a groundwater resource (Michael et al, 2005). It is however worthy of note that groundwater vulnerability deals only with the hydrogeologic setting and does not include pollutant attenuation. The natural hydrogeologicfactors affect the different pollutants in different ways depending on their interactions and chemical properties.

3.1.3.2 The Drastic Model

Many approaches have been developed to evaluate aquifer vulnerability. They include process-based methods, statistical methods and overlay and index methods (Tesoriero et al, 1998). The process-based methods use simulation models to estimate the contaminant migration but they are constrained by data shortage and computational difficulties (Barbash and Resek, 1996). Statistical methods use statistics to determine associations between spatial variables and actual occurrence of pollutants in the groundwater. Their limitation includes insufficient water quality observations, data accuracy and careful selection of spatial variables (Barbiker et al, 2005). Overlay and index methods combine factors controlling the movement of pollutants from the ground surface into the saturated zone resulting in vulnerability indices at different locations. The main advantage is that some of the factors such as rainfall and depth to groundwater can be available over large areas which make them suitable for regional scale assessment (Thapinta and Hudak, 2003). However, their major drawback is the subjectivity in assigning numerical values to the descriptive entities and relative weights for the different attributes (Barbiker et al, 2005).

The DRASTIC model has been the most commonly used aquifer sensitivity assessment method (US EPA, 1985). DRASTIC is an index model designed to produce vulnerability scores for different locations by combining several thematic layers. The model was developed by the US Environmental protection Agency (EPA) to evaluate groundwater pollution potential for the entire United States (Aller et al,). The model is based on the concept of the hydrogeological setting that is defined as a composite description of all the major geologic and hydrogeologic factors that affect and control groundwater movement into, through and out of an area (Aller et al, 1987). The acronym DRASTIC corresponds to the initials of the seven parameters used in the model which are;

i. Depth to water
ii. Net Recharge
iii. Aquifer Media
iv. Soil Media
v. Topography
vi. Impact of the Vadose Zone and
vii. Hydraulic conductivity.

Each of the seven DRASTIC parameters is mapped and classified into ranges or into significant media types which have an impact on pollution potential. Each factor or parameter is assigned a rating which varies from 1 to 10 based on their relative effect on the aquifer vulnerability. Weight multipliers are then used for each parameter to balance and enhance its importance. Every parameter in the model has a fixed weight indicating the relative influence of the parameter in transporting contaminants to the groundwater. The parameter ratings are variable which allow the user to calibrate the model to suit a given region (Dixon, 2005). The final vulnerability map is based on the DRASTIC index (D_i) which is computed as the weighted sum overlay of the seven parameters using the following equation:

DRASTIC Index $(D_i)=D_rD_w+R_rR_w+A_rA_w+S_rS_w+T_rT_w+I_rI_w+C_rC_w$ ………… (3.11)

Where D, R, A, S,I, C, are the seven parameters and the subscripts **r** and **w** are the corresponding ratings and weights respectively.

3.1.3.3 Drastic Model Parameters

Depth to Water (D): This is the distance from the ground to the water table. It represents the thickness of material through which infiltrating water must travel before reaching the aquifer-saturation zone. The depth to water table controls the degree of interaction between the percolating contaminants and the surface materials (minerals, water). Hence there is a greater possibility of attenuation to occur as the depth of water increases. Areas with high water table are vulnerable because pollutants have short distances to travel before contacting the groundwater. This means the deeper the groundwater the smaller the assigned rating.

In general, the aquifer potential protection increases with depth to water. The depth to water is assigned a factor weight of 5 and the DRASTIC rating is as shown in table 3.1.

Table 3.1: Ratings and Weight for Depth to Water table after (Mogaji et al., 2014)

DRASTIC Parameters	Ranges (Classes)	Pollution potentiality for groundwater	Rating	Weight
Depth to water table	0-15	High	10	5
	15-30	Medium high	8	
	30-50	Medium	6	
	50-75	Low	4	
	75-100+	Very low	2	

Net Recharge (R): -This is the amount of water per unit area that penetrates the ground surface and reaches the water table. The net recharge is the vehicle that transports pollutant to the groundwater. Greater contaminant transport is possible during periods of intense rainfall especially during the rainy seasons. Areas with high recharge rate are at high risk of being polluted. The net recharge was taken as 12% of the average annual rainfall (Al Hallaq& Abu Elaish 2008). The annual rainfall of the study area is 2270mm (89.4 inches) and net recharge assumed for the entire locations is put at 10.73 inches. Net recharge can also be calculated using the following formula:

Net Recharge= (Rainfall Evaporation) x Recharge Rate.

Net recharge is assigned a relative weight of 4. The DRASTIC rating for Net Recharge is given in table Table 3.2:

Table 3.2: Assigned rating for Net Recharge

Recharge (Inches)	Rating
0-2	1
2-4	3
4-7	6
7-10	8
>10	9

Aquifer Media (A): -This refers to potential area for water storage. The contaminant attenuation of aquifer depends on the amount and sorting of fine grains. In general, the larger grain size, the higher the permeability and lower the attenuation capacity; consequently, the greater the pollution potential. So coarse media were assigned a high rating value compared to fine media. The relative weight for Aquifer media characteristics is 3. Table 3.3 shows the DRASTIC rating for aquifer media parameter.

Table 3.3: Assigned rating for aquifer media

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

Soil Media (S): -This parameter represents the uppermost and weathered part of the ground. The characteristics of soil influence the amount of recharge infiltrating the ground surface, the amount of potential dispersion, the purifying process of contaminants. Etc. soil cover containing fine grain size materials such as clay and silt as well as a higher percentage of organic matter will retard contaminant migration. Coarse soil media have high rating in comparison to fine soil media. Relative weight assigned to soil media is 2 and the DRASTIC rating is shown in table 3.4.

Table 3.4: Assigned rating for Soil Media

Soil type	Rating
Clay/organic soil	1
Loamy clay	4
Clayey loam	5
Loam	7
Sandy loam	8
Loam sand	9
Sand/gravel	10

Topography (T): -This refers to the slope or steepness of the land surface. It dictates whether the runoff will remain on the surface to allow contaminant percolation to the saturated zone. Area with low slope tends to retain water for longer period and thus allows a greater infiltration of recharge of water and greater potential for contaminant migration. Flat areas were assigned high rates because the runoff tends to be less. The study area was found to be relatively flat with slope ranging from 0 – 2%. The contribution of Topography to aquifer vulnerability is relatively small; hence a relative weight of 1 is assigned to it. Table 3.5 shows the DRASTIC rating for Topographic parameter.

Table 3.5: Assigned rating for Topography

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

Impact of Vadose Zone (I): -This refers to the ground portion found between the aquifer and the soil cover in which pores and joints are unsaturated. The influence of the Vadose zone on aquifer pollution potential depends on its permeability and on the attenuation characteristics of the media. The relative weight for the vadose zone is 5 and the assigned DRASTIC ratings are shown in Table 3.6.

Table 3.6: **Ratings and Weight for vadose zone (after Ibe et al., 2001)**

Impact of Vadose Zone	Rating **(R)**	Weight **(W)**
Clay	1	
Shale	2	
Silt	3	
Schist	4	
Till	4	
Green rocks	5	5
Sandstone	5	
Limestone	6	
Sand	8	
Sand and gravel	9	
Gravel	10	

Hydraulic conductivity(C): Aquifer hydraulic conductivity is the ability of the aquifer to transmit water. It depends on the intrinsic permeability of the material and on the degree of saturation. Hydraulic conductivity controls the rate at which groundwater will flow under a given gradient and hence contaminant migration and dispersion. An aquifer with high conductivity is vulnerable to contamination as a plume of contamination can move easily through the aquifer. The hydraulic conductivity is assigned a relative value weight of 3 and the DRASTIC ratings are assigned as shown in the table 3.7.

Table 3.7: Assigned rating for Hydraulic conductivity

Hydraulic Conductivity(gpd/ft^2)	Rating
1-100	1
100-300	2
300-700	4
700-1000	6
1000-2000	8

3.2 Data Acquisition

This study adopted Vertical Electrical Sounding (VES) using the Schlumberger array. A total of twenty(20) resistivity sounding were carried out across the study area using the following;

i. ABEM Terameter SAS 300B
ii. Two current electrodes
iii. Two potential electrodes
iv. A power source (12 Volts car battery)
v. Electrical cables
vi. Hammer
vii. Measuring Tapes

3.2.1 Instrumentation

The ABEM SAS 300B model consists of a basic unit called the Terameter SAS 300B.

Signal Averaging System is a system whereby series of readings are taken automatically and the results are averaged continuously.

The Terameter SAS 300B can operate in two modes. First, in the resistivity survey mode, it comprises of a battery powered deep penetration resistivity meter with an output sufficient for a current electrode separation of 2000 meters under good surveying conditions. Secondly in the voltage measuring mode, the SAS 300B comprises of a self-potential instrument that measures natural DC potentials. The result is displayed in Volts or millivolts (Mv). The overall range from 0.01Mv to 500V.

The transmitter, receiver and microprocessor- the three main units of the Terameter SAS 300B are all housed in a single casing. The electrically insulated transmitter sends in well-defined and regulated signal currents. The receiver discriminates noise and measures voltage correlated with transmitted signal current and also measures uncorrected DC potential with the same discrimination and noise rejection. The microprocessor monitors and controls operation and calculates the final resistivity result of interest. The equipment permits natural or induced signal to be measured at extremely low levels with excellent penetration and low power consumption. Moreover, it can be used in a wide variety of application where effective signal/noise discrimination is needed.

3.3 Field Procedure

Direct current resistivity sounding was made at various locations with a maximum electrode spread of 1000m. The ABEM Terameter SAS 300B gave a direct readout of resistance. The interval between the potentials and current electrode were increased at appropriate steps in order to obtain potential differences large enough to be measured with satisfactory precession. Readings were taken at different electrode spacing and the resulting values for each distance recorded. The data obtained was plotted as a graph of apparent resistivity against current electrode spacing (AB/2) on a log-log graph scale. The electrode spacing at which inflection occurs on the graph provides an idea of the depth of the interface. A useful approximation is that the depth of the interface is equal to two-third (2/3) of the electrode spacing at which the point of inflection occurs (Vingoe, 1972). The approximation has found useful application in iterative modeling.

3.4 Data Processing

The observed field data were converted to apparent resistivity values by multiplying with the Schlumberger geometric factor K given as:

$k = \pi(\frac{a2}{b} - \frac{b}{4})$recall equation 3

The sounding curve for each point was obtained by plotting the apparent resistivity on the ordinate against the half current electrode spacing on the abscissa on a bi-logarithmic paper. The parameters such as apparent resistivity and thickness obtained from partial curve matching and the method of asymptotes were used as input data for computer iterative modeling (Zohdy, 1976; Koefoed, 1977). Hence the computer program allowed the reading obtained from the field to be converted to apparent resistivity values and to be stored for the detailed interpretation using the OFFIX software.

3.5 Qualitative Curve Description

The interpretation of the apparent resistivity curve began by the entering of a model represented by the apparent resistivity and thickness of each layer of the curve.

Theoretically,curve is drawn automatically with these two parameters. The theoretical curve may not match the field curve and the other models are tried until the curves match.

Generally, the apparent resistivity curve for a three-layer structure has one of four typical shapes determined by the vertical sequences of the resistivity of the layers. Theoretically, these curves include type A, type H, type K, and type Q curves (fig 3.2)

K-type curve: thiscurve type rises to a maximum and then decreases, indicating that the intermediate layer has higher resistivity than the top and bottom layer

A-type VES curve: This curve shows a continuous increase in resistivity

down the passing layer.

Q-type curve: This curve shows direct opposite of A-type curve with continuous decrease in resistivity down

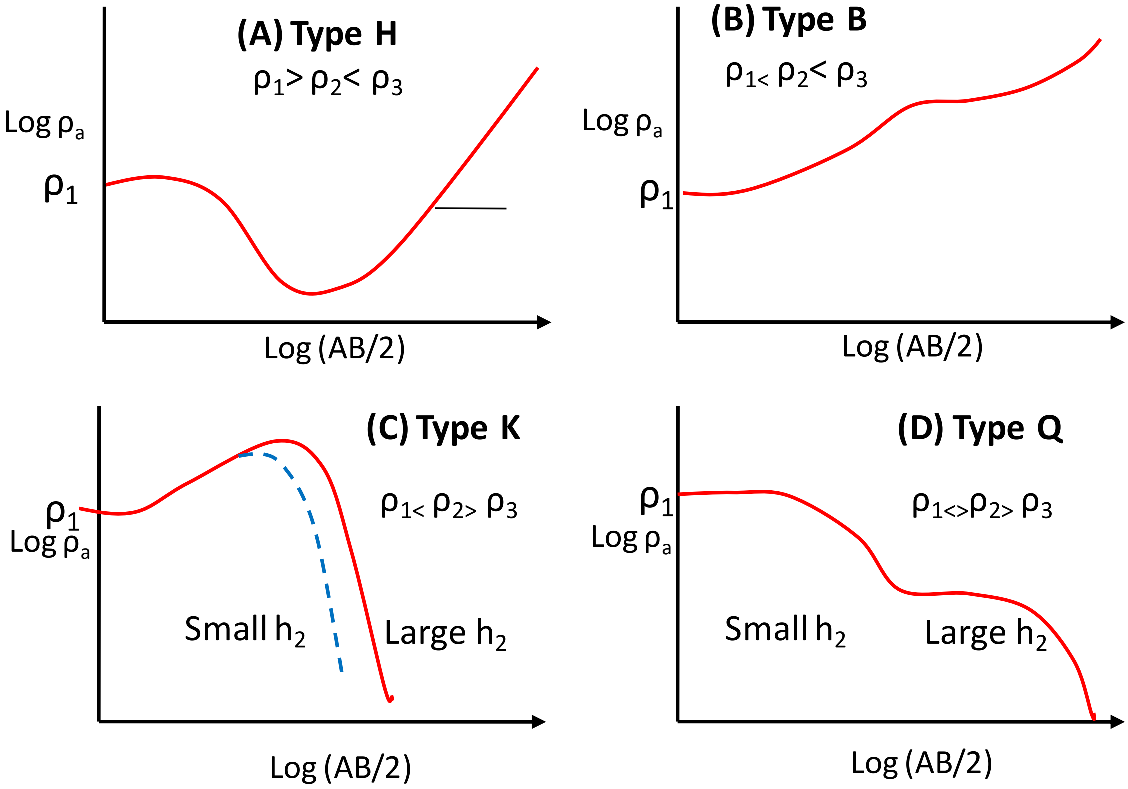

Fig 3.2. Typical VES types curves

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Geophysical Field Data Results

Results of the curve matching obtained by the analysis of the field data were studied. The type curve for each sounding gave an insight on the character of the beds or layers between the surface and the maximum depth of penetration. This is because the shape of a VES curve depends on the number of layers in the subsurface; the thickness of each layer, and the ratio of the resistivity of the layers (Osemeikhian et al, 1982). Considering the quantitative curve description shown earlier, the types identified in this work ranges from K, Q, HK, KH, KKH, KK and HKH.

The aquifer parameters and characteristics obtained from the interpretation of the VES sounding from the study area are shown in table 4.1 below. The properties of interest in this study are aquifer conductivity, aquifer resistivity, aquifer thickness and Hydraulic conductivity.

Groundwater takes the chemistry of the surrounding rocks; the amount of dissolved inorganic and organic ions present in aquifer affects the electrical conductivity of the aquifer. Electrical conductivity is the inverse of electrical resistivity hence, once the electrical resistivity is obtained from the interpreted VES sounding, the electrical conductivity is obtained by taking the inverse of the resistivity value.

The amount of the total dissolved solids (TDS) present in the underground water determines the electrical conductivity of the underground water. When TDS value is higher beyond the acceptable value, the underground water quality is reduced and unsafe for domestic use.

When the TDS value falls within the WHO acceptable range, the underground water is assumed safe and qualitative.

Table 4.1: Results of Interpretation of VES obtained in The Study Area

Location	Aquifer Bottom h_2 (m)	Aquifer Top h_1 (m)	H (m)	$\rho(\Omega m)$	$\delta(\Omega m)^{-1}$	T=hk	C=kδ	K(mday^{-1})	S=3 x 10^6 h	D= T/S
Avor Ntigha	260	97.1	162.9	1747.5	$5.722x10^{-4}$	633.7	$2.22x10^{-3}$	3.89	$4.887x10^{-4}$	$1.2967x10^{6}$
Nsirimo	>260	139.0	>67.8	5120	$1.953x10^{-4}$	468.5	$1.349x10^{-3}$	6.91	$2.034x10^{-4}$	$2.3033x10^{6}$
Umunwanwa	25.4	16.9	8.5	1119.8	$8.93x10^{-4}$	229.8	$1.35x10^{-3}$	2.35	$2.934x10^{-4}$	$7.8323x10^{5}$
	106		8.5	1735	$5.763x10^{-4}$	20.23	$1.372x10^{-3}$	2.38	$2.55x10^{-5}$	$7.9333x10^{5}$
Ogbodinaibe	23.5	1.1	22.4	786	$1.272x10^{-3}$	87.1	$3.02x10^{-3}$	2.38	$6.72x10^{-5}$	$1.2961x10^{6}$
Ehume	63.1	17.3	45.8	3003.7	3.329x10-4	53.3	$7.89x10^{-4}$	2.37	$1.37x10^{-4}$	$3.8791x10^{5}$
Mgbarakuma	190	11.4	178.6	5785	1.728x10-4	694.8	$6.721x10^{-4}$	3.89	$5.358x10^{-4}$	$1.2967x10^{6}$
Umuokwom Ohiya	80.1	28.6	51.5	1470	$6.802x10^{-4}$	172.5	$2.279x10^{-3}$	3.35	$1.545x10^{-4}$	$4.8656x10^{7}$
Deeper Life Camp	>172	20.7	>151.3	3815	$2.621x10^{-4}$	506.9	$8.78x10^{-4}$	3.35	$4.539x10^{4}$	$1.1167x10^{6}$
Amachara	17.3	2.3	15	5080	$1.968x10^{-4}$	51.0	$6.69x10^{-4}$	3.40	$1.53x10^{-4}$	$3.3333x10^{5}$
	>102	52	>50	1270	$7.874x10^{-4}$	170.0	$2.677x10^{-3}$	3.40	$1.5x10^{-4}$	$1.1333x10^{6}$
Umuawa Alaocha	72.5	18.6	53.9	3450	$2.898x10^{-4}$	172.5	$9.275x10^{-4}$	3.20	$1.617x10^{-4}$	$1.0667x10^{6}$
Umuovo Eluelu OLD Umuahia	79.5	7.0	72.5	2915	$3.43x10^{-4}$	23.1	$1.09x10^{-3}$	3.19	$2.175x10^{-4}$	$1.0620x10^{5}$
	>244	125	119	3602.5	$2.775x10^{-4}$	379.6	$8.854x10^{-4}$	3.19	$3.57x10^{-4}$	$1.063305x10^{6}$
Umuobutu old-Umuahia	41.9	8.2	33.7	4180	$2.392x10^{-4}$	107.2	$7.607x10^{-4}$	3.18	$1.011x10^{-4}$	$1.060336x10^{6}$
Ohobo Okwulaga	5.9	2.3	3.6	7610	$1.314x10^{-4}$	11.8	$4.31x10^{-3}$	3.28	$1.08x10^{-9}$	$1.092592x10^{6}$
	73.3	73.3	>50	8400	$1.19x10^{-4}$	161.5	$3.845x10^{-4}$	3.23	$1.5x10^{-4}$	$1.076666x10^{6}$
World Bank Housing	80.4	21.4	59	6000	$1.666x10^{-4}$	197.7	5.583x10-4	3.35	$1.77x10^{-4}$	$1.116949x10^{6}$
Agbama	19.9	1.4	18.5	2626.7	$3.807x10^{-4}$	59.9	$1.23x10^{-3}$	3.24	$5.55x10^{-5}$	$1.079279x10^{6}$
	179	58.3	120.7	7110	1.407x10	391.1	$4.556x10^{-3}$	3.24	$3.621x10^{-4}$	$1.096658x10^{6}$
Okwu	52.1	3.6	39.5	7685	$1.301x10^{-4}$	93.6	$3.08x10^{-3}$	2.37	$1.185x10^{4}$	$7.89873x10^{5}$
	>131	131	>50	1130	$8.849x10^{-4}$	118.5	$2.1x10^{-3}$	2.37	$1.5x10^{-4}$	$7.9000x1010^{5}$
Itaja Olokoro	92.4	1.5	90.9	4347.5	$2.3x10^{-4}$	216.3	$5.474x10^{-4}$	2.38	$2.97x10^{-5}$	$7.28228x10^{6}$
Umuajiji	11	2.6	8.4	3870	$2.583x10^{-4}$	15.5	$4.78x10^{-4}$	1.85	$4.65x10^{-5}$	$3.3333x10^{5}$
	17.9	2.6	15.3	2121.5	$4.713x10^{-4}$	28.3	$8.72x10^{-4}$	1.85	$8.49x10^{-5}$	$3.3333x10^{5}$
Amuzu-Oro	77.8	21.8	56	3585	$2.789x10^{-4}$	106.4	$5.30x10^{-4}$	1.90	$1.68x10^{-4}$	$6.3333x10^{5}$
Umudike	111	44.7	66.3	1115	$8.968x10^{-4}$	189.6	$2.56x10^{-3}$	2.86	$1.989x10^{-4}$	$9.5324x10^{5}$

4.1.1 Electrical Conductivity of the Study Area

The values of Electrical conductivity of the study area obtained from the inverse of the resistivity shows varying electrical conductivity across the entire study area with exceptional value in Ogbodi Nibe whose value is unusually very high. The value of the electrical conductivity in this community is attributed to higher ions content. The high value of electrical conductivity obtained from the VES in Ogbodi is in corroboration with the known geological history of the community which is known for its high ions content within its aquifer.

