HYDROGEOPHYSICAL AND AQUIFER PROTECTIVE CAPACITY STUDIES OF ENUGU AND ENVIRONS SOUTHEASTERN NIGERIA.

BY

UDEH, MOSES HARRY

B. TECH (HONS) UPH

REG NO: 20184144038

A

THESIS

SUBMITTED TO

THE DEPARTMENT OF GEOLOGY

SCHOOL OF PHYSICAL SCIENCES

FEDERAL UNIVERSITY OF TECHNOLOGY OWERRI

SUPERVISORS: PROF. A. I OPARA

DR. A.A ONUNKWO

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE, M.Sc. IN HYDROGEOLOGY

AUGUST, 2022.

CERTIFICATION

his is to certify that this work "Hydrogeophysical and Aquifer Protective Capacity Studies of Enugu ıd Environs Southeastern Nigeria" was carried out by Udeh Moses Harry with Registration Number 0184144038 in partial fulfillment for the award of the degree of M.Sc. in Hydrogeology in the ›epartment of Geology of Federal University of Technology, Owerri.

.... | ...... 14/6/24 ......

'rof. A.I. Opara
Supervisor) | Date

.... | .... 14-06-2024 ....

Dr. A.A Onunkwo
(Co-Supervisor) | Date

.... | ....

Dr. D.O Ikoro
(Head of Department) | Date

.... | ....

Prof. C. E Ogukwe
(Dean, School of Physical Sciences) | Date

.... | ....

Prof. B. O Esonu
(Dean, Postgraduate School) | Date

.... | ....

External Examiner | Date

DEDICATION

This thesis is dedicated to God Almighty who is the Author and Finisher of my life.

ACKNOWLEDGEMENT

My sincere and heartfelt gratitude goes to God almighty for his love, guidance and unmerited favour towards my life. I express my profound gratitude to my Supervisors, Prof. A.I. Opara and Dr. A.A Onunkwo for their suggestions and assistance and encouragement rendered throughout the period of this work, thank you Sirs, God bless you.

My special thanks to the present H.O.D of geology department Dr. D.O Ikoro whose dynamic and excellent leadership spurred my spirit again when I was down spirited. I owe my sincere appreciation to my wife Victoria "Omalicham" and also to my family, Princeken, Anthony, Darlington, Onyinye and Chinenye for their prayers and making me stands strong.

Also grateful and indebted to my friends, I.C. Oli , C.I Eze, C.P Amaliri, I. Osi-Okeke , C. Onwubu, C. Azu, K.P. Owhorji, K.M. Lawson (Odenigbo 1) for vetting the work and others too numerous to mention who supported me with all the needed information necessary to having a finished work, remain bless in Jesus name. Amen.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Hydrogeophysical Studies of Enugu and environs were carried out using geophysical and hydrogeological method. This study was designed to evaluate the aquifer system of the study area as well its protective capacity and vulnerability by applying the models (Lc and IEC, GOD and DRASTIC), and also to evaluate soil corrosivity of the area by utilizing the topsoil (first layer) resistivity values obtained from the interpreted VES results. A total of eighty-five (85) vertical electrical sounding points were made in the study area that has three to nine geo-electric layers using the digital ABEM SAS 4000 model Terrameter with its accessories. The Schlumberger electrode configuration was adopted for data acquisition with half current electrode separation (AB/2) of 500m and half potential electrode separation (MN/2) of 55m. Nineteen (19) parametric soundings were carried out near existing boreholes where pumping data was available for correlative purposes and to constrain model predicting parameters. The aquifer resistivity of the area ranged from a value of 2.8 Ωm to 88745.0 Ωm, with a mean value of 5434.6 Ωm. The estimation of the characteristics of the aquifer hydraulic using the new set of model equations showed that hydraulic conductivity values varied between 1.05m/day and 34.06m/day with a mean value of 5.59m/day, while transmissivity values varied between 25.70 m^2/day and 2767.81 m^2/day with a mean value of 500.05 m^2/day. Generally, the groundwater potentials of the area are classified into three categories: moderate, high, and very high potential zones. The multiple geophysical models were used together to develop maps of hydraulic parameters. The obtained GOD, and DRASTIC models were together used for the production of the vulnerability map. Results based on the GOD model clearly show that about 60% of the study area is within the class of extremely low groundwater vulnerability zones, 33% is within the class of low vulnerability zones, and 7% of the area is within the class of moderate vulnerability zone. Also, results based on the DRASTIC model revealed that about 31% of the study area is within the low class of vulnerability zones, 67% is within the class of moderate zones, while 2% is within the high class of vulnerability zones. The evaluated soil corrossivity of the area showed that 78% of the area is practically non-corrosive (PNC) and can be rated as moderately competent to highly competent strata; 13% of the area is said to be slightly corrosive, which is rated as moderately competent to incompent strata; and the remaining 9% is moderately and very strongly corrosive, which is rated as an incompenet material to construct on. The aquifer protective capacity of the study area were determined using longitudinal conductance technique. The protective capacity of the area classified into zone of excellent, very good, good, moderate, weak and poor protective capacity rating. Similarly, Integrated Electrical Conductivity technique was also used to determine the protective capacity of the area, the result indicates that the aquifer system in the study area has low protective capacity and the areas are susceptible to contamination based on the IEC technique.

Keywords: Vertical Electrical Sounding, Pumping Test, Aquifer Hydraulics, Vulnerability, Soil Corrossivity.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

In the world today, water is a universal solvent whose main sources include springs, rivers, wells and other numerous freshwater bodies. These sources provide water for drinking, industrial, domestic and agricultural purposes. The geophysical surveys provide a comprehensive knowledge of geology and structure of the subsurface. Electrical resistivity method has been successfully used to delineate and exploit groundwater. It is also provides extensive details on the groundwater reservoirs and hydrogeological settings (George, Emah, and Ekong (2015); Ibuot, Akpabio and George (2013); Obiora, Ajala, and Ibuot (2015)). Hydrogeology includes the interrelationships between geological materials and water processes, it is a branch of geology that deals with the distribution and movement of groundwater generally in aquifers in the soil and rocks of the Earth's crust. Hydrogeology can be defined as the study of groundwater at a particular importance given to each geological formation for its evaluation. Groundwater is water located beneath the ground surface on the cracks and spaces of soil, sand, and rocks where it is stored and moves gradually through geologic formations (Nwosu and Iwuoha, 2018). Groundwater is a renewable source, with over 90% of the liquid freshwater supplies underground as groundwater deposit (Balsubramanian, 2017). It is of major importance to humanity in the world today, because it is the largest drinkable water reservoir and major supply sources in regions where humans live. Water is found underground in fractured and porous rock strata which is aquifers, and soil. On the surface it appears as springs and streams. The upper level of the surface of saturated zone is called the water table, between the water table and the land surface is called unsaturated zone or vadose zone. In unsaturated zone, moisture descends to the water table to recharge the groundwater. Groundwater said to be Meteoric in origin, this implies is originating from the surface and atmosphere (Offodile, 2014). A small percentage from underground source is known to enter the hydrologic cycle and is describe as Juvenile. A Juvenile water includes water of magmatic and volcanic sources, which is water from the interior of the earth. In the Hydrological cycle, groundwater occurs when surface water from rainfall flows into the earth and fills the pores of the soil and rock fragments (Offodile, 2014; Harter, 2003; Okoli, Johnson and Ejikeme (2017)). Hydrological cycle is the continuous movement of water below and on the earth's surface and between the atmosphere and the earth. The hydrological cycle is governed by the processes of evaporation, transpiration, and condensation of water vapor in the atmosphere, which leads to precipitation and the subsequent movement of surface water and groundwater on earth.

Groundwater occurs in sub-surface geological formations as aquifers and aquitard. An aquifer is a geological formation that is capable of yielding economic quantities of water to man through wells. It must be porous, permeable, and saturated. An aquitard is a saturated geological unit that is not permeable enough to transmit water to Productive well, occur in when unfractured. (Ward and Robinson, 2000., Freeze and Cherry, 1979).

Groundwater exploration is the investigation of underground formations to understand the hydrologic cycle, know the groundwater quality, and identify the nature, number and type of aquifers. Groundwater exploration is placing increasing consideration as supply demand increases, and different geological factors influence the occurrence, storage and distribution of the groundwater. Chukwuma, Orakwe, Anizoba, Amaefule, Odoh and Nzediegwu (2015) Stated that exploration and stratigraphy analysis are a few reliable ways of determining the location and characteristics of an aquifer. The failure in most groundwater development projects has been tied to insufficient information of the groundwater characteristics of any given area; therefore, the use of geophysical surveys as a determinant of success development of groundwater resources was reaffirmed. In groundwater exploration, vertical electrical sounding (VES) adopting Schlumberger electrode configuration is a common geophysical technique (Ezeh and Ugwu, 2010; Olawuyi and Abolarin, 2013; George, Obianwu and Udofia (2011); Ibuot, et al. (2013); Obiora, et al. (2015); Onyekuru, Akiang, Ohenhen and Ibeneme (2019); Oli, Ahairakwem, Opara, Ekwe, Osi-Okeke, Urom, Udeh, and Ezennubia (2020)). The resistivity method is designed to measure the potential surface differences due to the current flow inside the ground. Given that the mechanisms that control fluid flow and electrical current and conduction are generally controlled by the same physical parameters and lithological attributes, the hydraulic and electrical conductivities are interdependent (George et al . (2015). Using this resistivity method, which is also aided by a modern algorithm, is a very useful tool for identifying areas of maximum aquifer thickness and serves as a good predictive tool for estimating the depth of a borehole (Mogaji, et al. 2011; Draskovic, Mayar, and Pattantyus, (1995; Lashkarripour, 2003; Omosuyi, Ojo and Olorunfemi (2008); Lenkey, Hamori and Mihalffy (2005)).

Hydraulic conductivity and depth of the aquifer are fundamental features which characterize hydrology of the subsurface. As a consequence, many research techniques are widely used to estimate the spatial distribution of hydraulic parameters such as hydraulic conductivity, transmissivity and depth of the aquifer (Amos-Uhegbu, 2013). According to Opara, Inyang, Onyekuru, Emberga, Ekwe and Eke (2015); Ekwe, Onuoha and Onu (2006); Mbazi and Onuoha, (1998); Igbokwe, Okwueze and Okereke (2006); Ekwe and Opara, (2012); and Opara, Onu and Okereafor (2012), over the years many scholars have successfully estimated aquifer hydraulic characteristics from Dar-Zarrouk parameters from surface electrical resistivity sounding data in many parts of Southeastern Nigeria. Therefore, the aquifer hydraulic characteristics are best determined on the basis of data obtained from the pumping test, and these characteristics are very important in predicting the natural flow of water through an aquifer and its reaction to the extraction of fluids (Opara, et al. (2015). Pumping test is a veritable scientific means of determining the immediate and perennial yield or capacity of a drilled well. The principle of pumping test involves applying stress to an aquifer by extracting groundwater from a pumping well and measuring the response of the aquifer to that stress by monitoring the drain as a function of time. These measurements above are integrated into an appropriate well-flow equation for estimating the hydraulic parameters of the aquifer (Venkatarao, Kalpana and Srinivasa Rao (2015). Groundwater is the main source of water supply in the study area, and the hydrological conditions supporting groundwater supply in the area are mainly rainfall and thick aquifer formation underlying the region (Onwe, Akudinobi, and Aghamelu (2016). The groundwater supply is primarily from precipitating ambient moisture, which has percolated down into the layers of soil and subsoil. This is only possible when the rocks in the saturation zone are sufficiently permeable to convey enough water to wells, and streams (Daniel, Adeolu and Johnson (2015). Groundwater has been identified as a major source of water supply due to its extensive storage capacity and relatively low susceptibility to pollution compared to surface water (USEPA, 1985). Nevertheless, there are significant sources of diffuse and point source pollution of groundwater from land use activities especially mining and agricultural practices, and Intrusion of these pollutants into groundwater modifies the quality of the water and reduces its portability. Hence, the need to evaluate the aquifer vulnerability of the study area is thus extremely valuable.

The vulnerability studies are seen as good approaches to developing good knowledge to avoid environmental degradation (Mendoza and Barmen 2006; Al- Mallah and Al- Qurnawi, 2018). The term vulnerability is used to explain the degree to which human or environmental systems are susceptible to harm due to disruption or stress and may be recognized for a particular system, hazard or group of hazards (Popescu, Gardin, Brouye're and Dassargues (2008; Oroji, 2018). An aquifer vulnerability defines as sensitivity of groundwater quality to an imposed contaminant load, which is defined by the intrinsic characteristics of the aquifer (Duijvenbooden and Waegeningh, 1987). The parameters affecting vulnerability are mostly permeability and thickness of each protective layer. For unconsolidated sediments, the permeability is strongly linked to the content of clay which can be indirectly deduced from resistivity methods (Mogaji, Adiat and Oladapo (2011). According to Oroji (2018), groundwater vulnerability is considered an intrinsic property of groundwater and can be characterized as the possibility of percolating and spreading contaminants from the ground surface into the groundwater system. An assessment of an aquifer's vulnerability to pollution is an important element of any groundwater quality protection plan and can help to develop practical guidelines and policies to minimize groundwater pollution and thus enable sustainable management of the resource (Hashimoto, Stedinger and Loucks (1982). The principle of vulnerability assessment is based on the assumption that the system, which includes soil, rock and groundwater, may provide a level of defense against groundwater contamination through 'natural attenuation (Opara, et al. (2015); Inyang and Opara, 2017). Groundwater vulnerability assessment is carried out on the idea that the aquifer does not have the same characteristics at all locations and that certain specific land areas are more vulnerable to quality and quantity deterioration (Gogu and Dassargeus, 2000). Hence, it also delineates the areas that are more vulnerable or prone to pollution and can enable scientists to remediate (if contaminated), protect and avoid (if highly sensitive) and policy makers to manage the resource in a sustainable manner in order to ensure that this precious resource is used sustainably, thereby contributing to sustainability, which is now the central goal of all of the resources economy of the world (Gupta, 2014). The concept was first introduced in France to raise public awareness of groundwater contamination by the late 1960's (Vrba and Zaporozec, 1994). The aquifer vulnerability is of two forms. The first is intrinsic vulnerability which is due to the geology of the aquifer like that of the clay layer thickness, overlaying media, thickness of lateritic layer (Gupta, 2014). And second one is, specific vulnerability, acquired for a particular contaminant (Madl-Szonyi and Fu¨ le, 1998) or some other integrated sources coupled with the integrated vulnerability (Vrba and Zoporozec, 1994). Aquifer vulnerability provides a detailed understanding of environmental assessment of the waste's economic impacts in highly vulnerable areas. They also provide valuable information for decision-making and water resource management, monitoring and protecting the quality of groundwater (Hamamin, (2011); Al Mallah and Al Qurnawi, 2018). The vulnerability maps have been considered important for groundwater safety and a valuable tool in environmental management resources (Daly and Warren 1998).

Many criteria for assessing groundwater vulnerability have been enhanced and are divided into three main categories; a. overly and index methods, b. Methods using process-based simulation models, c. Statistical methods (Tesoriero, Inkpen and Voss 1998). These methods have been used by different scientists until now, but the decision of the technique depends to a large extent on the data available and also on the type of aquifer being studied and one of the most significant and frequently used methods for assessing aquifer vulnerability is IEC, DRASTIC and GOD. DRASTIC is a relatively simple indexing method developed in the USA (Aller, Bennet, Lehr and Petty (1985 and 1987) as a convenient way of identifying the risk of aquifer contamination due to surface polluta1nt sources (Abbasi, Mohammadi, Kholghi, and Howard (2013)). It is an Index model designed and considers seven physical characteristics of the system and integrates them to provide a measure of an aquifer's vulnerability for different locations. The DRASTIC model rates the susceptibility of land units by combining information on depth to groundwater, impact of vadose zone, soils, recharge, hydraulic conductivity, topography (slope), and aquifer media to determine a groundwater sensitivity ranking (Inyang and Opara, 2017; Abbasi, et al. (2013); Opara, et al. (2015)). The GOD method is an analytical model that established to assess the vulnerability of aquifer pollution in Great Britain (Oroji, 2018). It was established by Foster in 1987 for evaluation of aquifer vulnerability, and centered on three parameters, (G - Groundwater Confinement, O - Overlying Lithology, D - Depth to groundwater) across wide regions. The GOD index is divided into five classes; negligible (0-0.1), Low (0-0.3), moderate (0.3-0.5), high (0.5-0.7), and very high (0.7-1) (Foster, Hirata, Gomes, D'Elia, and Paris (2002); Akpan, Ebong, and Emeka (2015)).

Many researchers have looked into the significance of soil potential as a corrosive environment over the years. For soil, corrosivity can be described as the ability of a soil to corrode a material buried in it. Agunloye, (1984), states that the corrosivity of soil can be influenced by its mineralogy and/or structure. Soil corrosive potential may modify by the geology of the area where the soil is formed, as well as anthropogenic activities.

This present study is designed to evaluate the aquifer system of Enugu and Environs using Surface Resistivity Method. It assesses the nature of the aquifers, their distribution, characteristics and thus, provides data to assess the productivity of the aquifers. This study is also geared towards the assessing the vulnerability indices of these aquifers in order to identify areas prone to pollution by applying DRASTIC and GOD Models and to evaluate the soil corrossivity of the area using resistivity data to map the zones that were non-corrosive to bury utilities/pipes.

1.2 Statement of Problem

Groundwater constitutes the only reliable water supply in the study area, it is very necessary for all basic human needs, including food, potable water, sanitation, health, energy and shelter. Some of the wells drilled in parts of the area have become unproductive this is due to lack of improper geophysical investigation and lack of appropriate expertise. In addition, pumping test have proved to be very expensive and time consuming, therefore there is a need to introduce alternative and dependable methods; less invasive and less expensive way of determining aquifer hydraulic parameters. Furthermore, because of the growing population in the area, more wastes, which are potential contaminants are being generated by the increasing population, these waste being deposited into landfills and surface dumps. The location of these dumps was chosen for ease and accessibility to sources of waste rather than for environmental and hydrogeological considerations, posed a serious uncertainty to the safety of the groundwater resource in the area and resulting in potential groundwater pollution and contamination. Intrusion of these pollutants into groundwater modifies the quality of the water and reduces its portability, and this polluted when consumed by humans most times result into illness. Given the above, it has become necessary to conduct a thorough geophysical and hydrogeological assessment of the region to enhance understanding of the hydraulic characteristics of the aquifer as well as its vulnerability. This is to reduce the risks associated with management of the groundwater in the area.

1.3 Aim and Objectives

The aim of this research work is to assess the aquifer system of Enugu and environs and recognized the sensitive area against pollution using DRASTIC and GOD Models. In achieving this aim, the following objectives are set out;

1. To determine the aquifer geometric parameters such as resistivity, conductivity, thickness, depth and Transverse resistance across the study area using vertical electrical sounding method.
2. To establish Iso-resistivity model of the area.
3. To estimate the Hydraulic conductivity of the area using Pumping test and geophysical data.
4. To estimate aquifer vulnerability of the study area using DRASTIC and GOD Models.
5. To estimate the soil corrossivity of the study area from vertical electrical sounding data.
6. To estimate the aquifer protective capacity of the area using Longitudinal conductance (Lc) and Integrated Electrical Conductivity (IEC).

1.4 Justification of the Study

A deep understanding of the complexity of its processes is absolutely essential for a proper assessment and management of groundwater resources. This study will only showcase how effective geoelectric methods can be, when applied in the estimation of aquifer hydraulic parameters and also provide useful information on the potential sites for groundwater development in the study area. This will help to assess the geoelectric parameters of the near-surface aquifers to near-surface contaminants and helps to provide much needed information that will help relevant authorities in effective water resource management strategies.

1.5 Scope of the Study

The scope of the study is to establish model used in estimating aquifer hydraulic parameters, to recognize the sensitive areas against pollution and identify the zones that were non-corrosive to bury utilities/pipes in Enugu and environs, Southeastern Nigeria.

CHAPTER TWO

LITERATURE REVIEW

2.1 Previous Work

Sedimentary basin of Nigeria comprises a Central and Eastern Southern portions stretching from the Atlantic to the River Benue, a middle portions in the basin of the River Niger and River Benue and the Northern Portions, one in the northwest the other in in the northeast (NWRI, 2012). The rocks are stratified formations of late Cretaceous to Recent and consist of siltstones, sandstone, shale, limestones, mudstones etc). Sedimentary basin is a low area in the earth crust of tectonic origin, where sediments accumulate. Generally, sedimentary basins have been shown to have a huge hydrological and hydrogeological prospects due to its unique porosity, permeability and hydraulic conductivity (Opara, et al. (2015); Ugada, Ibe, Akaolisa and Opara (2013); Okereke and Edet, (2002)

Vrba and Zaporozec, (1994) described groundwater vulnerability study has proved to be a veritable tool to delineating areas that are vulnerable to groundwater contamination and the concept was first introduce in France to raise public awareness of groundwater contamination in the late 1960's.

Tesoriero, Inkpen and Voss (1998) reviewed many criteria to conduct aquifer vulnerability studies, they include Overlay and index methods, Process based methods, and Statistical methods.

Adelana, Olasehinde, Bale, Vrbka, Edet and Goni (2008) generally described that Southeastern Nigeria falls in three broad Hydrogeological Groups which are; Lower, Middle and Upper Hydrogeological Groups.

Rahman, (2008) described DRASTIC is an index model designed to generate vulnerability ratings for different regions by combining several thematic layers.

Adeniji, Omonona, Obiora and Chukudebelu (2012) made use of resistivity method to conducted vulnerability studies combined with soil corrosivity and aquifer-protective capacity assessments with the aimed to delineate areas which are very susceptible to groundwater contamination from surface contaminants and subsurface soils which are corrosive to underground utility pipes.

Ezeh, Ugwu, Okonkwo and Okamkpa (2013), Made use of geoelectrical sounding and hydrogeological parameters to assess the aquifer productivity within Udi region, Southeastern Nigeria with the aim to correlate surface resistivity with hydrogeological parameter in order to reveal the groundwater potential of the area. Results revealed a strong correlation between borehole yield and aquifer resistivity (r 2 = 0.8).

Aweto and Akpoborie (2014) were able to estimate the transmissivity and hydraulic conductivity of Orerokpe, Western Niger Delta, Nigeria, using borehole and geolectric data.

Bayowa and Olayiwola, (2015) made use of Electrical Resistivity method to evaluate soil corrosivity and determined its Competence in Ladoke Akintola University.

Opara et al (2015) made use of geophysical sounding for the determination of aquifer hydraulic parameters and its Vulnerability in Ugep and Environs Southeastern Nigeria.

Okonkwo, Ezeh and Amoke (2016) Evaluated Groundwater Potential Status in Nkanu, Enugu State, Nigeria.

Onwe, et al (2016) made of hydrogeological data for estimation of Hydraulic Conductivity of the Ajali Sandstone in the Udi Area of South Eastern Nigeria.

Okeke, Ezeh and Okonkwo (2017) made use of geophysical sounding for the determination of Groundwater Prospect in Awgu and Environs, Enugu State, Southeastern Nigeria.

Okoli, et al. (2017), Delineated Groundwater Potential Zones in Enugu State using Remote Sensing and GIS Techniques.

Inyang, Opara, Ibechu, Nwachukwu, Eluwa, Amadi, Emberga, and Eke (2017), Evaluate the Vulnerability Indices of Aquifer in Ugep and Environs, Southeastern Nigeria. Using Resistivity Data

Oroji, (2018) made use of DRASTIC and GOD Models to assess the groundwater vulnerability of Asadabad plain, Balal Oroji.

Ejiogu, Opara, Nwosu, Nwofor, Onyema and Chinaka (2019), Estimated Aquifer Hydraulic Characteristics and its Vulnerability in Imo State and Environs, Southeasthern Nigeria using Electrical Conductivity Data

Ekwe, Opara, Okeugo, Azuoko, Nkitnam, Abraham, Chukwu and Mbaeyi (2020), established a graphical linear relationship between a set of pumping test data and vertical electrical sounding data and subsequently applied the relationship in determining aquifer parameters in areas where pumping test data were not available in parts of Afikpo Sub Basin, Southeastern Nigeria

Oli, et al. (2020), delineated water-bearing zones of Ezza and Ikwo areas and also assess its Protective Capacity.

Osi-Okeke, Opara, Oli, Udeh and Abiahu (2021), made use of Geo-sounding data for estimation of Aquifer Protective Capacity in Abakaliki/ Afikpo area and Environs, Southeastern Nigeria.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Hydrogeological Studies

3.1.1 Pumping Test Analysis

A total of nineteen (19) pumping test data were used in this study. The pumping test data used in this study were carried out by self and some were obtained during the yearly appropriation of water projects embarked on by the Federal Ministry of Water Resources (FMWA) through its executing agency; Anambra-Imo River Basin Development Authority (AIRBDA) in which I was part of the team. AIRBDA is a Federal Government Parastatal covering Southeastern region of Nigeria. Two (2) of the pumping test data were carried out at Comm. Sec Sch Olo and Akpugo-Eze, penetrating the Imo Shale, two (2) at Umuna-ndiagu and Iwollo penetrating the Nsukka Formation, six (6) in Amokwe, Abor, Obioma, Ihuonayia, Oghe and Nachi penetrating the Ajali Formation, two (2) at Winners Estate Trans-Ekulu and Phase 6 Winners Estate Trans-Ekulu, penetrating the Mamu Formation, two (2) at Obeagu Enugu and Ozalla, penetrating the Nkporo Shale Group, three (3 in Agbani, Nara and Ndiuno

Akpugo, penetrating the Awgu Shale Group, while the remaining two (2) at Umuoika Enuogu and Obodo-ebunabo, penetrating the Ezeaku Shale. Materials used for the work were; 2HP Submersible Pump, Water level Indicator (dip meter), Risers, Marine rope, Stop watch, Power source (Generator), Calibrated bucket and GPS Device.The pumping test data were evalutated using constant pumping rate discharge method. The pumping test rates were within 10 l/min – 91 l/min, and the time of pumping varies from 1 - 4 hrs. The principle of pumping test involves applying stress to an aquifer by extracting groundwater from a pumping well and measuring the response of the aquifer to that stress by monitoring the drain as a function of time. These measurements above are integrated into an appropriate well-flow equation for estimating the hydraulic parameters of the aquifer by employing procedures such as Cooper-Jacob's method (Venkatarao et al. 2015). Samples field pictures of pumping test at the study area are shown below in figure 3.1a and 3.1b.

3.1.2 Data Analysis of Pumping Test

Thereafter, the Cooper and Jacob solution model was utilized to estimate the aquifer-derived parameters (transmissivity and hydraulic conductivity). This was done by using a computer software (Aquifer Win32) plotting drawdown against their respective time data obtained in semi-log format during the pumping test exercise. The average pumping rate (Q) in meter cube per day (m^3/day) for the duration of the test and the slope (which is the change in drawdown over one logarithmic cycle(Δs) were estimated and then integrated into Cooper and Jacob well flow equation (for single well) (Freeze and cherry 1979; Cooper and Jacob, 1946) as described below for the computation of the transmissivity (Diloha 2018), while the hydraulic conductivity was calculated from the transmissivity and aquifer depth value, which is in this case assumed to be the length of the screen.

$$T = \frac{2.3\,Q}{4\pi\Delta S} \qquad (3.1)$$

T = Transmissivity in m²/day

Q = Discharge Rate in m³/day

ΔS = Change in drawdown over one logarithmic cycle

$$Sc = \frac{Q}{\Delta S} \tag{3.2}$$

Where Sc = Specific capacity in m²/day

Q = Discharge Rate in m³/day

ΔS = Change in drawdown over one logarithmic cycle

$$K = \frac{T}{b} \quad \text{(Freeze and cherry, 1979)} \tag{3.3}$$

Where K = Hydraulic conductivity in m/day, b = Aquifer thickness in m

T = Transmissivity in m²/day

Figure 3.1a: Field Picture of Pumping test at the area by Constant Rate Tests

Figure 3.1b: Field Pictures of Pumping test in the study area by Constant Rate Tests

3.2 Geophysical Studies

3.2.1 Data Acquisition

The electrical reistivity sounding was carried out using vertical electrical sounding by deploying the Schlumberger array technique. The locations of the sounding stations are shown in Figure 3.5a. During the field exercise the following materials and field equipment were used to gather the data; ABEM 4000 model Terrameter. This equipment displays apparent resistivity values digitally as computed by Ohm's law, this were used to acquire the resistivity readings alongside with battery (12V.5 DC, 60Ah Battery) used to boost the current supply by the terrameter. Other accessories to this equipment include one Garmin 12 Global Positioning System (GPS) used in acquiring the VES point coordinates;

measuring tape used in acquiring accurate electrode spacings; four metal electrodes used in transmitting the current supplied to the ground; four reel of cables used in transmitting the currents to the electrodes; four pieces of hammer for driving down of the electrodes to the ground were used for resistivity measurements.

A total of Eighty-Five (85) Vertical Electrical Sounding points were made in the study area with one parametric sounding performed at each of the wells where the pumping test had already been completed. The Schlumberger electrode configuration was adopted with a maximum current electrode separation (AB) of 1000m, the sounding points being geo-referenced using a GPS held by hand. The current and potential pairs of electrodes have a similar midpoint in the Schlumberger array but the distances between adjacent electrodes vary greatly. Theoretically, the resistivity (ρ) of a material is directly proportionally to the resistance (R) of the material to current flow. Thus;

$$\rho = KR \tag{3.4}$$

Where K is the Geometric factor and is obtained using the formular in equation (3.5) below:

$$K = \pi \left\{ \frac{\left[\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2 \right]}{MN} \right\} = \pi \left(\frac{a^2}{b} - \frac{b}{4} \right) \tag{3.5}$$

The profiles were taken for the purpose of regional correlation across the study area. The field data were converted to apparent resistivity values by multiplying with the Schlumberger geometric factor K (Keller and Frischnechk, 1979) as shown in equation (3.6) below;

$$\rho = \pi \left(\frac{a^2}{b} - \frac{b}{4} \right) R \tag{3.6}$$

Recall $\rho = KR$

Where R is the resistance

Moreover, the geometric factor K lies 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 milliamperes respectively and the distance of separations in meters, then the resistivity ρ is expressed in ohm-meter. Samples of field pictures of geophysical study at the study area are shown in figure 3.2a and 3.2b.

Figure 3.2a: Field Picture of Geophysical Study of the area using direct current resistivity Method.

Figure 3.2b: Field Picture of Geophysical Study of the area using direct current resistivity Method.

Figure 3.2b: Field Picture of Geophysical Study of the area using direct current resistivity Method.

3.2.2 Data Processing and Interpretation of Geoelectric Sounding

All raw field data were processed by using the appropriate constants and analyzed using the iterative / inversion method of IPI2Win computer software to generate the layer parameters. The apparent resistivity field values were then plotted against the half current electrode separation to generate geo-electric curves. An initially created field curve was compared with adjustable theoretical curve until a good match was obtained that yielded true apparent resistivity, depth, and thickness values. All the sounding curves are displayed on the appendix

3.2.3 Qualitative and Quantitative Analyses

The qualitative interpretation of the depth sounding curves was carried out based on distinctive geo-electric characteristics on the number of layers represented by the four types of the auxiliary curves (H, K, A, and Q). The quantitative evaluation of the depth sounding curves was conducted by employing the partial curve matching technique (Bhattacharya and Patra, 1968). To achieve this, the data from the VES is plotted on a transparent overlay. A standard two (2) layer master curve and four (4) auxiliary type curves (H, K, A, and Q) were used for the partial curve matching technique. 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 cure. Using iteration software known as WINRESIST, the results of the VES curves obtained from partial curve matching were then used to constrain computer interpretation. Invariably this reduces depth overestimation. The computer iteration results demonstrates the quantitative analysis for knowing the resistivity, thickness and depth. Generally, the apparent resistivity curve for a three-layer structure has one or four typical shapes determined by the vertical sequences of the resistivity of the layers. Theoretically, these curves (type A, type H, type K and type Q curves) are described below (Figure 3.3a-d).

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

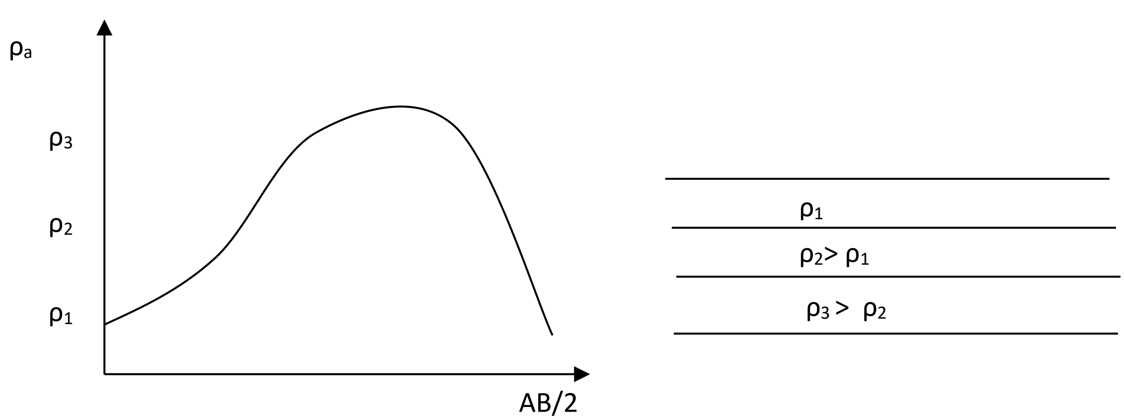


Fig 3.3a: K Type curve for a three-layered horizontal structure

b. H-type curve: this curve shows the opposite effect of the K-type curve; it falls to a minimum, then increases again, due to an intermediate layer that is a better conductor than the top and bottom layers (Lowrie, 1997).

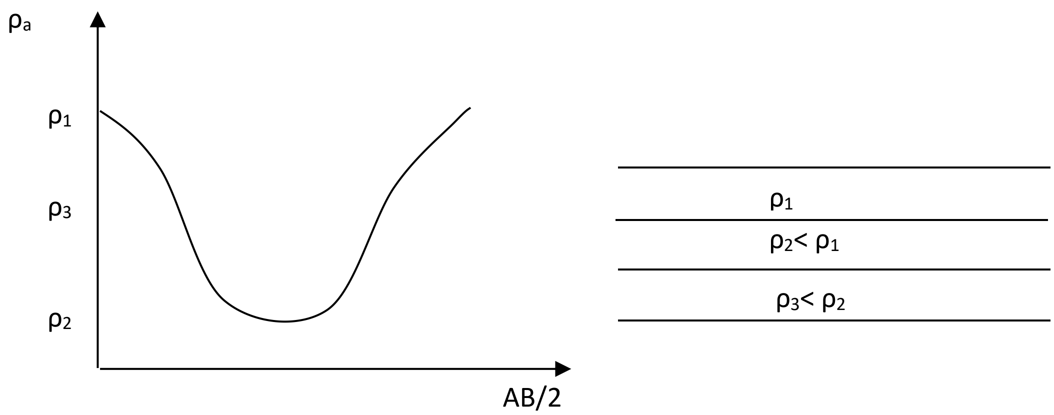


Fig 3.3b: H-type curve for a three- layered horizontal structure

c. A-type curve: In this curve type the apparent resistivity generally increases continuously with increasing electrode separation, indicating that the true resistivity increases with depth from layer to layer.

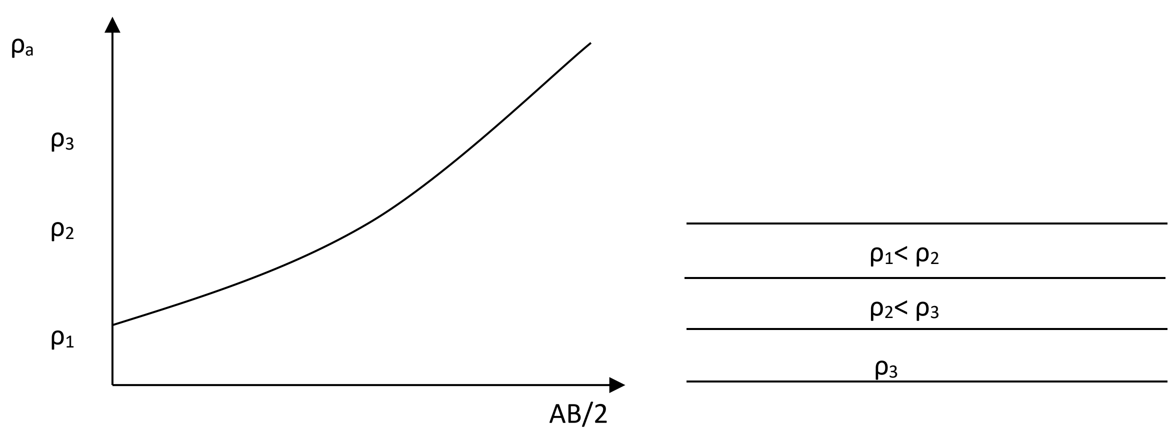


Fig 3.3c: A-type curve for a three-layered horizontal structure

d. **Q-type curve:** this curve type exhibit the opposite effect to A-type. It decreases continuously along with a progressive decrease of resistivity with depth.

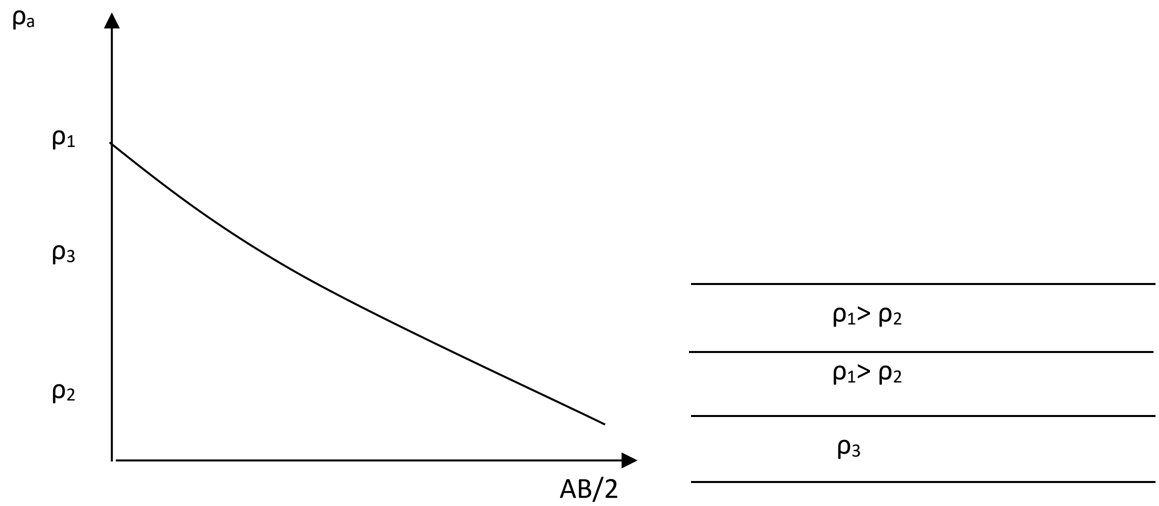


Fig 3.3d: Q-type curve for a three-layered horizontal structure.

e. **Others:** these include curves obtained from the combination of the types listed above. They include: AK, AQ, KQ, HQ, KH, QH,AH, etc

3.3 Estimation of Aquifer Hydraulic Parameters

The aquifer parameters (transmissivity and hydraulic conductivity) will be estimated from the interpreted vertical electrical sounding data, for all sounding points including those points without existing pumping test data. Therefore different methods can be used to achieve this, and they include;

a) Estimation from Niwas and Singhal. 1981

The estimation of aquifer hydraulic characteristics can be achieved by using parameters of transverse resistance and longitudinal conductance from Dar-Zarrock. Niwas and Singhal (1981) identified, on the one hand, an analytical relation between transmissivity and transverse resistance and, on the other, transmissivity and longitudinal conductance.

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

$$Q = KIA \tag{3.7}$$

And from ohm's law

$$J = \delta E \tag{3.8}$$

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 δ =electrical conductivity (inverse of resistivity),

Considering a prism of aquifer material having a unit cross-sectional area and thickness h, Niwas and Singhal (1981) combined equations (3.7) and (3.8) to get

$$T = K\delta R = \frac{KL}{\delta} \tag{3.9}$$

Where T = aquifer transmissivity,

R= Transverse resistance

L= longitudinal conductance

The quantitative interpretations of vertical electrical sounding data often result in geoelectric layers being generated. The information from these geoelectric layers helps improve the identification of aquifer depth and thickness layer parameters. The Dar-Zarrock parameters will be evaluated using these layer parameters thus obtained. . The transverse resistance (R) is the product of the aquifer apparent resistivity (ρ) and the aquifer thickness (h) while the longitudinal conductance is obtained by dividing the aquifer thickness (h) by the apparent resistivity (ρ) of the aquifer.

$$R = h\rho \qquad (3.10)$$

$$L = \frac{h}{\rho} \qquad (3.11)$$

In areas of similar geologic setting and water quality the product Kδ remains fairly constant (Niwas and Singhal, 1981). This allows the determination of transmissivity and its differences from place to place, including those areas without boreholes, to be made possible by using K values determined from boreholes where pumping test was conducted and δ values derived from the sounding interpretation for the aquifer at borehole locations.

b) Estimation from Heigold, Gilkeson, Cartwright and Reed (1979)

The Heigold et al model utilizes the relationship between hydraulic conductivity (K) obtained from other methods and aquifer resistance to generate an equation that enables us to estimate hydraulic conductivity using aquifer resistance. The equation is expressed as;

$K = 386.40 Rw^{-0.93283}$

(3.12)

Where K = hydraulic conductivity and *Rw* = the resistivity of the water saturated aquifer.

The aquifer transmissivity (Tr) can now be determined using the relation (Niwas and Singhal 1981):

$$Tt = k\delta T = ks/\delta = kh \qquad (3.13)$$

Where;

δ = the electrical conductivity (inverse of resistivity),

S = the longitudinal conductance

T = the transverse resistance.

c) Estimation using new generated model from the study area

Methodology of Estimation of New Generated Model

Enugu and environs which is the study area falls within the geological formation of Ezeaku Shale, Awgu Formation, Nkporo Shale Group, Mamu Formation, Ajali Formation, Nsukka Formation and Imo Shale Group respectively. It has an aquifer thickness which ranges approximately from 10m to 224m. This technique of estimating the new generated model targets on the understanding the ideas of Heigold model which is centered on the relation between hydraulic conductivity and aquifer resistivity, makes it feasible to create a new model that is more relevant to the geology of the study area. Therefore, the hydraulic conductivities acquired from the pumping tests data was plotted against aquifer resistivity values obtained from parametric soundings on the well locations in the different Formations.

Table 3.1: Hydraulic conductivity from pumping test and corresponding Aquifer resistivity from VES in different geologic Formations

Location	Aquifer Resistivity (Ohm-m)	Hydraulic Conductivity k (m/day) from pumping test	Geologic Formation
Comm. Sec Sch Olo	27.3	2.6396	Imo Shale
Akpugo-Eze	1250.0	2.7000	
Umuna-ndiagu,	326.0	6.4622	Nsukka

Iwollo	107.2	4.1242	
Amokwe	105.3	4.1099	Ajali
Abor	37.5	3.4953	
Obioma	9000.0	6.4617	
Ihuonayia	47.9	4.0194	
Oghe	192.6	4.4105	
Nachi	60.0	3.8461	
Winners Estate Trans-Ekulu	2.8	2.7486	Mamu
Phase 6 Trans-Ekulu	23.4	2.3418	
Obeagu Enugu	9.6	2.5696	Nkporo Shale
Ozalla	22.0	2.5479	
Ojiagu Agbani	42.0	1.6114	Awgu
Nara	60.0	1.5671	
Ndiuno Akpugo	733.0	1.1538	
Umuoika Enuogu	792.0	1.5796	Ezeaku
Obodo-ebunabo	498.0	1.5895	

Similarly, Heigold et al. (1979) used an equation given in equation (3.12) above to determine the hydraulic from resistivity data. However, due to complex nature of the geology of the study area, the above models under-predicted in most of the formations within the study area. By using the method adopted by Heigold et al. (1979), an equation of the type as shown in equation 3.14 was derived;

$$K=c\rho_w^{d} \qquad (3.14)$$

Where *c* and *d* are constants that depend on the geologic formations overlying the aquifer unit, ρw is the aquifer resistivity in ohm meter and *K* is the aquifer hydraulic conductivity in meter per day. These constants were integrated from the plots of aquifer hydraulic conductivity *K* from existing wells versus aquifer resistivity ρw from geo-electric soundings close to the existing wells. For the seven geologic formations, specific equations were therefore generated for each of the formation as shown in equation 3.15a – g. Analysis of the bivariate regression models gave a set of power equations (each for the seven different formations). From the seven geologic formations the following formation specific model equations were therefore generated as shown in Eq. 3.15a – g;

$\mathbf{K}_{\mathbf{imsh.}} = 2.5885Rw^{0.0059}$ (3.15a)

$\mathbf{K}_{\mathbf{nskfm.}} = 0.6245Rw^{0.4035}$ (3.15b)

$\mathbf{K}_{\mathbf{ajafm.}} = 2.545Rw^{0.1028}$ (3.15c)

$\mathbf{K}_{\mathbf{mafm.}} = 2.9645Rw^{-0.073}$ (3.15d)

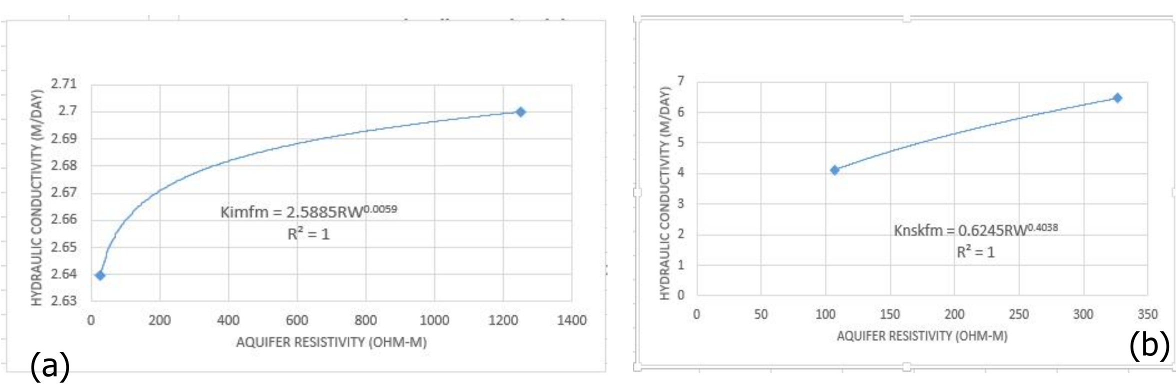
$\mathbf{K}_{\mathbf{nkpsh.}} = 2.6297Rw^{-0.01}$ (3.15e)

$\mathbf{K}_{\mathbf{awfm.}} = 2.4939Rw^{-0.117}$ \

(3.15f)

$\mathbf{K}_{\mathbf{ezesh.}} = 1.7282Rw^{-0.013}$ (3.15g)

The correlation coefficient was 1 in all cases which showed a positive relationship between the two parameters.



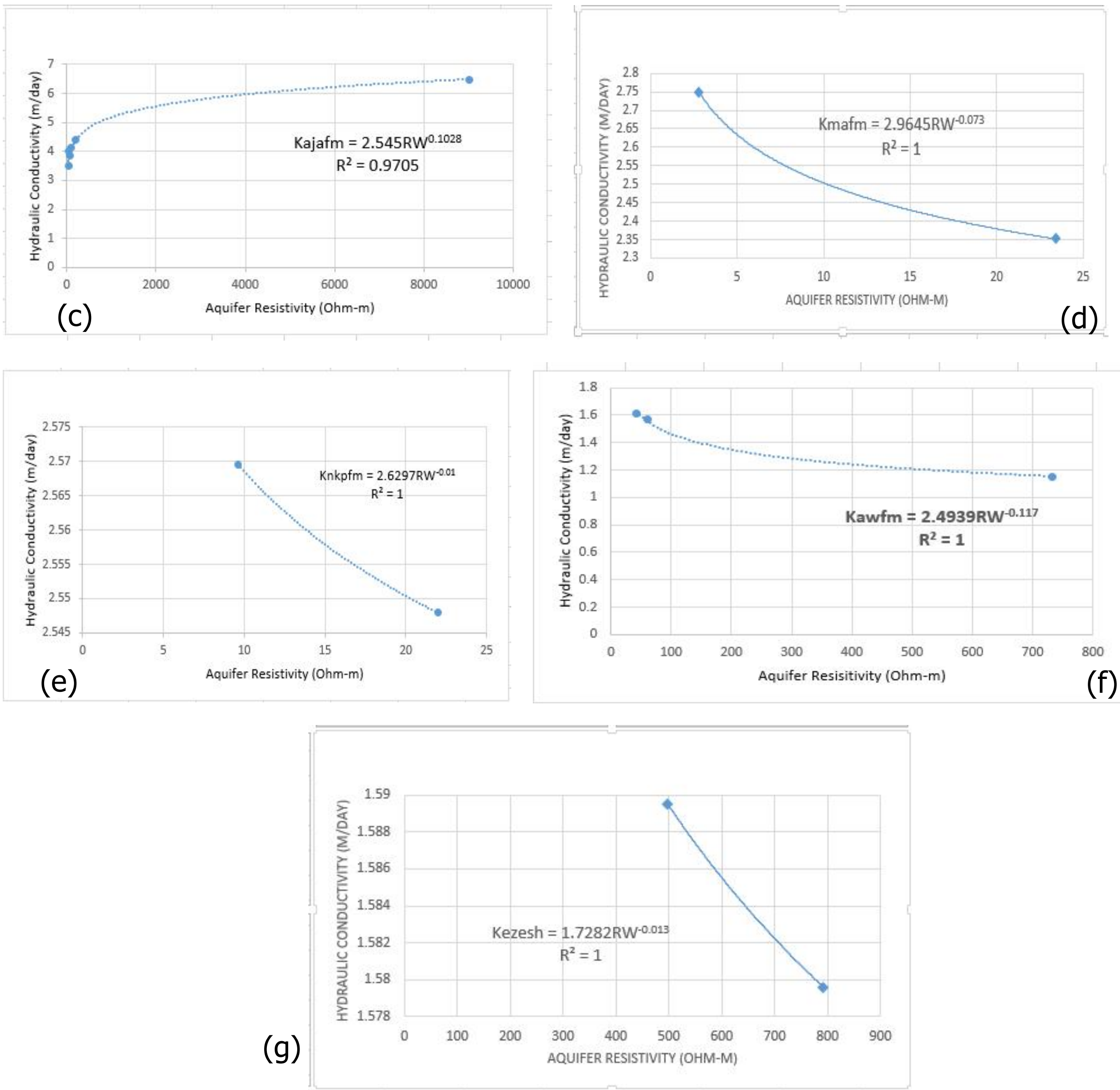


Fig. 3.4 Bivariate regression plots of aquifer hydraulic conductivity K derived from well data vs aquifer resistivity (ρw) for**; (a)** Imo SH **(b)** Nsukka Fm **(c)** Ajali Fm **(d)** Mamu Fm **(e)** Nkporo SH **(f)** Awgu and **(g)** Ezeaku SH

3.4 Assessment of Aquifer vulnerability from DRASTIC and GOD Models

Groundwater has been identified as a major source of water supply due to its extensive storage capacity and relatively low susceptibility to pollution compared to surface water (USEPA, 1985). Nevertheless, there are significant sources of diffuse and point source pollution of groundwater from land use activities especially mining and agricultural practices, and Intrusion of these pollutants into groundwater modifies the quality of the water and reduces its portability. Hence, the need to assess the aquifer vulnerability of the area is thus extremely valuable.

The quantitative expressions of aquifer protection against contaminants is known as vulnerability. An aquifer vulnerability defines as sensitivity of groundwater quality to an imposed contaminant load, which is defined by the intrinsic characteristics of the aquifer.

3.4.1 DRASTIC Model

Many criteria for assessing groundwater vulnerability have been enhanced and DRASTIC is one of the most commonly applied and well-known qualitative assessment model. DRASTIC is a relatively simple indexing method developed in the USA (Aller et al. 1985, 1987) as a convenient way of identifying the risk of aquifer contamination due to surface pollutant sources (Abbasi, et al. 2013). It is an Index model designed and considers seven physical characteristics of the system and integrates them to provide a measure of an aquifer's vulnerability for different locations. The model was designed by the US Environmental Protection Agency (EPA) to assess groundwater pollution potential for the entire United States. This model is based on the concept of the hydrogeological setting that is described 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 DRASTIC model rates the susceptibility of land units by consolidating information on depth to groundwater, impact of vadose zone, soils, recharge, hydraulic conductivity, topography (slope), and aquifer media to determine a groundwater sensitivity ranking (Abbasi, et al. 2013; Opara, et al. 2015; Inyang and Opara, 2017).

The name DRASTIC represents the use of the first letter of each hydrological component in calculating the vulnerability index, (D) depth to water, (R) net recharge, (A) aquifer media, (S) soil media, (T) topography, (I) impact of vadose zone media, and (C) hydraulic conductivity of the aquifer. These parameters control the groundwater contamination potential. The DRASTIC ranking system consists of three major parts: Range, Rating, and Weight: (Aller et al. 1987).

- **Range:** Each factor in DRASTIC assigned in ranges or significant media type which have an impact on pollution potential.
- **Rates:** Each range for each DRASTIC factor is assessed with respect to each other to estimate the relative significance of each range with respect to the impact on pollution potential. The rating for each DRASTIC factor is assigned a value between 1 and 10. The higher rating is the more significant on pollution potential.
- **Weights**: Each DRASTIC factor is assessed with respect to each other to estimate the relative importance of each factor. Each factor is assigned a relative weight ranging from 1 to 5. DRASTIC comprises of two weight classifications, one for normal (standard) conditions and the other for conditions with intense agricultural activity which represent as Pesticide Index (See Table 3.2). The weighted ratings are merged to obtain the DRASTIC index DI (AL-Qurnawi 2014), thus, it is expressed as:

$$DI = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw \quad (3.16)$$

Table 3.2: Weights of the factors in the DRASTIC Scenarios (Aller et al. 1987).

Factors	DRASTIC	
	Normal	Pesticides

D: depth to groundwater	5	5
R: net recharge	4	4
A: aquifer media	3	3
S: soil media	2	5
T: topography	1	3
I: impact of Vadose zone	5	5
C: hydraulic conductivity of the Aquife	3	2

where DI DRASTIC index, Dr rating for the depth to water table, Dw weights assigned to the depth to water table, Rr rating for ranges of aquifer recharge, Rw weight for the aquifer recharge, Ar ratings assigned to aquifer media, Aw weights assigned to aquifer media, Sr ratings for the soil media, Sw weights for soil media, Tr ranges for topographic (slop), Tw weights assigned to topography, Ir ratings assigned to vadose zone, Iw weights assigned to vadose zone, Cr ratings for hydraulic conductivity, Cw weights given to hydraulic conductivity.

Therefore, the Index is calculated according to the equation below

$$V = \sum_{i=1}^{7} (W_i \times R_i)$$ (Abbasi, et al. 2013) (3.17)

Where; V = the calculated index value,

Wi = the weighting coefficient for parameter i, and

Ri = the rating value for parameter i.

The weighting coefficients range from 1 to 5 (Table 3.2 above), depending on their relative importance, and D (depth to water) has a high weighting coefficient of 5. The estimated index provides a relative measure of possible vulnerability of the aquifer to contamination with higher index values showing greater vulnerability than lower values (Javadi and Mohammadi 2008; Abbasi, et al. 2013)

3.4.1.1 DRASTIC Model Parameters

Depth to water table (D)

This is the distance from the ground to the water table. It represents the material thickness through which water that infiltrates must travel before reaching the aquifer-saturated zone. The water table depth helps to control the degree of interactivity between the contaminants percolating and the materials (minerals, water) on the subsurface. Therefore, there is a greater probability to occur as the depth of water increases Areas with high water tables are vulnerable, this due to pollutants have short distances to travel before contacting the groundwater. That means the smaller the assigned rating the deeper the groundwater. The potential protection of aquifers generally increases with depth. Table 3.3a below present the assigned range of the Depth to water and the DRASTIC rating (Oroji, 2018).

Table 3.3a: Assigned rating for Depth to water table (m).

Range	0 -1.5	1.5-4.5	4.5-9	9-15	15-22	22-30	>30.4
Rating	10	9	7	5	3	2	1

Net Recharge(R)

This is the amount of water per unit area that penetrates the ground surface and enters the water table. The net recharge is the device which carries pollutants into the ground water. In particular during the rainy seasons, greater transport of contaminants is possible during periods of extreme rainfall. Areas with a high rate of recharge run a high risk of being polluted. The Net Recharge was taken as 12% of the average annual rainfall (Al Hallaq and Abu Elaish 2008). The annual rainfall in the study area is 2500mm per year and net recharge assumed for the entire locations is put at 300mm Table 3.3b below present the assigned rating for Net Recharge (Oroji, 2018).