The high ions content (in the aquifer is responsible for the increase in the electrical conductivity in the area and this has adverse effect in water quality within this community.

4.1.2 Aquifer Thickness

The physical properties of an aquifer such as thickness, rock or sediment type and location, play a large role in determining whether the contaminants from the land surface will reach the ground water. The risk of contamination is greater for unconfined aquifers than confined aquifers because they usually are nearer to the land surface and lack an overlying confining layer to impede the movement of contaminants.

From the result of the interpreted VES data from the study area, the average aquifer thickness of the entire study area is 71.47m. The ratio of aquifer thickness to the aquifer resistivity is proportional to the protective overburden of the aquifer against contamination by movement of polluted water down the aquifer.

4.2 **Interpretative Profiles**

For the purpose of lithological correlation and classification, five profiles were taken across the study area as shown in the figure 4.1 to figure 4.6 below. The profiles revealed about six distinct geo-electric units; the ranges in the aquifer thickness and aquifer resistivity across the entire area were identified as shown below.

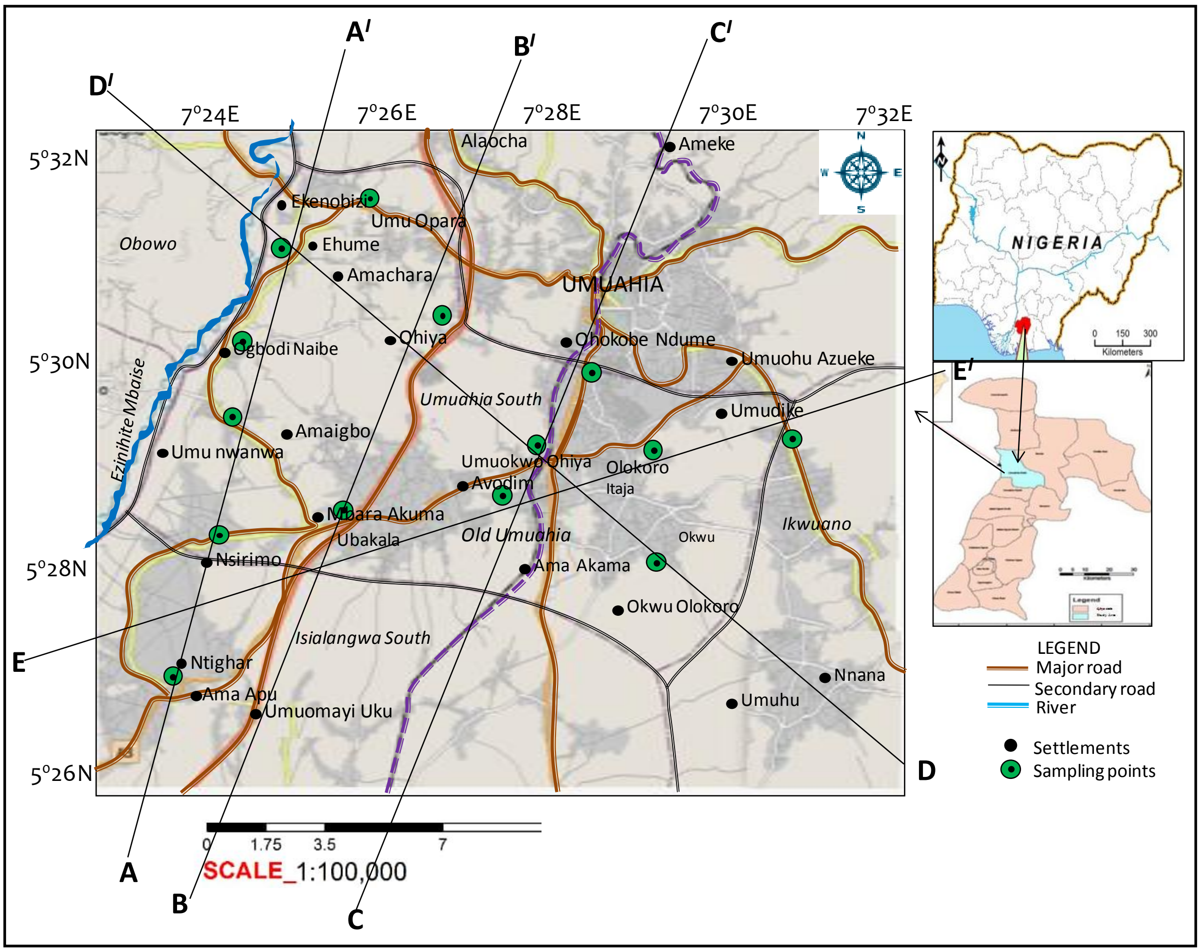

Fig 4.1 Profile Map of the Study Area

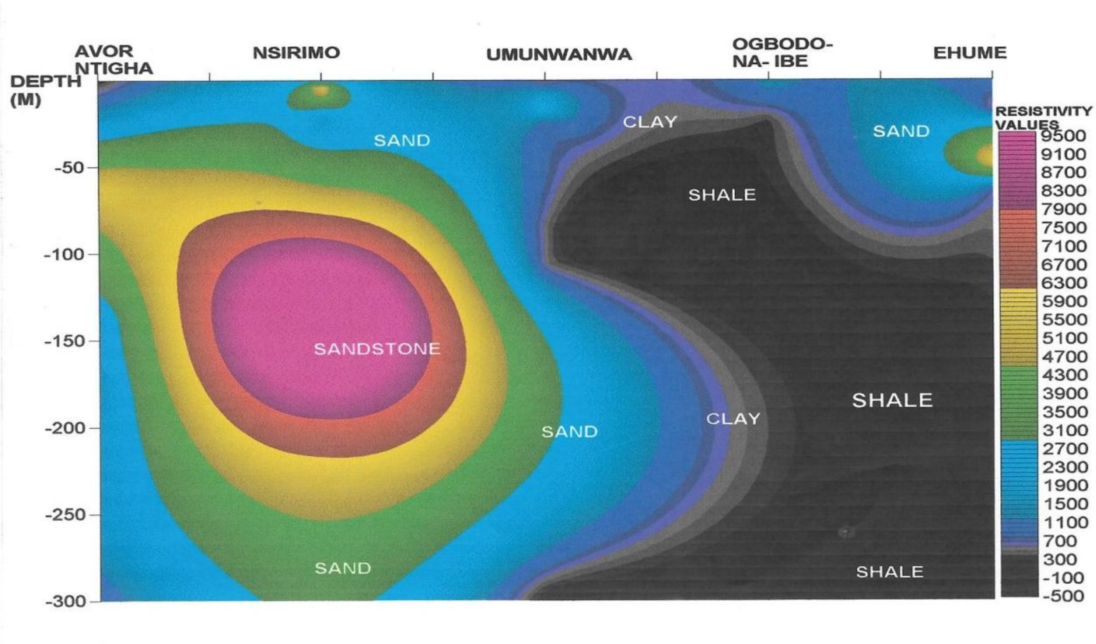

Fig 4.2 Map showing the geo-electric layer along profile A-A[I]

The communities in the North-South direction of the study area comprises Avor Ntigha, Nsirimo, Umunwanwa,Ogbodinaibe and Ehume. The aquifer thickness in this direction ranges between 8.5m-162.9m and the resistivity ranges between 786 Ωm-5120Ωm. The lithological units in this direction are mostly sand, sandstone with interaction of clay/shale within Umunwanwa and Ogbodinaibe.

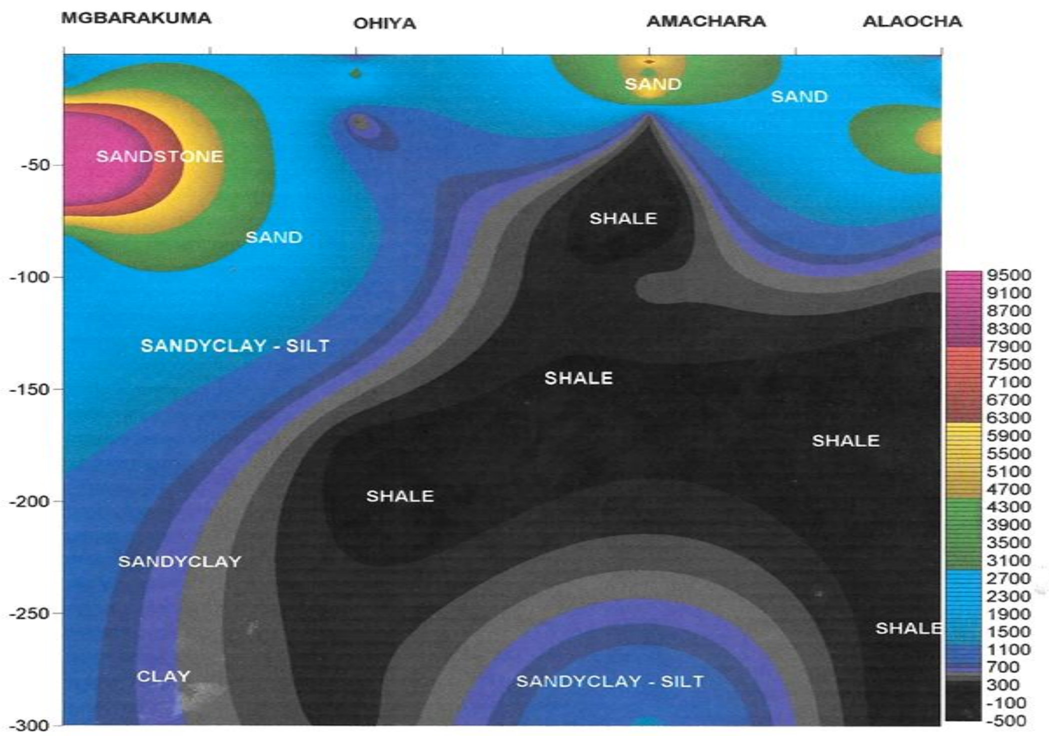

Fig 4.3Map showing the geo-electric layer along profile B-B^{I}

The communities in the North East- South West direction in the main study area are Mgbarakuma(Ubakala), Ohiya, Amachara and Alaocha. The aquifer thickness in this direction is between 15m-178.6m while the resistivity is between 1270Ωm-5785Ωm. The lithological units in this direction are mainly sand, sandstone, sandyclay, sandy-silt, clay and shale

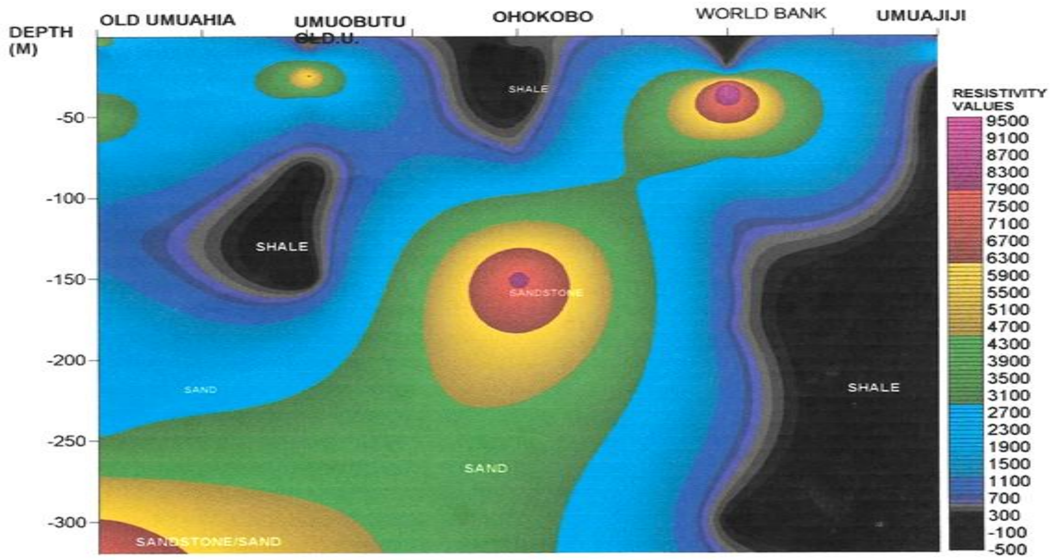

Fig 4.4 Map showing the geo-electric layer along profile $C\text{-}C^{I}$

The communities along this direction include Old Umuahia, Umuobutu, Ohokobo, World bank Housing Estate and Umuajija. The aquifer thickness along this direction is between 11.85m -59m and the aquifer resistivity along the profile is between 2121.5Ωm-8400Ωm. The lithological units along this direction are mainly sand, sandstone and shale.

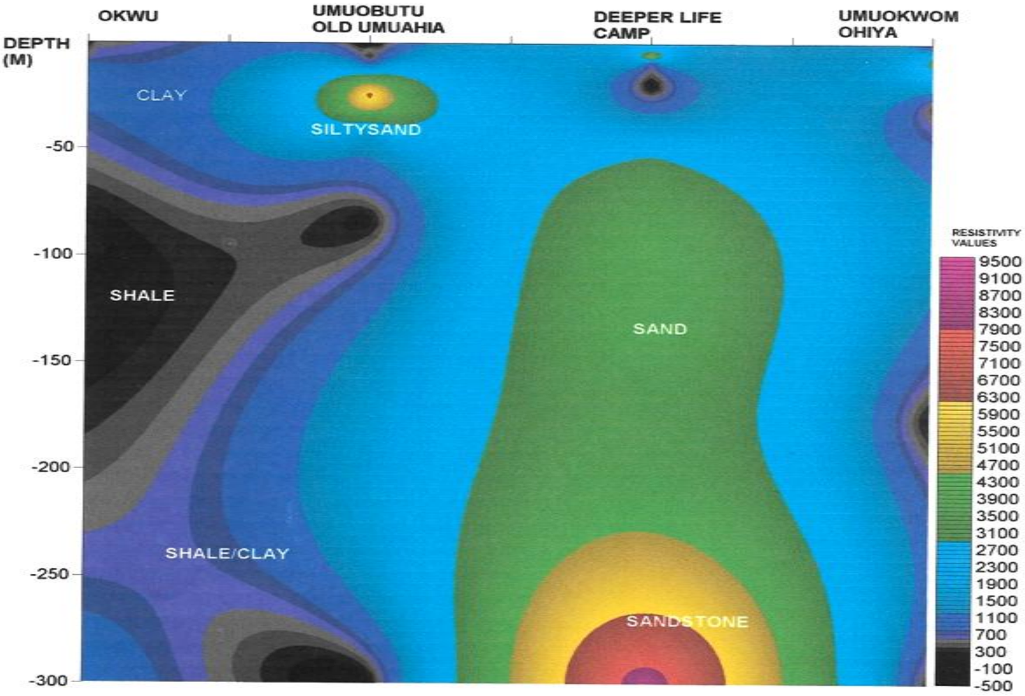

Fig.4.5 Map showing the profile along the profile D-D^{I}

The communities along this direction include Okwu, Umuobutu Old Umuahia, Deeper Life Camp Ohiya and Umuokwom Ohiya. The aquifer thickness along the profile is between 39.5m-151.3m and the resistivity along the profile is between 1,130Ωm -4,406.5Ωm. The lithological units revealed along the profile are mainly sand, sandstone, shale/clay and shale.

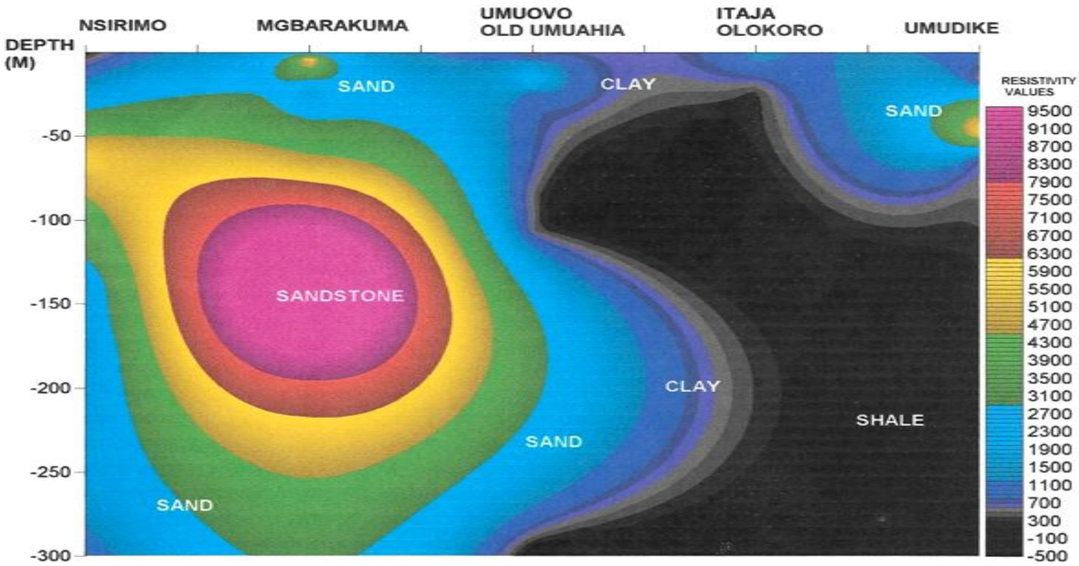

Fig 4.6 Map showing the profile along E-E^{I}

The communities along this direction include Nsirimo,Mgbarakuma, Umuovom Old Umuahia, Itaja Olokoro and Umudike. The aquifer thickness along the profile is between 66.m-178.6m (Umudike and Mgbarakuma). The aquifer resistivity along the profile is between 1115Ωm at Umudike and 5785Ωm at Mgbarakuma. The lithological units revealed along the profile are mainly sand, sandstone, clay and shale.

4.3 Iso- resistivity Modeling

The Iso-resistivity maps derived at depth intervals AB/2=80m, AB/2=150m, AB/2=200m, AB/2=250m, AB/2=300m and AB/2=350 revealed vertical variation of resistivity with depth. Figure 4.6 shows some Iso-resistivity maps generated from the VES data. The Iso-resistivity maps revealed a progressive decrease in the resistivity with depth suggesting a highly resistive overburden to less resistive layer at the base. However, at depth interval of AB/2=350, high resistivity values demarcated by intermittent low resistivity values were intercepted. The Iso-resistivity maps revealed distinct and distinguishable zones based on resistivity contrast. The contrasting resistivity zones are in line with the geology of the area underlain by the Ameki, Ogwashi-Asaba and Benin formations respectively. The western part of the area is homogenous in terms of the geo-electric properties and is distinct from the Northern axis and the Eastern axis. These distinct are visible on the maps presented in figure 4.7below. The Iso-resistivity maps also revealed multiple aquifer system in the study area separated by thick bands of clay, sandy clay and shales.