Net Recharge can also be estimated using the formula:

Net Recharge = (Rainfall- Evaporation) x Recharge Rate.

Table 3.3b: Assigned rating for Net Recharge (mm)

Range	0-50	50-100	100-175	175-225	>225
Rating	1	3	6	8	9

Aquifer Media (A)

This refers to the potential area for water storage. The contaminant attenuation of aquifer depends on the amount and sorting of fine grains. In general, the greater the size of grain, the higher the permeability and lower the attenuation capacity; hence the greater the pollution potential. So a high rating score was given to coarse media as comparison to fine media. Table 3.3c below indicates the assigned DRASTIC rating for aquifer media parameter (Oroji, 2018).

Table 3.3c: assigned rating for aquifer media

Range	Massive Shale	Metamorphic/Iqn	W.Metamorphic/I	Glacia Till	Beded Sandstone, L.stone	Massive Sandstone	Massive Limestone	Sand and Gravel	Basalt	Karst Limestone
Rating	2	3	4	5	6	6	8	8	9	10

Soil Media (S)

This factor represents the highest and most weathered part of the ground. Soil characteristics affect the amount of recharge that infiltrates the ground surface, the amount of potential dispersion, contaminant purification cycle etc. Soil cover containing materials of fine grain size such as clay and silt, as well as a higher percentage of organic matter will retard the migration of contaminants. Coarse soil media rate high compared with fine soil media. Table 3.3d below indicates the assigned DRASTIC rating for soil media (Oroji, 2018).

Table 3.3d: assigned rating for soil media

Range	Thin or Absent, Gravel	Sand	Peat	Shrinking Clay	Sandy Loam	Loam	Silt Loam	Clay Loam
Rating	10	9	8	7	6	5	4	3

Topography (T)

This refers to the slope or steepness of the land surface. It specifies whether the runoff will remain on the surface to allow percolation of contaminants into the saturated zone. Area with low slope tends to retain water for longer periods and thus allows a greater infiltration of recharge of water and greater potential for contaminant migration. Flat areas have been given high rates, as run-off tends to be lower. Table 3.3e below present the assigned DRASTIC rating for Topographic parameter (Oroji, 2018).

Table 3.3e: Assigned rating for Topography (%)

Range	0-2	2-6	6-12	12-18	>18
Rating	10	9	5	3	1

Impact of Vadose Zone (I)

This refers to the ground portion found between the aquifer and the soil cover whereby the pores and joints are unsaturated. The effect of the vadose zone on the potential for aquifer contamination depends on its permeability and on media attenuation characteristics. Table 3.3f below present the assigned DRASTIC rating for Impact of vadose zone (Oroji, 2018).

Table 3.3f: Assigned rating for Impact of Vadose zone

Range	Confining Layer	Silt/Clay	Shale	Limestone	Sandstone	Beded L.stone, S.stone	Sand and Gravel W.Silt	Sand and Gravel	Basalt
Rating	1	3	3	3	6	6	6	8	9

Hydraulic Conductivity (C)

Aquifer hydraulic conductivity is the ability of the aquifer to transmit water. It relies on the material's intrinsic permeability, and the degree of saturation. Hydraulic conductivity controls the rate at which groundwater flows under a given gradient, and thus the migration and dispersion of contaminants. A highly conductive aquifer is vulnerable to contamination as a contamination plume can easily move through the aquifer. Table 3.3g below present the assigned DRASTIC rating for Hydraulic Conductivity (Oroji, 2018).

Table 3.3g: Assigned rating for Hydraulic Conductivity (m/day)

Range	0.04-4.1	4.1-12.3	12.3-28.7	28.7-41	41-82	>82
Rating	1	2	4	6	8	10

Table 3.4: Aquifer vulnerability rating based on the final DRASTIC index (Oroji, 2018).

DRASTIC Index (D_i)	**1-100**	**101-140**	**141-200**	**>200**
Vulnerability category	Low	Moderate	High	Very high

3.4.2 GOD Model

The GOD method is an analytical model that established to assess the vulnerability of aquifer pollution in Great Britain (Oroji, 2018). This model is characterized by a rapid evaluation of the aquifer vulnerability; it was established by Foster in 1987 for evaluating the vulnerability of the aquifer against the vertical infiltration of pollutants through the unsaturated zone, without considering their lateral migration in the saturated zone (Foster, et al. 2002). As DRASTIC, GOD is an overlay and index system built to map groundwater vulnerability centered on three parameters, across wide regions. The lowest level for aquifer vulnerability is linked to values <0.1 (negligible), while the highest level is attributed to values >0.7 (extreme), (Ghazavi and Ebrahimi, 2015). Values are assigned to each of the grades and then multiplied to give the final result. The assigned weight of each of the GOD parameters is 1 (Ghazavi and Ebrahimi, 2015). The parameters are;

1. G - Groundwater Confinement

2. O - Overlying Strata (Lithology)
3. D - Depth to groundwater table.

The letter G expresses the level of groundwater confinement and it measures the water circulating within the aquifers, the letter O describe the character of the materials overlying the aquifers with respect to the capacity to impede the flow of contaminants, while the letter D represent the depth to water table (Akpan, et al. 2015)

The GOD index which is used to evaluate and map the aquifer vulnerability caused by the pollution, it was estimated by multiplication of the influence of the three parameters using the equation (3.18) below.

$$\text{GOD Index} = Ci \times Ca \times Cd \quad (3.18)$$

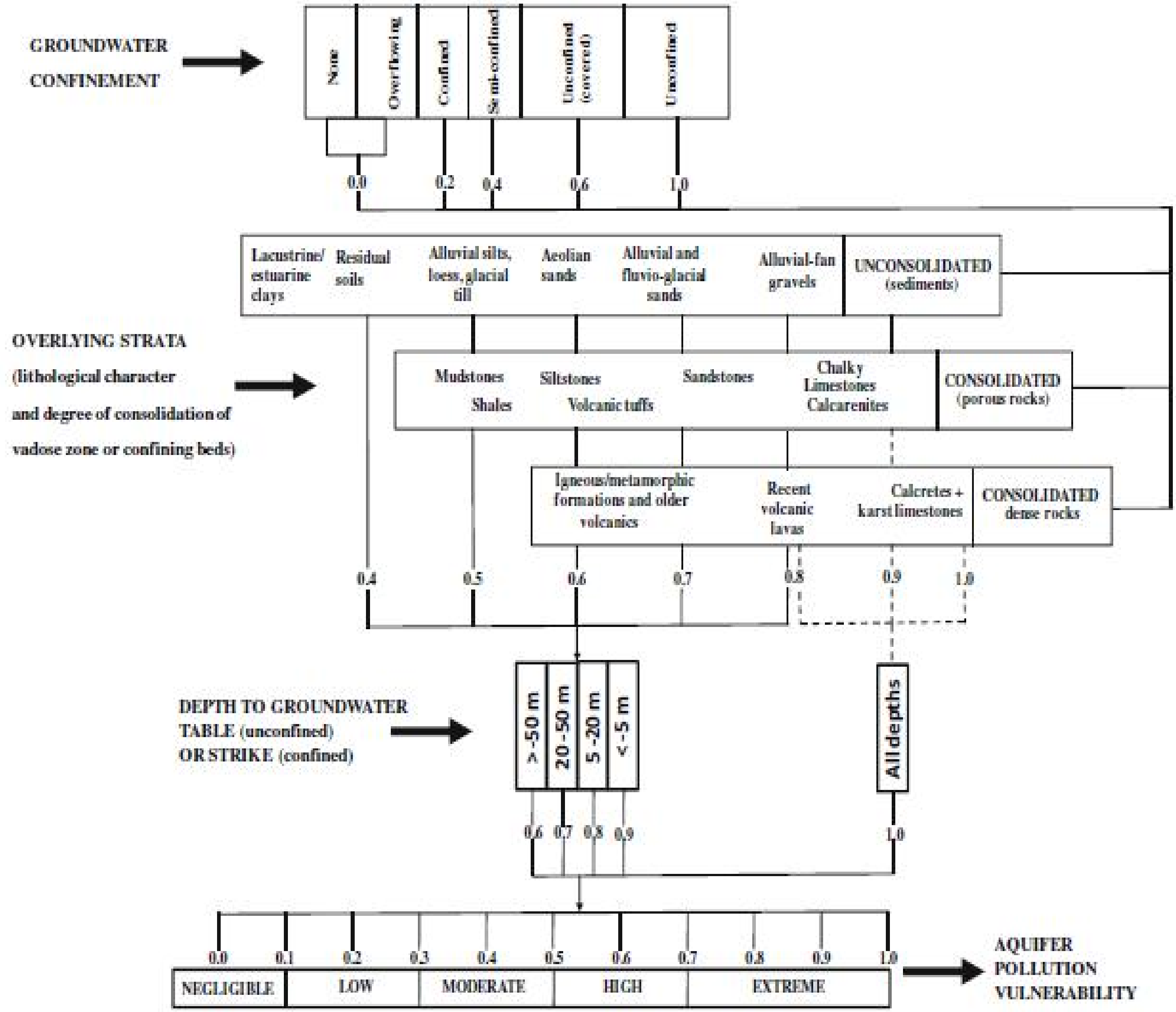
Where, Ca = the type of aquifer,

Ci = the Overlying strata and

Cd = the depth to water.

The GOD index can be divided into five classes; negligible (0-0.1), Low (0.1-0.3), moderate (0.3-0.5), high (0.5-0.7), and Extreme (0.7-1) (Foster et al. 2002). The higher number shows the greater relative pollution potential risk to another one. (See Table 3.5)

Table 3.5: The GOD vulnerability index for various geologic material (Adapted from Fosteri et al., 2002).



3.5 Evaluation of Soil Corrossivity of the study area.

Corrosivity described as the ability of a soil to corrode a material buried in it. Akintorinwa and Abiola (2011), stated that if the host soil medium is corrosive and aggressive, subterranean pipes are subject to corrosion and subsequent failure. Topsoil constitutes the layer within which normal civil engineering foundations and utility pipes are buried. To evaluate the corrosivity of the subsoils in the study area, the topsoil (first layer) resistitvity values obtained from the interpreted VES results were utilized. Topsoil resistivity values were classified in terms of soil corrosion based on (Baeckmann and Schwenk 1975; Agunloye 1984; Bayowa and Olayiwola, 2015) soil resistivity classification model and competent rating (See table 3.6 and 3.7).

Table 3.6: Soil Resistivity and its Corresponding Corrosivity based on Baeckmann and Schenwenk, 1975

S/N	Soil resistivity (Ωm)	Soil corrosivity
1	< 10	Very strongly corrosive (VSC)
2	10–60	Moderately corrosive (MC)
3	60–180	Slightly corrosive (SC)
4	>180	Practically non corrosive (PNC)

Table 3.7: Soil Competence Rating based on Bayowa and Olayiwola, 2015

S/N	Apparent Resistivity (Ωm)	Lithology	Competence Rating
1	<100	Clay	Incompetent
2	100-350	Sandy clay	Moderately Competent
3	350-750	Clayey sand	Competent
4	>750	Sand/Laterite/Bedrock	Highly Competent

3.6 Assessment of Aquifer Protective Capacity

Aquifer protective capacity is the capability of the overburden zone to decelerate and filter percolating ground surface polluting fluid into the aquiferous unit. The protective capacity of the overburden may therefore be regarded as being proportional to the ratio of thickness to resistivity. The combination of thickness and resistivity into single variables, other words known as the Dar Zarrouk parameters

(Mailet, 1974) are usuaally used as a basis for assessing aquifer properties such as aquifer transmissivity and protection of ground- water resources (Henriet, 1976).

3.6.1 Assessment of Aquifer Capacity from Dar Zarrouk parameters

The Dar Zarrouk parameters comprises of the transverse resistance (R_T) and longitudinal conductance (L_c). Kirsch et al. (2003) showed that the protection degree of an aquifer may be regarded as directly proportional to the longitudinal conductance (S) of the overburden materials. This implies that the higher the longitudinal conductance of overburden, the higher the degree of aquifer protection and vice vasa. For a horizontal, homogeneous, and isotropic layer, the transverse resistance R_T (Ωm^2) is defined as:

$$R_T = \rho h \tag{3.19}$$

and the longitudinal conductance L_c (mho) is defined as:

$$L_c = h/\rho \tag{3.20}$$

Where h = the thickness of the layer (in metres) and ρ is the electrical resistivity of the layer in ohm-metres. But aquifer transmissivity (T) is expressed as:

$$T = Kh \tag{3.21}$$

Where K = the hydraulic conductivity (m/day).

Since the hydraulic conductivity is directly proportional to the resistivity (Kelly, 1977), on a merely theoretical basis, it can be accepted that the transmissivity of an aquifer is directly proportional to its transverse resistance (Henriet, 1976; Ward, 1990). The hydraulic conductivity of clayey sediment could be linked to electrical resistivity through the concept of clay content. High clay content generally correlates with lower resistivities and lower hydraulic conductivities, and vice versa. The protective capacity of the overburden may therefore be regarded as being proportional to the ratio of thickness to resistivity, or in other words to the longitudinal conductance. Therefore, Equation (3.20) were used to assess the aquifer protective capacity of the aquifer overburden. The second order geo-electric parameter, longitudinal conductance (Dar Zarrouk parameter) is estimated from the first order parameters (thickness and resistivity) of the geo-electric subsurface layers which were used in the classification of the Aquifer Protective Capacity. The illustration of the longitudinal conductance/protective capacity ratings are present below (See table 3.8). This longitudinal unit conductance/protective capacity rating illustration after (Henriet, 1975; Oladapo and Akintoriwa, 2007) enables the classification of ratings into poor, weak, moderate and good protective capacity zones. Areas that are classified poor and weak are susceptible to contamination.

Table 3.8: Longitudinal conductance/protective capacity rating (after Henriet, 1975)

Proctective capacity rating	Longituninal unit conductance
Excellent	>10
Very Good	5 - 10
Good	0.7 - 4.9
Moderate	0.2 - 0.69
Weak	0.1 -0.19
poor	<0.1

3.6.2 Assessing Aquifer Capacity by Integrated Electrical Conductivity (IEC)

Integrated Electrical Conductivity (IEC) method quantifies groundwater vulnerability by hydraulic resistance to vertical flow of wastewater through the unsaturated layers. The IEC is usually determined using Eq. 10 (Rottger et al. 2005).

$$IEC = \sum_{i\sigma i h i} \tag{3.22}$$

Where σi and hi are the electrical conductivities and equivalent thickness of each layer above the aquifer layer.

The unit of IEC is given as siemens (S). A similar technique previously used by earlier scholars in evaluating aquifer vulnerability (Obiora, Alhassan, Ibuot and Okeke. (2016a); Obiora, Ibuot and Geroge (2016b); Madi, Meddi, Boutoutaou and Pulido-Bosch (2016)). Madi, et al. (2016) established a vulnerability assessment criteria vary from extremely high (less than 500 mS) to extremely low aquifer vulnerability (greater than 4000 mS) using IEC method as shown in Table 3.9.

The above expression means that the bigger the thickness of the layer, the larger the penetration time of the contaminants (implying large filter) and the lower the resistivity, the more clayey and less permeable the material will be (Braga, Filho, and Dourado 2006).

Table 3.9 Intrinsic aquifer vulnerability classification based on integrated electrical conductivity (IEC) showing aquifer protective capacity (Madi et al. 2016)

S/N	Vulnerability index	Degree of vulnerability	Percolation time
1	Extremely high	< 500	Several months
2	High	500–1000	Several months–3 years
3	Moderate	1000–2000	3–10 years
4	Low	2000–4000	10–25 years
5	Extremely low	> 40,000	> 25 years

3.7 Location and Physiography of the Study Area

The study area is situated within latitudes 6° 13' 04.97''N and 6° 31' 26.4''N of the equator and longitudes 7° 08' 51.05''E and 7° 41' 29.84''E of the Greenwich Meridian (Fig. 3.5a) in the Southeastern part of Nigeria encompassing an area of 0.16Km^2, with an elevation ranging from 58m t0 550m above mean sea level.

The topography in the study area shows two major types of landforms which consists of a high relief central zone with undulating hills and ridges and the lowland, which may be due to weathering and erosion of the rocks in the area, (Figure 3.5b). These features are related to the geology of the area. The high relief zone is geologically associated with the outcrops of Ajali Sandstone and Nsukka Formation, while the lowland zone is associated with outcrops of Awgu/Ndeabor Shale group. Generally, the Ajali Sandstone usually underlies areas of height above 300m while the Nsukka Formation is characterized by abundant residual hills area (Ezeh, 2012).

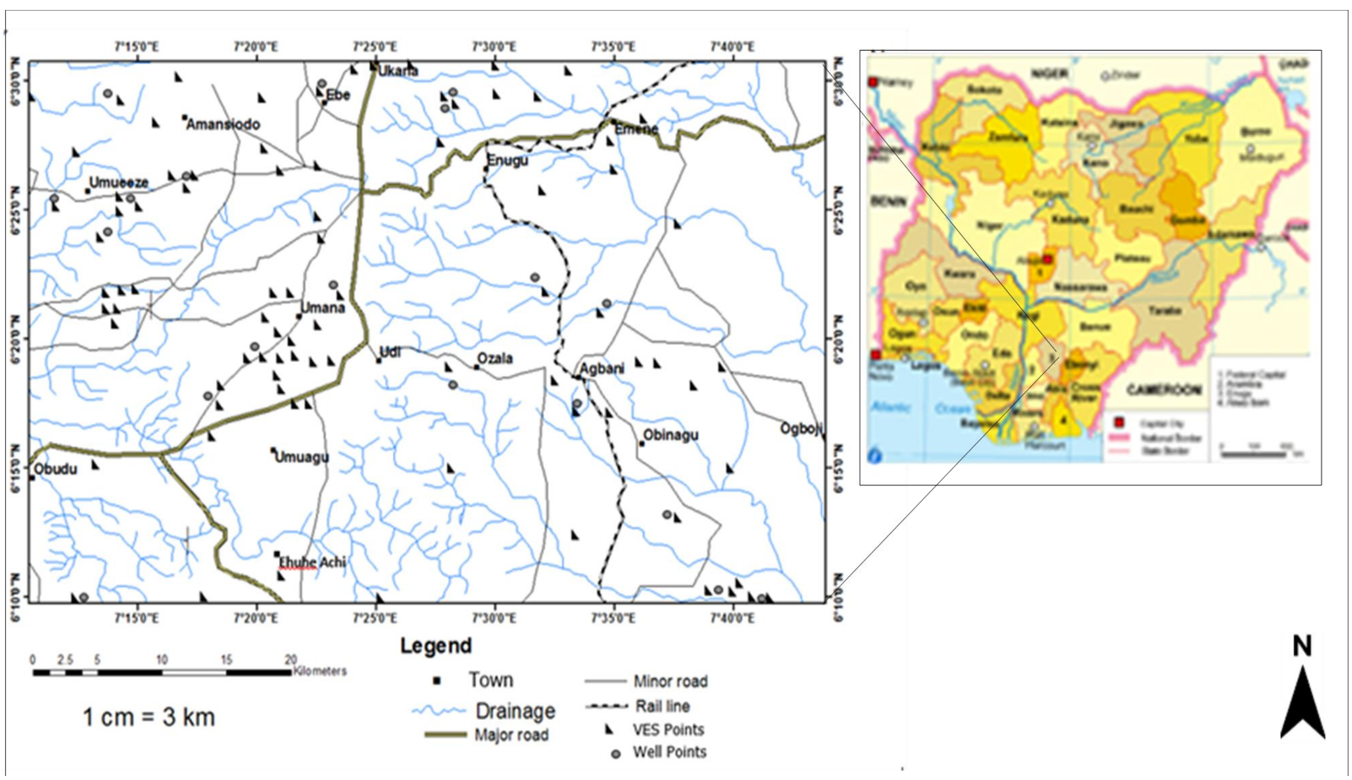


Fig 3.5a Location map of the Study area

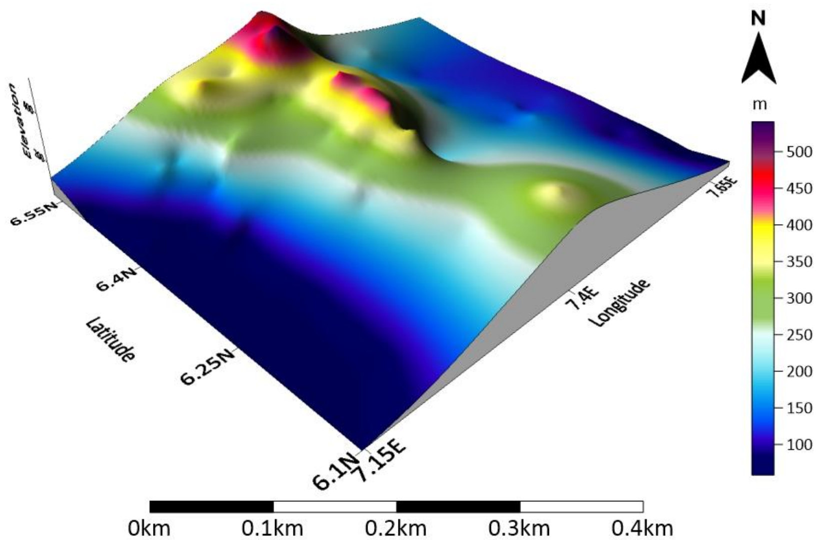


Fig 3.5b 3-D Digital Elevation Model of the Study Area

3.8 Drainage, Climate and Vegetation

The study area is well drained. The drainage pattern of the area is typically dendritic. The area is drained mainly by the Anambra River and its main tributaries and Atavu, Nyaba, Uham and its tributaries flow in general direction of Southeast to the Cross River Plain, and empties into the southeast corner of the Atlantic Ocean (Offodile, 2014; Okoli and Ejikeme, 2017). Rainfall is seasonal with a wet rainy season and a dry harmattan season controlled by the north-east and south-west wind (Nwobodo, et al. 2015). Most of the streams are seasonal, the streams originate from the highland areas and flows downward to the lowlands. During the rainy season, the stream banks are flooded, while in the dry season most of the stream dry up. Offodile, (2014) and Iloeje, (1981) reported that the area is characterized by a subequatorial climate with a moderately hot temperature of 75°F (21°C) is October to November to 80°F (27°C) in March. The climate of the area is hot and humid with mean annual rainfall of about 1875 and 2500mm (Moanu and Inyang, 1975). The maximum temperature is

34°C, while towards the end of rains, is 18°C - 21°C. Vegetation is characterized with abundant palm trees. The vegetation is tropical rain forest alternated with substantial overgrowth of shrubs, stunted trees and grasses of elephants.

3.9 Geology Setting of the Study Area

The study area is underlain by the following geological Formations (Figure 3.6), the Eze Aku Formation, Awgu/Ndeabor Shale group, Nkporo Shale, Mamu Formation, Ajali Formation, Nsukka Formation and Imo Shale Group respectively (Okonkwo, Ezeh and Akaerue 2017; Ezeh, 2012).

The Eze-Aku formation sediments consists of fossil limestone and shale. The thickness varies but in places can exceed 1000 m.

Awgu Formation is about 900meters thick and gently folded, the lithology consists of bluish and gray, well-bedded shales which are occasionally intercalated with fine yellow calcareous sandstones and shelly limestone (Reyment, 1965,. Kogbe, 1981). Also, fine to coarse grained, massive sandstone, locally cross-bedded with some pebble beds and subordinate bands of siltstone and carbonaceous shale are present. The Awgu Shale units is a lateral equivalent of Agbani Sandstone unit, it has two Lithostrategraphic units characterized by sequence of shale and sand (Okeke, et al. 2017). The sandstone is laterally not extensive, as it outcrops only around Agbani. It consist of medium to coarse grained, white to reddish brown, moderately consolidated at depth and highly consolidated at outcrop areas. The thickness variation and lateral gradation is predominant in areas (towns) far from Agbani town center (Okonkwo, et al. 2016).

The Nkporo Formation is overlain by Mamu Formation (Figure. 1.4), and composed dark shales and mudstones, with occasional thin beds of sandy shale and sandstone and thickness of about 150m (Ezeh, 2012). It was deposited in Early Maastrichtian (Kogbe, 1989 and Obi, 2000). It comprises succession of siltstone, shale, coal seam and sandstone Kogbe, (1989); Adeigbe and Salufu, (2009); Ezeh, (2012) reported that the Owelli sandstone, Enugu Shale and Asata shales are lateral equivalents of the Nkporo Shale. The Owelli sandstone consists of medium to coarse-grained sandstones with pebble bands while the Enugu/Asata shales consists of soft dark grey shales and mudstones with often thick beds of white sandstones and sandy shales.

The Mamu Formation is the coal-bearing stratigraphic unit of the Anambra Basin. The Formation has a thickness of about 450m, (Lower Maastrichtian) previously known as, the Lower Coal Measures (Odunzeakasiugwu, Obi and Yuan (2013), Tattam, 1944; Simpson, 1954; Reyment, 1948; and Barber, 1956) overlies the Nkporo/Enugu Shales without evidence of a break in sedimentation. The Formation consists of a heterolithic succession of wave ripple laminated and fine grained sandstone, alternating with thin beds of shale, mud laminated sandstone, mudstone and coal beds.

The Ajali Formation is generally characteristically friable white coloured sandstone and unconsolidated (Reyment, 1965). The Formation, also known as False Bedded Sandstone, and estimated of about 450 m in thickness (Reyment, 1965). The Ajali Sandstone covers about 80 % of the study area (Figure 3). The sandstone consists of thick friable, poorly sorted arkosic sandstones usually white in colour but sometimes stained with iron with reddish brown or yellow colour in the zone of aeration (Nwobodo, et al. 2015; Onwe, et al. 2016). The Ajali Sandstone outcrops on the crestal and towards the dip-slopes of the Enugu – Awgu – Okigwe Escarpment (Cuesta), it is overlain by diachronous Nsukka Formation (Maastrichtian-Danian) which is also known as the Upper Coal Measure (Reyment, 1965 and Obi, 2000). The Ajali Sandstone within this area is characterized by good groundwater potentials. The top of the lateritic sand and the weathered top of the Ajali Sandstone provide the suitable conditions for water storage which allow high infiltration rate and high permeability (Onwe, et al. 2016).

The Nsukka Formation, originally known as the upper coal measures (Tattam, 1944; Reyment and Barber, 1956) conformably overlies the Ajali Sandstone. The Nsukka Formation is the youngest Upper Cretaceous sediment in the Anambra Basin in Southeastern Nigeria. The Formation lies conformably on the Ajali sandstone. They exist as reddish ironstone covers of Ajali Sandstone and as outliers marked undulating hills (Ezeh, et al. 2013). The lithology is very equivalent to that of Mamu Formation and composed of an alternating succession of sandstone, dark shale and sandy shale, with thin coal seams at various horizons. Simpson (1954) and Reyment (1965) classified the formation as a paralic sequence, and they also described the formation consist of 15 m thick basal sandstone, overlain by 10 m thick, well bedded blue clays, and fine grained dark clayey sandstones and carbonaceous shales with lenses of impure coal (Odunzeakasiugwu, et al. (2013).

The Imo Formation conformably rests on Nsukka Formation with a thickness of about 500m. The Formation consists dominantly of blue to dark grey shales with occational bands of clay – ironstone and subordinate thin sandstone (Ezeh, 2012). The Formation includes thick sandstone units at several horizons.

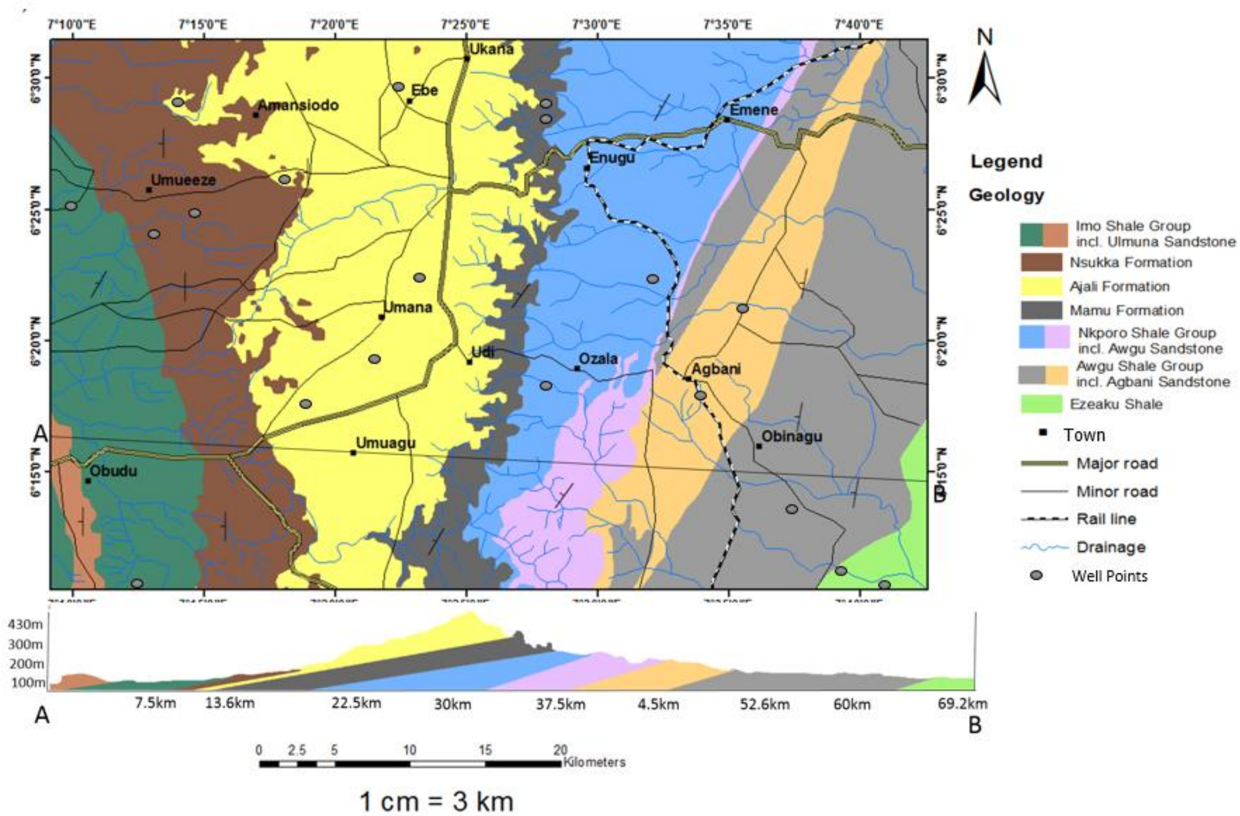


Figure 3.6. Geology map of the Study Area

3.10 Hydrogeology of the Study Area

The study area consists of the following Hydrogeologic units; these include confined, semi-confined, unconfined, and fractured shale aquifers (Offodile, 2002; Ezeh, 2012). Confined conditions occur over the Ajali Sandstone in areas overlain by the Nsukka Formation and Imo Formation, and in the Mamu Formation where the overlying Ajali Sandstone and Nsukka Formation are substantially reduced in thickness or eroded. Semi-confined situation occur in places and generally consist interbedded thick sequence of sand (aquifer) and sandy clay or clayey-sand aquicludes. The various aquifers in this category occur in the upper to middle horizons of Ajali Sandstone and in the upper section of the Mamu Formation and form the partial recharge zones for the deeper – seated confined aquifers. (Egboka and Onyebueke, 1990; Akudinobi and Egboka, 1996). Unconfined aquifer situations in the area usually occur in the Ajali Sandstone, and represent parts of the formation where the semi-permeable or impermeable cap beds were either eroded or absent. These aquifer units vary in thickness from shallow to deep in places. The conditions of fractured and fissured shale aquifers occur mostly in the shale groups, Ezeaku, Awgu and Nkporo shale, where repeated fractures and weathering result in economic water yield in the upper units of the shales (Ezeh, 2012).

Southeastern Nigeria generally falls in three broad Hydrogeological Group namely; Lower, Middle and Upper Hydrogeological Group (Adelana, et al. 2008). The first group which is Lower Hydrogeological Group occurs within the area underlain by the predominantly shaley formations. These include the Asu River Group, Mfamosing Limestone Formation, Ekenkpon Shale, New Ntetim Marl, the Eze-Aku Shale, the Awgu Shale, Nkporo Shale, and Enugu Shale. The second group (Middle Hydrogeological Group) develops in the formations of Mamu, Ajali and Nsukka with prominent sandy horizons. And the third group occur in Imo Shale, Bendi-Ameki, Ogwashi-Asaba and the Benin Formations forms the Upper Hydrogeological Group (See Table 3.10).

Table 3.10: Lithostratigraphic and hydrostratigraphic Sequence of southern part of Nigeria, Modified from Murat (1972)

AGE/BASIN	NIGER DELTA	CALABAR FLANK	ABAKALIKI TROUGH	ANAMBRA BASIN	Hydrostratigraphic Units	Hydrogeological groups
PLIOCENE	Benin Formation			Benin Formation	Benin Formation aquifer	Upper
MIOCENE OLIGOCENE	Agbada Shale Formation			Ogwashi-Asaba Formation	Ogwashi-Asaba aquitard	
EOCENE				Bende-Ameki Formation	Bende-Ameki Aquifer	
PALEOCENE	Akata Shale			Imo Shale Group	Imo Shale aquitard	
MAASTRICHTIAN	Nkporo Shale	Nkporo Shale		Nsukka Formation Ajali Sandstone Mamu Formation	Nsukka aquitard Ajali Sandstone aquifer Mamu aquiclude	Middle
CAMPANIAN				Enugu Shale Nkporo Shale	Enugu shales aquitard Nkporo shales aquitard	Lower
SANTONIAN						
CONIACIAN	Nkalagu Formation	New Netim Marl	Nkalagu Formation	Agwu Shale	Agwu aquitard	
TURONIAN		Ekenkpon Shale Formation	Eze Aku Group: Agu-Ojo Sandstones Nara Shale	Eze Aku Group	Eze Aku aquitard	
CENOMANIAN			Asu River Group: Ezillo Ibir/Aglla Sandstone	Asu River Group	Asu River aquitard	
ALBIAN		Mfamosing Limestone Formation	Ngbo Ekebeligwe			
APTIAN ?		Awi Formation				
OLDER	Basement Complex				Basement aquifer	

CHAPTER FOUR

RESULTS INTERPRETATION AND DISCUSSION

4.1. Results of Pumping Test

The summary of interpreted aquifer parameters obtained from the nineteen wells are presented in Table 4.1 below. The pumping test data were carefully examined and plotted using the method; Copper-Jacob straight line curve with the aid of AquiferWin32 software as shown in Fig. 4.1a, 4.1b, 4.1c, and 4.1d below.

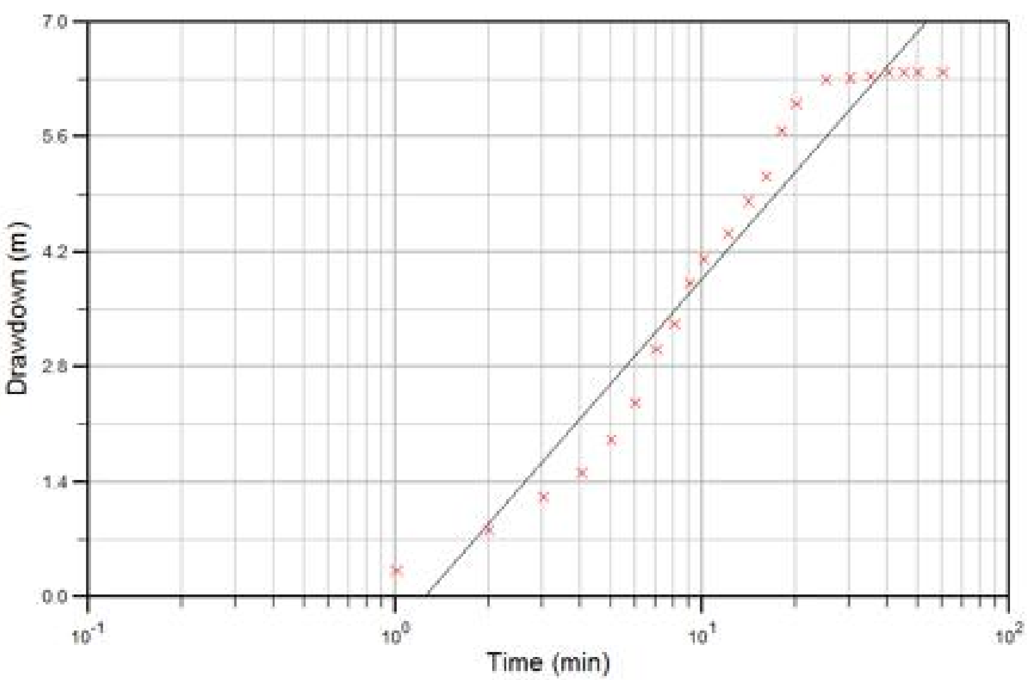


Fig 4.1a Jacob straight line on drawdown versus log (time) graph for Ojiagu Agbani Nkanu West

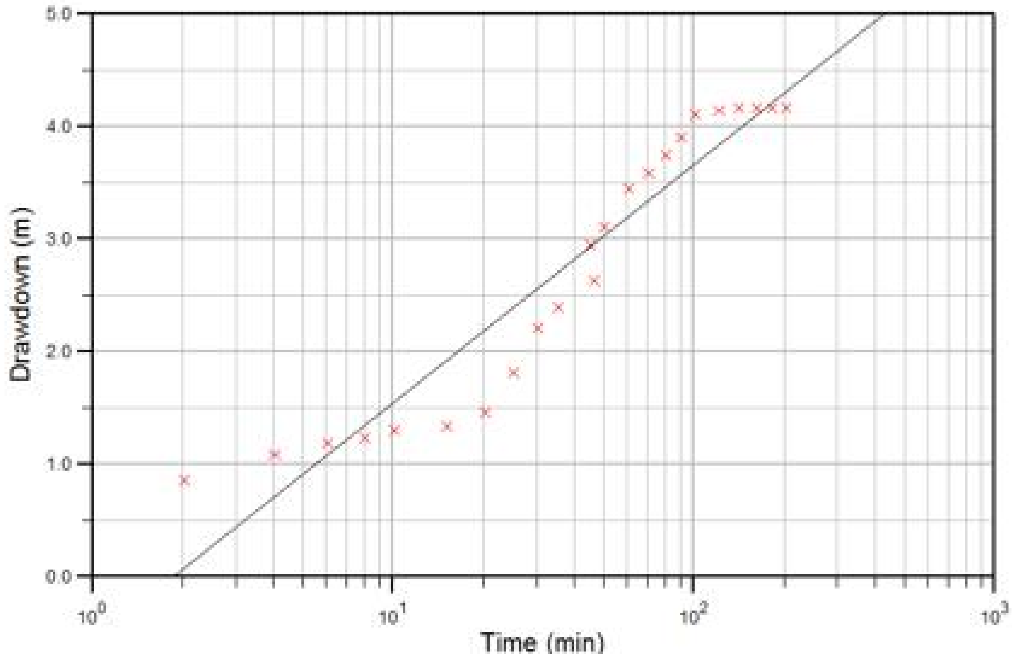


Fig 4.1b Jacob straight line on drawdown versus log (time) graph for Amokwe Udi

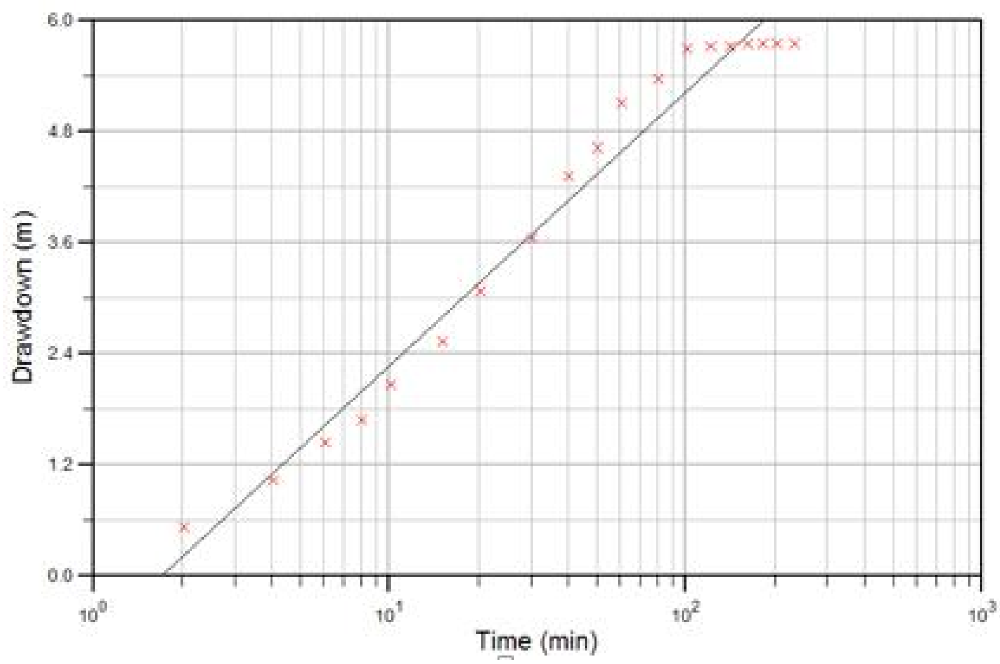


Fig 4.1c Jacob straight line on drawdown versus log (time) graph for Afor Primary Sch. Abor Udi

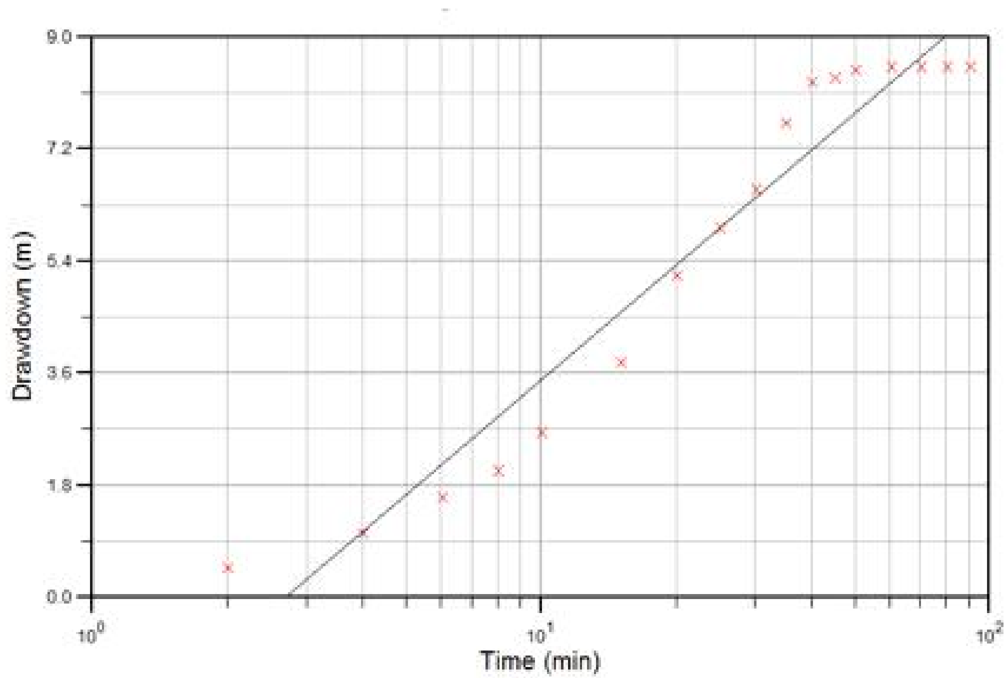


Fig 4.1d Jacob straight line on drawdown versus log (time) graph for Umuaji Aguobu-owa Ezeagu

Table 4.1 Summary of Hydraulic Parameters Obtained from Pumping Test Data in the study area

WELL No.	LOCATION	LATIITUDE	LONGITUDE	FORMATIOM	Transmissivity (m^2/day) from Pumping Test	Hydraulic Conductivity (m/day) from Pumping Test	Screen Length (m)	DrawDown per Log cycle (m)	Static Water Level (m)
1	OJIAGU TOWN HALL AGBANI NKANU WEST	6°17"49.6'N	7°34"39.4'E	AWGU	19.1546	1.6114	11.887	6.37	29.00
2	NARA NKANU EAST	6°13'04.97"N	7°38'53.20"E	AWGU	11.5963	1.5671	7.40	13.50	19.40
3	OGBASHI VILLAGE SQ NDIUNO AKPUGO NKANU WEST	6°21'57.35"N	7°35'49.7"E	AWGU	13.7151	1.1538	11.887	15.40	18.30
4	AMOKWE, UDI	6°19'08.34"N	7°21'49.95"E	AJALI	16.4394	4.1099	4.00	4.15	99.00
5	AFOR PRIMARY SCH ABOR UDI	6°29'47"N	7°23'34"E	AJALI	48..4631	6.4617	7.50	5.73	35.30
6	OBIOMA COMM. HIGH SCH, UDI	6°22'50"N	7°24' 17"E	AJALI	14.3308	3.4953	4.10	2.12	46.06
7	IHUONAYIA CITY OGHE, EZEAGU	6°29'01.2"N	7°14'52.2"E	AJALI	20.0972	4.0194	5.00	8.50	48.70
8	OGHE, EZEAGU	6°26'03"N	7°18'26"E	AJALI	30.8738	4.4105	7.00	6.10	87.50
9	NACHI, UDI	6°17'38.54"N	7°19'26.60"E	AJALI	36.5382	3.8461	9.50	6.25	95.07
10	AGUAGBAJA UMUNADIAGU, EZEA	6°24'08.92"N	7°13'41.23"E	NSUKKA	76.7714	6.4622	11.88	3.50	142.30
11	IWOLLO TOWN, EZEAGU	6°25'32.4"N	7°15'54"E	NSUKKA	43.3041	4.1242	10.50	3.66	123.48
12	COMM. SEC SCH OLO, EZEAGU	6°25'04"N	7°10'11"E	IMO SH	31.6756	2.6396	12.00	6.00	9.70
13	AKPUGO-EZE, OJI RIVER	6°09'00.18"N	7°12'45.49"E	IMO SH	18.9001	2.7000	7.00	9.40	68.80
14	WINNERS ESTATE TRANS-EKULU, E	6°29'45.5"N	7°28'43.8"E	MAMU	27.4864	2.7486	10.00	5.39	19.21
15	PHASE 6 TRANS-EKULU, ENUGU	6°29'57"N	7°28'34"E	MAMU	23.5175	2.3518	10.00	5.85	46.38
16	OZALLA NKANU, ENUGU	6°19'00.51"N	7°28'33.59"E	NKPORO	30.2702	2.5479	11.88	6.20	31.10
17	OBEAGU ENUGU SOUTH	6°22'59.07"N	7°32'42.12"E	NKPORO	21.842	2.5696	8.50	7.30	32.10
18	GIRLS SEC. SCH. UMUOIKA ENUOGU NKEREFI NKANU EAST	6°08'57.20"N	7°41'24.95"E	EZEAKU	18.7655	1.5796	11.90	12.10	99.30
19	OBODO EBUNABO NKEREFI NKANU EAST	6°10'21.33"N	7°39'45.53"E	EZEAKU	18.8833	1.5895	11.88	11.60	97.20

4.2 Quantitative Results of VES

The result of the field estimate were carefully interpreted. The summary of layer parameter interpreted Vertical Electrical Sounding data and geoelectric curve types obtained from the study area are presented in table (4.2). A qualitative estimate of the relationship between electrode spacing and the depth of penetration was made using curve matching technique to obtain initial model parameters which were used as input for computer iterative modelling using the OFFIX 3.1 software. Results of the curve matching was studied in details, the shape of the 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 due to the shape of a VES curve lies on the number of layers in the subsurface, the thickness of each layer, and ratio of the resistivity of the layers (Osemeikhian, and Asokhia, 1982; Opara, et al. 2015). Figure 4.2(a-f) shows a typical geoelectric curve types generated in the study area.

However, twenty-two (25) geoelectric curve types were encountered in the study area with the QH-type being prevalent which occurred fifteen times, which was followed by KHA-type which occurred twelve times, AAK-type occurred eight times, HAK, KHK types occurred six times, HK-type occurred four times, AKH, KQH, QQ, QHK, HAA types occurred three times, KH, AK, HKA, KQQ, QHA types occurred twice, and HA, Q, HKQ, KQA QKA, QKH, QQH, AAA, AKQ types occurred once. The percentage of occurrence of these respective geo-electric curve types are presented in figure 4.3.

The results of the study revealed the presence of 3 to 9 geoelectric layer models. The four-layer model were the most prevalent, occurring twenty-seven times; it was trailed by the six-layer model which occurred eighteen times, five-layer model which occurred seventeen times, seven-layer model occurred thirteen times, eight-layer model occurred five times, nine-layer model occurred four times and the three-layer model which occurred once respectively as presented in figure 4.4 below.

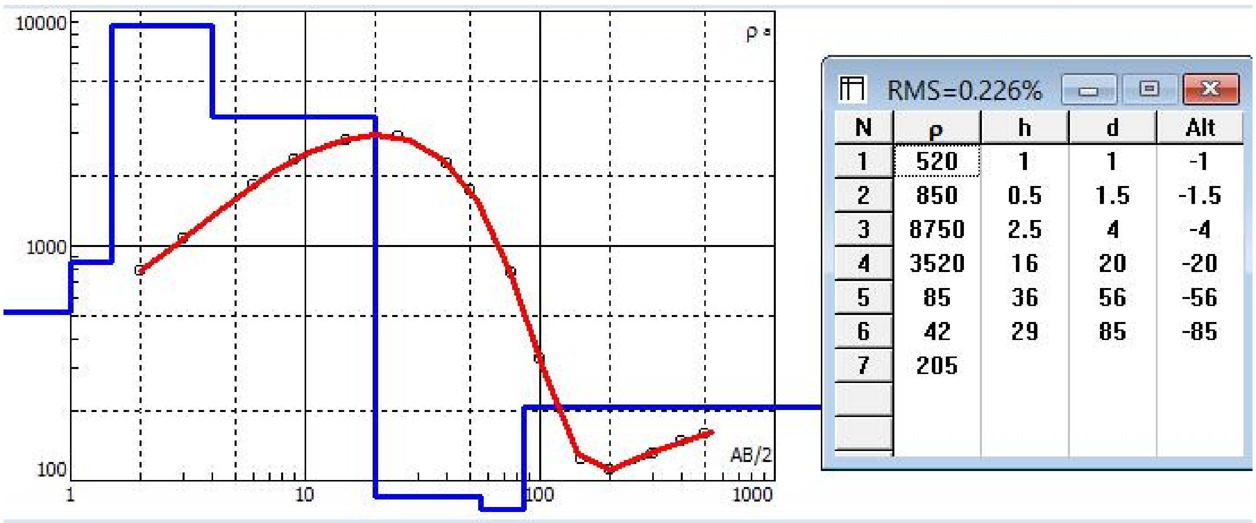


Fig 4.2a. Typical geoelectric curve type in the study area at VES 1 (Ojiagu Agbani Nkanu West)

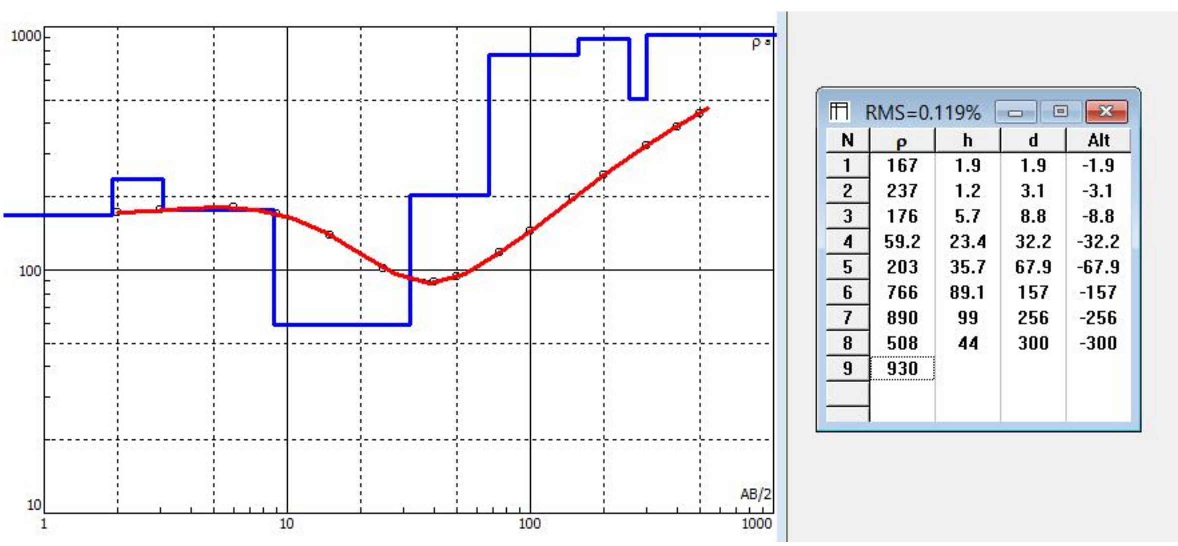


Fig 4.2b. Typical geoelectric curve type in the study area at VES 6 (Amankpume Nkerefi Nkanu East)

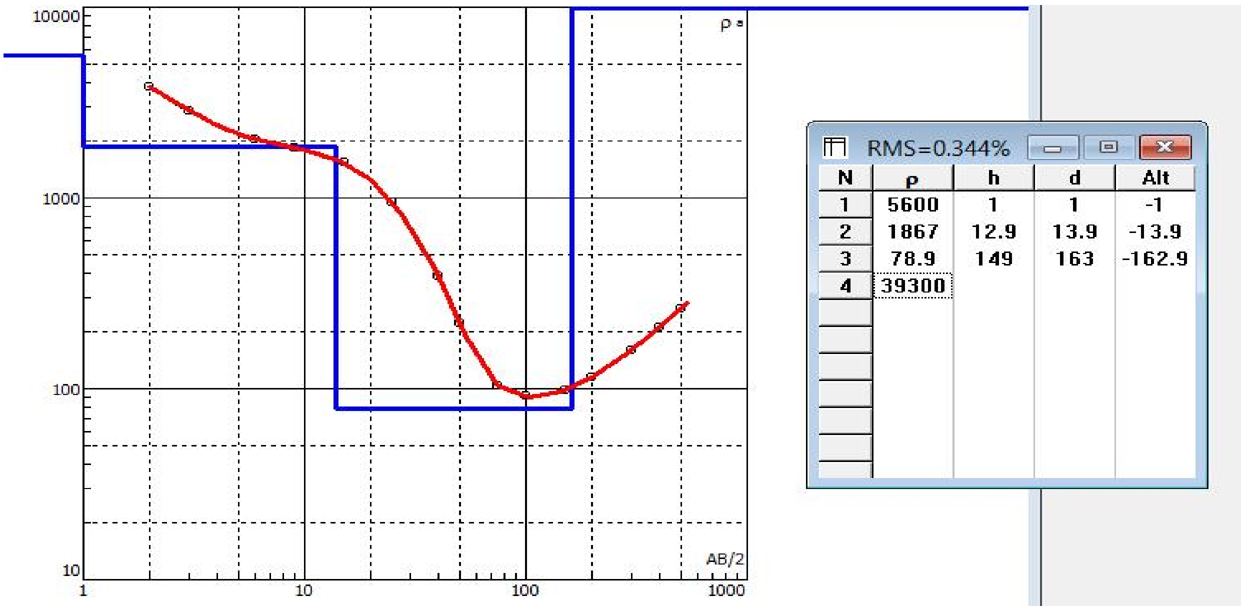


Fig 4.2c. Typical geoelectric curve type in the study area at VES 24 (Amaokwe, Udi)