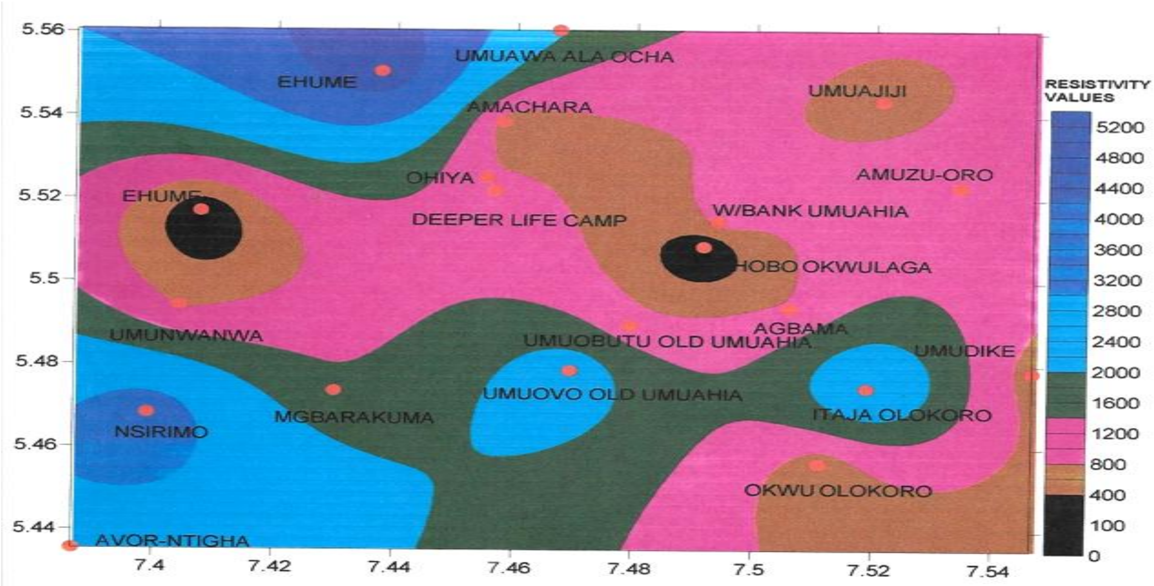

Fig 4.7(a) Iso-resistivity map at AB/2=80m

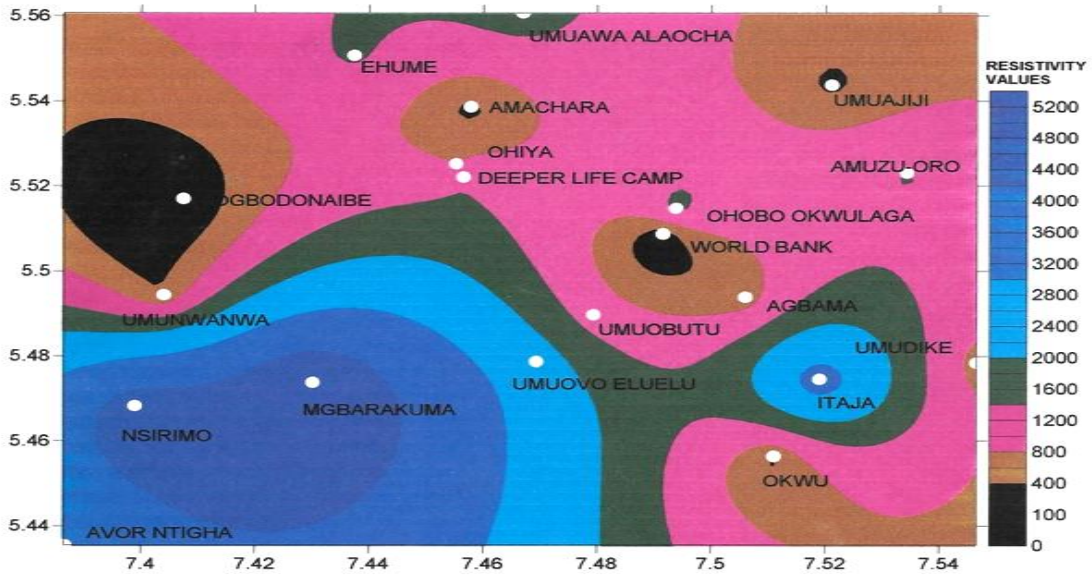

Fig 4.7(b) Iso-resistivity map at AB/2=150m

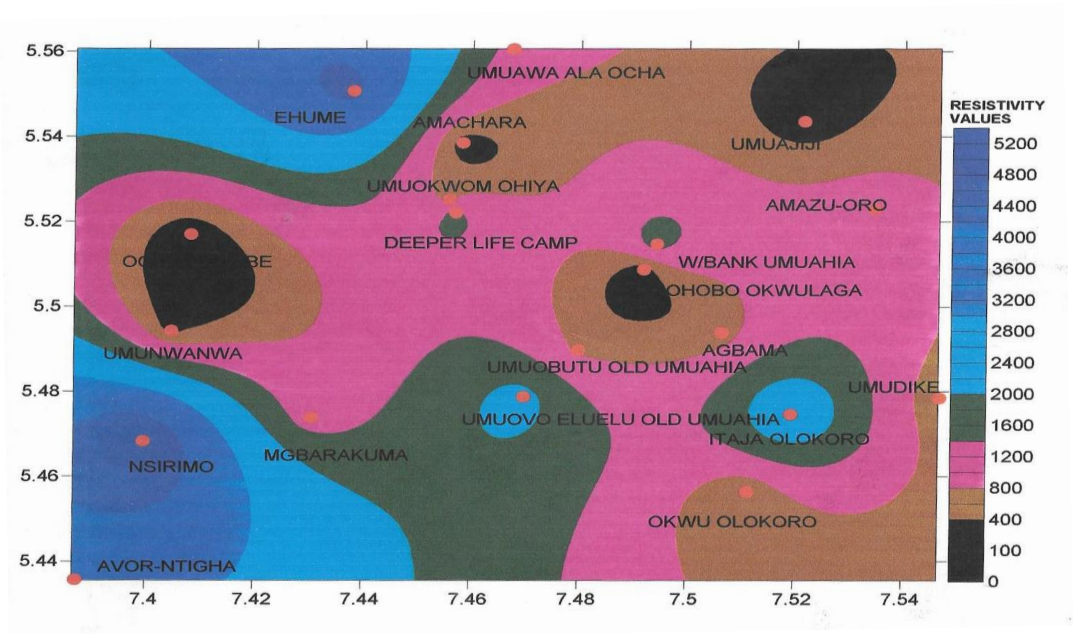

Fig 4.7(c) Iso-resistivity map at AB/2=200m

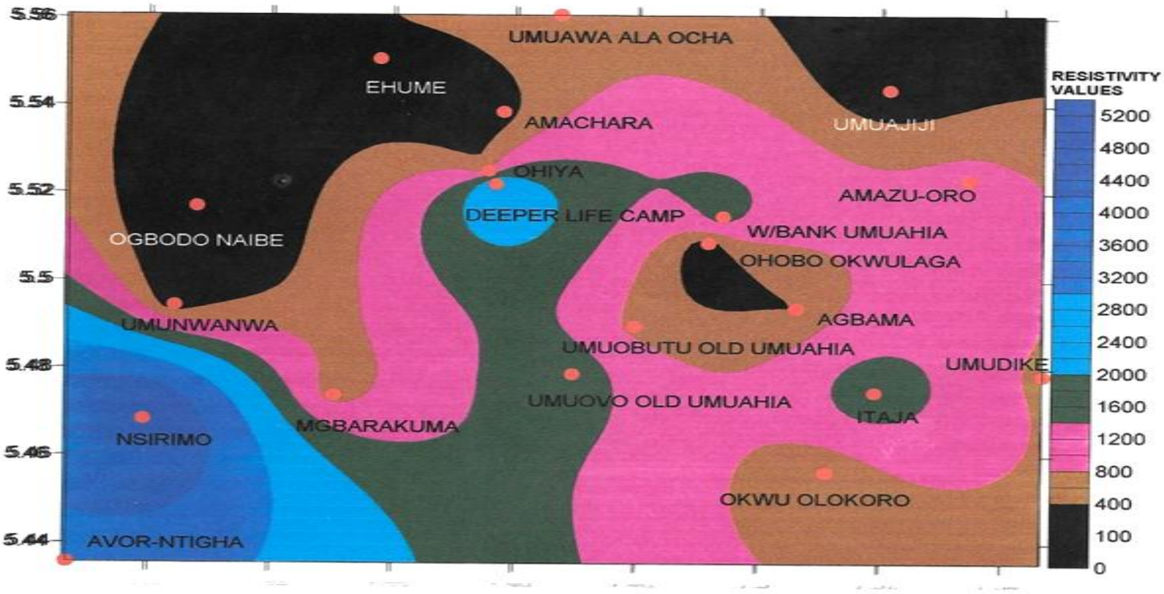

Fig 4.7(d) Iso-resistivity map at AB/2=250m

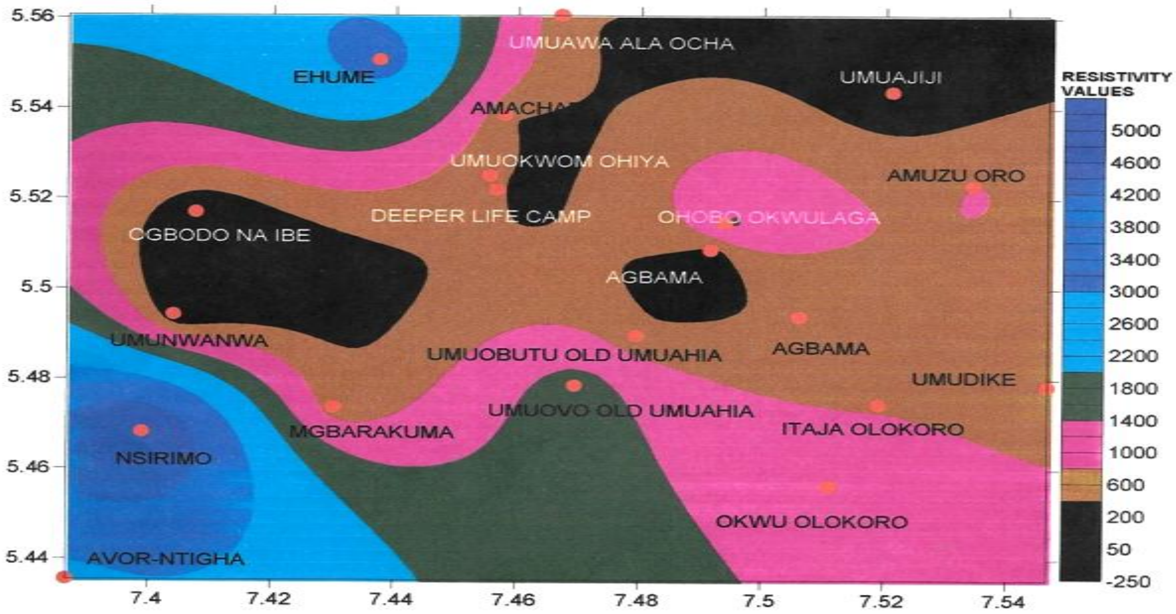

Fig 4.7(e) Iso-resistivity map at AB/2=300m

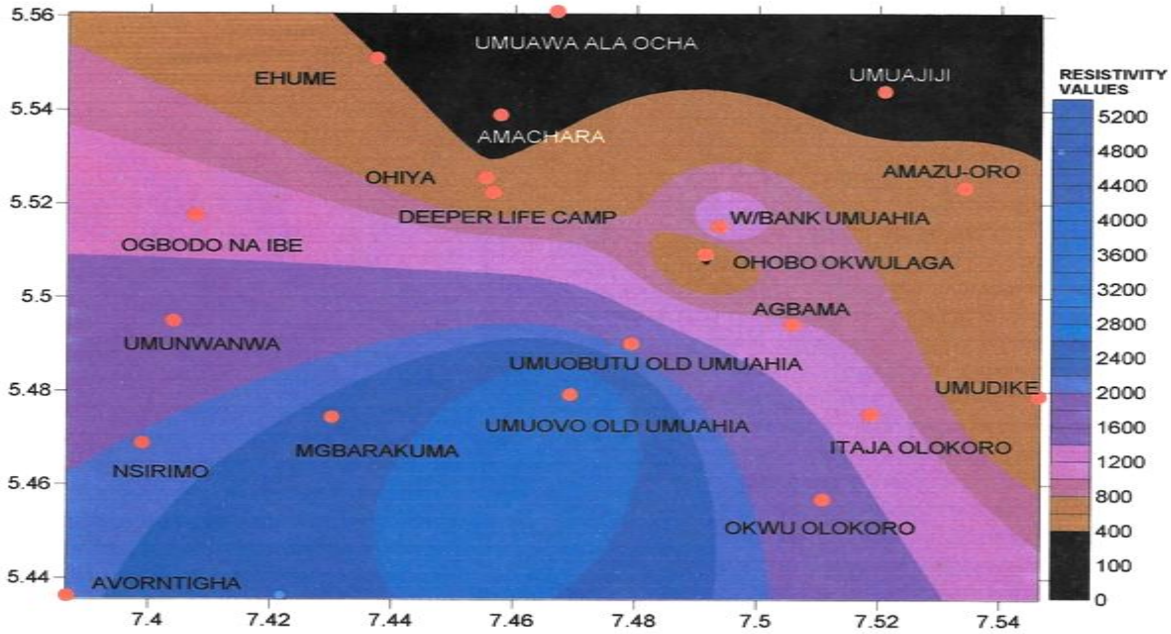

Fig 4.7(f) Iso-resistivity map at AB/2=350m

4.4 Evaluation of Aquifer Protective Capacity: Aquifer Protective capacity (APC) is the ability of the overlying layers of rock (i.e the overburden) above the aquifer unit to impede, slow-down, filter and contain percolating ground surface contaminating fluids and run-offs.

The second order geoeletric parameter-Longitudinal conductance (which is a Dar Zarrouk parameter) was evaluated from the first order parameters (thickness and resistivity of the geoelectric layers which wereused in the classification of the APC of the area.

Highly impervious materials such as clay and shale have low longitudinal conductance values (resulting from their low resistivity values) while pervious materials such as sand and gravel have low longitudinal values (resulting from their high resistivity values. High longitudinal conductance value corresponds to excellent and good APC, while low longitudinal conductance values are associated with poor and weak APC according to Henriet, 1976 and Oladapo et tal, 2004 shown in the Table 4.2 and 4.3 below.

The result of the acquifer longitudinal conductance(s) and the corresponding overburden protective capacity ratings of the study area are as shown in the Table 4.4 below.

The map obtained for the aqcifer protective conductance of the study area is as shown in Fig 4.8 below.

Table 4.2 Longitudinal Conductance/Protective Capacity Rating (Henriet, 1976)

Total Longitudinal Unit Conductance (Mhos)	Overburden Protective Capacity Classification
<0.10	Poor
0.1-0.19	Weak
0.2-0.69	Moderate
0.7-10	Good

Table 4.3 Modified Longitudinal Conductance/Protective Capacity Rating (Oladapo et tal.. 2004)

Total Longitudinal Unit Conductance (Mhos)	Soil Protective Capacity Classification
>10	Excellent
5-10	Very Good
0.7-4.9	Good
0.2-0.69	Moderate
0.1-0.19	Weak
<0.1	Poor

Table 4.4 Aquifer Longitudinal Unitconductances (S)And Overburden Protective Capacity Rating In The Study Area

LOCATION	Aquifer Thickness(m)	Aquifer resistivity ρ(Ωm)	Longitudinal Conductance S(Mhos)	Overburden Protective Capacity Rating(After Henriet, 1976; Oladapo et al 2004)
Avor Ntigha	162.9	1747.3	0.0932	weak
Nsirimo	67.8	5120	0.0132	Poor
Umunwanwa	8.5	1119.8	0.0076	Poor
Ogbodinibe	22.4	786	0.0285	poor
Ehume	45.8	3003.7	0.0152	Poor
Mgbarakuma Ubakala	178.6	5785	0.0309	Poor
Umuokwom Ohiya	51.5	1470	0.0350	poor
Deeper Life Camp	151.3	3815	0.0397	Poor
Amachara	15 50	5080 1270	0.0423	Poor
Umuawa alaocha	53.9	3450	0.0156	poor
Umuovo Old Umuahia	72.5	2915	0.0249	Poor
Ohobo Okwulaga	3.6 50	7610 8400	0.0065	Poor
World Bank Housing	59 18.5 120.7	6000 2626.7 7110	0.0338	poor
Okwu	39.5 50	7685 1130	0.0493	Poor
Itaja Olokoro	90.9	4347.5	0.0209	Poor
Umuajiji	8.4 15.3	3870 2121.5	0.0094	poor
Amuzu-Oro	56	3585	0.0156	Poor
Umudike	66.3	1115	0.0594	Poor

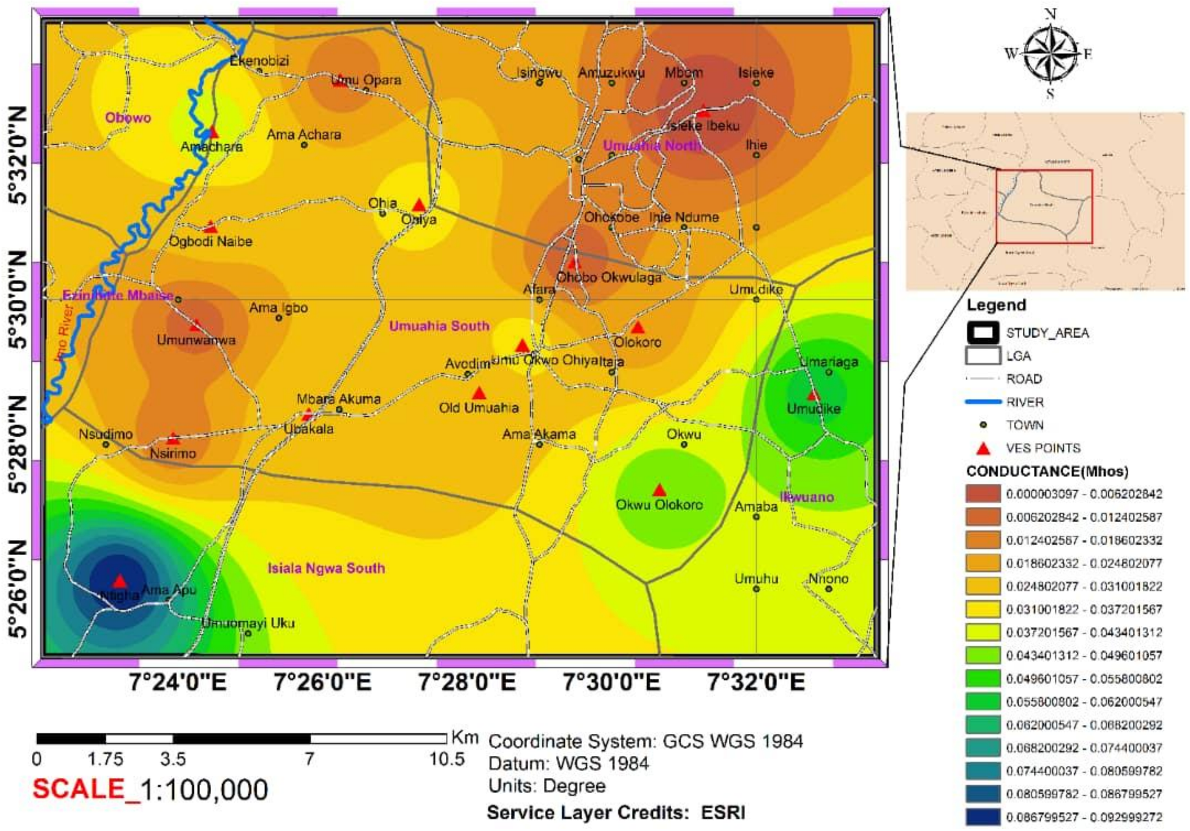

Fig 4.8 Longitudinal Aqifer Protective Conductance Map of the study Area.

4.5 Groundwater Vulnerability Assessment Using DRASTIC Model

The DRASTIC Vulnerability index (DVI) is calculated as the sum of product of ratings and weights assigned to each of the parameter. That is, pollution potential (DI) = $D_RD_W + R_RR_W + A_RA_W + S_RS_W + T_RT_W + I_RI_W + C_RC_W$.

4.5.1 Thematic Raster Map of Depth to Water table

The depth to water table map was developed from geophysical investigations in the study area (Table 4.1).

Table 4.1 was used in developing the depth to water table map and Fig 4.9 shows the map of depths to water table as derived from the Geophysical investigation and well log.