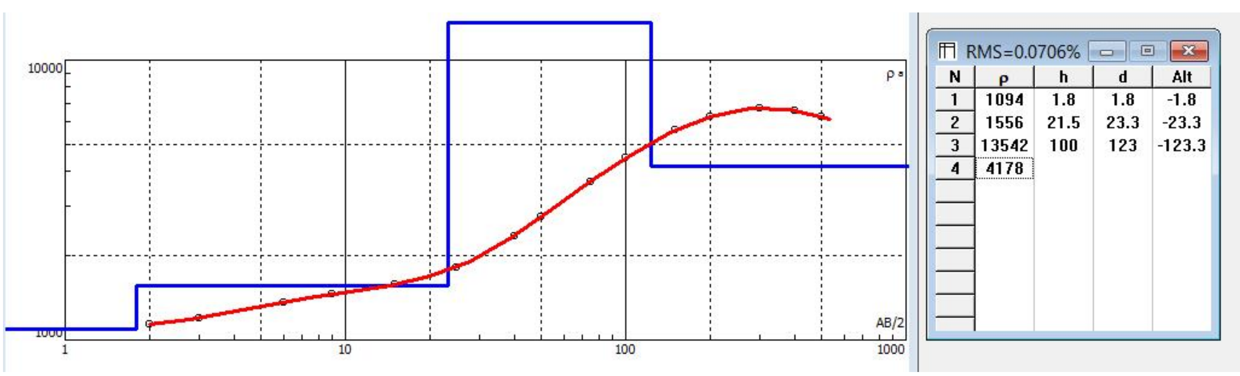


Fig 4.2d. Typical geoelectric curve type in the study area at VES 38 (Umuaga Udi)

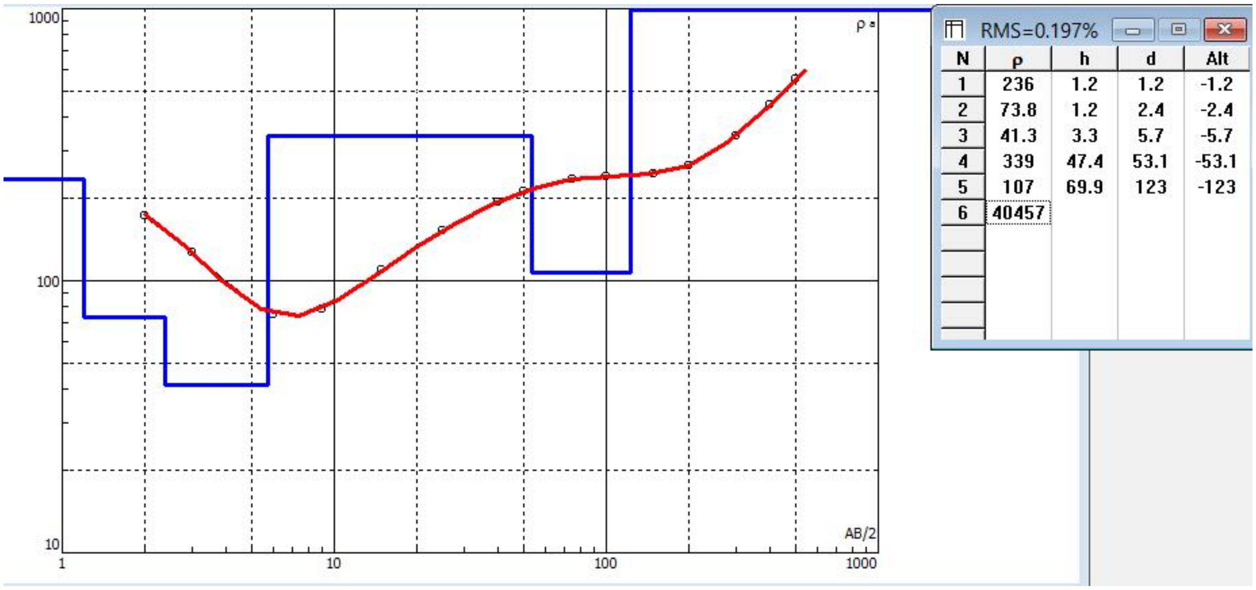


Fig 4.2e. Typical geoelectric curve type in the study area at VES 51 (Iwollo town, Ezeagu)

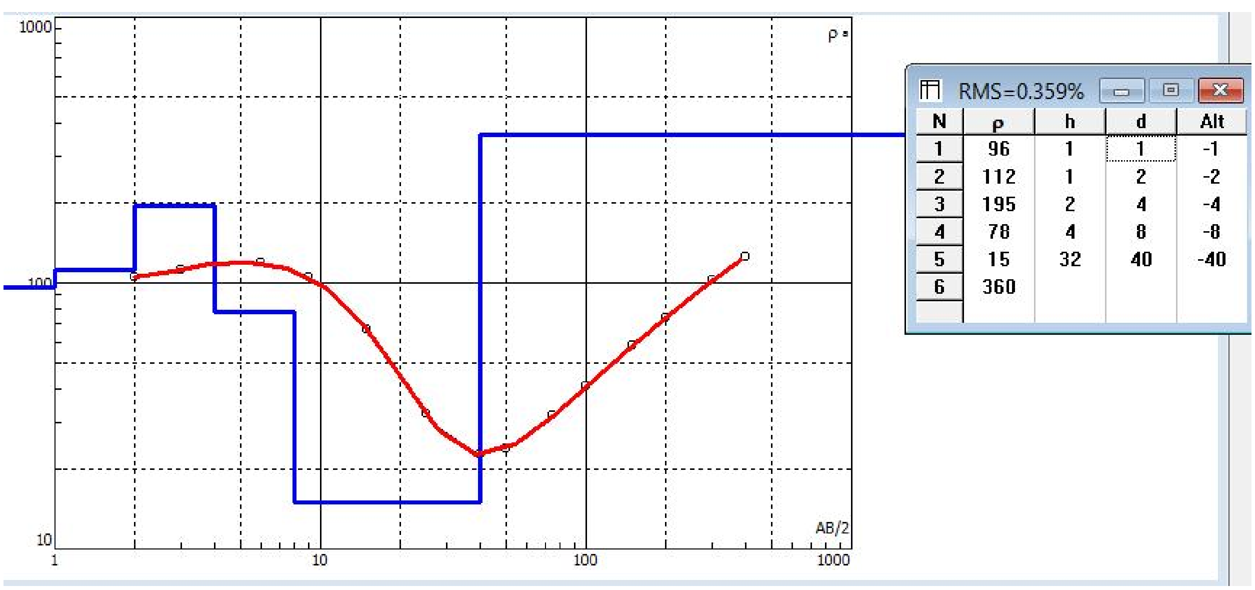


Fig 4.2f. Typical geoelectric curve type in the study area at VES 73 (Coal Camp Enugu)

Table 4.2 Summary of Layer Parameters Interpreted from the study area

VES POINTS	LAYER RESISTIVITY (Ohm-1)									NUMBER OF LAYERS
	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	ρ_7	ρ_8	ρ_9	
VES 1*	520.0	850.0	8750.0	3520.0	85.0	42.0	205.0			7
VES 2	365.0	510.0	2518.0	1542.0	265.0	250.0	235.0			7
VES 3*	1011.1	1512.1	129.8	733.0	53.4					5
VES 4	160.0	322.0	85.0	92.0	106.0	1040.0	647.0	3630.0	1510.0	9
VES 5*	158.0	284.0	103.0	56.7	287.0	446.0	553.0	792.0	920.0	9
VES 6	167.0	237.0	176.0	59.2	203.0	766.0	890.0	508.0	930.0	9
VES 7	164.0	219.0	175.0	49.5	266.0	331.0	478.0	1100.0	800.0	9
VES 8*	240.0	100.0	260.0	80.0	153.0	283.0	498.0	800.0		8
VES 9	159.0	287.0	72.4	105.0	345.0	494.0	599.0			7
VES 10	578.0	1413.0	41.0	17.0	30.0					5
VES 11	1112.7	454.7	634.4	85.3	144.2	46.5	6453.0			7
VES 12*	130.0	98.0	45.0	5.0	15.0	60.0	6.0			7
VES 13	817.0	70.9	9.04	9.51	1628.0	18.8				6
VES 14	33.6	4.8	10.7	0.0106						4
VES 15	307.0	88.1	16.8	5.3						4
VES 16*	280.0	1000.0	770.0	5000.0	11000.0	9000.0	8000.0	-	-	7
VES 17	170.0	198.0	400.0	615.1	733.0	589.0	-	-	-	6
VES 18	1540.0	1325.0	1356.0	2150.0	3215.0	4587.0	25178.0	13250.0	-	8
VES 19	205.0	250.0	450.0	1002.0	3580.0	32587.0	2578.0	-	-	7
VES 20	700.0	100.0	4500.0	1000.0	-	-	-	-	-	4
VES 21*	6700.0	1675.0	60.0	73666.0	-	-	-	-	-	4
VES 22	4800.0	1600.0	54.0	24142.0	-	-	-	-	-	4
VES 23	7000.0	1750.0	57.5	247000.0	-	-	-	-	-	4
VES 24	5600.0	1866.7	79.0	39300.0	-	-	-	-	-	4
VES 25	7168.0	199975.0	7857.0	40707.0	1143.0	-	-	-	-	5
VES 26	8000.0	2566.7	261.1	84000.0	-	-	-	-	-	4

VES POINTS	LAYER CONDUCTIVITY (σ)								
	σ_1	σ_2	σ_3	σ_4	σ_5	$\sigma6$	$\sigma7$	$\sigma8$	$\sigma9$
VES 1*	0.002	0.001	0	3E-04	0.01176	0.02381	0.00488		
VES 2	0.003	0.002	0	6E-04	0.00377	0.004	0.00426		
VES 3*	1E-03	7E-04	0.01	0.001	0.01873				
VES 4	0.006	0.003	0.01	0.011	0.00943	0.00096	0.00155	0.00028	0.000662
VES 5*	0.006	0.004	0.01	0.018	0.00348	0.00224	0.00181	0.00126	0.001087
VES 6	0.006	0.004	0.01	0.017	0.00493	0.00131	0.00112	0.00197	0.001075
VES 7	0.006	0.005	0.01	0.02	0.00376	0.00302	0.00209	0.00091	0.00125
VES 8*	0.004	0.01	0	0.013	0.00654	0.00353	0.00201	0.00125	
VES 9	0.006	0.003	0.01	0.01	0.0029	0.00202	0.00167		
VES 10	0.002	7E-04	0.02	0.059	0.03333	-	-		
VES 11	9E-04	0.002	0	0.012	0.00693	0.02152	0.00015		
VES 12*	0.008	0.01	0.02	0.2	0.06667	0.01667	0.16667		
VES 13	0.001	0.014	0.11	0.105	0.00061	0.05319			
VES 14	0.03	0.209	0.09	94.34					
VES 15	0.003	0.011	0.06	0.188					
VES 16*	0.004	0.001	0	2E-04	9.1E-05	0.00011	0.00013		
VES 17	0.006	0.005	0	0.002	0.00136	0.0017			
VES 18	6E-04	8E-04	0	5E-04	0.00031	0.00022	4E-05	7.5E-05	-
VES 19	0.005	0.004	0	1E-03	0.00028	3.1E-05	0.00039	-	-
VES 20	0.001	0.01	0	0.001	-	-	-	-	-
VES 21*	1E-04	6E-04	0.02	1E-05	-	-	-	-	-
VES 22	2E-04	6E-04	0.02	4E-05	-	-	-	-	-
VES 23	1E-04	6E-04	0.02	4E-06	-	-	-	-	-
VES 24	2E-04	5E-04	0.01	3E-05	-	-	-	-	-
VES 25	1E-04	5E-06	0	2E-05	0.00087	-	-	-	-
VES 26	1E-04	4E-04	0	1E-05	-	-	-	-	-

VES POINTS	LAYER DEPTH (m)								LAYER THICKNESS (m)								CURVE TYPE	GEOLOGIC FM.
	d1	d2	d3	d4	d5	d6	d7	d8	h1	h2	h3	h4	h5	h6	h7	h8		
VES 1*	1.0	1.5	4.0	20.0	56.0	85.0			1.0	0.5	2.5	16.0	36.0	29.0			AKH	AWGU
VES 2	1.0	1.5	5.0	14.0	32.0	85.0			1.0	0.5	3.5	9.0	18.0	53.0			AKQ	AWGU
VES 3*	2.8	7.9	39.9	143.9					2.8	5.1	32.0	104.0					KHK	AWGU
VES 4	2.5	4.2	12.3	58.6	85.6	132.0	151.0	375.0	2.5	1.7	8.1	46.3	27.0	46.4	19.0	224.0	KHA	EZEAKU SH
VES 5*	1.9	3.3	11.6	33.5	57.3	83.3	116.0	203.0	1.9	1.4	8.3	21.9	23.8	26.0	32.7	87.0	KHA	EZEAKU SH
VES 6	1.9	3.1	8.8	32.2	67.9	157.0	256.0	300.0	1.9	1.2	5.7	23.4	35.7	89.1	99.0	44.0	KHA	EZEAKU SH
VES 7	1.7	2.9	9.4	30.3	54.1	81.3	119.0	270.0	1.7	1.2	6.5	20.9	23.8	27.2	37.7	151.0	KHA	EZEAKU SH
VES 8*	0.5	1.2	3.9	37.8	60.1	131.0	153.0		0.5	0.7	2.7	33.9	22.3	70.9	22.0	-	KHA	EZEAKU SH
VES 9	2.4	4.3	29.1	51.4	91.0	149.0			2.4	1.9	24.8	22.3	39.6	58.0	-	-	KHA	EZEAKU SH
VES 10	0.8	3.2	6.5	76.7					0.8	2.4	3.3	70.2	-	-	-	-	KQA	AWGU
VES 11	1.5	4.0	7.7	25.2	39.7	70.1			1.5	2.4	3.8	17.5	14.5	30.4	-	-	KHA	AWGU
VES 12*	0.8	1.5	6.5	18.0	38.0	85.0			0.8	0.7	5.0	11.5	20.0	47.0			KHK	AWGU
VES 13	0.6	11.6	20.7	31.4	98.3				0.6	11.0	9.1	10.7	66.9				QKA	AWGU
VES 14	1.1	28.5	52.5						1.1	27.4	24.0						HK	AWGU
VES 15	0.6	8.1	58.8						0.6	7.5	50.7						QQ	AWGU
VES 16*	0.5	1.0	9.0	50.0	180.0	300.0			0.5	0.5	8.0	41.0	130.0	120.0	-	-	HAK	AJALI
VES 17	3.5	53.0	120.0	190.0	260.0	-	-	-	3.5	49.5	67.0	70.0	70.0	-	-	-	AAK	AJALI
VES 18	0.8	2.0	4.0	15.0	20.0	45.0	155.0	-	0.8	1.2	2.0	11.0	5.0	25.0	110.0	-	HAK	AJALI
VES 19	0.8	1.5	4.0	8.0	15.0	150.0	-	-	0.8	0.7	2.5	4.0	7.0	135.0	-	-	AAK	AJALI
VES 20	1.2	3.0	150.0	-	-	-	-	-	1.2	1.8	147.0	-	-	-	-	-	HK	AJALI
VES 21*	0.7	14.2	154.7	-	-	-	-	-	0.7	13.5	140.5	-	-	-	-	-	QH	AJALI
VES 22	1.4	22.4	169.4	-	-	-	-	-	1.4	21.0	147.0	-	-	-	-	-	QH	AJALI
VES 23	0.9	15.1	210.6	-	-	-	-	-	0.9	14.3	195.5	-	-	-	-	-	QH	AJALI
VES 24	1.0	13.9	162.9	-	-	-	-	-	1.0	12.9	149.0	-	-	-	-	-	QH	AJALI
VES 25	1.6	2.9	46.4	115.0	-	-	-	-	1.6	1.4	43.5	69.0	-	-	-	-	KHK	AJALI
VES 26	1.5	10.0	130.0	-	-	-	-	-	1.5	8.5	120.0	-	-	-	-	-	QH	AJALI

VES 27	1900.0	8142.0	347.4	240000.0	-	-	-	-	-	4	5E-04	1E-04	0	4E-06	-	-	-	-	-	1.9	21.9	57.9	-	-	-	-	-	1.9	20.0	36.0	-	-	-	-	-	KH	NSUKKA
VES 28	2500.0	8142.0	293.7	93000.0	-	-	-	-	-	4	4E-04	1E-04	0	1E-05	-	-	-	-	-	2.0	24.0	112.0	-	-	-	-	-	2.0	22.0	88.0	-	-	-	-	-	KH	AJALI
VES 29	24500.0	1856.0	357.9	61833.0	-	-	-	-	-	4	4E-05	5E-04	0	2E-05	-	-	-	-	-	1.4	19.9	103.1	-	-	-	-	-	1.4	18.5	83.3	-	-	-	-	-	QH	AJALI
VES 30	4300.0	2866.7	115.8	22500.0	-	-	-	-	-	4	2E-04	3E-04	0.01	4E-05	-	-	-	-	-	1.0	26.0	216.0	-	-	-	-	-	1.0	25.0	190.0	-	-	-	-	-	QH	AJALI
VES 31	1420.0	5680.0	22100.0	60.0	82000.0	-	-	-	-	5	7E-04	2E-04	0	0.017	1.2E-05	-	-	-	-	1.3	6.6	30.6	126.0	-	-	-	-	1.3	5.3	24.0	95.0	-	-	-	-	AKH	AJALI
VES 32	4500.0	2423.0	105.3	8900.0	-	-	-	-	-	4	2E-04	4E-04	0.01	1E-04	-	-	-	-	-	0.8	27.8	127.8	-	-	-	-	-	0.8	27.0	100.0	-	-	-	-	-	QH	AJALI
VES 33	10000.0	5384.6	705.9	51333.0	-	-	-	-	-	4	1E-04	2E-04	0	2E-05	-	-	-	-	-	1.8	19.8	181.8	-	-	-	-	-	1.8	18.0	162.0	-	-	-	-	-	QH	AJALI
VES 34	22500.0	7500.0	777.7	41787.0	-	-	-	-	-	4	4E-05	1E-04	0	2E-05	-	-	-	-	-	1.8	30.3	153.3	-	-	-	-	-	1.8	28.5	123.0	-	-	-	-	-	QH	AJALI
VES 35	3600.0	1938.4	85.0		-	-	-	-	-	3	3E-04	5E-04	0.01		-	-	-	-	-	1.4	23.4		-	-	-	-	-	1.4	22.1		-	-	-	-	-	Q	AJALI
VES 36	1057.9	578.8	2303.7	5961.2	316.0					5	9E-04	0.002	0	2E-04	0.00316					1.0	10.4	17.9	118.2					1.0	9.4	7.5	100.3					AAK	AJALI
VES 37	221.3	3019.0	18693.2	2822.3						4	0.005	3E-04	0	4E-04	-					3.8	21.5	136.2						3.8	17.7	114.7	-					AK	AJALI
VES 38	1094.4	1555.6	13542.4	4178.1						4	9E-04	6E-04	0	2E-04	-					1.8	23.3	123.5						1.8	21.5	100.2	-					AK	AJALI
VES 39	2121.1	1721.2	2641.0	22838.5	7470.7					5	5E-04	6E-04	0	4E-05	0.00013					0.2	3.0	18.5	152.3					0.2	2.8	15.5	133.8					HAK	AJALI
VES 40	31001.7	27203.4	26372.6	18929.2						4	3E-05	4E-05	0	5E-05						0.9	1.3	171.0						0.9	0.4	169.7						HK	AJALI
VES 41	31001.7	27203.4	26372.6	18929.2						4	3E-05	4E-05	0	5E-05						0.9	1.3	171.0						0.9	0.4	169.7						HK	AJALI
VES 42	991.9	1581.1	3981.0	2878.7	11117.3	4479.2	11365.8	-		7	0.001	6E-04	0	3E-04	9E-05	0.00022	8.8E-05			2.7	8.5	19.8	38.6	88.8	143.1			2.7	5.9	11.3	18.8	50.2	54.2			HAA	AJALI
VES 43	1055.5	32062.7	1191.1	27453.4	10514.1	-				5	9E-04	3E-05	0	4E-05	9.5E-05	-				1.4	22.5	53.8	103.0	-				1.4	21.1	31.3	49.2	-				AKH	AJALI
VES 44	520.9	755.7	6450.5	2754.2	7284.5	5823.7				6	0.002	0.001	0	4E-04	0.00014	0.00017				1.5	6.4	35.4	97.7	177.1				1.5	4.9	29.0	62.3	79.4	-	-		HKA	AJALI
VES 45	23500.0	4147.0	170.0	520000.0						4	4E-05	2E-04	0.01	2E-06						1.5	19.1	191.0						1.5	17.6	171.9						QH	AJALI
VES 46	4000.0	2666.0	71.1	23250.0						4	3E-04	4E-04	0.01	4E-05						0.8	16.0	133.0						0.8	15.2	117.0						QH	AJALI
VES 47	2900.0	725.0	37.5	1661.0						4	3E-04	0.001	0.03	6E-04						0.7	16.8	93.5						0.7	16.1	76.8						QH	AJALI
VES 48	462.0	4300.0	327.0	3100.0	3560.0	13100.0				6	0.002	2E-04	0	3E-04	0.00028	7.6E-05				6.5	16.9	49.4	96.4	125.0				6.5	10.4	32.5	47.0	28.6				HKA	NSUKKA
VES 49	565.0	11200.0	1060.0	1130.0	326.0	236.0				6	0.002	9E-05	0	9E-04	0.00307	0.00424				20.3	45.8	96.4	124.8	178.0				20.3	25.5	50.6	28.4	53.2				HKQ	NSUKKA
VES 50	1100.0	10.0	30.0	150.0	200.0	5000.0				6	9E-04	0.1	0.03	0.007	0.005	0.0002				1.3	35.0	80.0	180.0	250.0				1.3	33.7	45.0	100.0	70.0				QHA	NSUKKA
VES 51*	235.5	73.8	41.3	338.5	107.2	40457.9				6	0.004	0.014	0.02	0.003	0.00933	2.5E-05				1.2	2.4	5.7	53.1	123.0				1.2	1.1	3.4	47.4	69.9				QKH	NSUKKA
VES 52	1057.9	578.8	2303.7	5961.2	3164.6					5	9E-04	0.002	0	2E-04	0.00032					1.0	10.4	17.9	118.2	-				1.0	9.4	7.5	100.3	-				HAK	AJALI
VES 53	821.4	1598.6	2035.7	5627.1	3856.7					5	0.001	6E-04	0	2E-04	0.00026					1.0	3.8	16.3	100.9	-				1.0	2.8	12.5	84.6					AAK	NSUKKA
VES 54	2574.5	549.4	14.5	47.9	106.1					5	4E-04	0.002	0.07	0.021	0.00943					1.5	9.0	26.3	142.1					1.5	7.5	17.3	115.8					QHA	AJALI

VES 55	563.0	670.1	16.7	97.9	253.0					5	0.002	0.001	0.06	0.01	0.00395	-				0.5	5.8	14.4	165.7	-				0.5	5.3	8.6	151.3					KHA	NSUKKA
VES 56	13566.0	8283.4	576.2	271.0	2037.0					5	7E-05	1E-04	0	0.004	0.00049					2.4	11.3	30.2	179.3	-				2.4	8.9	18.9	149.1					QQH	NSUKKA
VES 57	718.7	28.6	82.4	212.1						4	0.001	0.035	0.01	0.005	-					4.8	8.4	97.5	-					4.8	3.6	89.1	-					HA	NSUKKA
VES 58	125.1	888.2	125.1	192.6	8.9					5	0.008	0.001	0.01	0.005	0.11236					0.5	1.0	35.8	228.4					0.5	0.5	34.8	192.6	-				KHK	AJALI
VES 59	644.6	522.6	104.4	984.8						4	0.002	0.002	0.01	0.001						0.9	12.9	119.8						0.9	12.0	106.9						QH	AJALI
VES 60	203.0	7732.0	16515.0	987.0	7344.0	118.0				6	0.005	1E-04	0	0.001	0.00014	0.00847				1.1	2.0	3.1	6.5	91.4				1.1	0.9	1.1	3.4	84.9				AAK	NSUKKA
VES 61	3740.0	264.0	5.4	27.3	1.1					5	3E-04	0.004	0.19	0.037						1.3	4.1	15.6	76.5					1.3	2.8	11.5	60.9					QHK	IMO SHALE
VES 62	7000.0	4333.0	529.0	20428.0						4	1E-04	2E-04	0	5E-05						1.1	13.1	108.0						1.1	12.0	94.9						QH	AJALI
VES 63	2047.0	3350.0	3002.0	2512.0	12500.0	54200.0	88745.0	28740.0		8	5E-04	3E-04	0	4E-04	0.00008	1.8E-05	1.1E-05	3.5E-05		0.8	2.5	3.5	6.0	15.0	35.0	130.0		0.8	1.7	1.0	2.5	9.0	20.0	95.0		HAK	AJALI
VES 64	351.0	520.0	1006.0	5214.0	9875.0	14320.0	5142.0			7	0.003	0.002	0	2E-04	0.0001	7E-05	0.00019			0.6	1.2	4.0	18.0	60.0	158.0			0,6	0.6	2.8	14.0	42.0	98.0			HAA	AJALI
VES 65	698.0	978.0	4528.0	675.0	4212.0	9786.0	3120.0			7	0.001	0.001	0	0.001	0.00024	0.0001	0.00032			0.8	1.5	5.0	12.0	45.0	130.0			0.8	0.7	3.5	7.0	33.0	85.0			KHK	AJALI
VES 66	2406.9	530.0	124.3	711.5	20994.0	3200.3	932.1			7	4E-04	0.002	0.01	0.001	4.8E-05	0.00031	0.00107			3.6	10.7	31.9	71.8	122.6	178.2			3.6	7.1	21.2	39.9	50.8	55.6			KHA	AJALI
VES 67	42.0	45.0	14.0	25.0	125.0	1250.0	250.0	1000.0		8	0.024	0.022	0.07	0.04	0.008	0.0008	0.004	0.001		1.0	1.5	5.0	11.0	50.0	100.0	120.0		1.0	0.5	3.5	6.0	39.0	50.0	20.0		HAA	IMO SHALE
VES 68	3.0	15.0	20.0	60.0	65.0	250.0	1258.0	6587.0		8	0.333	0.067	0.05	0.017	0.01538	0.004	0.00079	0.00015		1.0	1.5	2.0	8.0	20.0	50.0	120.0		1.0	0.5	0.5	6.0	12.0	30.0	70.0		AAA	IMO SHALE
VES 69	4500.0	6000.0	7000.0	1200.0	20000.0	800.0	-	-	-	6	2E-04	2E-04	0	8E-04	0.00005	0.00125	-	-	-	1.2	11.2	23.2	43.2	103.2	-	-	-	1.2	10.0	12.0	20.0	60.0	-	-	-	KHK	NSUKKA
VES 70	9.1	6842.1	11243.7	5642.8	3723.9	796.2	-	-	-	6	0.11	1E-04	0	2E-04	0.00027	0.00126	-	-	-	0.4	1.5	5.3	125.8	192.3	-	-	-	0.4	1.2	3.8	120.5	66.5	-	-	-	AAK	NSUKKA
VES 71	9.8	6635.7	8558.9	13562.0	6176.6	1091.5	-	-	-	6	0.102	2E-04	0	7E-05	0.00016	0.00092	-	-	-	0.3	1.5	5.1	128.0	200.1	-	-	-	0.3	1.2	3.6	122.9	72.1	-	-	-	AAK	NSUKKA
VES 72	5.9	6404.8	9195.4	269030.3	6428.0	1160.0	-	-	-	6	0.169	2E-04	0	4E-06	0.00016	0.00086	-	-	-	0.4	1.6	4.5	7.5	136.0	-	-	-	0.4	1.1	2.9	3.1	128.5	-	-	-	AAK	NSUKKA
VES 73	96.0	112.0	195.0	78.0	15.0	360.0				6	0.01	0.009	0.01	0.013	0.06667	0.00278				1.0	2.0	4.0	8.0	40.0				1.0	1.0	2.0	4.0	32.0				KHA	MAMU
VES 74	498.7	383.5	2.8	2.3						4	0.002	0.003	0.36	0.435						0.7	15.7	98.9						0.7	15.0	83.2						QQ	MAMU
VES 75	773.5	130.4	23.4	15.9						4	0.001	0.008	0.04	0.063						2.8	17.2	99.2						2.8	14.4	82.0						QQ	MAMU
VES 76	765.0	1105.0	500.0	100.0	22.0	16.0				6	0.001	9E-04	0	0.01	0.04545	0.0625				1.0	2.2	10.0	20.0	38.0				1.0	1.2	7.8	10.0	18.0				KQQ	NKPORO
VES 77	1036.0	345.0	10.0	156.0	14.0					5	1E-03	0.003	0.1	0.006	0.07143					3.0	8.0	60.0	100.0					3.0	5.0	52.0	40.0					KQH	NKPORO
VES 78	350.0	209.0	66.0	8.0	28.0	2.0				6	0.003	0.005	0.02	0.125	0.03571	0.5				0.5	1.5	2.8	20.0	40.0				0.5	1.0	1.3	17.2	20.0				QHK	NKPORO
VES 79	25.4	11.9	90.69	996.3	9.89					5	0.039	0.084	0.01	0.001	0.10111					1.3	4.01	6.34	67.69					1.3	2.8	2.3	61.4					HAK	NKPORO
VES 80	180.0	286.0	276.0	200.0	100.0	20.0				6	0.006	0.003	0	0.005	0.01	0.05				1.0	2.0	5.0	12.0	36.0				1.0	1.0	3.0	7.0	24.0				KQH	NKPORO
VES 81	358.0	712.0	500.0	300.0	95.0	3.0	2.0			7	0.003	0.001	0	0.003	0.01053	0.33333	0.5			1.0	2.0	2.8	6.0	22.0	36.0			1.0	1.0	0.8	3.2	16.0	14.0			KQQ	NKPORO
VES 82	40.0	46.0	132.0	115.0	15.0	10.0	354.0			7	0.025	0.022	0.01	0.009	0.06667	0.1	0.00282			0.8	1.5	3.0	7.3	20.0	30.0			0.8	0.7	1.5	4.3	12.7	10.0			KHA	NKPORO
VES 83	299.7	548.5	10.64	160.10	312.4					5	0.003	0.002	0.09	0.006	0.0032					1.3	7.1	20.6	63.3					1.3	5.8	13.5	42.7					KHA	NKPORO
VES 84	109.2	702.1	1.3	9.6	1.1	16.3				6	0.009	0.001	0.77	0.104	0.87581	0.06138				1.2	3.5	24.3	47.7	110.8				1.2	2.3	20.8	23.4	63.1				KQH	NKPORO
VES 85	355.0	226.0	69.0	10.0	30.0	3.0				6	0.003	0.004	0.01	0.1	0.03333	0.33333				0.6	1.7	3.5	22.0	40.0				0.6	1.1	1.8	18.5	18.0				QHK	NKPORO

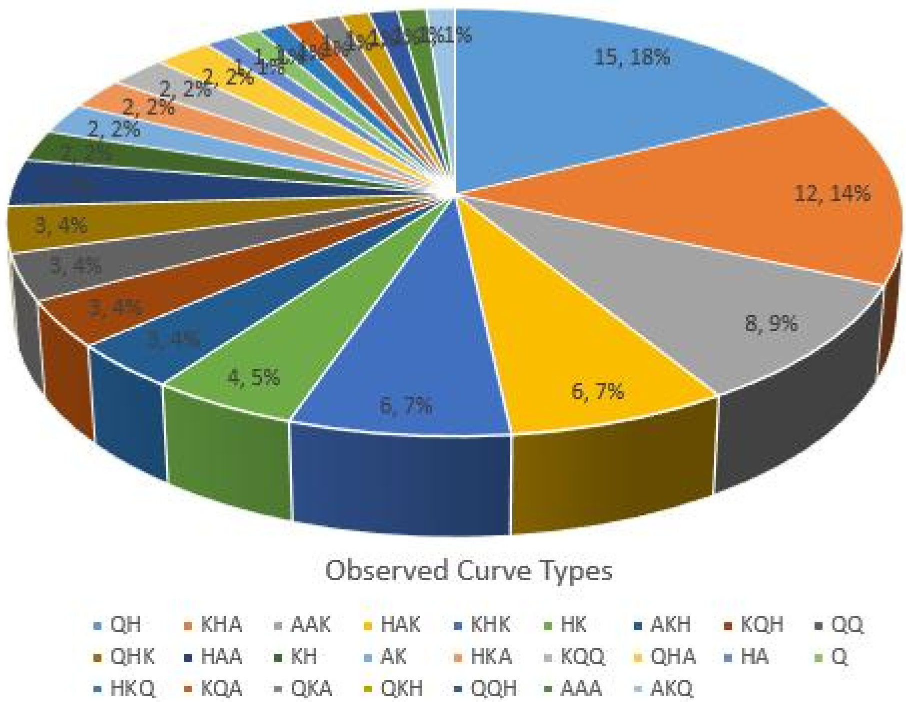


Fig 4.3 Frequency Distribution of Observed Curve-types in the study area

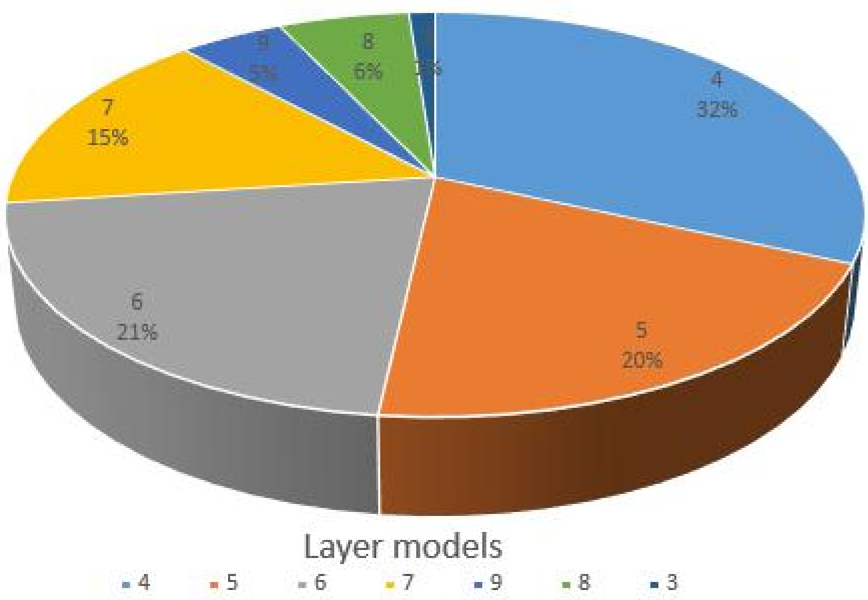


Fig 4.4 Distribution of different layer-models in the study area

4.3 Iso-Resistivity Modelling of the Study Area

Iso-resistivity indicates variance in apparent resistivity at a given depth for different locations within a specified setting. The differences can be a good indication of low or high resistivity areas that can help determine places with or without aquifers. The apparent resistivity values at specified spread of AB/2 = 5m, 8m, 10m, 15m, 20m, 50m, 80m, 100m, 150m and 200m of all the locations were collated as shown in (table 4.3).

Table 4.3 Iso-Resistivity Parameters Integrated from the study area

S/N	VES POINTS	LOCATION	AB/2-5	AB/2-8	AB/2-10	AB/2-15	AB/2-20	AB/2-50	AB/2-80	AB/2-100	AB/2-150	AB/2-200
1	VES 1*	OJIAGU TOWN HALL AGBANI NK	1700	2200	2500	2900	2900	1800	680	350	140	120
2	VES 2	SPECIAL SCI GIRLS SEC. SCH. A	900	1200	1300	1500	1300	600	300	290	2800	2700
3	VES 3*	OGBASHI VILLAGE SQ NDIUNO	1100	1100	1250	800	600	210	240	280	290	300
4	VES 4	EZEMEZUOBODO IKORO UMUOI	180	170	160	140	120	100	120	140	160	210
5	VES 5	GIRLS SEC. SCH. UMUOIKA ENU	180	170	150	120	100	90	140	160	190	250
6	VES 6	AMANKPUME NKEREFI NKANU	180	120	160	150	120	90	140	150	180	250
7	VES 7	AMAOFU NKANU EAST	185	180	170	150	130	100	150	170	220	280
8	VES 8	OBODO EBUNABO NKEREFI NKA	180	179	150	120	100	90	130	140	170	200
9	VES 9	UMUOVUDU 1 UMUOIKA NKERE	180	170	150	120	90	90	130	140	170	220
10	VES 10	OBUOHIA NKANU EAST/ WEST	800	500	350	150	45	18	18.5	19	21	24
11	VES 11	ONUACHI AGBANI NKANU WES	600	490	450	350	250	110	120	130	150	200
12	VES 12*	NARA NKANU EAST	55	38	30	20	13	13	17	18	19	19.5
13	VES 13	OBINAGU UWANI AKPUGO NKA	75	96	68	60	45	25	35	45	60	80
14	VES 14	OBINAGU UWANI NKANU	6.5	5.4	5	5	5	5	4.5	4	2.5	1.1
15	VES 15	OBINAGU UWANI NKANU	90	85	80	55	40	18	15	13	9	8
16	VES 16*	AFOR PRIMARY SCH ABOR UDI	700	800	860	1200	1400	2500	3500	4000	4500	5600
17	VES 17	OBINAGU UDI	185	190	190	195	198	210	250	270	300	350
18	VES 18	AMAGU UMUENE IBITE OKPATU	1600	1700	1800	1900	2200	3500	4800	3500	7500	9000
19	VES 19	OGENE OJEBE, UDI	350	510	600	800	1100	2600	2650	4800	6000	7500
20	VES 20	EKE-UDI SQUARE UDI	160	350	460	650	800	1800	2400	2600	3000	3400
21	VES 21*	NACHI, UDI	1900	1880	1600	1500	1200	200	80	70	80	90
22	VES 22	OFF NACHI, UDI	2200	1900	1800	1700	1500	550	150	100	75	80
23	VES 23	NACHI BY AMOKWE RD, UDI	2000	1800	1700	1600	1200	200	700	650	680	700
24	VES 24	AMOKWE, UDI	2200	1900	1800	1600	1400	220	100	90	100	220
25	VES 25	AMOKWE BY NACHI RD, UDI	24000	25000	23000	22000	20000	22000	28000	29000	30000	32000
26	VES 26	EKEAGU OBELEAGU, EZEAGU	3500	2600	2500	1900	1400	300	340	350	300	450
27	VES 27	UMUGHU OBELEAGU, EZEAGU	3500	4200	4900	5500	6000	3800	2000	1600	1500	1900
28	VES 28	UMANA OBELEAGU, EZEAGU	4000	5000	5500	6000	6200	4200	2000	1200	600	700
29	VES 29	OBELEAGU BY AMOKWE ROAD,	4000	2400	2000	1900	1800	800	600	550	650	850
30	VES 30	UDI BY AMOKWE RD, UDI	3000	2900	2900	2800	2600	1500	600	320	170	160
31	VES 31	AMOKWE, UDI	3200	4000	5000	6000	7000	10000	8000	4000	6000	1000
32	VES 32*	AMOKWE, UDI	2500	2400	2400	2300	2200	1400	600	350	300	220
33	VES 33	UDI, UDI	7500	6500	6000	5400	4800	2000	1200	850	800	1000
34	VES 34	OBELEAGU UMANA, EZEAGU	14000	8800	8000	7500	6500	4800	2500	1800	1300	1400
35	VES 35	NSUDE, UDI	2500	2100	2000	1900	1800	800	300	180	100	90
36	VES 36	AMAOKWE, UDI	1600	1800	1900	2200	2500	3500	4000	4200	4000	3500
37	VES 37	UMUABI, UDI	300	420	500	700	900	2000	3000	3500	4800	5000
38	VES 38	UMUEZE UMUAGA, UDI	1400	1500	1600	1700	1800	2800	4000	4500	5500	6500
39	VES 39	NSUDE II, UDI	1950	2200	2500	2800	3000	5200	7000	8000	12000	14000
40	VES 40	EZIAMA EBE	16000	18000	20000	24000	25000	27000	28000	28000	28000	27000
41	VES 41	OKPATU II, UDI	16000	18000	20000	24000	25000	27000	28000	28000	28000	27000
42	VES 42	AMACHALA OBIOMA, UDI	1300	1500	1600	1800	2000	3200	4000	4500	5200	6000
43	VES 43	AMAOKWE, UDI	5000	8000	8500	13000	15000	17000	12000	8500	6500	6000

44	VES 44	OBEAGU UKANA, UDI	700	850	1000	1400	1700	2800	3200	3500	3800	4000
45	VES 45	OFF OBIOMA, UDI	7000	5000	4500	4000	3600	1000	300	250	200	250
46	VES 46	UMUDIM, UDI	2800	2600	2500	2400	2000	400	120	90	100	140
47	VES 47*	OBIOMA COMM. HIGH SCH, UDI	780	740	730	650	600	180	60	55	650	80
48	VES 48	UMUAJI MGBAGBU OWA, EZEA(	500	560	650	750	1000	1400	1200	1100	1250	1500
49	VES 49	AGUAGBAJA UMUNADIAGU, EZ	1000	1600	1800	2500	3000	5200	5500	5400	4500	3000
50	VES 50	IBITO OLO, EZEAGU	70	17	12	11	11	14	18	20	26	35
51	VES 51	IWOLLO TOWN, EZEAGU	85	80	85	120	140	220	140	245	250	260
52	VES 52	AGULU OBELEAGU UMANA, EZE	650	650	700	750	900	1900	2700	2900	3500	3800
53	VES 53	UMUAJI AGUOBU-OWA, EZEAGI	1500	1700	1750	1850	2200	3400	3800	4000	4500	4600
54	VES 54*	IHUONAYIA CITY OGHE, EZEAGU	800	550	480	300	180	28	30	35	42	49
55	VES 55	EZEAMA AGU AGUOBU-OWA	600	500	350	210	100	54	70	75	80	45
56	VES 56	IMEZI .O, EZEAGU	12000	9000	8000	7000	4200	700	380	350	320	360
57	VES 57	AGUOBI IWOLLO, EZEAGU	640	420	320	180	90	75	80	85	100	120
58	VES 58*	OGHE, EZEAGU	220	170	160	145	140	150	160	170	180	175
59	VES 59	ANIKE IWOLLO, EZEAGU	540	510	500	460	380	160	130	130	150	180
60	VES 60	NDIAGU-UMANA, EZEAGU	750	1200	1500	1850	2100	3500	4000	4500	4200	3800
61	VES 61	COMM. SEC SCH OLO, EZEAGU	400	150	80	18	6	9	12	13	14	12
62	VES 62	OGWUOFIA, EZEAGU	4800	4500	4200	3800	3000	850	700	740	800	1100
63	VES 63	NGWO, UDI	3000	3500	4000	5000	6500	15000	20000	20400	30000	30500
64	VES 64	EHUHE ACHI OJI RIVER	200	250	320	490	600	1500	2000	2500	3000	4000
65	VES 65	UMUEKE OZEGU INYI OJI RIVER	1800	1950	2000	2000	1900	2400	3000	3500	4000	4800
66	VES 66	OBEAGU, AWGU	1800	1400	1000	550	350	240	350	400	600	800
67	VES 67*	AKPUGO-EZE, OJI RIVER	22	20	21	28	30	90	100	120	180	200
68	VES 68	UGWUOBA OJI RIVER	12	18	19	25	35	65	100	140	180	220
69	VES 69	UMUEZE, EZEAGU	5500	5600	5800	5700	5600	4500	3900	4000	4800	5000
70	VES 70	AMANSIODO EZEAGU	120	180	220	350	400	900	1500	1800	2200	2500
71	VES 71	OKPOGHO, EZEAGU	180	250	340	500	600	1500	1700	2600	3500	4000
72	VES 72	AFOR- UGWU, UDI	70	140	160	200	280	700	1400	1500	2000	2400
73	VES 73	COAL CAMP, ENUGU	140	110	100	700	45	24	30	40	60	75
74	VES 74*	WINNERS ESTATE TRANS-EKULU, ENUGU EAST	400	390	380	350	280	450	6	4	3	2.6
75	VES 75*	PHASE 6 TRANS-EKULU, ENUGI	480	280	220	150	120	45	28	25	22	20
76	VES 76*	OZALLA NKANU, ENUGU	700	600	500	400	250	45	22	19	18	17
77	VES 77	OBODOAKPU AGBOGUGU, AWG	650	600	380	180	60	12	15	18	20	24
78	VES 78	EMENE INDUSTRIAL LAYOUT, ENUGU	50	20	12	9	9	12	10	9	6	4
79	VES 79	ENUGU INDEPENDENT LAYOUT	20	28	32	50	65	150	200	240	260	270
80	VES 80	UMUGHOKENE IJI-NIKE ENUGU	250	250	240	200	180	90	50	40	25	22
81	VES 81	UMUGHOKENE IJI-NIKE ENUGU	450	350	300	180	140	25	6	3	2.2	2
82	VES 82	NIKE LAKE ROAD, ENUGU	70	80	75	60	50	28	40	45	65	80
83	VES 83	HARMONY ESTATE NIKE, ENUGU	420	400	380	280	170	38	50	58	78	100
84	VES 84*	OBEAGU ENUGU SOUTH	240	220	190	140	50	3	2.8	3	3.2	3.2
85	VES 85	9 ABAKALIKI ROAD EMENE	80	28	20	14	12	14	12	10	7	4.5

The iso- resistivity models were generated at depth intervals of 10m, 50m, 100m, and 200m (See figure 4.5a-d).

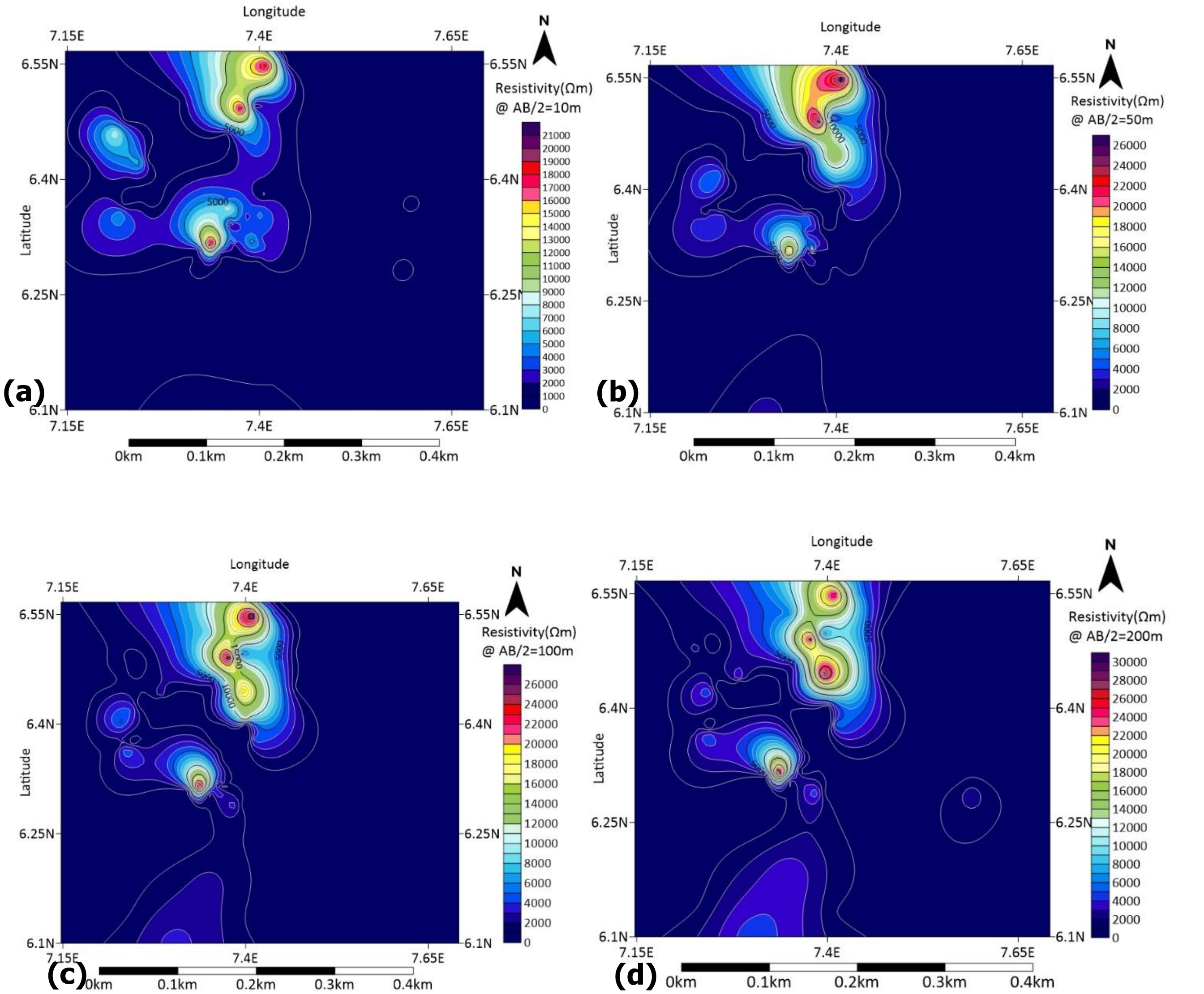


Fig 4.5 2D Spatial Distribution Maps of Iso-Resistivity across the study area: (a) AB/=10m (b) AB/2=50m (c) AB/2=100m (d) AB/2=200m

4.3.1 Explanation of the Iso-Resistivity model of the study area

The iso-resistivity map for AB/2 = 10m, AB/2 = 50m, AB/2 = 100m and AB/2 = 200m in Fig. 5a-d shows that most parts of the study region have relatively low resistivity, except for some sections in the northern and northwestern regions. These low resistive areas with deep blue color codes in Fig. 5a have resistivity values ranging between 0 and 2000Ωm. The iso-resistivity model of the study area at this half current electrode spacing with an effective depth of penetration of 3.33 m generally revealed that across the study area, the resistivity values increased from about 2000Ωm (blue) to 32,000 Ωm (purple). The low resistivity areas may indicate silt/shale/clay units with the deep blue color indicators, while the high resistivity areas other colors of the map may reflect areas underlain by sand/sandstone/siltstone.

4.4 Spatial Variation of Aquifer Geometric Properties of the Study Area

4.4.1 Resistivity of the Aquiferous Layer

The resistivity of an aquifer serves as a basis for the assessment of any locations water bearing unit or aquifer unit. The aquifer resistivity of the study area was evaluated from the Vertical Electrical Sounding (VES) data and it ranges from a value of 2.8 Ωm at Winner estate Trans-Ekulu (VES 74) to 88745.0 Ωm at Ngwo,Udi (VES 63), with a mean value of 5434.61 Ωm. The resistivity map of the study area in Fig. 4.6 below shows that most parts have high aquifer resistivity value, but there are some areas that have higher resistivity value than others. The resistivity value is higher towards the northern and southwestern Part of the study area when compared to north eastern and south-eastern parts which has low resistivity. Generally, the reasons some areas have higher resistivity than the other is because areas with a higher resistivity have more alternation of sandstones when compare to the areas with a low resistivity which are predominantly shales.

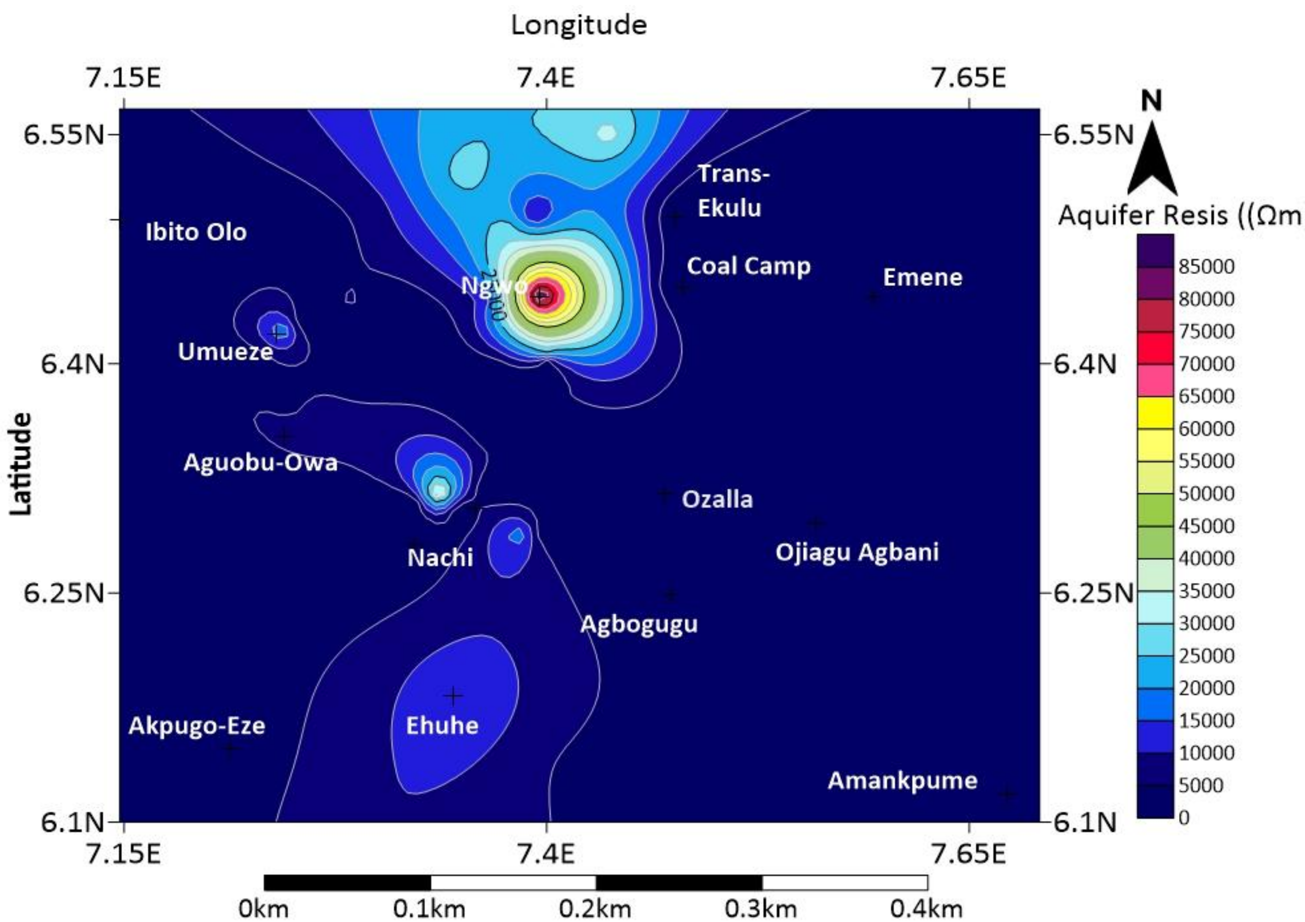


Fig 4.6 Spatial Distribution Map of Aquifer Resistivity (Ωm) of the study area

4.4.2 Aquifer Conductivity

Aquifer conductivity is the inverse of aquifer resistivity, and it ranged between a value of 1.12682E-05 mhos at Ngwo (VES 63) and 0.357142857 mhos at Winners Estate Trans-Ekulu (VES 74) (see Table 4.4), with a mean value of 0.02019914 mhos. The aquifer conductivity map of the study area in Fig 4.7 below reveals that conductivity is increasing towards the northeastern part of the study area and decreasing towards the northwestern and southwestern parts of the area. However, what that implies is that areas with high conductivity, on the contrary have a low resistivity; and this is an indication that those places are overlain by clay, mud, shale and silt while areas with low conductivity have a high resistivity, and this is because it contains a thick volume of sand and sandstone lithologies.