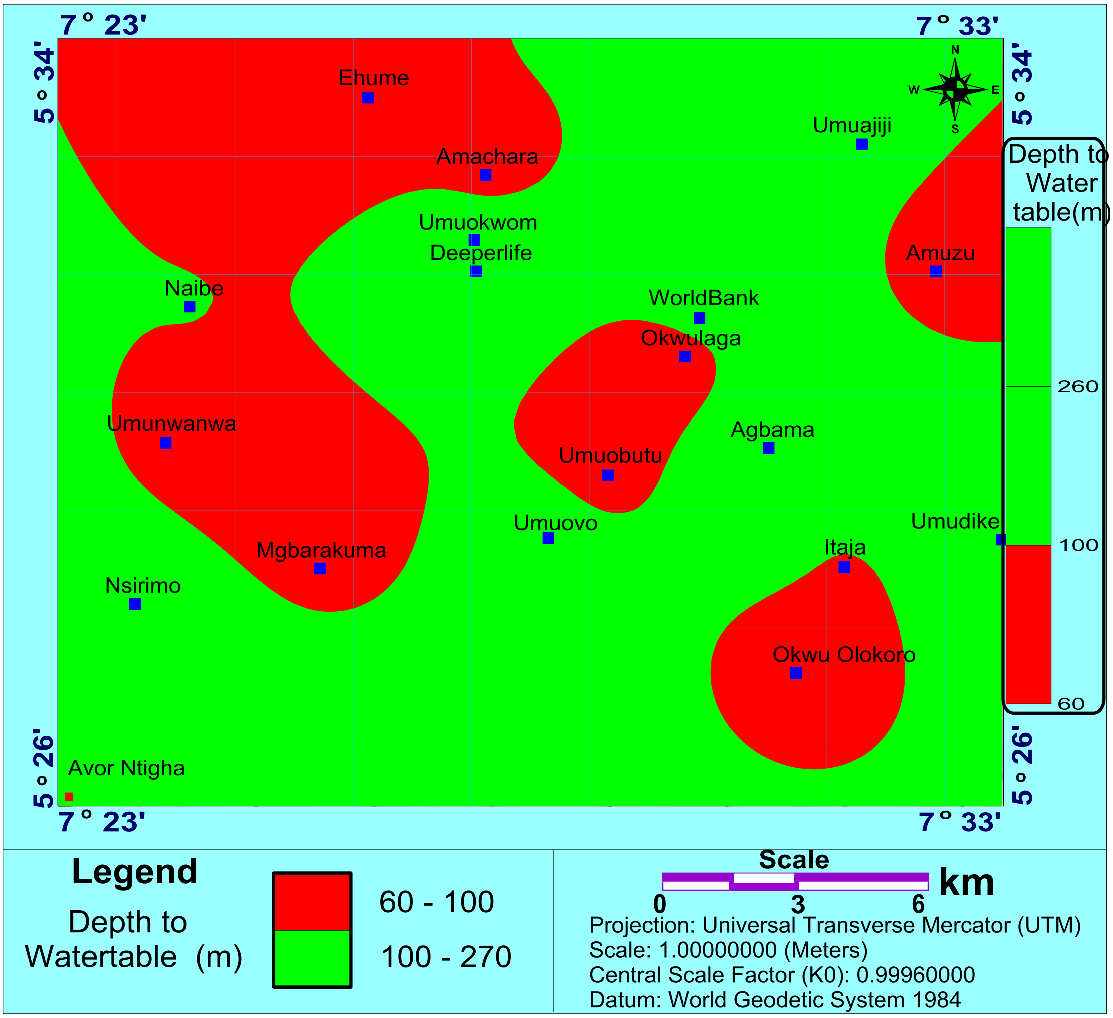

Fig. 4.9: Reclassified Depth to Water table map derived from Geophysical Investigation and well log.

This map shows the distribution for pollution potential based on the ranges of depth-to-water table in the area.

The hydro-geological implication of the map indicated that the areas with red colour have high pollution potential for groundwater; whereas areas with the green colour indicate low pollution potential for groundwater. Hence, the pollution potential weights and ratings of depth to water thematic map classes are in accordance with Delphi technique AtiqurRahman (2008).

4.5.2 Net Recharge

The net recharge values were integrated into the GIS software to generate net recharge (R) thematic map (Fig.4.10).

The net recharge was considered to be uniform within and around the study area and also represents the annual average amount of water that infiltrates the vadose zone and reaches the water table Aller *et al.* (1987). The higher the net recharge, the more vulnerable is the groundwater reservoir.

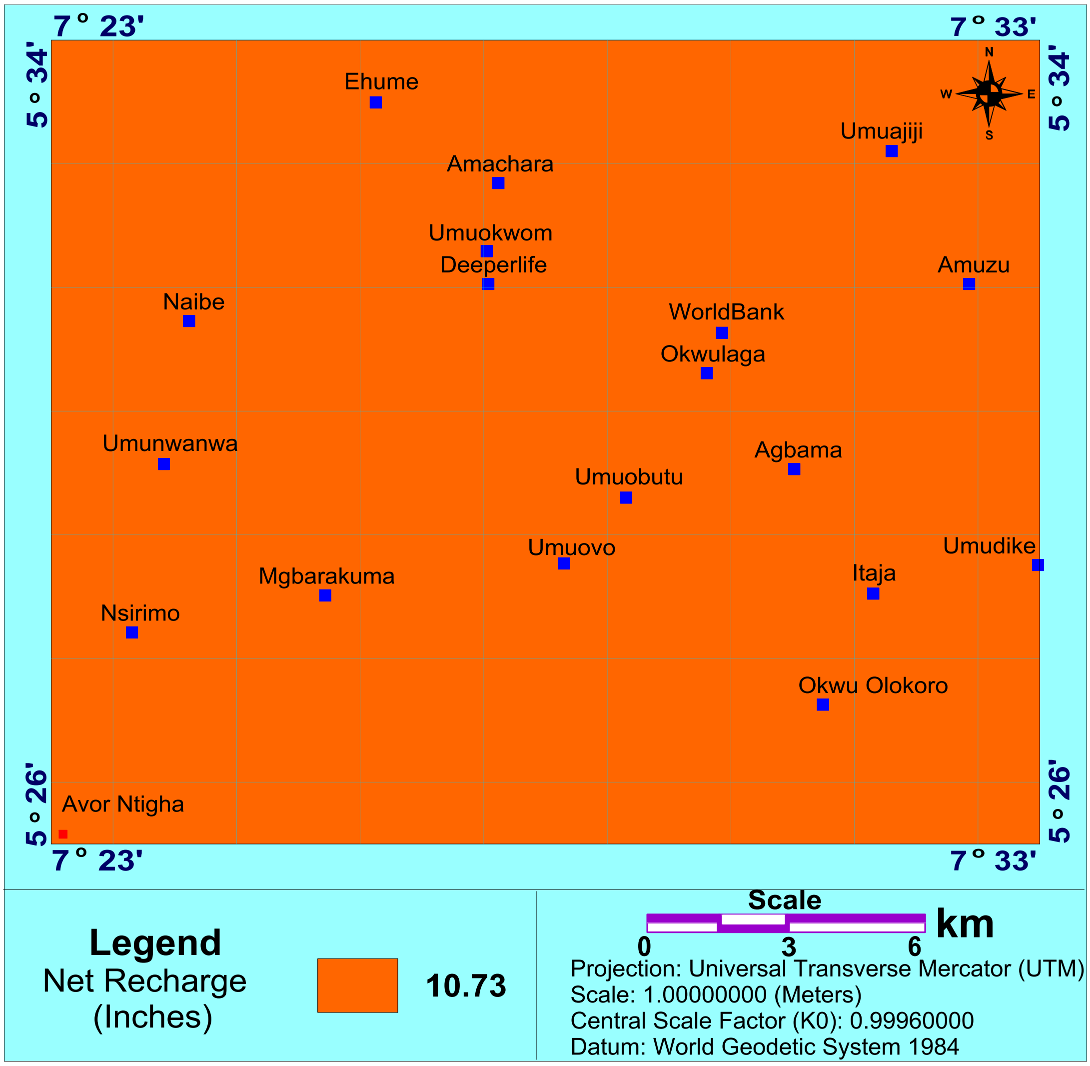

Figure 4.10: Reclassified Net recharge map derived from the Rainfall Data.

4.5.3 Aquifer Media

Aquifer media is used to produce a rating based on the permeability of each layer of media. High hydraulic conductivity allows much water and therefore greater contaminants to enter the aquifer. Therefore, a high hydraulic conductivity will yield a high vulnerability rating. The rating charts shown (Table 4.5) illustrate the evaluation procedure for aquifer media.

Table 4.5)Ratings and Weights for Aquifer Media (Ibe et al., 2001

Aquifer material	Rating	Weight
Shale	1	
Till	3	
Silt	3	
Schist	4	
Sandstone	5	
Limestone	6	3
Green rocks	6	
Sand	8	
Sand and gravel	9	
Gravel	10	

The aquiferous material in the area covered by red colour is composed of sand and gravel. This type of aquiferous material is found within Benin Formation.

It suggests that the aquifer with sand and gravel is more permeable than sandy clay. It is the large pore spaces between aquifer materials that promote advection flow of contaminants.

The Fig. 4.11 below shows the acqifer media map derived from Geophysical investigation and lithologs of the study area.

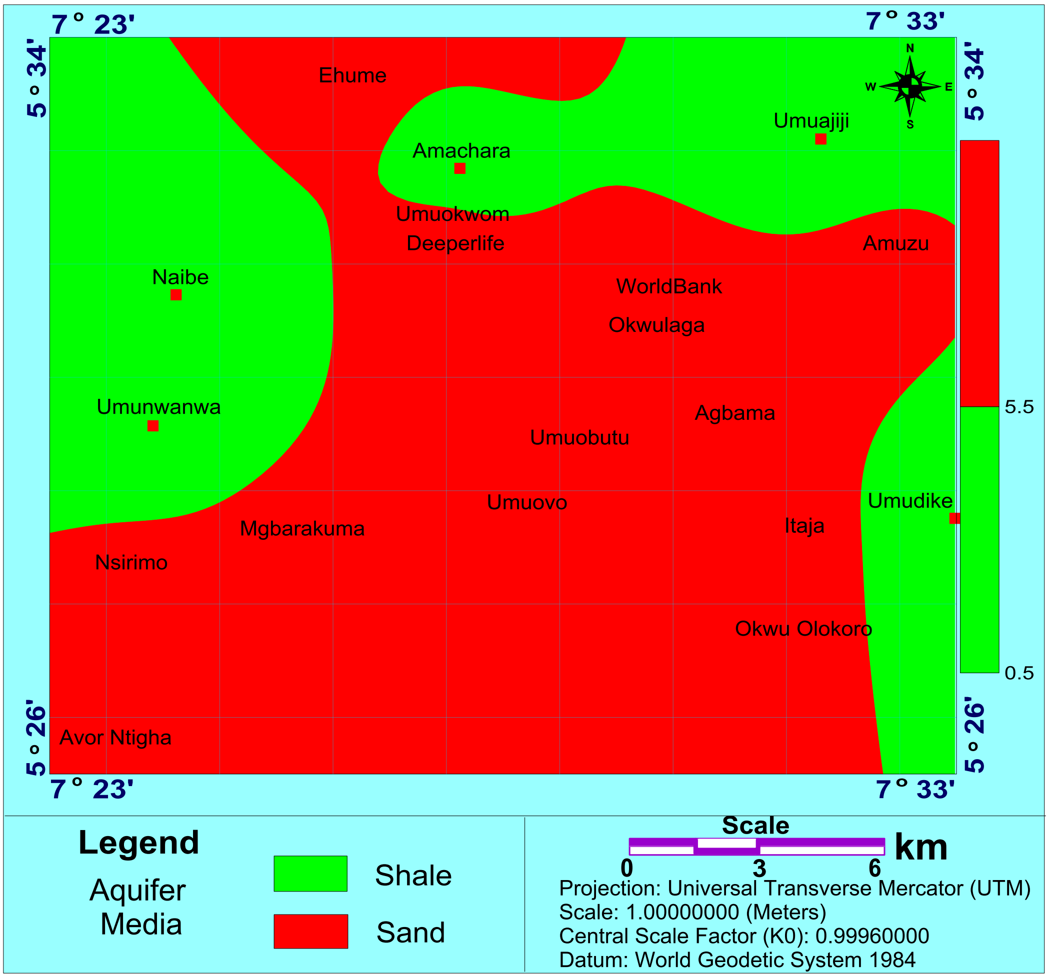

Figure 4.11: Reclassified Aquifer Media map derived from Geophysical Investigation and Lithologs.

4.5.4 Soil Media

The varying properties of the different soil types were used in rating pollution potential of this layer. Values in Table 4.6 were used as input in producing the soil media thematic map.

Table 4.6: Assignment of Ratings and Weight for Soil Media (after Ibe et al., 2001)

Parameter	Soil Material	Rating (R)	Weight (W)
Soil Media	Clay/organic soil	1	
	Loamy clay	4	
	Clayey Loam	5	
	Loam	7	2
	Sandy loam	8	
	Loamy sand	9	
	Sand and gravel	10	

The area with red colour in Fig 4.12 below represents area underlain by sandy loam. The soil type feels gritty but contains some silt and small amount of clay. The amount of silt and clay is sufficient to hold the soil particles together when moist. Besides, the surface soil colour is dark which indicate high organic matter content with relatively free movement of air and water in the soil mass.

The area designated with pink colour represents clayey loam soil. This soil type is smooth when dry and silky when wet. Though silt and sand are present in appreciable amount but are dominated by clay. Also, the surface soil colour is yellow which indicate low organic matter content with high water content and not well, aerated in the soil mass.

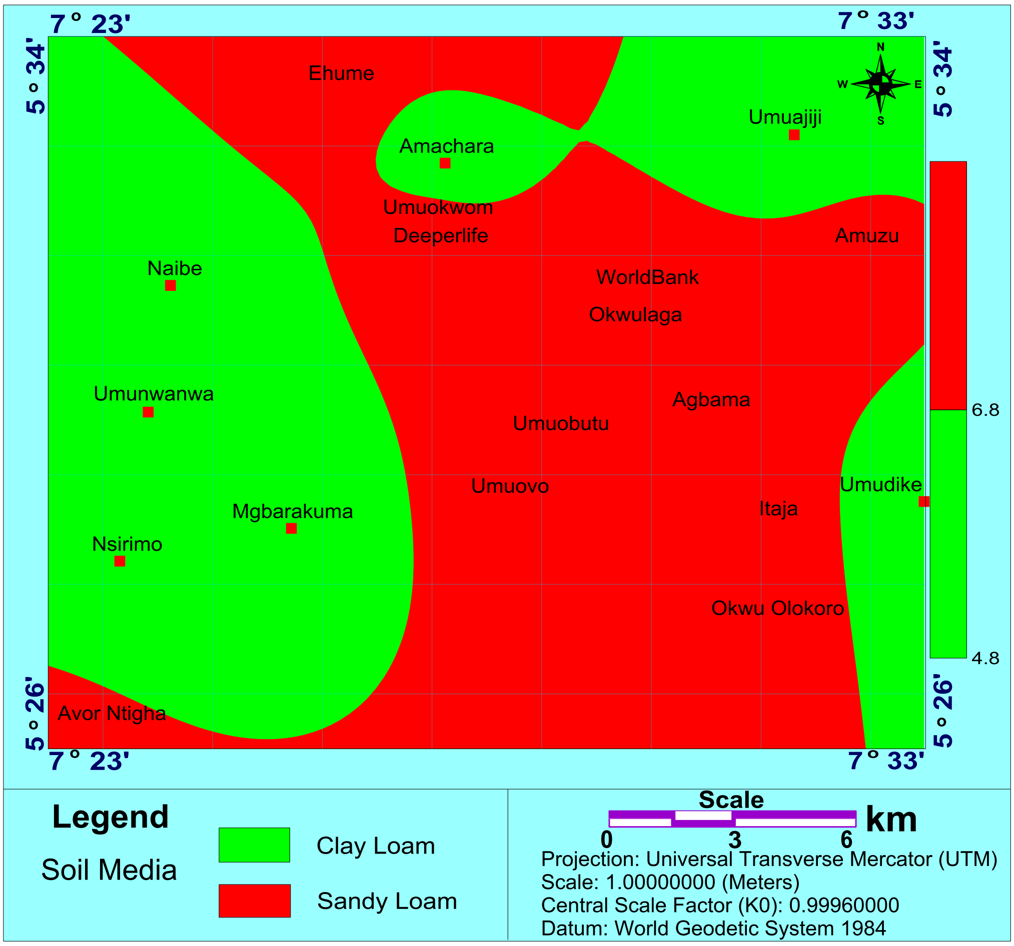

Figure 4.12: Reclassified Soil Media Map derived from Geophysical Investigation and Lithologs.

The soil profile is somewhat uniform throughout the study area. Generally, the study area is underlain by intensely weathered and leached uniform sands, loamy sands and clays.

4.5.5 Topography

The degree of slope, which varies from one place to another controls the likelihood that rainfall and the contained pollutants have to run off or be retained in one area long enough to infiltrate it. The slope layer (Fig. 4.13) was derived from the processed ASTER DEM image of 30m resolution. Meanwhile, the standard descriptions of varying types of slopes used in the evaluation of the slope layer are presented in Table 4.7.

Table 4.7: Slope used in the evaluation of the slope layer after (Ibe et al 2001)

Parameter	Ranges (Classes)	Rating	Pollution potentiality for groundwater	Weight
Slope	0 - 2 (Flat)	10	High	1
	2– 4	9		
	4 – 6 (Undulating)	8	Medium high	
	6 – 8	7		
	8 – 10 (Rolling)	6	Medium	
	10 – 12	5		
	12 – 14 (Moderately steep)	4	Low	
	14 – 16	3		
	16 – 18	2	Very low	
	> 18 (very Steep)	1	Very low	

Class rank of 10 was assigned to very steep slope areas and subsequently low ranking to areas according to decreasing magnitude of slope.

The area with the red colour (Ehume, Amachara, Naibe, Umunwanwa, Nsirimo, ItajaOlokoro, AgbamaOlokoro and OkwuOlokoro) are characterized by low slope degree (flat) and tend to retain water for longer time, hence providing greater chance for the infiltration of recharge water, which may contain a considerable amount of pollutants. Other areas have undulating slope on the account of having slope percentage above 2%. This implies that the pollution potential for groundwater maybe low (Fig.4.13).