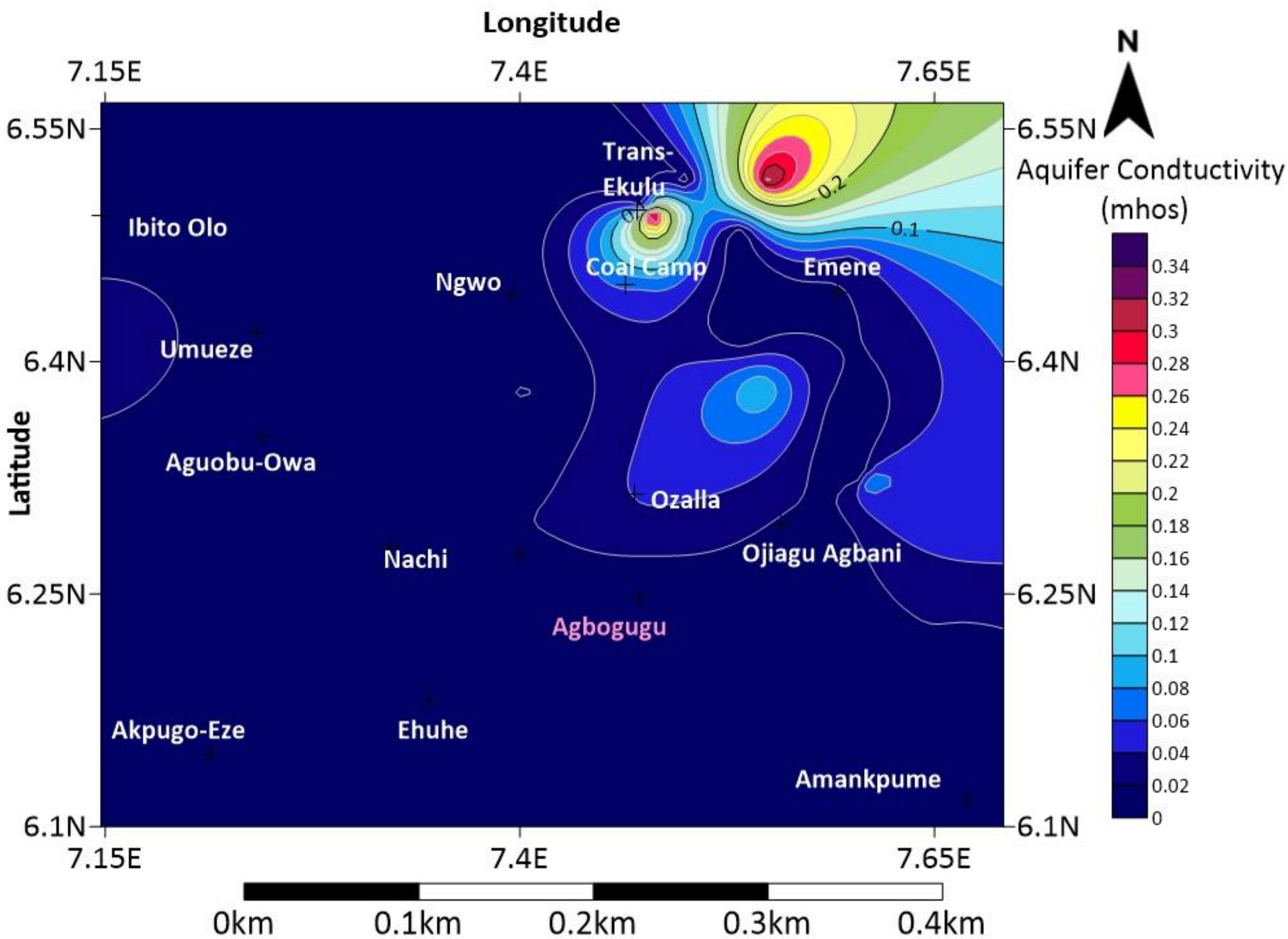


Fig 4.7 Spatial Distribution Map of Aquifer Conductivity (mhos) of the study area

4.4.3 Aquifer Depth

The depth to water table across the study area varies between 23.4 m at Nsude (VES 35) and 375.0 m at Umuoika Nkerefi Nkanu (VES 4) obtained from the Table 4.4 above with a mean value of 132.5 m. The distribution map of depth to water table in Fig. 4.8(a) and Fig. 4.8(b) shows different aquifer depth in various parts of the area. The area that is indicated with dark blue colour has a shallow aquifer towards the central, northeastern and Southeastern parts of the study area, area that is represented with a light blue, sky blue, green, and white colour has a moderately deep aquifer towards the Northern, Eastern, Southern Western and Central parts of the study area. Hence, the area that has a relatively deeper aquifer is represented with an orange and dark purple colour towards the northern, north-western and south-eastern parts of the study area.

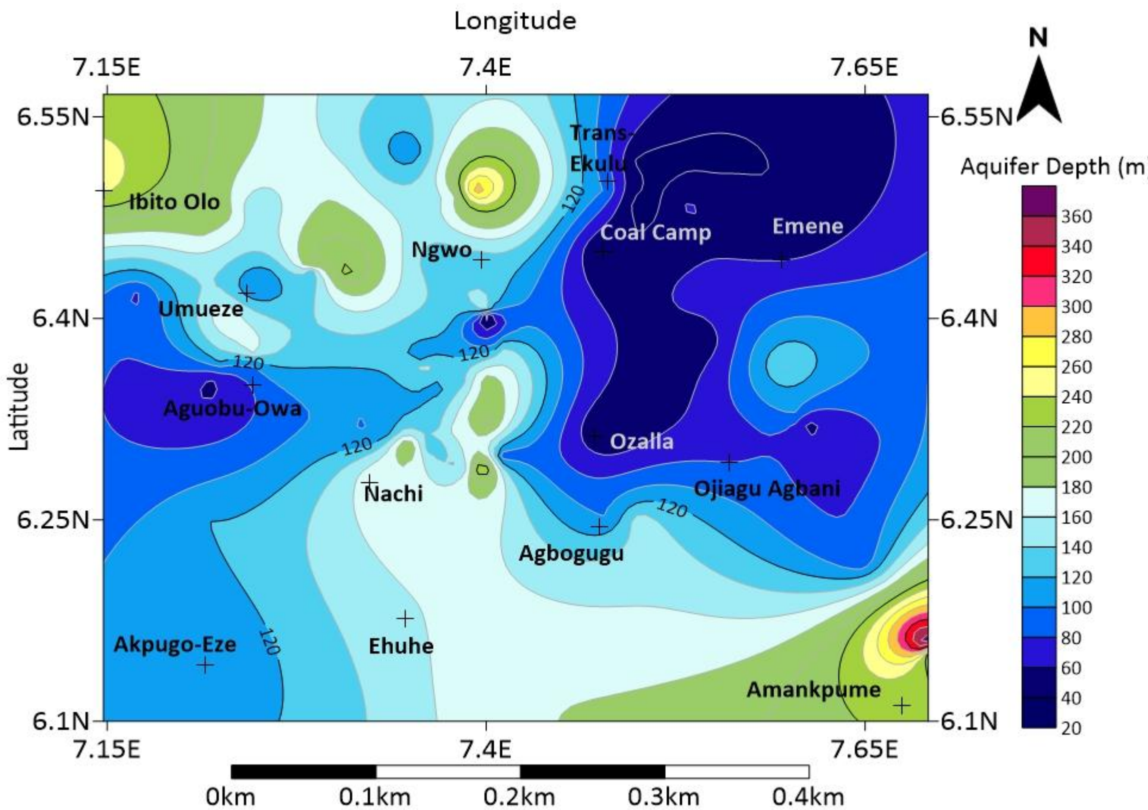


Fig 4.8(a) 2D Spatial Distribution Map of Aquifer Depth (m) of the study area

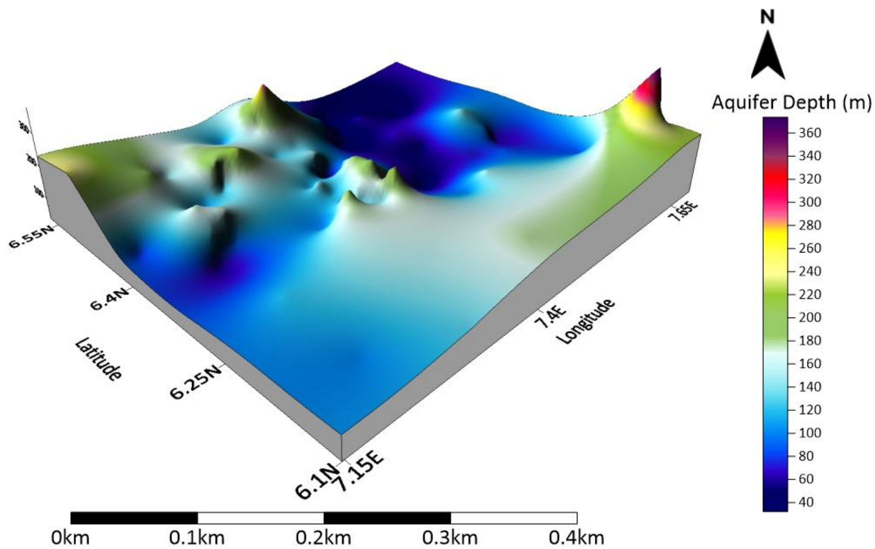


Fig 4.8(b) 3D Topography of the Aquifer Surface Depth (m) of the study area

4.4.4 Aquifer Thickness

The result of the study shows a strong spatial distribution of aquifer thickness across the study area with values varies between 10.0 m at Nike lake road (VES 82) and 224.0 m at Umuoika Nkerefi Nkanu (VES 4) with a mean value of 86.96 m. The distribution map of aquifer thickness of the study area in Fig. 4.9(a) and Fig. 4.9(b) reveals how various aquifers in the area vary in thickness. The area marked with purple colour have a thicker aquifer towards the southeastern and northwestern parts of the study area whereas area marked with a blue colour have a relatively thinner aquifer towards the southeastern, southwestern, northwestern and central parts of the study area.

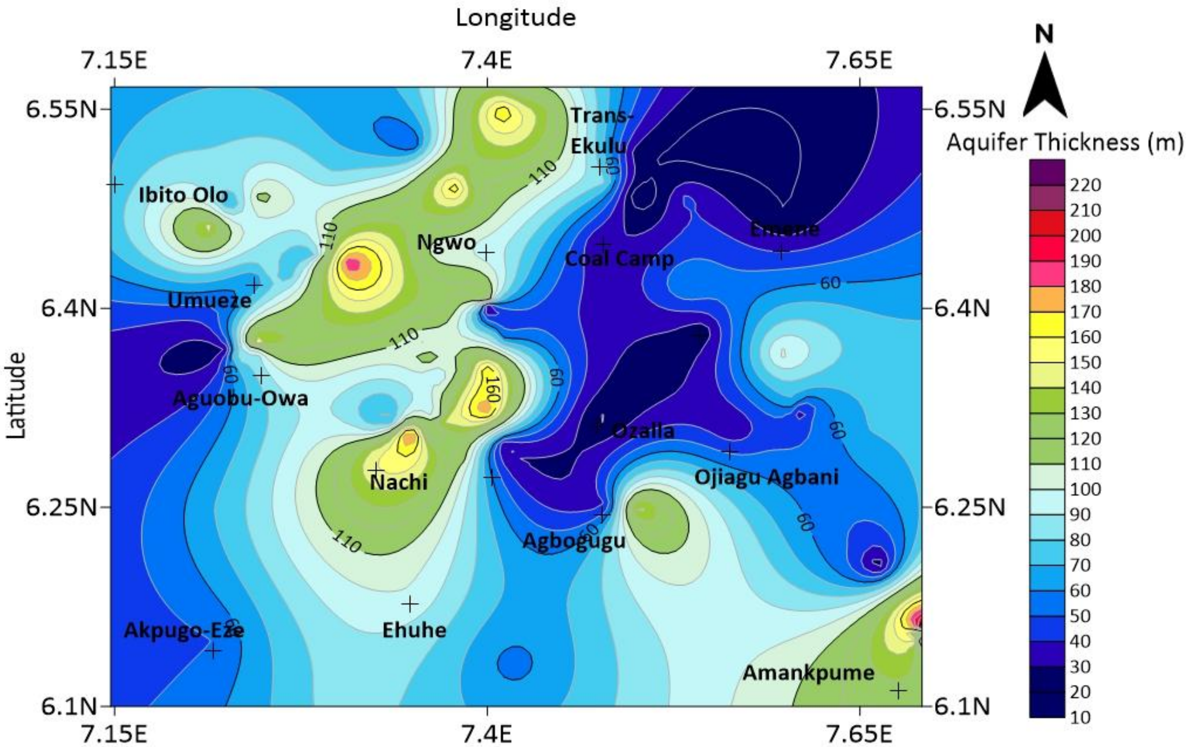
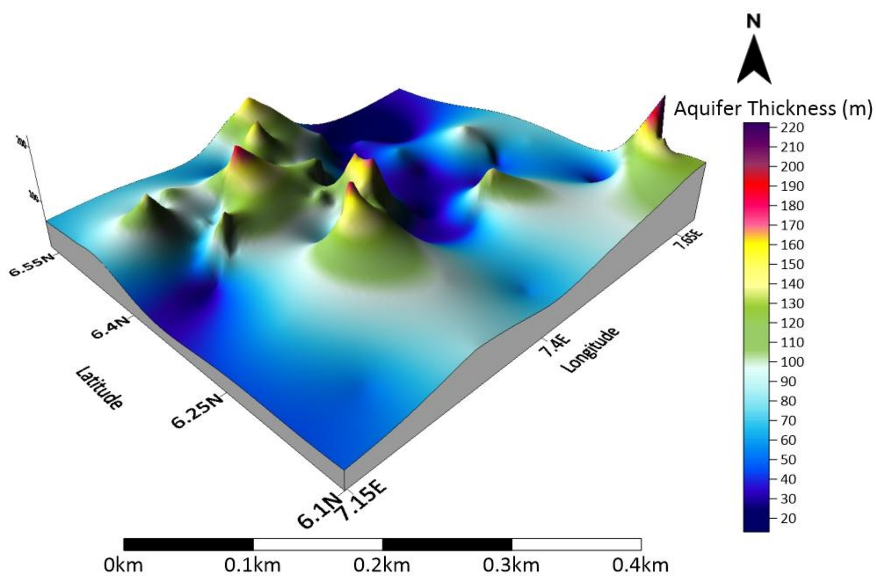


Fig 4.9(a) Spatial Distribution Map of Aquifer Thickness (m) of the study area



Z

Fig 4.9(b) 3D Topography of the Aquifer Surface Thickness (m) of the study area

4.4.5 Transverse Resistance

The transverse resistance (R) is one of the parameters employed to describe target areas of desirable groundwater potential. It has a direct relationship with transmissivity such that highest transverse resistance values reflect most likely the highest transmissivity values of aquirous zones and vice versa (Opara, et al. 2015). The transverse resistance which is the product of aquifer resistance and thickness was estimated from the Vertical Electrical Sounding across the study area and was varies between 42.0 Ωm^2 at Umughokene Iji-Nike Enugu 2 (VES 81) to 8, 4430,775.00 Ωm^2 at Ngwo Udi (VES 63) with a mean value of 560,402.77 Ωm^2 (Table 4.4). Spartial distribution map of transverse resistance in Figure (4.10) reveals that transverse resistance increases from the northwestern region to the northern region of the study area (areas with sky blue, white, Orange, Green, and purple colours). By implication, high values of transverse resistance is associated with high transmissivity which in turn pictures high groundwater potential (Oli, et al. 2020). However, transverse resistance decreases towards the central, eastern, and southwestern region of the study area (areas with a dark blue colour).

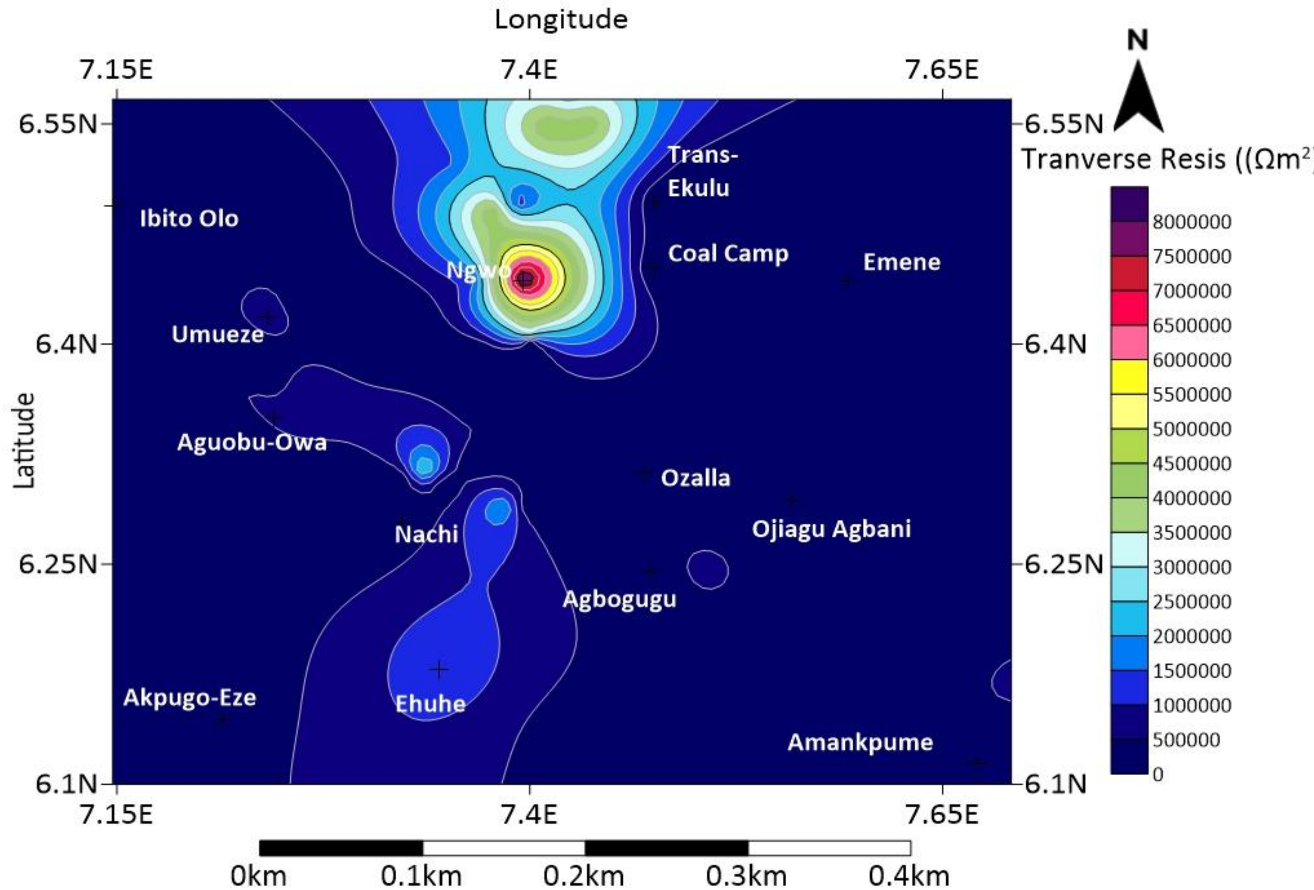


Fig 4.10 Spatial Distribution Map of Transverse Resistance (Ωm^2) of the study area

Table 4.4 Summary of Aquifer Parameters Integrated from the study area

S/N	VES POINTS	LATITUDE	LONGITUDE	LOCATION	AQUIFER RESISTIVITY (ohm-1)	AQUIFER DEPTH (m)	AQUIFER THICKNESS (m)	AQUIFER CONDUCTIVITY (σ)	TRANVERSE RESISTANCE (R)
1	VES 1*	6º17"49.6'N	7º34"39.4'E	OJIAGU TOWN HALL AGBANI NKANU WEST	42.0	85.0	29.0	0.023809524	1218.00
2	VES 2	6˚17'16.7"N	7˚35'18.7"E	SPECIAL SCI GIRLS SEC. SCH. AGBANI NKANU WEST	250.0	85.0	53.0	0.004	13250.00
3	VES 3 *	6˚21'57.35"N	7˚35'49.7"E	OGBASHI VILLAGE SQ NDIUNO AKPUGO NKANU WEST	733.0	143.9	104.0	0.001364256	76232.00
4	VES 4	6˚09'35.89"N	7˚41'29.84"E	EZEMEZUOBODO IKORO UMUOIKA NKEREFI NKANU EAST	3630.0	375.0	224.0	0.000275482	813120.00
5	VES 5*	6˚08'57.20"N	7˚41'24.95"E	GIRLS SEC. SCH. UMUOIKA ENUOGU NKEREFI NKANU EAST	792.0	203.0	87.0	0.001262626	68904.00
6	VES 6	6˚09'05.67"N	7˚41'19.0"E	AMANKPUME NKEREFI NKANU EAST	508.0	300.0	44.0	0.001968504	22352.00
7	VES 7	6˚10'40.09"N	7˚40'14.00"E	AMAOFU NKANU EAST	1100.0	270.0	151.0	0.000909091	166100.00
8	VES 8*	6˚10'21.33"N	7˚39'45.53"E	OBODO EBUNABO NKEREFI NKANU EAST	498.0	153.0	22.0	0.002008032	10956.00
9	VES 9	6˚09'03.38"N	7˚41'20.46"E	UMUOVUDU 1 UMUOIKA NKEREFI NKANU EAST	494.0	149.0	58.0	0.002024291	28652.00
10	VES 10	6˚18'31.51"N	7˚39'19.22"E	OBUOHIA NKANU EAST/ WEST FED. CONSTITUENCY	17.0	76.7	70.2	0.058823529	1193.40
11	VES 11	6˚18'36"N	7˚33'57.60"E	ONUACHI AGBANI NKANU WEST	46.5	70.1	30.4	0.02151926	1412.69
12	VES 12 *	6˚13'04.97"N	7˚38'53.20"E	NARA NKANU EAST	60.0	85.0	47.0	0.016666667	2820.00
13	VES 13	6˚19'38.5"N	7˚36'21.5"E	OBINAGU UWANI AKPUGO NKANU WEST	1628.0	98.3	66.9	0.000614251	108913.20
14	VES 14	6˚19'22.2"N	7˚36'41.0"E	OBINAGU UWANI NKANU	10.7	52.5	24.0	0.093457944	256.80
15	VES 15	6˚19'6.0"N	7˚37'0.5"E	OBINAGU UWANI NKANU	16.8	58.8	50.7	0.05952381	851.76
16	VES 16 *	6˚29'47"N	7˚23'34"E	AFOR PRIMARY SCH ABOR UDI	9000.0	300.0	120.0	0.000111111	1080000.00
17	VES 17	6˚17'19.65"N	7˚23'51.36"E	OBINAGU UDI	733.0	260.0	70.0	0.001364238	51310.70
18	VES 18	6˚34'0.49"N	7˚25'26.7"E	AMAGU UMUENE IBITE OKPATU, UDI	25178.0	155.0	110.0	3.97172E-05	2769580.00
19	VES 19	6˚33'1.01"N	7˚26'12.5"E	OGENE OJEBE, UDI	32587.0	150.0	135.0	3.06871E-05	4399245.00
20	VES 20	6˚27'28.00"N	7˚21'27"E	EKE-UDI SQUARE UDI	4500.0	150.0	147.0	0.000222222	661500.00
21	VES 21 *	6˚17'38.54"N	7˚19'26.60"E	NACHI, UDI	60.0	154.7	140.5	0.016666667	8430.00
23	VES 23	6˚18'18.57"N	7˚20'52.30"E	NACHI BY AMOKWE RD, UDI	57.5	210.6	195.5	0.017391304	11241.25
24	VES 24	6˚19'03.63"N	7˚22'04.54"E	AMOKWE, UDI	79.0	162.9	149.0	0.012666244	11763.55
25	VES 25	6˚18'52.22"N	7˚20'10.39"E	AMOKWE BY NACHI RD, UDI	40707.0	115.0	69.0	2.45658E-05	2808783.00
26	VES 26	6˚23'49.0"N	7˚22'15.0"E	EKEAGU OBELEAGU, EZEAGU	261.1	130.0	120.0	0.00382995	31332.00

27	VES 27	6°21'18.0"N	7°13'06.0"E	UMUGHU OBELEAGU, EZEAGU	347.4	57.9	36.0	0.002878775	12505.32
28	VES 28	6°20'58.0"N	7°22'01.0"E	UMANA OBELEAGU, EZEAGU	293.7	112.0	88.0	0.003405067	25843.84
29	VES 29	6°18'35.0"N	7°19'19.0"E	OBELEAGU BY AMOKWE ROAD,	357.9	103.1	83.3	0.002794155	29812.24
30	VES 30	6°19'20.24"N	7°24'01.20"E	UDI BY AMOKWE RD, UDI	115.8	216.0	180.0	0.008635579	20844.00
31	VES 31	6°19'07.53"N	7°22'00.77"E	AMOKWE, UDI	60.0	126.0	95.0	0.016666667	5700.00
32	VES 32 *	6°19'08.34"N	7°21'49.95"E	AMOKWE, UDI	105.3	127.8	100.0	0.009500285	10526.00
33	VES 33	6°19'05.90"N	7°23'31.22"E	UDI, UDI	705.9	181.8	162.0	0.001416651	114354.18
34	VES 34	6°21'54.0"N	7°21'33.0"E	OBELEAGU UMANA, EZEAGU	777.7	153.3	123.0	0.001285843	95657.10
35	VES 35	6°24'06.23"N	7°23'59.75"E	NSUDE, UDI	1938.4	23.4	22.1	0.000515889	42838.64
36	VES 36	6°18'20.3"N	7°21'48.9"E	AMAOKWE, UDI	5961.2	118.2	100.3	0.000167751	597908.36
37	VES 37	6°17'19"N	7°23'06"E	UMUABI, UDI	18693.2	136.2	114.7	5.34954E-05	2144110.04
38	VES 38	6°26'39"N	7°22'500"E	UMUEZE UMUAGA, UDI	13542.4	123.5	100.2	7.38422E-05	1356948.48
39	VES 39	6°24'20"N	7°23'56"E	NSUDE II, UDI	22838.5	152.3	133.8	4.37857E-05	3055791.30
40	VES 40	6°29'29"N	7°22'40"E	EZIAMA EBE UDI	26372.6	171.0	169.7	3.79181E-05	4475430.22
41	VES 41	6°31'54.3"N	7°24'36.3"E	OKPATU II, UDI	26372.6	171.0	169.7	3.79181E-05	4475430.22
42	VES 42	6°22'43.20"N	7°24'38.40"E	AMACHALA OBIOMA, UDI	4479.2	143.1	54.2	0.000223254	242772.64
43	VES 43	6°19'26.4"N	7°21'00"E	AMAOKWE, UDI	27453.4	103.0	49.2	3.64254E-05	1350707.28
44	VES 44	6°30'10.8"N	7°17'49.20"E	OBEAGU UKANA, UDI	7284.5	177.1	79.4	0.000137278	578389.30
45	VES 45	6°21'17"N	7°23'59"E	OFF OBIOMA, UDI	170.0	191.0	171.9	0.005882353	29223.00
46	VES 46	6°21'05"N	7°23'04"E	UMUDIM, UDI	71.1	133.0	117.0	0.014074595	8312.85
47	VES 47 *	6°22'50"N	7°24' 17"E	OBIOMA COMM. HIGH SCH, UDI	37.5	93.5	76.8	0.026666667	2880.00
48	VES 48	6°22'06.83"N	7°13'26.98"E	UMUAJI MGBAGBU OWA, EZEAGU	3560.0	125.0	28.6	0.000280899	101816.00
49	VES 49*	6°24'08.92"N	7°13'41.23"E	AGUAGBAJA UMUNA-NDIAGU, EZEAG	326.0	178.0	53.2	0.003067485	17343.20
50	VES 50	6°29'57.41"N	7°08'51.05"E	IBITO OLO, EZEAGU	200.0	250.0	70.0	0.005	14000.00
51	VES 51*	6°25'32.4"N	7°15'54"E	IWOLLO TOWN, EZEAGU	107.2	123.0	69.9	0.009328358	7493.28
52	VES 52	6°20'34.5"N	7°21'48.3"E	AGULU OBELEAGU UMANA, EZEAGU	5961.2	118.2	100.3	0.000167751	597908.36
53	VES 53	6°21'59"N	7°14'43"E	UMUAJI AGUOBU-OWA, EZEAGU	5627.1	100.9	84.6	0.000177711	476052.66
54	VES 54 *	6°29'01.2"N	7°14'52.2"E	IHUONAYIA CITY OGHE, EZEAGU	47.9	142.1	115.8	0.020876827	5546.82
55	VES 55	6°22'29.1"N	7°14'42.5"E	EZEAMA AGU AGUOBU-OWA	97.9	165.7	151.3	0.010214505	14812.27
56	VES 56	6°27'38.5"N	7°12'46.9"E	IMEZI .O, EZEAGU	271.0	179.3	149.1	0.003690037	40406.10
57	VES 57	6°25'38"N	7°15'20"E	AGUOBI IWOLLO, EZEAGU	82.4	97.5	89.1	0.012135922	7341.84
58	VES 58 *	6°26'03"N	7°18'26"E	OGHE, EZEAGU	192.6	228.4	192.6	0.005192108	37094.76
59	VES 59	6°26'05.04"N	7°17'03.9"E	ANIKE IWOLLO, EZEAGU	104.4	119.8	106.9	0.009578544	11160.36
60	VES 60	6°21'48.95"N	7°13'55.2"E	NDIAGU-UMANA, EZEAGU	7344.0	91.4	84.9	0.000136166	623505.60
61	VES 61*	6°25'04"N	7°10'11"E	COMM. SEC SCH OLO, EZEAGU	27.3	76.5	60.9	0.036630037	1662.57
62	VES 62	6°22'14"N	7°21'29"E	OGWUOFIA, EZEAGU	529.0	108.0	94.9	0.001890359	50202.10
63	VES 63	6°26'38.79"N	7°23'45.16"E	NGWO, UDI	88745.0	130.0	95.0	1.12682E-05	8430775.00
64	VES 64	6°11'00.57"N	7°21'00.44"E	EHUHE ACHI OJI RIVER	14320.0	158.0	98.0	6.98324E-05	1403360.00
65	VES 65	6°06'00.18"N	7°18'00.27"E	UMUEKE OZEGU INYI OJI RIVER	9786.0	130.0	85.0	0.000102187	831810.00
66	VES 66	6°07'57.25"N	7°25'00.09"E	OBEAGU, AWGU	3200.3	178.2	55.6	0.000312471	177936.68
67	VES 67*	6°09'00.18"N	7°12'45.49"E	AKPUGO-EZE, OJI RIVER	1250.0	100.0	50.0	0.0008	62500.00
68	VES 68	6°15'00.42"N	7°13'00.62"E	UGWUOBA OJI RIVER	1258.0	120.0	70.0	0.000794913	88060.00
69	VES 69	6°25'17.92"N	7°14'39.42"E	UMUEZE, EZEAGU	20000.0	103.2	60.0	0.00005	1200000.00