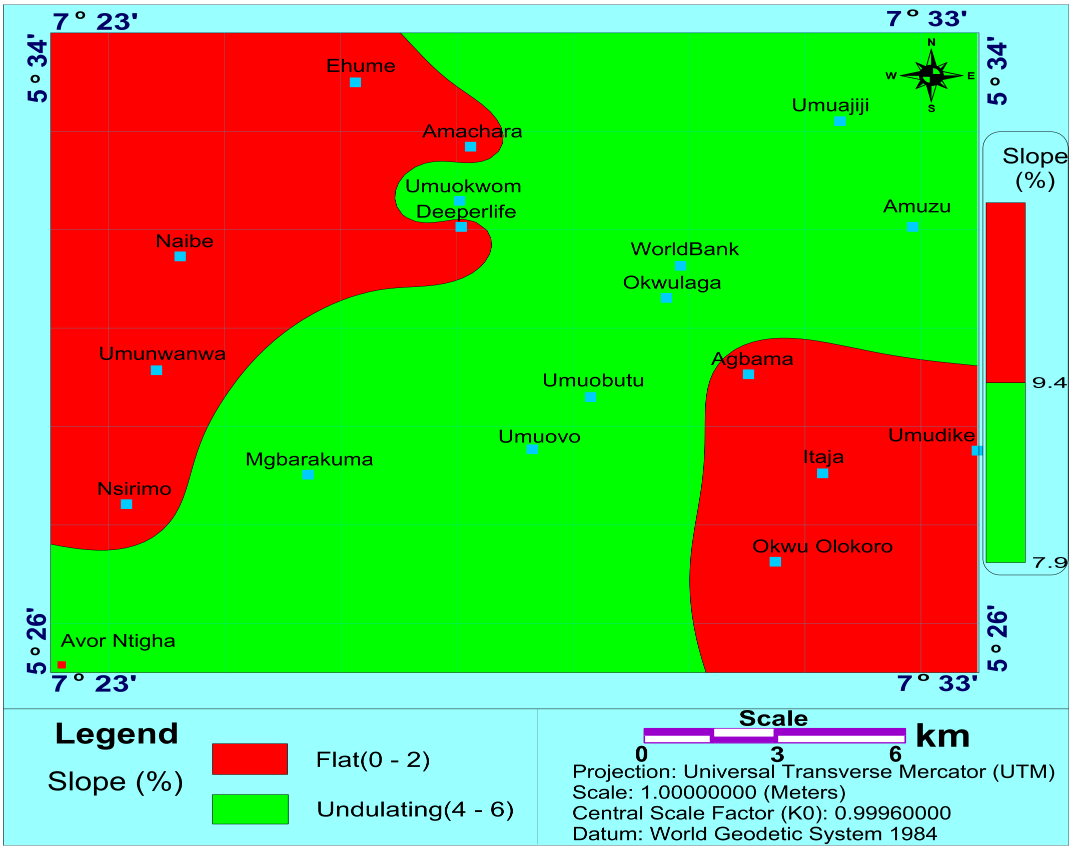

Figure 4.13: Thematic Slope Map of the Study Area

4.5.6 Impact of Vadose Zone

The vadose zone influences the aquifer pollution potential depending on the permeability and attenuation characteristics of its soil cover media. The vadose zone thematic layer (Fig. 4.14) was generated using the ratings and weight assignment

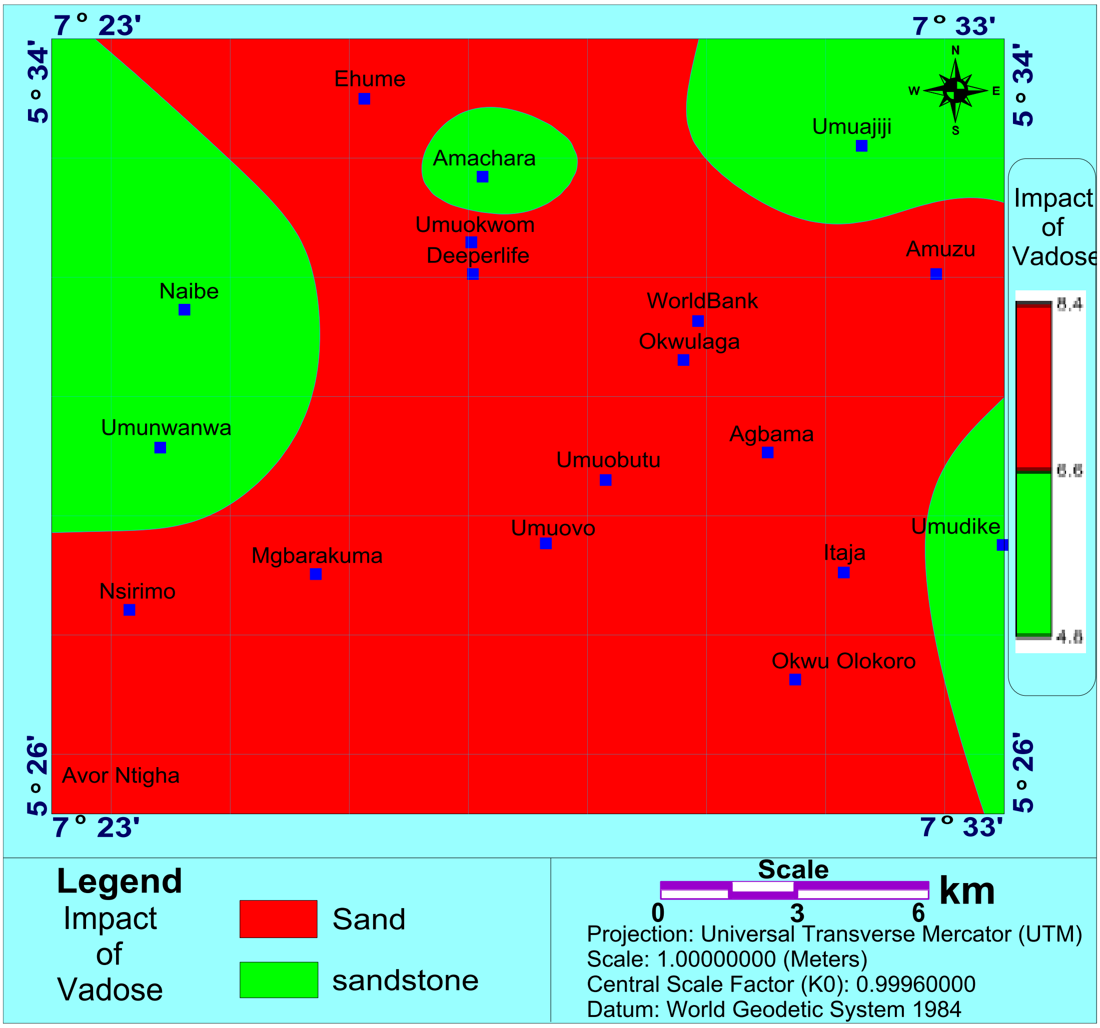

Fig.4.14: Vadose Zone Map of the Study Area

4.5.7 **Hydraulic Conductivity** (C)

The transmission rate of water in subsurface formation is determined by this parameter, which in turn controls contaminant movement rate (Atiqur Rahman, 2008). High groundwater flow rate represents high contaminant advection; hence a high rating was assigned to high conductivity zone. Since hydraulic conductivity is directly proportional to transmissivity. The rating was assigned as ‘2’.

Table 4.8: Assignment of Ratings and Weight for Hydraulic Conductivity

Hydraulic Conductivity(gpd/ft^2)	Rating
1-100	1
100-300	2
300-700	4
700-1000	6
1000-2000	8

The hydraulic conductivity layer (Fig. 4.15) was prepared from electrical resistivity data and evaluated for pollution potential mapping

Table 4.9 Hydraulic conductivity obtained from VES data

Location	K (mday^{-1})	1mday^{-1} = 24.542 gpdft^{-2}	K (gpdft^{-2})
Avor Ntigha	3.89	3.89 * 24.542	95.47
Okwu	6.50	6.50 * 24.542	159.52
Itaja Olokoro	6.50	6.50 * 24.542	159.52
Umudike	2.86	2.86 * 24.542	70.19
Mgbarakuma	3.89	3.89 * 24.542	95.47
Nsirimo	6.91	6.91 * 24.542	169.59
Umunwanwa	2.38	2.38 * 24.542	58.41
Ogbodinaibe	6.50	6.50 * 24.542	159.52
Deeper Life Camp	3.35	3.35 * 24.542	82.22
Ehume	2.37	2.37 * 24.542	58.16
Amuzu-Oro	1.90	1.90 * 24.542	46.63
Ohobo Okwulaga	3.28	3.28 * 24.542	80.50
Umuajiji	1.85	1.85 * 24.542	45.40
Agbama	3.24	3.24 * 24.542	79.52
Umuawa Alaocha	3.20	3.20 * 24.542	78.53
Umuobutu old-Umuahia	3.18	3.18 * 24.542	78.04
Umuovo	3.19	3.19 * 24.542	78.29
Amachara	3.40	3.40 * 24.542	83.44
World Bank Housing	3.35	3.35 * 24.542	82.22
Umuokwom Ohiya	3.35	3.35 * 24.542	82.22

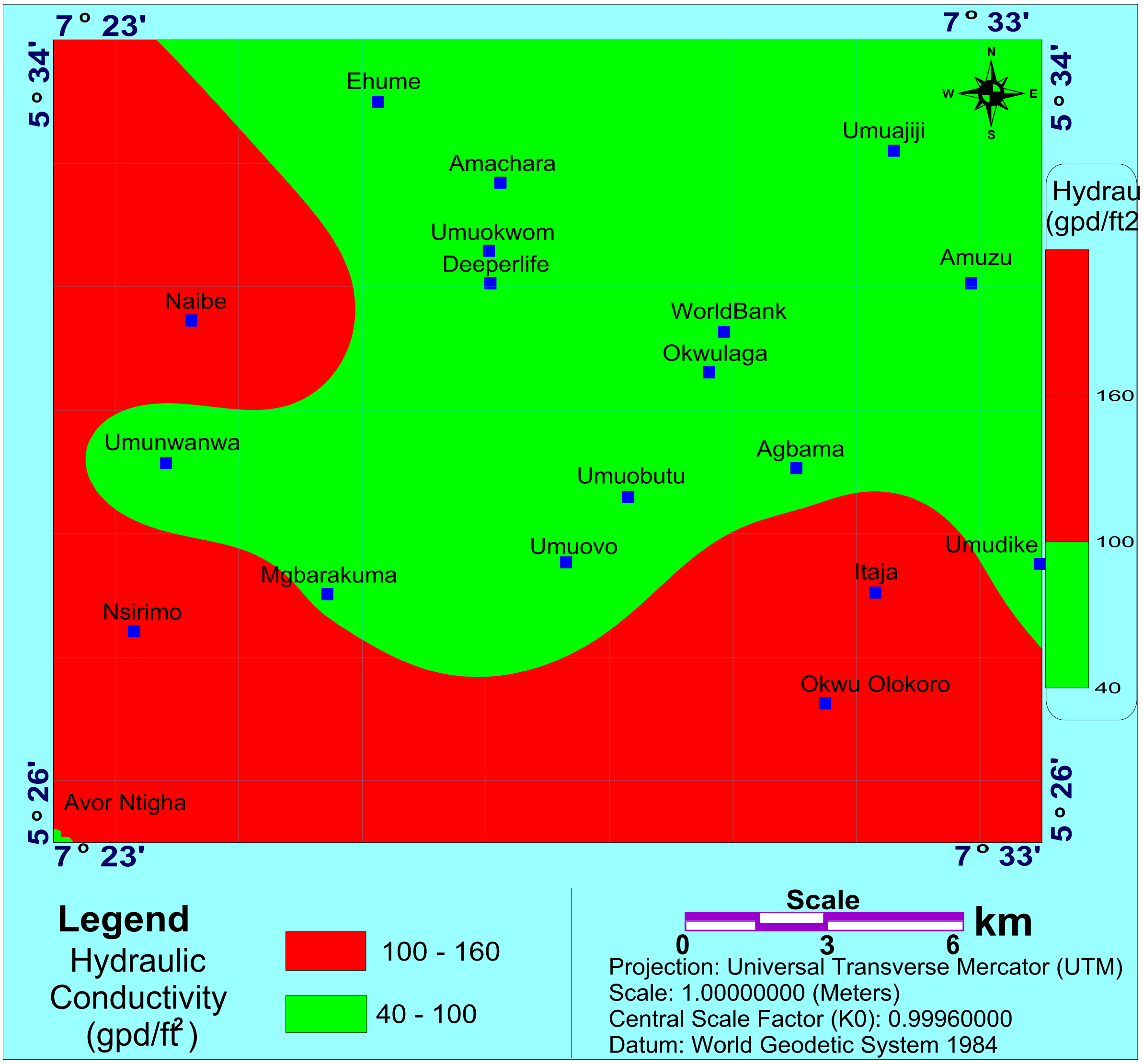

Figure 4.15: Thematic Map Showing Hydraulic Conductivity of the Study Area

The areas with red colourhave higher hydraulic conductivity whereas areas with green colour represent low hydraulic conductivity. Areas with higher hydraulic conductivity are more vulnerable to potential contamination, relative to other areas (green colour) with lower hydraulic conductivity.

4.5.8 Stacking and Overlay of all the Thematic Maps

The thematic maps of DRASTIC parameters were stacked and overlaid to generate the final vulnerability map for DRASTIC (Fig. 4.16)

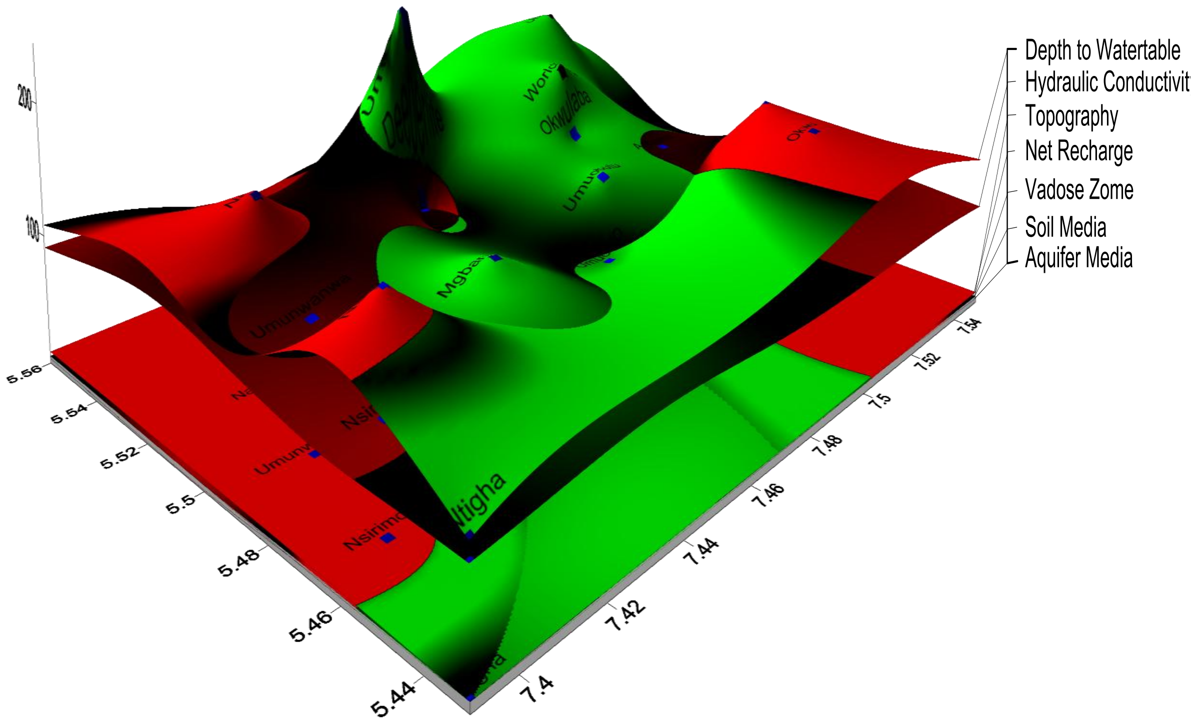

Fig. 4.16: Stacking and Overlay of all the Thematic Maps of the DRASTIC Parameters

4.6 Groundwater Vulnerability Assessment Using DRASTIC Model Map

Using the coordinates of the locations, the obtained DRASTIC Vulnerability index (DVI) values were utilized for modeling the groundwater vulnerability maps (GVM) shown in Figure 4.17 using the kriging interpolation technique in GIS environment.

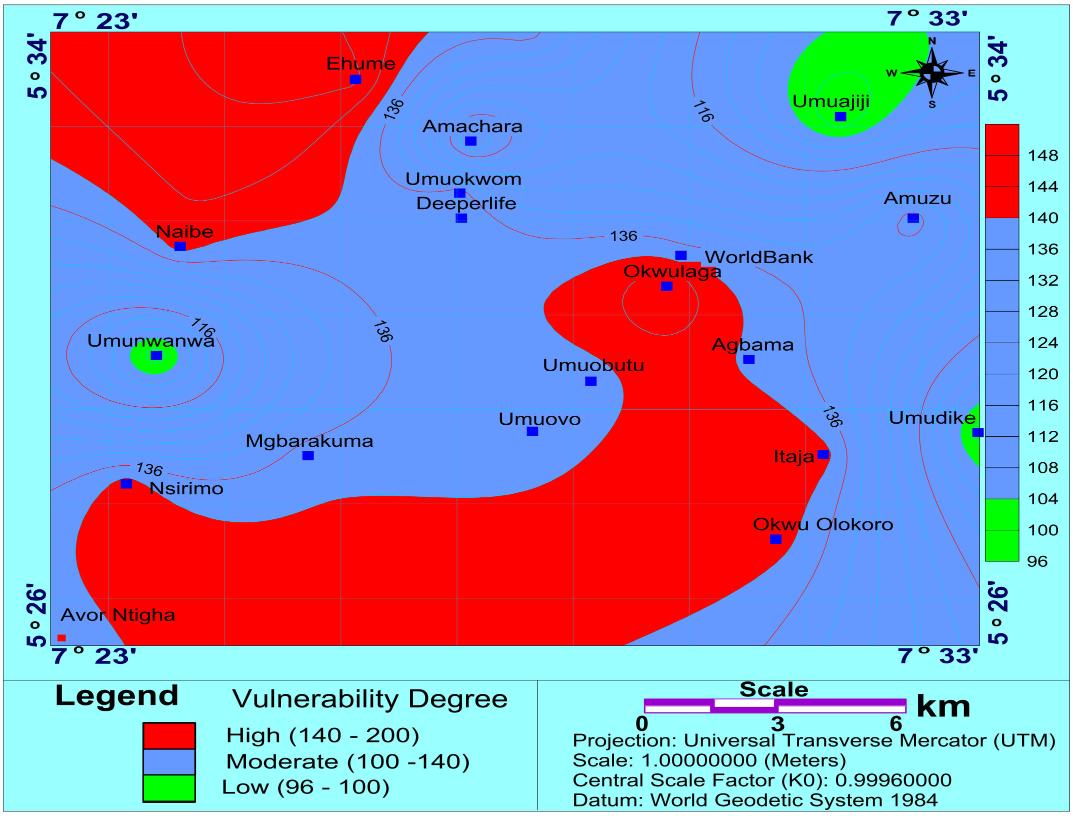

Figure 4.17: Vulnerability Map of the Study Area

The governing equation of DRASTIC Index = 5Dr + 4Rr + 3Ar + 2Sr + Tr + 5Ir + 3Cr. Hence the results of groundwater vulnerability assessment based on the DRASTIC model are presented in Table 4.10.

Table 4.10: Calculations of DRASTIC Index (DI)

Location	D (W=5)		R(W=4)		A(W = 3)		S (W = 2)		T(W =1)		I(W= 5)		C(W=3)		DI
	R	R×W	R	R×W	R	R×W	R	R×W	R	R×W	R	R×W	R	R×W	∑ R×W
Avor Ntigha	2	10	9	36	8	24	8	16	9	9	8	40	1	3	138
Okwu	2	10	9	36	8	24	8	16	10	10	8	40	2	6	142
Itaja Olokoro	2	10	9	36	8	24	8	16	10	10	8	40	2	6	142
Umudike	2	10	9	36	1	3	5	10	10	10	5	25	1	3	97
Mgbarakuma	2	10	9	36	8	24	8	16	9	9	8	40	1	3	138
Nsirimo	2	10	9	36	8	24	8	16	10	10	8	40	2	6	142
Umunwanwa	2	10	9	36	1	3	5	10	10	10	5	25	1	3	97
Naibe	2	10	9	36	8	24	8	16	10	10	8	40	2	6	142
Deeperlife	2	10	9	36	8	24	8	16	10	10	8	40	1	3	139
Ehume	4	20	9	36	8	24	8	16	10	10	8	40	1	3	149
Amuzu	2	10	9	36	8	24	8	16	9	9	8	40	1	3	138
Okwulaga	4	20	9	36	8	24	8	16	9	9	8	40	1	3	148
Umuajiji	2	10	9	36	1	3	5	10	9	9	5	25	1	3	96
Agbama	2	10	9	36	8	24	8	16	10	10	8	40	1	3	139
Umuawalocha	2	10	9	36	8	24	8	16	9	9	8	40	1	3	138
Umuobutu	2	10	9	36	8	24	8	16	9	9	8	40	1	3	138
Umuovo	2	10	9	36	8	24	8	16	9	9	8	40	1	3	138
Amachara	4	20	9	36	1	3	5	10	10	10	5	25	1	3	107
WorldBank	2	10	9	36	8	24	8	16	9	9	8	40	1	3	138
Umuokwom	2	10	9	36	8	24	8	16	9	9	8	40	1	3	138

The groundwater vulnerability (GV) model (Figures 4.9) was evaluated for the distribution of the different groundwater vulnerable zones in GIS environment. The DRASTIC vulnerability Index varied from 96 to 149.

The DI values in Tables 4.11 were classified into possible three levels of groundwater vulnerability zones namely; Low vulnerable (LV), Moderate vulnerable (MV) and High vulnerability according to the final DRASTIC index after Engel et al (1996).

Table 4.11: Aquifer Vulnerability Rating Based on the Final DRASTIC Index after (Engel, et al 1996)

DRASTIC Index (DI)	1-100	101-140	141-200	>200
Vulnerability Category	Low	Moderate	High	Very high

Similarly, the DRASTIC index classification of this research project is consistent with Mondal, et al., (2017) who classified DRASTIC index ranging from 110–132 as high vulnerability; 93–109 as moderate vulnerability 70–92 as low vulnerability and 39 – 69 as negligible vulnerability

Table 4.12: Classification of Groundwater Vulnerability Zones using DI Values

DI Values	Classifications	Colour	Area Covered
1 – 100	Low Vulnerability (LV)	Green	2%
101 – 140	Moderate Vulnerability (MV)	Blue	63%
141 - 200	High Vulnerability (HV)	Red	35 %

The result of groundwater vulnerability analysis using the DRASTIC model reveals that the high vulnerability zones are present in areas designated with red colour. These areas include Ogbodinibe, Amakama Olokoro and Itaja Olokoro. These areas are more prone to contamination as observed from the interpretation of VES because of the thin aquifer thickness. The aquifer thicknesses of these areas are far below the average thickness of the entire study area. The thin aquifer thickness in these communities contributed to migration of dissolved ions found in the aquiferous zones in these areas.

These areas have high vulnerability in respect to pollution. This implies that urgent attention is required to protect groundwater resource within and around these areas.

Consequently, this area is not suitable for siting waste dump because of the sensitivity of the area on the account of its high hydraulic conductivity and net recharge.

The vulnerability assessment using DRASTIC model in the study area revealed that the entire area which forms part of Imo River Basin is **moderately vulnerable** to groundwater contamination (Eke, et al, 2015).

The area with blue code is classified as "Moderate vulnerability". The vulnerability potential in respect to pollution is neither low nor high.

The areas with low groundwater vulnerability zones are designated with green colour. These areas found to have low groundwater vulnerability include Umudike, Umunwanwa and Umuajiji. These areas indicate low vulnerability potential in respect to pollution (Fig. 4.9). Major contributory factors responsible for the low vulnerability include high absorption and attenuation properties of the soil media and vadose zone. Hence, the higher the DRASTIC index, the greater the groundwater pollution potential.

4.6.1 Distribution of Vulnerable Zones in the Area

Apart from the fact that the groundwater vulnerability (GV) model (Fig. 4.9) shows different vulnerable zones namely LV, MV and HV, it also reveals the area percentage distribution covering different vulnerability zones. The high vulnerability zones cover35 %, the moderate vulnerability zonescover about 63 %, whereas low vulnerability zone covers about 2 % of the total study area.

Consequently, the high vulnerability zones are highly susceptible to contamination AtiqurRahman (2008). It is apparently obvious from the vulnerability map that more than 50 % of the study area is dominated by moderate vulnerable zones.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The increasing need for multi facets and interdisciplinary approach in underground water quality and vulnerability assessment prompted the integration the VES and DRASTIC Index modeling assessing the underground water vulnerability potential of the study area. The underground water quality of the area has been a burning issue amongst scholars in the area. The present study is a contribution of Geophysics (VES) and DRASTIC Index model tool in providing insight on the underground water vulnerability of the area.

Vertical electrical sounding technique as a geophysical tool involves surface measurement of physical properties which does not require the drilling of borehole to investigate the underground water. Hence, the method can be very economical despite huge information deep down the earth it provides.

The computer modeled interpretation techniques have helped to resolve the true aquifer thickness, resistivity and electrical conductivity of the aquiferous zone in the area basically required to qualitatively delineate the aquifer parameters (second order Dar-Zarrouk parameter) used in the study.

The results obtained, from the second order geoeletric parameter interpretation (Da zarrouk parameter) and the DRASTIC Index revealed that the area as being vulnerable and susceptible to groundwater pollution.

Aquifer Protective Capacity (APC) values obtained from the area is less than 0.1 which portends poor protective capacity of the aquifers within the area against contamination movement. The APC values tends to increase towards the extreme south of the area (Ntigha Ngwa) which has an APC value 0.0932 close to 0.1(weak) protective capacity.

The DRASTIC model of vulnerability assessment of the study area provided further insight by helping to delineate areas with Low, moderate and high vulnerability. The model revealed about 63% of the entire area as moderately vulnerable, 35% as highly vulnerable and only about 2% of the area as low. The inference shows the area as being susceptible to contamination.

The results of the interpretation VES show that the entire area consists of good prolific aquifers whose groundwater is susceptible to contamination as revealed by the two methods adopted in the study.

5.2 Recommendation

The following recommendations are made based on the obtained results from the VES data and the DRASTIC Index model. The aquifer protective capacity map and the DRASTIC Index vulnerability map both revealed the aquifers in the area are poorly and moderately protected. The implication is that the earth materials overlaying the aquifers have poor protective capacity rating.

i. The citing of Facilitates like an automobile mechanic settlement and abattoir/meat processing factory in the study area should be discouraged. The nature of the operations of these facilities has a high potential to contaminate and eventually pollute the sub-surface aquifers on the long- run

ii A thorough biological and geochemical evaluation of the underground water of the area is recommended to ascertain further the actual microbial and chemical contents for a holistic study of the ground water quality of the area.

iii Boreholes drilled within the area should be treated to minimize the danger of consuming contaminated water.

iv In prospecting for underground water in the area, it is recommended that aquifers with higher overburden capacity be sought for to minimize the rate of contamination by percolation of contaminants

v The government should encourage interdisciplinary approach in the study of underground water quality and vulnerability to reduce water borne diseases prevalent in our society.

5.3 Contribution to Knowledge

- The interpreted VES data as a geophysical tool and the DRASTIC model have enhanced knowledge and contributed in providing insight in groundwater vulnerability assessment of the area.
- The obtained APC values and rating from the VES data and the DRASTIC index result obtained added to knowledge in assessing groundwater quality and vulnerability of a given area.
- The study helped to delineate the aquiferous units within the study area and further revealed the protective capacity rating of these aquifers against contaminants flow.
- The knowledge provided in the study is a guide for groundwater resource management of the area by the Government.

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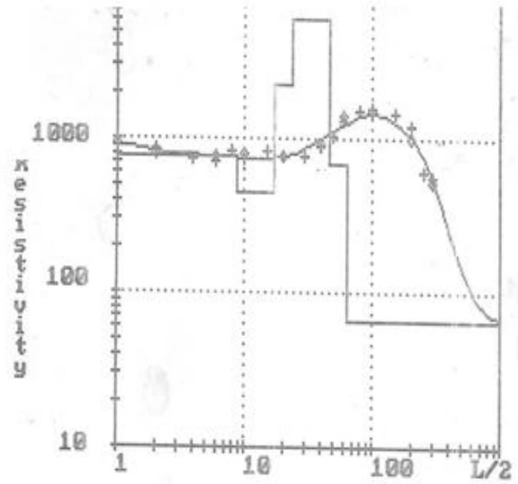
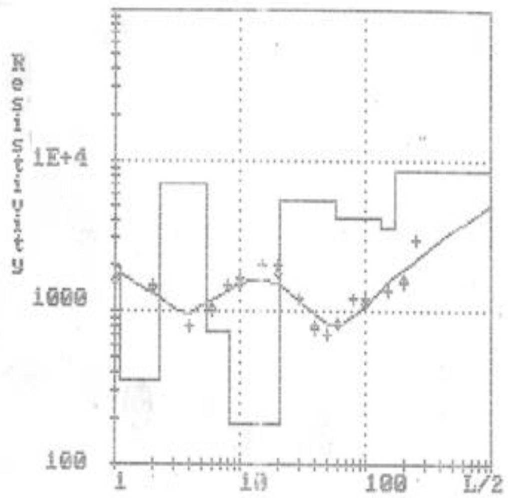
APPENDICES



Data (File) name F
Project name M.Sc PROJECT
Code name VES 6
UMUAHIA SOUTH L.G.A. ABIA STATE
Coordinates EHUME UMUOPARA
Date 23-11-2011
Direction lay out NE-SW
Remarks
Schlumberger O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	925.0	15.0	814.0	80.0	1500.0
2.0	858.0	20.0	762.0	100.0	1592.0
2.0	780.0	20.0	745.0	100.0	1523.0
4.0	737.0	30.0	745.0	150.0	1477.0
6.0	716.0	40.0	802.0	200.0	1219.0
6.0	768.0	40.0	902.0	200.0	1003.0
8.0	819.0	50.0	1024.0	250.0	614.0
10.0	719.0	60.0	1306.0	300.0	553.0
10.0	801.0	60.0	1411.0	300.0	526.0

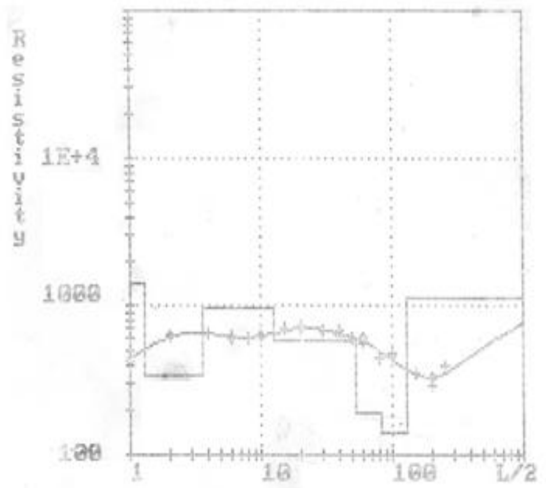
Resistivity (Ohm.m)	Depth (m)
970.0	0.6
768.0	8.9
452.0	17.3
3270.0	25.8
6050.0	47.1
691.0	63.1
65.3	



Data (File) name DLC
Project name WATER BOREHOLE
E-W(90),N5 31.322',E7 27.394',H378'L
Code name VES 17
Coordinates DEEPER LIFE CAMP GROUND OHIYA, UMUAHIA S, L.G.A
Date 15-12-2010
Direction lay out
Remarks ABIA STATE
Schlumberger O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	1569.4	15.0	2006.2	80.0	1119.7
2.0	1439.9	20.0	1999.7	100.0	1219.2
2.0	1416.0	20.0	1796.0	100.0	1108.4
4.0	782.6	30.0	1214.9	150.0	1350.2
6.0	953.4	40.0	768.2	200.0	1539.5
6.0	1046.3	40.0	730.2	200.0	1576.3
8.0	1481.0	50.0	693.5	250.0	2925.4
10.0	1630.3	60.0	815.8		
10.0	1450.0	60.0	830.2		

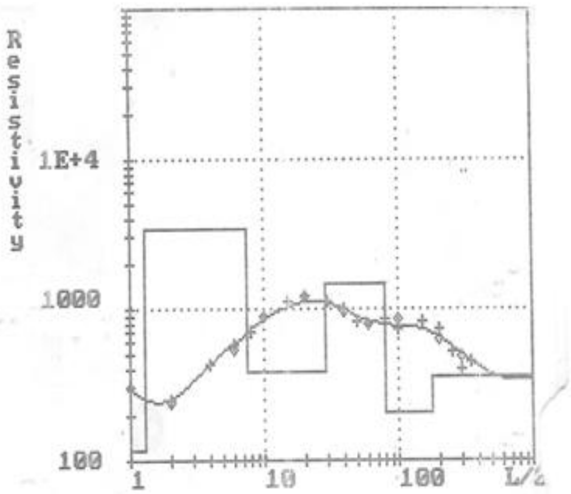
Resistivity (Ohm.m)	Depth (m)
1920.0	1.1
350.0	2.3
7020.0	5.4
739.0	8.3
187.0	20.7
5310.0	58.5
4160.0	93.2
4210.0	133.0
3580.0	172.0
8600.0	



Data (File) name ,VOKLK. Date 19-02-2005
Project name WATER BORSHOLE Direction lay out Dir: NE-SW,
Code name VES1A Remarks N5°22.594',E7°26.666'
Umuahia South L.G.A. Abia State.
Coordinates OKWU-OLOKORO Schlumberger O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	427.2	15.0	599.5	80.0	441.4
2.0	532.5	20.0	740.2	100.0	479.2
2.0	518.5	20.0	710.3	100.0	467.4
4.0	561.3	30.0	566.1	150.0	347.1
6.0	531.7	40.0	527.3	200.0	292.9
6.0	505.4	40.0	506.3	200.0	321.4
8.0	534.0	50.0	607.0	250.0	308.7
10.0	522.4	60.0	563.1		
10.0	535.6	60.0	607.6		

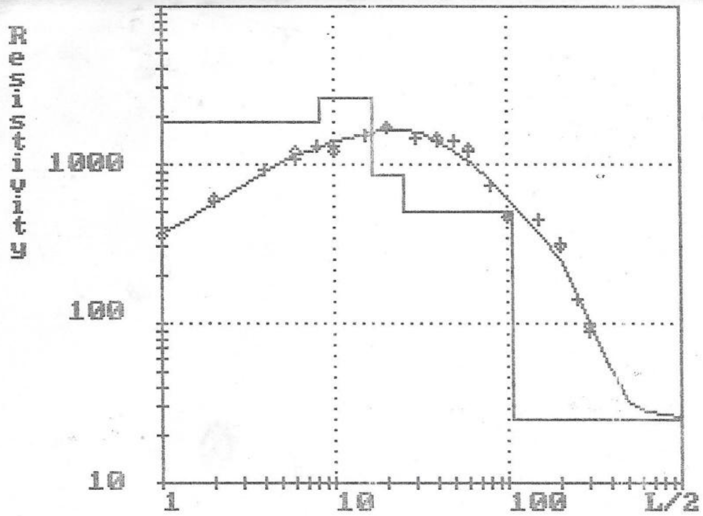
Resistivity (Ohm.m)	Depth (m)
221.0	0.4
1390.0	1.3
305.0	3.6
960.0	12.6
877.0	52.1
159.0	83.4
143.0	131.0
1100.0	



Data (File) name D Date 22-11-2011
Project name M.Sc PROJECT Direction lay out
N-S,N5 29.380',E7 28.764',H517ft
Code name VES 4 Remarks
UMUAHIA SOUTH L.G.A. ABIA STATE
Coordinates UMUOKWO OHIYA Schlumberger O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	304.4	20.0	1225.1	100.0	835.4
2.0	245.7	20.0	1223.0	150.0	822.7
2.0	241.5	30.0	1100.3	200.0	730.9
4.0	431.6	40.0	1009.5	200.0	632.6
6.0	571.2	40.0	950.0	250.0	511.2
6.0	532.9	50.0	827.9	300.0	398.9
8.0	709.8	60.0	779.0	300.0	473.8
10.0	898.6	60.0	780.2	350.0	441.5
10.0	900.5	80.0	854.9		
15.0	1125.8	100.0	739.2		

Resistivity (Ohm.m)	Depth (m)
476.0	0.5
115.0	1.3
3440.0	7.4
390.0	28.6
1470.0	80.1
206.0	176.0
355.0	

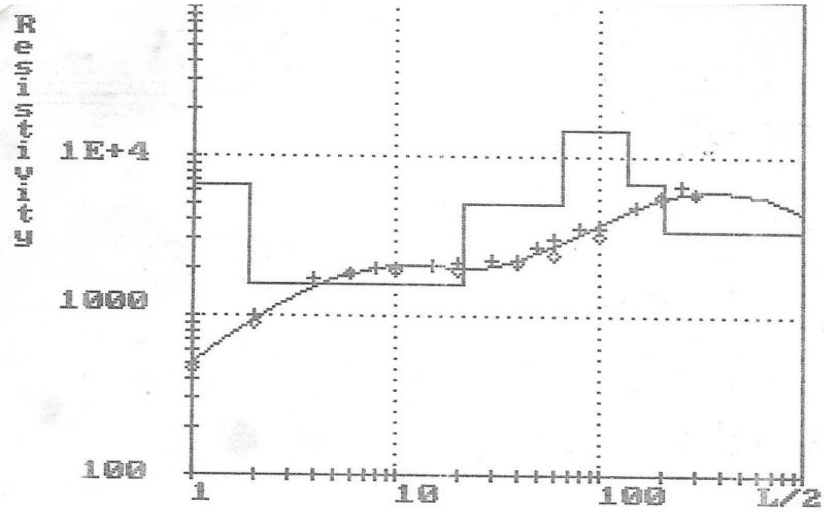


Data (File) name N
Project name M.Sc. PROJECT
Code name VES 14
UMUAHIA SOUTH L,G.A. ABIA STATE
Coordinates NGODO UMUEKWEA-UMUNWANWA

Date 24-11-2011
Direction lay out N-S
Remarks N5° 29.658', E7° 24.238', H393ft
Schlumberger O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	351.6	15.0	1531.2	80.0	726.4
2.0	583.9	20.0	1726.5	100.0	458.0
2.0	598.4	20.0	1682.9	100.0	461.4
4.0	923.7	30.0	1464.8	150.0	437.4
6.0	1066.2	40.0	1424.4	200.0	310.6
6.0	1182.5	40.0	1480.9	200.0	304.6
8.0	1284.0	50.0	1377.5	250.0	142.5
10.0	1308.8	60.0	1208.8	300.0	87.5
10.0	1215.7	60.0	1271.2	300.0	95.5

Resistivity (Ohm.m)	Depth (m)
285.0	0.8
1850.0	8.2
2600.0	16.9
870.0	25.4
505.0	84.8
504.0	106.0
25.2	

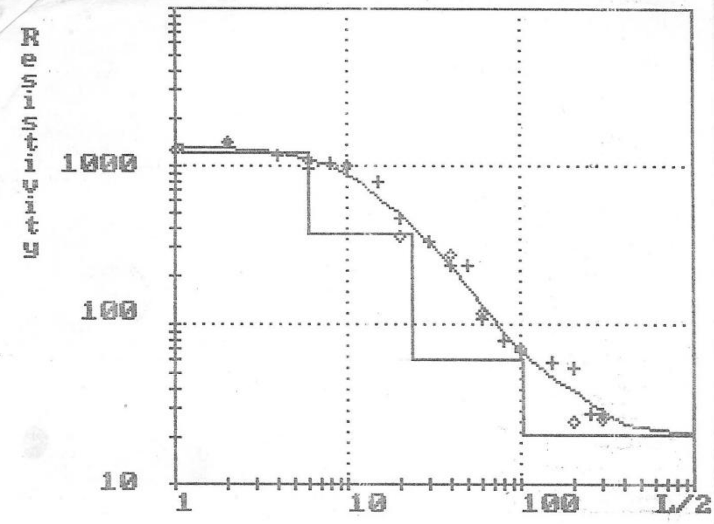


Data (File) name E
Project name M.Sc PROJECT
Code name VES 5
UMUAHIA SOUTH L.G.A. ABIA STATE
Coordinates UMUMBA NSIRIMO-UBAKALA

Date 23-11-2011
Direction lay out NE-SW
Remarks N5°28.090', E7°23.933', H450ft
Schlumberger O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	460.8	15.0	2030.6	80.0	3570.4
2.0	1002.0	20.0	2105.1	100.0	3451.0
2.0	894.1	20.0	1900.6	100.0	3106.5
4.0	1707.8	30.0	2204.1	150.0	4800.0
6.0	1851.2	40.0	2200.3	200.0	5358.0
6.0	1848.0	40.0	2112.5	200.0	5627.0
8.0	2009.7	50.0	2731.1	250.0	6503.7
10.0	2006.3	60.0	3068.8	300.0	5761.0
10.0	1892.7	60.0	2420.3	300.0	5689.0

Resistivity (Ohm.m)	Depth (m)
193.0	0.4
6470.0	1.9
1610.0	21.8
4980.0	66.8
14800.0	139.0
6880.0	206.0
3360.0	



Data (File) name A
Project name M.Sc PROJECT
E-W(70),N5 31.021′,E7 24.450′,H352ft
Code name VES 1
UMUAHIA SOUTH L.G.A. ABIA STATE
Coordinates OGBODO-NAIBE

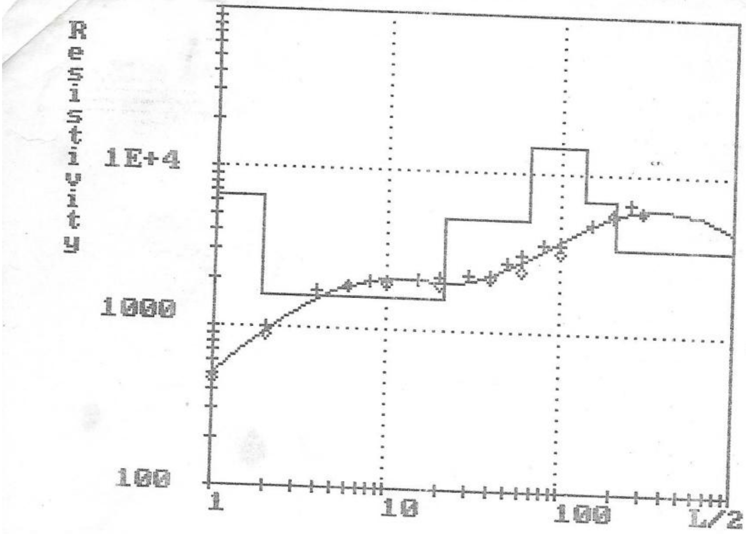
Date 22-11-2011
Direction lay out

Remarks

Schlumberger O′Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	1227.2	15.0	800.4	80.0	80.2
2.0	1410.2	20.0	463.9	100.0	69.0
2.0	1400.2	20.0	346.9	100.0	69.3
4.0	1138.3	30.0	331.6	150.0	58.3
6.0	969.9	40.0	230.1	200.0	53.7
6.0	1073.6	40.0	273.4	200.0	24.6
8.0	1026.6	50.0	230.5	250.0	27.9
10.0	978.1	60.0	109.4	300.0	28.0
10.0	1000.2	60.0	114.0	300.0	26.5

Resistivity (Ohm.m)	Depth (m)
1350.0	1.1
1210.0	6.0
362.0	23.5
60.9	102.0
20.6	

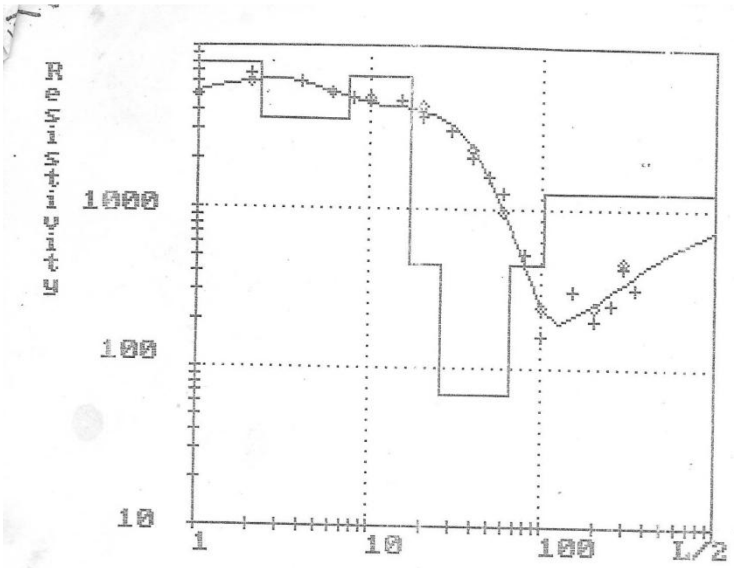


Data (File) name E
Project name M.Sc PROJECT
Code name VES 5
UMUAHIA SOUTH L.G.A. ABIA STATE
Coordinates UMUMBA NSIRIMO-UBAKALA

Date 23-11-2011
Direction lay out NE-SW
Remarks N5°28.090', E7°23.933', H45oft
Schlumberger O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	460.8	15.0	2030.6	80.0	3570.4
2.0	1002.0	20.0	2105.1	100.0	3451.0
2.0	894.1	20.0	1900.6	100.0	3106.5
4.0	1707.8	30.0	2204.1	150.0	4800.0
6.0	1851.2	40.0	2200.3	200.0	5358.0
6.0	1848.0	40.0	2112.5	200.0	5627.0
8.0	2009.7	50.0	2731.1	250.0	6503.7
10.0	2006.3	60.0	3068.8	300.0	5761.0
10.0	1892.7	60.0	2420.3	300.0	5689.0

Resistivity (Ohm.m)	Depth (m)
193.0	0.4
6470.0	1.9
1610.0	21.8
4980.0	66.8
14800.0	139.0
6880.0	206.0
3360.0	

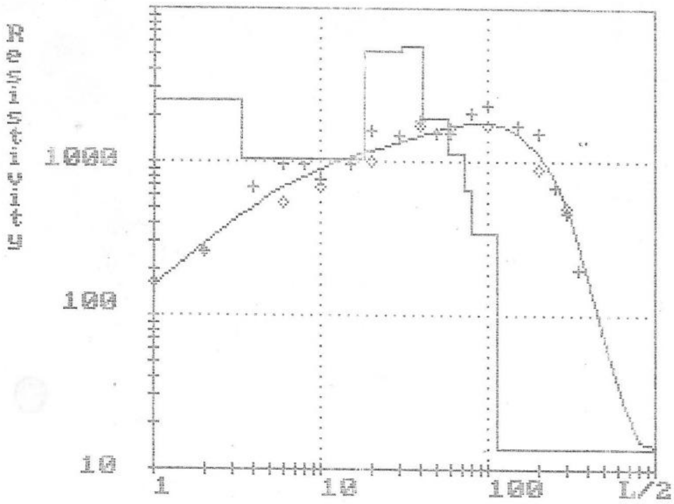


Data (File) name CHR
Project name WATER BOREHOLE
Code name VES 2
Coordinates AMA-ACHARA UMUAHIA

Date 21-01-2002
Direction lay out Dir:NW-SE
Remarks Abia State
Schlumberger O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	4938.3	20.0	3722.7	100.0	239.8
2.0	6828.2	20.0	4192.2	150.0	301.3
2.0	5984.2	30.0	2960.8	200.0	200.0
4.0	5940.0	40.0	2071.3	200.0	240.0
6.0	5219.2	40.0	2343.4	250.0	250.0
6.0	5170.0	50.0	1564.0	300.0	420.0
8.0	4791.6	60.0	1255.3	300.0	460.3
10.0	4524.0	60.0	954.6	350.0	315.7
10.0	4775.5	80.0	519.2		
15.0	4541.4	100.0	155.1		

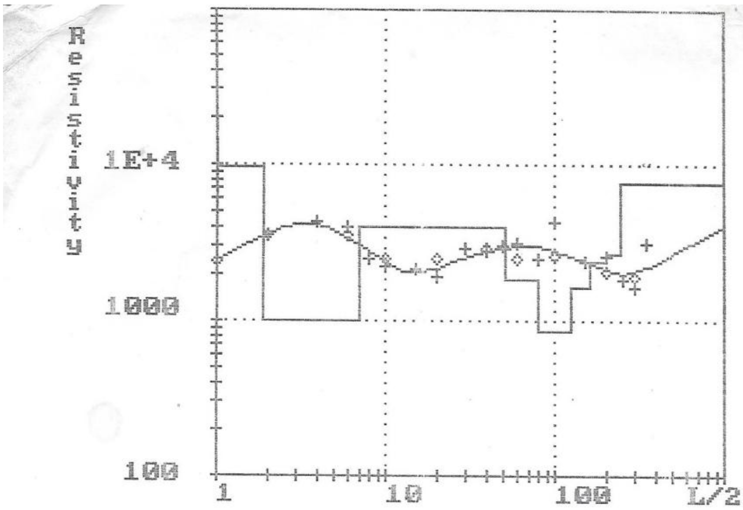
Resistivity (Ohm.m)	Depth (m)
4460.0	0.6
8000.0	2.3
3490.0	7.6
6670.0	17.3
442.0	26.3
68.1	65.4
443.0	102.0
1270.0	



Data (File) name WLH Date 10-06-2011
Project name WATER BOREHOLE Direction lay out
E-W(100),N5 33.642',E7 28.019',H553ft
Code name VES21 Remarks ABIA STATE
Coordinates UMUAWA ALAOCHA OHUHU,UMUAHIA NORTH L.G.A.
Schlumberger O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	164.6	20.0	1561.2	100.0	1696.5
2.0	262.7	20.0	1007.3	150.0	1675.9
2.0	260.3	30.0	1468.2	200.0	1527.4
4.0	674.7	40.0	1859.8	200.0	895.7
6.0	940.8	40.0	1679.9	250.0	680.5
6.0	531.3	50.0	1506.7	300.0	455.3
8.0	947.4	60.0	1495.2	300.0	505.7
10.0	751.2	60.0	1651.3	350.0	196.1
10.0	666.0	80.0	2047.3		
15.0	951.8	100.0	2322.2		

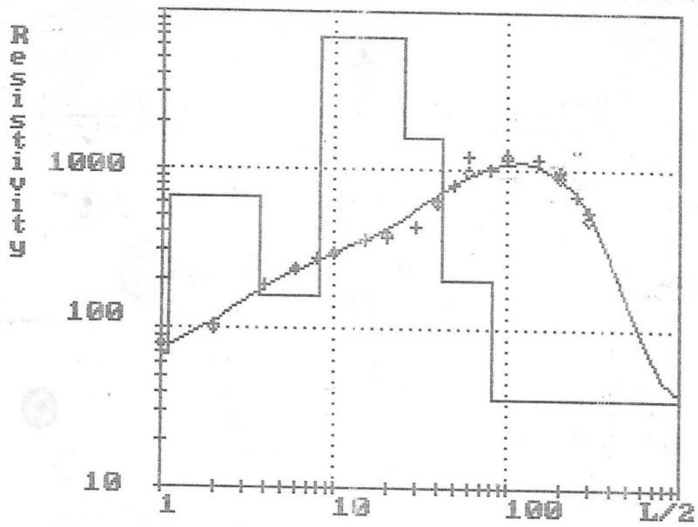
Resistivity (Ohm.m)	Depth (m)
102.0	0.6
2550.0	3.4
1040.0	18.6
5180.0	30.5
5550.0	40.4
1950.0	57.5
1120.0	72.5
661.0	81.1
344.0	115.0
13.4	



Data (File) name MVD   Date 12-12-2011
Project name WATER BOREHOLE   Direction lay out
NNW-SSE(340),N5 28.721′,E7 28.165′,H575ft
Code name VES 16 —9   Remarks ABIA STATE
Coordinates UMUOVO ELUELU,OLD UMUAHIA, UMUAHIA SOUTH L.G.A.
Schlumberger O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	2436.7	20.0	1906.4	100.0	2616.4
2.0	3461.1	20.0	2519.7	150.0	2435.8
2.0	3510.4	30.0	2919.1	200.0	2547.1
4.0	4311.5	40.0	2792.8	200.0	2037.0
6.0	3875.2	40.0	2868.2	250.0	1822.3
6.0	3454.0	50.0	3061.1	300.0	1623.5
8.0	2524.5	60.0	3089.6	300.0	1891.7
10.0	2218.3	60.0	2488.2	350.0	3118.8
10.0	2451.1	80.0	2456.7		
15.0	2141.9	100.0	4179.9		

Resistivity (Ohm.m)	Depth (m)
1550.0	0.5
9500.0	1.9
1010.0	7.0
4010.0	51.6
1820.0	79.5
860.0	125.0
1650.0	164.0
2460.0	204.0
2680.0	244.0
7620.0	

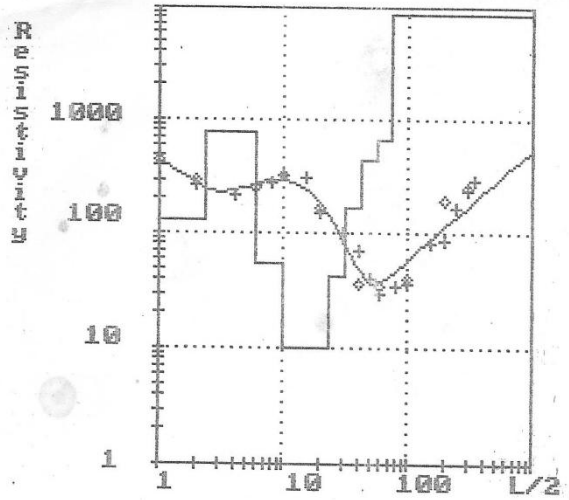


Data (File) name C
Project name M.Sc PROJECT
N-S,N5 29.380′,E7 28.764′,H517ft
Code name VES 3
UMUAHIA SOUTH L.G.A. ABIA STATE
Coordinates UMUOBUTU OLD UMUAHIA

Date 22-11-2011
Direction lay out
Remarks
Schlumberger O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	78.4	15.0	358.4	80.0	995.8
2.0	104.9	20.0	359.8	100.0	1174.0
2.0	98.8	20.0	375.5	100.0	1188.3
4.0	181.7	30.0	430.4	150.0	1150.8
6.0	234.1	40.0	623.2	200.0	970.4
6.0	234.3	40.0	612.3	200.0	884.4
8.0	267.3	50.0	799.7	250.0	680.5
10.0	289.5	60.0	1197.0	300.0	536.5
10.0	295.8	60.0	963.6	300.0	472.9

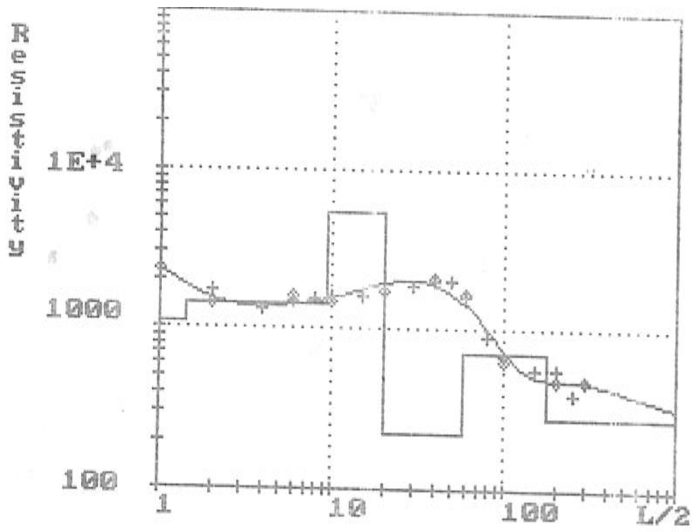
Resistivity (Ohm.m)	Depth (m)
67.5	1.1
661.0	3.7
159.0	8.2
6760.0	25.3
1600.0	41.9
203.0	82.9
35.0	



Data (File) name HKF Date 21-01-2011
Project name WATER BOREHOLE Direction lay out
E-W,100,N5 30.525',E7 29.490',H533ft
Code name VES 13 Remarks ABIA STATE
Coordinates OHOBO-OKWULAGA,AFARAUKWU,UMUAHIA NORTH L.G.A.
Schlumberger O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	436.6	20.0	150.5	100.0	38.9
2.0	269.4	20.0	168.3	150.0	82.5
2.0	289.8	30.0	100.2	200.0	87.1
4.0	215.3	40.0	70.9	200.0	196.5
6.0	261.0	40.0	35.3	250.0	165.2
6.0	249.7	50.0	39.5	300.0	234.6
8.0	280.2	60.0	28.8	300.0	248.1
10.0	322.9	60.0	33.3	350.0	289.4
10.0	328.6	80.0	34.8		
15.0	310.1	100.0	35.8		

Resistivity (Ohm.m)	Depth (m)
545.0	0.8
129.0	2.3
761.0	5.9
55.4	10.2
9.9	23.0
41.2	31.9
170.0	42.9
435.0	56.7
656.0	73.3
8400.0	



Data (File) name O
Project name M.Sc. PROJECT
Code name VES 15
UMUAHIA SOUTH L.G.A. ABIA STATE
Coordinates AGBAMA OLOKORO

Date 24-11-2011
Direction lay out NW-SE
Remarks

Schlumberger O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	2301.0	15.0	1539.5	80.0	[illegible]
2.0	1697.2	20.0	1891.6	100.0	665.7
2.0	1387.7	20.0	1778.2	100.0	636.4
4.0	1287.0	30.0	1832.7	150.0	555.0
6.0	1442.6	40.0	1946.9	200.0	567.6
6.0	1584.0	40.0	2033.9	200.0	470.9
8.0	1490.0	50.0	1931.0	250.0	395.1
10.0	1546.0	60.0	1596.9	300.0	482.8
10.0	1455.0	60.0	1606.0	300.0	479.8

Resistivity (Ohm.m)	Depth (m)
3170.0	0.5
1090.0	1.4
1400.0	9.4
5390.0	19.9
222.0	58.3
711.0	179.0
283.0	

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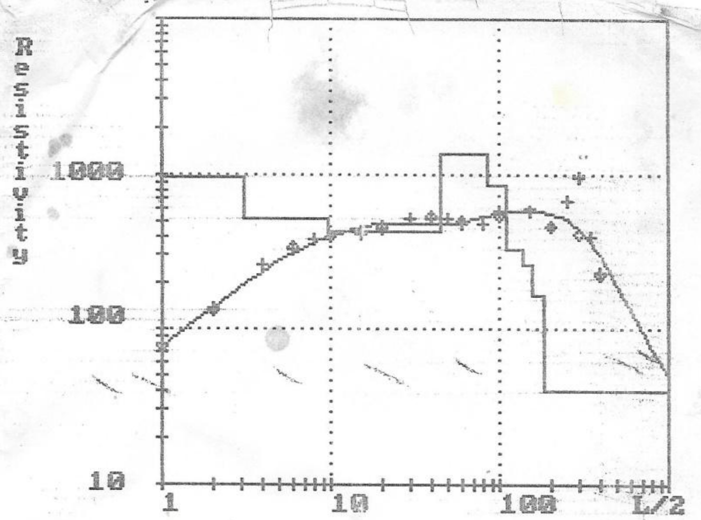
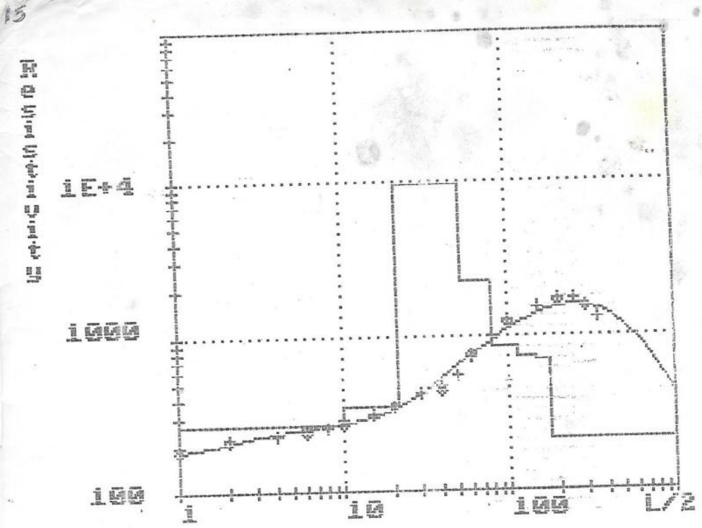


Data (File) name DKB Date 14-12-2009
Project name WATER BOREHOLE Direction lay out
NW-SE(340), N5 28.706′, E7 32.795′, H487ft
Code name VES 21 Remarks ABIA STATE
Coordinates NEAR CHOICE WORLD HOTEL UMUDIKE, IKWUANO L.G.A.
Schlumberger O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	76.4	20.0	446.3	100.0	533.1
2.0	133.1	20.0	452.4	150.0	590.1
2.0	128.6	30.0	516.1	200.0	469.6
4.0	255.3	40.0	515.0	200.0	452.4
6.0	321.4	40.0	540.8	250.0	683.8
6.0	339.4	50.0	518.5	300.0	956.4
8.0	375.2	60.0	476.3	300.0	413.7
10.0	402.5	60.0	491.8	350.0	395.4
10.0	388.9	80.0	476.6	400.0	231.4
15.0	412.4	100.0	570.2	400.0	222.7

Resistivity (Ohm.m)	Depth (m)
48.0	0.6
980.0	3.1
516.0	9.6
422.0	44.7
1360.0	84.6
870.0	111.0
324.0	136.0
265.0	158.0
163.0	186.0
40.0	

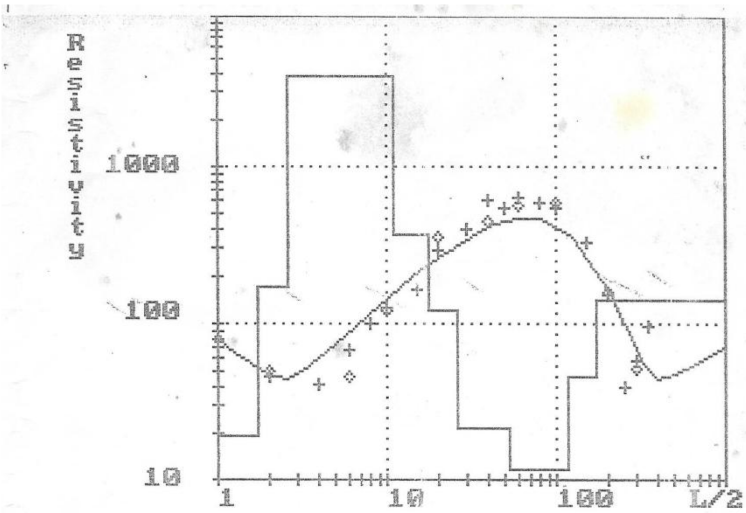
15



Data (File) name	KWB	Date	10-01-2011
Project name	WWATER BOREHOLE	Direction lay out	
4-ESE120,N5 30.884',E7 29.634',H543(L			
	VES 1.0	Remarks	ABIA STATE
Code name	H9 RD K CLOSE,WB	H/E UMUAHIA,UMUAHIA NORTH L.G.	
Coordinates		Schlumberger	O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	181.7	20.0	358.9	100.0	1190.4
2.0	220.9	20.0	349.9	150.0	1522.1
2.0	213.7	30.0	427.3	200.0	1709.5
4.0	231.2	40.0	472.1	200.0	1659.8
6.0	245.3	40.0	440.6	250.0	1681.2
6.0	244.8	50.0	567.7	300.0	1514.6
8.0	260.4	60.0	717.2	300.0	1489.2
10.0	295.9	60.0	754.2	350.0	1300.0
10.0	271.9	80.0	1004.8		
15.0	318.3	100.0	1250.2		

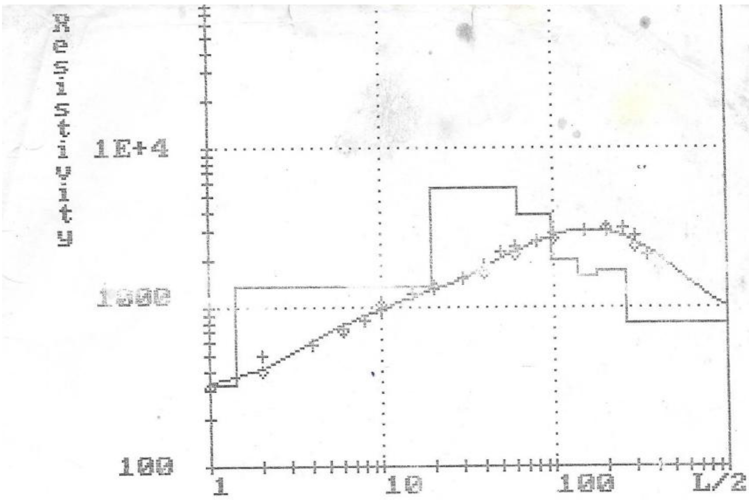
Resistivity (Ohm.m)	Depth (m)
176.0	0.9
270.0	10.0
354.0	21.4
9800.0	52.5
2200.0	80.4
860.0	112.0
738.0	145.0
707.0	180.0
218.0	



Data (File) name JKB Date 23-01-2010
Project name WATER BOREHOLE Direction lay out
E-W(80), N5 32.623', E7 31.265', H 566ft
Code name VES 19 Remarks ABIA STATE
Coordinates UMUAJIJI ISIEKE IBEKU, UMUAHIA NORTH L.G.A.
Schlumberger' O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	78.0	20.0	392.3	100.0	588.1
2.0	47.0	20.0	354.4	150.0	330.7
2.0	50.8	30.0	397.1	200.0	150.8
4.0	41.3	40.0	394.6	200.0	160.2
6.0	68.5	40.0	446.4	250.0	40.3
6.0	46.9	50.0	547.7	300.0	57.7
8.0	100.2	60.0	635.3	300.0	52.1
10.0	122.9	60.0	553.3	350.0	97.3
10.0	119.6	80.0	591.3		
15.0	166.9	100.0	532.8		

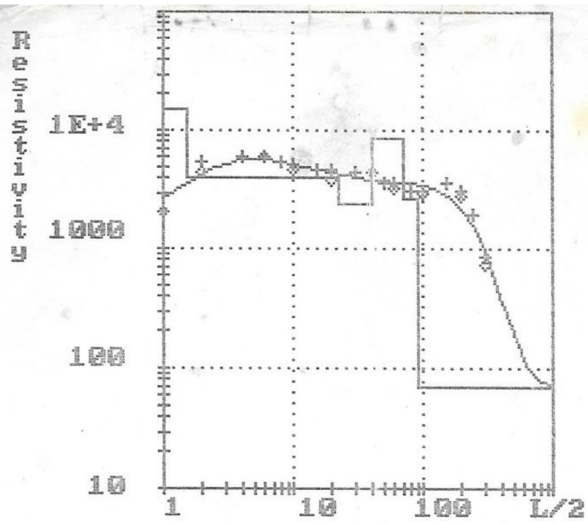
Resistivity (Ohm.m)	Depth (m)
109.0	0.6
19.2	1.7
168.0	2.6
3870.0	11.0
373.0	17.9
121.0	26.1
21.5	52.8
11.7	119.0
46.2	170.0
141.0	



Data (File) name SGB Date 25-02-2009
Project name WATER BOREHOLE Direction lay out
NW-SE(340), EL 529ft, N5 26.128′, E7 23.191′
Code name VES 12 Remarks ABIA STATE
Coordinates UMUNKWE-UMUOGIDI, AVOR NTIGHA, ISIALANORTH L.G.
Schlumberger O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	315.7	20.0	1303.1	100.0	2661.6
2.0	492.3	20.0	1345.1	150.0	2961.1
2.0	397.0	30.0	1485.6	200.0	2973.3
4.0	581.6	40.0	1828.7	200.0	3189.5
6.0	729.1	40.0	1658.8	250.0	3167.3
6.0	708.4	50.0	2209.8	300.0	2773.7
8.0	805.9	60.0	2360.6	300.0	2433.2
10.0	959.4	60.0	2126.3	350.0	2150.4
10.0	1021.4	80.0	2546.8		
15.0	1188.4	100.0	2889.8		

Resistivity (Ohm.m)	Depth (m)
323.0	1.4
1360.0	19.4
5620.0	62.3
3890.0	97.1
1980.0	138.0
1590.0	179.0
1730.0	219.0
1690.0	260.0
787.0	

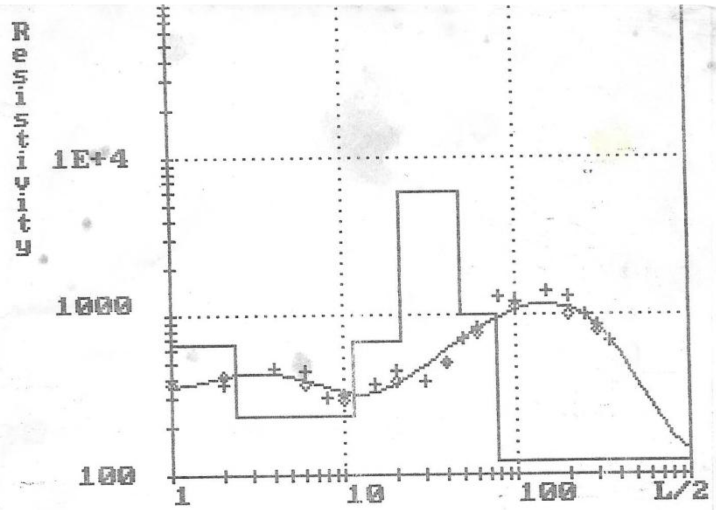


Data (File) name J
Project name M.Sc PROJECT
Code name VES 10
UMUAHIA SOUTH L,G,A. ABIA STATE
Coordinates AMANGWO-ELUELU, OLOKORO

Date 24-11-2011
Direction lay out E-W
Remarks N5°28·441, E7°31·14°
Schlumberger O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	2001.6	15.0	4495.1	80.0	3046.3
2.0	5294.4	20.0	4535.1	100.0	3000.0
2.0	4476.4	20.0	3754.9	100.0	2835.0
4.0	5841.0	30.0	4463.7	150.0	3540.5
6.0	6000.0	40.0	4401.2	200.0	3012.1
6.0	5879.5	40.0	4291.8	200.0	2704.4
8.0	5300.0	50.0	3630.3	250.0	1902.1
10.0	5200.0	60.0	3503.2	300.0	851.3
10.0	4693.5	60.0	3225.6	300.0	718.5

Resistivity (Ohm.m)	Depth (m)
1030.0	0.3
14700.0	1.5
4060.0	22.5
2350.0	40.4
8400.0	70.7
2580.0	92.4
68.5	

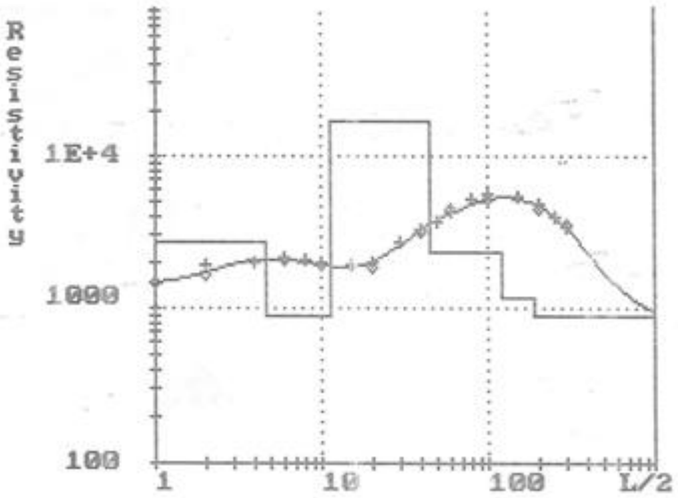


Data (File) name B
Project name M.Sc PROJECT
E-W(100),N5 31.377',E7 32.058',H622ft
Code name VES 2
UMUAHIA SOUTH L.G.A. ABIA STATE
Coordinates AMUZU-ORO IBEKU

Date 22-11-2011
Direction lay out
Remarks
Schlumberger O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	366.4	20.0	440.6	100.0	1119.7
2.0	366.4	20.0	380.0	150.0	1425.1
2.0	414.7	30.0	384.9	200.0	1290.7
4.0	458.4	40.0	490.1	200.0	984.7
6.0	439.0	40.0	504.9	250.0	1000.0
6.0	370.7	50.0	716.0	300.0	858.4
8.0	307.9	60.0	824.1	300.0	777.5
10.0	315.1	60.0	748.3	350.0	669.3
10.0	289.8	80.0	1277.5		
15.0	367.1	100.0	1186.9		

Resistivity (Ohm.m)	Depth (m)
335.0	0.9
650.0	2.4
231.0	11.2
692.0	21.8
6170.0	47.8
1000.0	77.8
121.0	



Data (File) name	L	Date	24-11-2011
Project name	M.Sc. PROJECT	Direction lay out	N-S
Code name	VES 12	Remarks	N5° 11·414', E7° 26·857', H53oft
UMUAHIA SOUTH L,G.A.	ABIA STATE		
Coordinates	MGBARAKUMA	Schlumberger	O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho .Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	1439.6	15.0	1868.8	80.0	5175.5
2.0	1875.3	20.0	1984.2	100.0	5521.6
2.0	1630.4	20.0	1566.9	100.0	5172.4
4.0	1980.0	30.0	2679.6	150.0	5293.9
6.0	2128.0	40.0	3284.0	200.0	4724.2
6.0	2046.0	40.0	3554.0	200.0	4483.4
8.0	2088.9	50.0	3706.0	250.0	3970.3
10.0	2007.7	60.0	4307.5	300.0	3433.7
10.0	1884.9	60.0	4401.9	300.0	3300.0

Resistivity (Ohm.m)	Depth (m)
1340.0	0.9
2680.0	4.6
890.0	11.4
17300.0	45.3
2290.0	82.3
2370.0	120.0
1180.0	190.0
800.0	

Location	Aquifer Bottom h_2 (m)	Aquifer Top h_1 (m)	H (m)	*ρ(Ωm)*	*δ(Ωm)*$^{-1}$	T=hk	C=kδ	K(mday^{-1})	S=3 x 10^6 h	D= T/S
Avor Ntigha	260	97.1	162.9	1747.5	$5.722x10^{-4}$	633.7	$2.22x10^{-3}$	3.89	$4.887x10^{-4}$	$1.2967x10^{6}$
Nsirimo	>260	139.0	>67.8	5120	$1.953x10^{-4}$	468.5	$1.349x10^{-3}$	6.91	$2.034x10^{-4}$	$2.3033x10^{6}$
Umunwanwa	25.4	16.9	8.5	1119.8	$8.93x10^{-4}$	229.8	$1.35x10^{-3}$	2.35	$2.934x10^{-4}$	$7.8323x10^{5}$
	106		8.5	1735	$5.763x10^{-4}$	20.23	$1.372x10^{-3}$	2.38	$2.55x10^{-5}$	$7.9333x10^{5}$
Ogbodinaibe	23.5	1.1	22.4	786	$1.272x10^{-3}$	87.1	$3.02x10^{-3}$	2.38	$6.72x10^{-5}$	$1.2961x10^{6}$
Ehume	63.1	17.3	45.8	3003.7	3.329x10-4	53.3	$7.89x10^{-4}$	2.37	$1.37x10^{-4}$	$3.8791x10^{5}$
Mgbarakuma	190	11.4	178.6	5785	1.728x10-4	694.8	$6.721x10^{-4}$	3.89	$5.358x10^{-4}$	$1.2967x10^{6}$
Umuokwom Ohiya	80.1	28.6	51.5	1470	$6.802x10^{-4}$	172.5	$2.279x10^{-3}$	3.35	$1.545x10^{-4}$	$4.8656x10^{7}$
Deeper Life Camp	>172	20.7	>151.3	3815	$2.621x10^{-4}$	506.9	$8.78x10^{-4}$	3.35	$4.539x10^{4}$	$1.1167x10^{6}$
Amachara	17.3	2.3	15	5080	$1.968x10^{-4}$	51.0	$6.69x10^{-4}$	3.40	$1.53x10^{-4}$	$3.3333x10^{5}$
	>102	52	>50	1270	$7.874x10^{-4}$	170.0	$2.677x10^{-3}$	3.40	$1.5x10^{-4}$	$1.1333x10^{6}$
Umuawa Alaocha	72.5	18.6	53.9	3450	$2.898x10^{-4}$	172.5	$9.275x10^{-4}$	3.20	$1.617x10^{-4}$	$1.0667x10^{6}$
Umuovo Eluelu OLD Umuahia	79.5	7.0	72.5	2915	$3.43x10^{-4}$	23.1	$1.09x10^{-3}$	3.19	$2.175x10^{-4}$	$1.0620x10^{5}$
	>244	125	119	3602.5	$2.775x10^{-4}$	379.6	$8.854x10^{-4}$	3.19	$3.57x10^{-4}$	$1.063305x10^{6}$
Umuobutu old-Umuahia	41.9	8.2	33.7	4180	$2.392x10^{-4}$	107.2	$7.607x10^{-4}$	3.18	$1.011x10^{-4}$	$1.060336x10^{6}$
Ohobo Okwulaga	5.9	2.3	3.6	7610	$1.314x10^{-4}$	11.8	$4.31x10^{-3}$	3.28	$1.08x10^{-9}$	$1.092592x10^{6}$
	73.3	73.3	>50	8400	$1.19x10^{-4}$	161.5	$3.845x10^{-4}$	3.23	$1.5x10^{-4}$	$1.076666x10^{6}$
World Bank Housing	80.4	21.4	59	6000	$1.666x10^{-4}$	197.7	5.583x10-4	3.35	$1.77x10^{-4}$	$1.116949x10^{6}$
Agbama	19.9	1.4	18.5	2626.7	$3.807x10^{-4}$	59.9	$1.23x10^{-3}$	3.24	$5.55x10^{-5}$	$1.079279x10^{6}$
	179	58.3	120.7	7110	1.407x10	391.1	$4.556x10^{-3}$	3.24	$3.621x10^{-4}$	$1.096658x10^{6}$
Okwu	52.1	3.6	39.5	7685	$1.301x10^{-4}$	93.6	$3.08x10^{-3}$	2.37	$1.185x10^{4}$	$7.89873x10^{5}$
	>131	131	>50	1130	$8.849x10^{-4}$	118.5	$2.1x10^{-3}$	2.37	$1.5x10^{-4}$	$7.9000x1010^{5}$
Itaja Olokoro	92.4	1.5	90.9	4347.5	$2.3x10^{-4}$	216.3	$5.474x10^{-4}$	2.38	$2.97x10^{-5}$	$7.28228x10^{6}$
Umuajiji	11	2.6	8.4	3870	$2.583x10^{-4}$	15.5	$4.78x10^{-4}$	1.85	$4.65x10^{-5}$	$3.3333x10^{5}$
	17.9	2.6	15.3	2121.5	$4.713x10^{-4}$	28.3	$8.72x10^{-4}$	1.85	$8.49x10^{-5}$	$3.3333x10^{5}$
Amuzu-Oro	77.8	21.8	56	3585	$2.789x10^{-4}$	106.4	$5.30x10^{-4}$	1.90	$1.68x10^{-4}$	$6.3333x10^{5}$
Umudike	111	44.7	66.3	1115	$8.968x10^{-4}$	189.6	$2.56x10^{-3}$	2.86	$1.989x10^{-4}$	$9.5324x10^{5}$

S/N	Location	East	North	D	R	A	S	T (%)	I	C (gpd/ft^2)
1	Avor Ntigha			260	10.73	sandy	sands	2 - 4	sands	95.47
2	Okwu	7.514898	5.452551	83.4	10.73	sandy	sands	0 - 2	sands	58.16
3	Itaja Olokoro	7.523061	5.47051	92.4	10.73	sandy	sands	0 - 2	sands	58.41
4	Umudike	7.549728	5.475136	136	10.73	shaly	clay l	0 -2	sandstone	70.19
5	Mgbarakuma	7.434354	5.470238	82.3	10.73	sands	sands	2 - 4	sands	95.47
6	Nsirimo	7.403061	5.464252	139	10.73	sandy	sands	0 - 2	sands	169.6
7	Umunwanwa	7.408231	5.491463	84.8	10.73	shaly	clay l	0 - 2	sandstone	58.41
8	Naibe	7.412313	5.514592	102	10.73	shaly	clay l	0 - 2	sandstone	58.41
9	Deeperlife	7.460748	5.520578	133	10.73	sandy	sands	0 - 2	sands	82.22
10	Ehume	7.442517	5.549966	63.1	10.73	sandy	sands	0 - 2	sands	58.16
11	Amuzu	7.538571	5.520578	77.8	10.73	sandy	sands	2 - 4	sands	46.63
12	Okwulaga	7.496122	5.506156	56.7	10.73	sandy	sands	2 - 4	sands	80.50
13	Umuajiji	7.526054	5.542075	119	10.73	shaly	clay l	2 - 4	limestone	45.40
14	Agbama	7.510272	5.490646	179	10.73	sandy	sands	0 - 2	sands	79.52
15	Umuawalocha	7.472449	5.558673	113	10.73	sandy	sands	2 - 4	sands	78.53
16	Umuobutu	7.483061	5.48602	82.9	10.73	sandy	sands	2 - 4	sands	78.04
17	Umuovo	7.472993	5.475408	125	10.73	sandy	sands	2 - 4	sands	78.29
18	Amachara	7.462381	5.536905	65.4	10.73	shaly	clay l	0 -2	limestone	83.44
19	WorldBank	7.498571	5.512687	143	10.73	sandy	sands	2 - 4	sands	82.22
20	Umuokwom	7.460476	5.525884	176	10.73	sandy	sands	2 - 4	sands	82.22

S/N	Location	Height (ft)	Curve Type Characteristics
1	AVOR NTIGHA	529	K: $P_1<P_2>P_3$
2	NSIRIMO	450	KHK: $P_1<P_2>P_3<P_4>P_5$
3	UMUNWANWA	398	K: $P_1<P_2>P_3$
4	OGBODINAIBE	352	Q: $P_1>P_2>P_3$
5	EHUME	362	HK: $P_1>P_2<P_3>P_4$
6	MGBARAKUMA	530	HK: $P_1>P_2<P_3>P_4$
7	UMUOKWOM OHIYA	565	HK: $P_1>P_2<P_3>P_4$
8	DEPPER LIFE CAMP	376	HKH: $P_1>P_2<P_3>P_4<P_5$
9	AMACHARA	460	Q: $P_1>P_2>P_3$
10	UMUAWA ALAOCHA	553	K: $P_1<P_2>P_3$
11	UMUOVO ELUELU OLD UMUAHIA	575	KKH: $P_1<P_2>P_3<P_4>P_5<P_6$
12	UMUOBUTU OLD UMUAHIA	517	K: $P_1<P_2>P_3$
13	OHOBO OKWULAGA	533	HH: $P_1>P_2<P_3>P_4<P_5$
14	WORLD BANK HOUSING ESTATE	545	K: $P_1<P_2>P_3$
15	AGBAMA		HK: $P_1>P_2<P_3>P_4$
16	OKWU		KH: $P_1<P_2>P_3<P_4$
17	ITAJA OLOKORO		KK: $P_1<P_2>P_3$
18	UMUAJIJI	566	HKH: $P_1>P_2<P_3>P_4<P_5>P_6$
19	AMUZU-ORO	622	KK: $P_1<P_2>P_3<P_4>P_5$
20	UMUDIKE	487	KK: $P_1<P_2>P_3<P_4>P_5$