70	VES 70	6˚28'41.42"N	7˚16'15.68"E	AMANSIODO EZEAGU	3723.9	192.3	66.5	0.000268536	247639.35
71	VES 71	6˚26'16.54"N	7˚17'01.59"E	OKPOGHO, EZEAGU	6176.6	200.1	72.1	0.000161901	445332.86
72	VES 72	6˚22'16.17"N	7˚15'35.72"E	AFOR- UGWU, UDI	6428.0	136.0	128.5	0.000155569	825998.00
73	VES 73	6˚27'03.73"N	7˚28'23.27"E	COAL CAMP, ENUGU	15.0	40.0	32.0	0.066666667	480.00
74	VES 74*	6˚29'45.5"N	7˚28'43.8"E	WINNERS ESTATE TRANS-EKULU, ENU	2.8	98.9	83.2	0.357142857	232.96
75	VES 75*	6˚29'57"N	7˚28'34"E	PHASE 6 TRANS-EKULU, ENUGU	23.4	99.2	82.0	0.042735043	1918.80
83	VES 76*	6˚19'00.51"N	7˚28'33.59"E	OZALLA NKANU, ENUGU	22.0	38.0	18.0	0.045454545	396.00
76	VES 77	6º15'04.03"N	7º28'49.55"E	OBODOAKPU AGBOGUGU, AWGU	156.0	100.0	40.0	0.006410256	6240.00
77	VES 78	6º28'00.61"N	7º36'00.37"E	EMENE INDUSTRIAL LAYOUT, ENUGU	28.0	40.0	20.0	0.035714286	560.00
78	VES 79	6º25'00.67"N	7º32'00.09"E	ENUGU INDEPENDENT LAYOUT	996.3	67.69	61.4	0.001003714	61172.82
79	VES 80	6º31'00.12"N	7º30'00.00"E	UMUGHOKENE IJI-NIKE ENUGU	100.0	36.0	24.0	0.01	2400.00
80	VES 81	6º31'01.04"N	7º33'02.00"E	UMUGHOKENE IJI-NIKE ENUGU 2	3.0	36.0	14.0	0.333333333	42.00
81	VES 82	6º29'04.53"N	7º30'02.43"E	NIKE LAKE ROAD, ENUGU	10.0	30.0	10.0	0.1	100.00
82	VES 83	6º29'00.23"N	7º32'09.08"E	HARMONY ESTATE NIKE, ENUGU	160.1	63.3	42.7	0.006246096	6829.87
84	VES 84*	6˚22'59.07"N	7˚32'42.12"E	OBEAGU ENUGU SOUTH	9.6	47.7	23.4	0.104166667	224.64
86	VES 85	6˚27'50.34"N	7˚35'09.80"E	9 ABAKALIKI ROAD EMENE	30.0	40.0	18.0	0.033333333	540.00

4.5 Estimation of Aquifer Hydraulic Parameters across the study area Using Geophysical Data

Aquifer hydraulic parameters (Hydraulic conductivity and Transmissivity) across the study area was generated as shown in Table 4.5 below. Hydraulic conductivity (K) is employed to describe the ability of a material to conduct fluids under a unit hydraulic gradient (Fetter, 1994). It is a constant of proportionality that defines fluid flow through a porous media. Hydraulic conductivity which is the measure of the ease with which a fluid will pass through a medium (Heigold, et al. 1979) was assessed by employing Niwas and Singhal, Heigold and the newly generated geophysical model as presented in Table (4.5) below. The average mean hydraulic conductivity values of the areas measured by Niwas and Singhal model 1982 (ranges from 0.24m/day to 4494.67m/day with a mean value of 260.94m/day), Heigold model 1979 (ranges from 0.01m/day to 147.88m/day with a mean value of 9.22m/day), and the newly generated geophysical model (ranges from 1.05m/day to 34.06m/day with a mean value of 5.59m/day) for the different respective Geologic Formations are shown in Table (4.11) respectively. Consequently, there is a very higher level of understanding between hydraulic conductivity integrated from pumping test and that from the newly generated model when compared with Niwas and Singhal model and Heigold model (See Table 4.5). This reveals that the newly generated model is more efficacious in estimating aquifer hydraulic parameters across the study area. The estimated hydraulic conductivity values across the study area (from newly generated model) varies between 1.05m/day at VES (13) and 34.06 m/day at VES (69) with a mean value of 5.59 m/day. Therefore, the hydraulic conductivity values for the different geologic Formations are presented in Table (4.5). The highest hydraulic conductivity value was recorded within Nsukka Formation while the least value of aquifer hydraulic conductivity were identified within the Awgu Formation (See Table 4.5). The spatial distribution map of hydraulic conductivity in Fig. (4.11) revealed that areas marked with a dark blue colour have a low value of hydraulic conductivity occurring towards the northeastern, southeastern and western parts of the study area. However, the areas marked with green, yellow, light and dark red, and purple colors have a very high hydraulic conductivity occurring towards the northwestern part of the study area. A comprehensive analysis of the studied showed four major group; low hydraulic conductivity varies between 1.04 and 3.9 m/day, covering about 48% of the study area, moderate values varying between 4.0 and 5.9 m/day representing 20%, high values range of 6.0 and 13.9 m/day, representing 24% and extremely high aquifer hydraulic conductivity values ranged from 14.0 m/day to 34.06 m/day representing 8% of the area (Figure 4.11).

Table 4.5 Summary of Aquifer Hydraulic Parameters Integrated from the Geo-electric Sections in the Study area

VES POINTS	LATIITUDE	LONGITUDE	LOCATION	K-Value From Pumping Test (m/day)	K- Value from Newly Generated Model (m/day)	K-Value from Niwas and Singhal = KσR/h (m/day)	K- Value from Heigold (m/day)	Transmissivity (T) From Newly Generated Model = KNGM*h (m²/day)	Transmissivity From Niwas Singhal (T) = KσR (m²/day)	Transmissivity (T) From Heigold = KHEM*h (m²/day)	GEOLOGIC FM.
VES 1 *	6°17"49.6'N	7°34"39.4'E	OJIAGU TOWN HALL AGBANI NKANU WEST	1.6114	1.610493099	0.924825198	11.82555364	46.70429988	26.81993074	342.9410554	AWGU
VES 2	6°17'16.7"N	7°35'18.7"E	SPECIAL SCI GIRLS SEC. SCH. AGBANI NKANU WEST		1.307133828	5.505	2.23958082	69.2780929	291.765	118.6977834	AWGU
VES 3 *	6°21'57.35"N	7°35'49.7"E	OGBASHI VILLAGE SQ NDIUNO AKPUGO NKANU WEST	1.1537	1.15255556	16.14066	0.821073768	119.8657783	1678.62864	85.39167182	AWGU
VES 4	6°09'35.89"N	7°41'29.84"E	EZEMEZUOBODO IKORO UMUOIKA NKEREFI NKANU EAST		1.553514155	9.412973896	0.184607534	347.9871707	2108.506153	41.35208759	EZEAKU SH
VES 5*	6°08'57.20"N	7°41'24.95"E	GIRLS SEC. SCH. UMUOIKA ENUOGU NKEREFI NKANU EAST	1.5796	1.584566877	2.053739759	0.763869741	137.8573183	178.675359	66.45666744	EZEAKU SH
VES 6	6°09'05.67"N	7°41'19.0"E	AMANKPUME NKEREFI NKANU EAST		1.5937411	1.317297724	1.155915989	70.1246084	57.96109987	50.86030351	EZEAKU SH
VES 7	6°10'40.09"N	7°40'14.00"E	AMAOFU NKANU EAST		1.577814329	2.852416332	0.562256881	238.2499637	430.7148661	84.90078906	EZEAKU SH
VES 8*	6°10'21.33"N	7°39'45.53"E	OBODO EBUNABO NKEREFI NKANU EAST	1.5895	1.594153068	1.291366667	1.17755356	35.0713675	28.41006667	25.90617833	EZEAKU SH
VES 9	6°09'03.38"N	7°41'20.46"E	UMUOVUDU 1 UMUOIKA NKEREFI NKANU EAST		1.594320207	1.280994244	1.18644554	92.47057199	74.29766613	68.8138413	EZEAKU SH
VES 10	6°18'31.51"N	7°39'19.22"E	OBUOHIA NKANU EAST/ WEST FED. CONSTITUENCY		1.790261662	0.37434	27.49396974	125.6763687	26.278668	1930.076676	AWGU
VES 11	6°18'36"N	7°33'57.60"E	ONUACHI AGBANI NKANU WEST		1.591548335	1.0232694	10.76089599	48.38306938	31.10738976	327.1312381	AWGU
VES 12 *	6°13'04.97"N	7°38'53.20"E	NARA NKANU EAST	1.5671	1.544668673	1.3212	8.478602735	72.59942765	62.0964	398.4943285	AWGU
VES 13	6°19'38.5"N	7°36'21.5"E	OBINAGU UWANI AKPUGO NKANU WEST		1.049821518	35.84856	0.390040355	70.23305958	2398.268664	26.09369976	AWGU
VES 14	6°19'22.2"N	7°36'41.0"E	OBINAGU UWANI NKANU		1.889910045	0.235614	42.34450383	45.35784107	5.654736	1016.268092	AWGU
VES 15	6°19'6.0"N	7°37'0.5"E	OBINAGU UWANI NKANU		1.792742232	0.369936	27.79917199	90.89203114	18.7557552	1409.41802	AWGU
VES 16 *	6°29'47"N	7°23'34"E	AFOR PRIMARY SCH ABOR UDI	6.4617	6.489091778	455.8274465	0.079140917	778.6910134	54699.29358	9.496910031	AJALI
VES 17	6°17'19.65"N	7°23'51.36"E	OBINAGU UDI		5.014424357	37.12475747	0.821063319	351.009705	2598.733023	57.4744323	AJALI
VES 18	6°34'0.49"N	7°25'26.7"E	AMAGU UMUENE IBITE OKPATU, UDI		7.212947465	1275.190166	0.030313249	793.4242211	140270.9183	3.334457371	AJALI
VES 19	6°33'1.01"N	7°26'12.5"E	OGENE OJEBE, UDI		7.406768126	1650.433789	0.023830542	999.9136971	222808.5615	3.21712323	AJALI
VES 20	6°27'28"N	7°21'27"E	EKE-UDI SQUARE UDI		6.042797392	227.9115	0.151081361	888.2912166	33502.9905	22.20896007	AJALI
VES 21 *	6°17'38.54"N	7°19'26.60"E	NACHI, UDI	3.8461	3.876874435	3.03882	8.478602735	544.7008581	426.95421	1191.243684	AJALI
VES 22	6°16'57.23"N	7°19'16.68"E	OFF NACHI, UDI		3.835110354	2.734938	9.354234366	563.7612221	402.035886	1375.072452	AJALI
VES 23	6°18'18.57"N	7°20'52.30"E	NACHI BY AMOKWE RD, UDI		3.859949663	2.9122025	8.821981895	754.6201591	569.3355888	1724.697461	AJALI
VES 24	6°19'03.63"N	7°22'04.54"E	AMOKWE, UDI		3.987820358	3.99858065	6.563418945	594.1852333	595.7885169	977.9494227	AJALI
VES 25	6°18'52.22"N	7°20'10.39"E	AMOKWE BY NACHI RD, UDI		7.578125092	2061.687429	0.019364197	522.8906313	142256.4326	1.336129598	AJALI
VES 26	6°23'49.0"N	7°22'15.0"E	EKEAGU OBELEAGU, EZEAGU		4.509574158	13.2239317	2.150637249	541.1488989	1586.871804	258.0764699	AJALI
VES 27	6°21'18.0"N	7°13'06.0"E	UMUGHU OBELEAGU, EZEAGU		6.629860294	10.12491746	1.647820223	238.6749706	364.4970284	59.32152803	NSUKKA
VES 28	6°20'58.0"N	7°22'01.0"E	UMANA OBELEAGU, EZEAGU		4.564416557	14.87401096	1.927213671	401.668657	1308.912964	169.5948031	AJALI
VES 29	6°18'35.0"N	7°19'19.0"E	OBELEAGU BY AMOKWE ROAD, EZEAGU		4.658147559	18.12605483	1.602591785	388.0236917	1509.900367	133.4958957	AJALI
VES 30	6°19'20.24"N	7°24'01.20"E	UDI BY AMOKWE RD, UDI		4.147983561	5.8649226	4.591428887	746.637041	1055.686068	826.4571997	AJALI
VES 31	6°19'07.53"N	7°22'00.77"E	AMOKWE, UDI		3.876874435	3.03882	8.478602735	368.3030713	288.6879	805.4672598	AJALI
VES 32 *	6°19'08.34"N	7°21'49.95"E	AMOKWE, UDI	4.1099	4.107489488	5.33110322	5.018907393	410.7489488	533.110322	501.8907393	AJALI
VES 33	6°19'05.90"N	7°23'31.22"E	UDI, UDI		4.995028302	35.75121083	0.850451898	809.1945849	5791.696154	137.7732074	AJALI
VES 34	6°21'54.0"N	7°21'33.0"E	OBELEAGU UMANA, EZEAGU		5.045024393	39.3881719	0.776963948	620.5380004	4844.745144	95.56656559	AJALI
VES 35	6°24'06.23"N	7°23'59.75"E	NSUDE, UDI		5.541622887	98.1741448	0.331444861	122.4698658	2169.6486	7.32493143	AJALI
VES 36	6°18'20.3"N	7°21'48.9"E	AMAOKWE, UDI		6.220024428	301.9168964	0.116223136	623.8684501	30282.26471	11.65718053	AJALI
VES 37	6°17'19"N	7°23'06"E	UMUABI, UDI		6.99546948	946.7545004	0.040020495	802.3803493	108592.7412	4.590350778	AJALI
VES 38	6°26'39"N	7°22'500"E	UMUEZE UMUAGA, UDI		6.767466244	685.8819328	0.054058934	678.1001176	68725.36967	5.416705173	AJALI

VES 39	6°24'20"N	7°23'56"E	NSUDE II, UDI		7.14099639	1156.70151	0.033200241	955.465317	154766.662	4.442192307	AJALI
VES 40	6°29'29"N	7°22'40"E	EZIAMA EBE UDI		7.247401303	1335.693072	0.0290304	1229.884001	226667.1144	4.926458807	AJALI
VES 41	6°31'54.3"N	7°24'36.3"E	OKPATU II, UDI		7.247401303	1335.693072	0.0290304	1229.884001	226667.1144	4.926458807	AJALI
VES 42	6°22'43.20"N	7°24'38.40"E	AMACHALA OBIOMA, UDI		6.039920098	226.8580424	0.151735709	327.3636693	12295.7059	8.224075418	AJALI
VES 43	6°19'26.4"N	7°21'00"E	AMAOKWE, UDI		7.277386983	1390.43235	0.027962853	358.0474396	68409.27161	1.375772377	AJALI
VES 44	6°30'10.8"N	7°17'49.20"E	OBEAGU UKANA, UDI		6.349543177	368.9380715	0.096399496	504.1537282	29293.68288	7.654119944	AJALI
VES 45	6°21'17"N	7°23'59"E	OFF OBIOMA, UDI		4.314971542	8.60999	3.209278823	741.743608	1480.057281	551.6750297	AJALI
VES 46	6°21'05"N	7°23'04"E	UMUDIM, UDI		3.944832562	3.59846935	7.24173444	461.5454097	421.020914	847.2829295	AJALI
VES 47 *	6°22'50"N	7°24' 17"E	OBIOMA COMM. HIGH SCH, UDI	3.4953	3.694011142	1.8992625	13.14418098	283.7000557	145.86336	1009.473099	AJALI
VES 48	6°22'06.83"N	7°13'26.98"E	UMUAJI MGBAGBU OWA, EZEAGU		16.96711299	103.7645915	0.187991415	485.2594314	2967.667316	5.376554461	NSUKKA
VES 49*	6°24'08.92"N	7°13'41.23"E	AGUAGBAJA UMUNADIAGU, EZEAGU	6.4622	6.462041007	9.502038433	1.748365966	343.7805815	505.5084446	93.0130694	NSUKKA
VES 50	6°29'57.41"N	7°08'51.05"E	IBITO OLO, EZEAGU		5.305036239	5.829471431	2.757828827	371.3525367	408.0630002	193.0480179	NSUKKA
VES 51*	6°25'32.4"N	7°15'54"E	IWOLLO TOWN, EZEAGU	4.1242	4.124061158	3.124596687	4.934129187	288.2718749	218.4093084	344.8956302	NSUKKA
VES 52	6°20'34.5"N	7°21'48.3"E	AGULU OBELEAGU UMANA, EZEAGU		6.220024428	301.9168964	0.116223136	623.8684501	30282.26471	11.65718053	AJALI
VES 53	6°21'59"N	7°14'43"E	UMUAJI AGUOBU-OWA, EZEAGU		20.41255545	164.0150935	0.122647614	1726.902191	13875.67691	10.37598813	NSUKKA
VES 54 *	6°29'01.2"N	7°14'52.2"E	IHUONAYIA CITY OGHE, EZEAGU	4.0194	3.788142237	2.4259913	10.46091663	438.666871	280.9297925	1211.374145	AJALI
VES 55	6°22'29.1"N	7°14'42.5"E	EZEAMA AGU AGUOBU-OWA		3.97567151	2.853526266	5.370012534	601.5190995	431.738524	812.4828963	NSUKKA
VES 56	6°27'38.5"N	7°12'46.9"E	IMEZI .O, EZEAGU		5.997433516	7.898933789	2.077257684	894.2173373	1177.731028	309.7191207	NSUKKA
VES 57	6°25'38"N	7°15'20"E	AGUOBI IWOLLO, EZEAGU		3.70837676	2.40174223	6.306708192	330.4163694	213.9952327	561.9276999	NSUKKA
VES 58 *	6°26'03"N	7°18'26"E	OGHE, EZEAGU	4.4105	4.37069451	9.7546122	2.856545838	841.7957627	1878.73831	550.1707285	AJALI
VES 59	6°26'05.04"N	7°17'03.9"E	ANIKE IWOLLO, EZEAGU		4.104026893	5.2875468	5.057463202	438.7204748	565.2387529	540.6428163	AJALI
VES 60	6°21'48.95"N	7°13'55.2"E	NDIAGU-UMANA, EZEAGU		22.72982302	214.058191	0.095670743	1929.761974	18173.54041	8.122446082	NSUKKA
VES 61*	6°25'04"N	7°10'11"E	COMM. SEC SCH OLO, EZEAGU	2.6396	2.639499165	1.349284	17.67427124	160.7454991	82.1713956	1076.363119	IMO SHALE
VES 62	6°22'14"N	7°21'29"E	OGWUOFIA, EZEAGU		4.849076434	26.792263	1.113053304	460.1773536	2542.585759	105.6287586	AJALI
VES 63	6°26'38.79"N	7°23'45.16"E	NGWO, UDI		8.210261295	4494.668015	0.009359659	779.974823	426993.4614	0.889167652	AJALI
VES 64	6°11'00.57"N	7°21'00.44"E	EHUHE ACHI OJI RIVER		6.806419758	725.26504	0.051315527	667.0291363	71075.97392	5.028921633	AJALI
VES 65	6°06'00.18"N	7°18'00.27"E	UMUEKE OZEGU INYI OJI RIVER		6.545186145	495.631542	0.073194906	556.3408223	42128.68107	6.221567024	AJALI
VES 66	6°07'57.25"N	7°25'00.09"E	OBEAGU, AWGU		5.834738407	162.0855941	0.207629991	324.4114554	9011.959032	11.5442275	AJALI
VES 67*	6°09'00.18"N	7°12'45.49"E	AKPUGO-EZE, OJI RIVER	2.7000	2.69972755	61.78040293	0.499052862	134.9863775	3089.020147	24.95264309	IMO SHALE
VES 68	6°15'00.42"N	7°13'00.62"E	UGWUOBA OJI RIVER		2.699829169	62.17579751	0.496091773	188.9880418	4352.305826	34.72642414	IMO SHALE
VES 69	6°25'17.92"N	7°14'39.42"E	UMUEZE, EZEAGU		34.06342828	582.9471431	0.03757572	2043.805697	34976.82859	2.254543179	NSUKKA
VES 70	6°28'41.42"N	7°16'15.68"E	AMANSIODO EZEAGU		17.27831706	108.5418433	0.180261526	1149.008085	7218.03258	11.9873915	NSUKKA
VES 71	6°26'16.54"N	7°17'01.59"E	OKPOGHO, EZEAGU		21.19517865	180.0315662	0.112437785	1528.172381	12980.27592	8.106764327	NSUKKA
VES 72	6°22'16.17"N	7°15'35.72"E	AFOR- UGWU, UDI		21.53939389	325.558916	0.10833024	2767.812115	41834.32071	13.92043585	NSUKKA
VES 73	6°27'03.73"N	7°28'23.27"E	COAL CAMP, ENUGU		2.432746144	8.112898352	30.8989633	77.84787659	259.6127473	988.7668257	MAMU
VES 74*	6°29'45.5"N	7°28'43.8"E	WINNERS ESTATE TRANS-EKULU, ENUGU EAS	2.7486	2.749849455	1.514407692	147.8817875	228.7874747	125.99872	12303.76472	MAMU
VES 75*	6°29'57"N	7°28'34"E	PHASE 6 TRANS-EKULU, ENUGU	2.3418	2.355042219	12.65612143	20.40757915	193.1134619	1037.801957	1673.42149	MAMU
VES 76*	6°19'00.51"N	7°28'33.59"E	OZALLA NKANU, ENUGU	2.5479	2.549658291	4.218283333	21.61647965	45.89384924	75.9291	389.0966337	NKPORO
VES 77	6°15'04.03''N	7°28'49.55''E	OBODOAKPU AGBOGUGU, AWGU		2.500201206	29.91146364	3.477160189	100.0080483	1196.458545	139.0864076	NKPORO
VES 78	6°28'00.61''N	7°36'00.37''E	EMENE INDUSTRIAL LAYOUT, ENUGU		2.543516891	5.368724242	17.26174479	50.87033782	107.3744848	345.2348958	NKPORO
VES 79	6°25'00.67''N	7°32'00.09''E	ENUGU INDEPENDENT LAYOUT		2.45426981	191.030713	0.616664365	150.6921663	11729.28578	37.86319199	NKPORO
VES 80	6°31'00.12''N	7°30'00.00''E	UMUGHOKENE IJI-NIKE ENUGU		2.511344003	19.17401515	5.264742296	60.27225608	460.1763636	126.3538151	NKPORO
VES 81	6°31'01.04''N	7°33'02.00''E	UMUGHOKENE IJI-NIKE ENUGU 2		2.600967909	0.575220455	138.6641193	36.41355072	8.053086364	1941.29767	NKPORO
VES 82	6°29'04.53''N	7°30'02.43''E	NIKE LAKE ROAD, ENUGU		2.56984072	1.917401515	45.10317531	25.6984072	19.17401515	451.0317531	NKPORO
VES 83	6°29'00.23''N	7°32'09.08''E	HARMONY ESTATE NIKE, ENUGU		2.499552673	30.69759826	3.39402277	106.630917	1309.559542	144.7890114	NKPORO
VES 84*	6°22'59.07"N	7°32'42.12"E	OBEAGU ENUGU SOUTH	2.5696	2.570889994	1.840705455	46.85382417	60.15882587	43.07250764	1096.379486	NKPORO
VES 85	6°27'50.34"N	7°35'09.80"E	9 ABAKALIKI ROAD EMENE		2.541762651	5.752204545	16.18579732	45.75172772	103.5396818	291.3443517	NKPORO

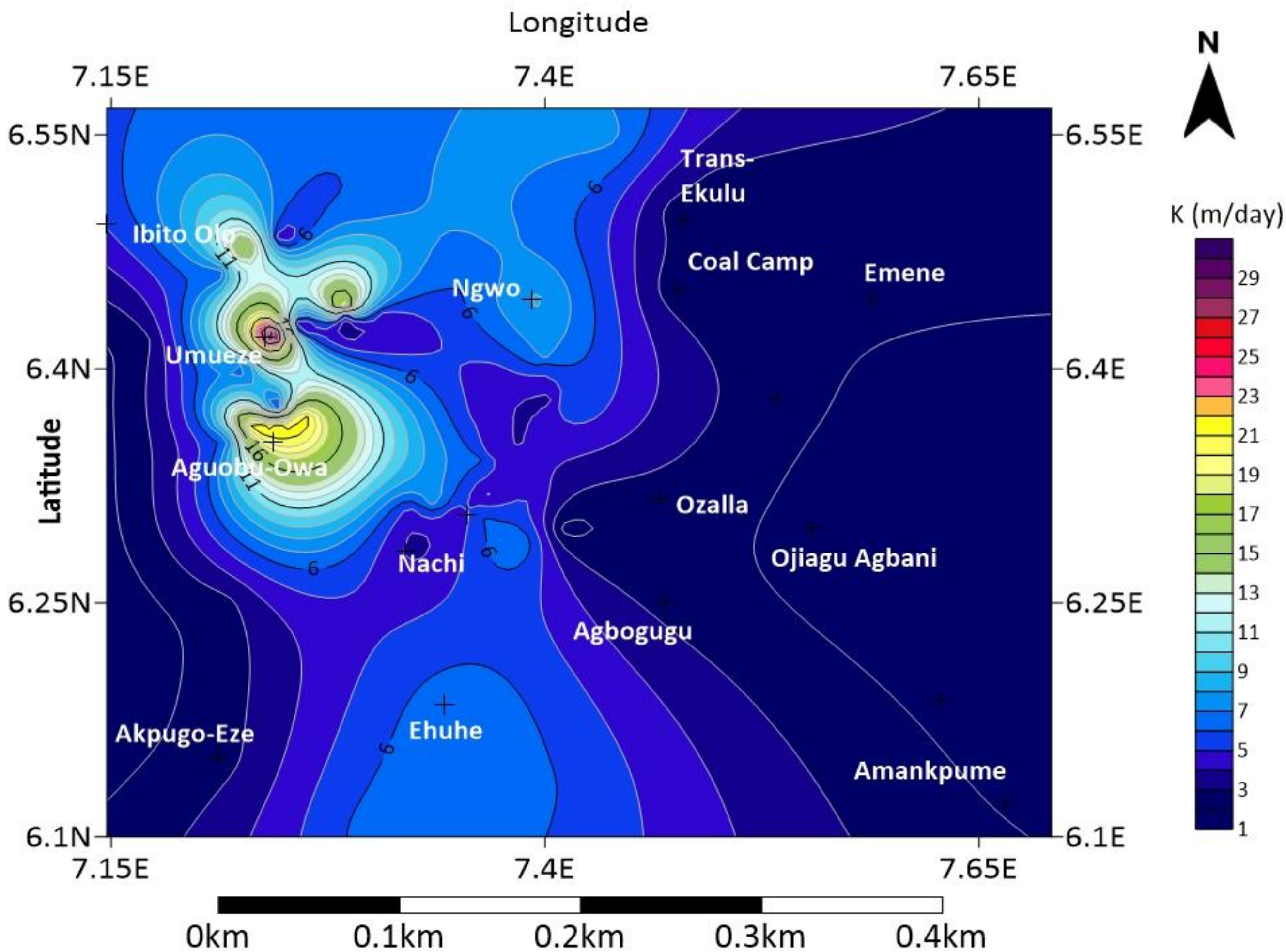


Fig 4.11 Spatial Distribution Map of Hydraulic Conductivity (m/day) of the study area

Similarly, the aquifer transmissivity which is an importance hydraulic parameter to determine the amount of water that flows horizontally across a unit hydraulic gradient through a unit width of aquifer of a given saturated thickness (Freeze and Cherry, 1979; Paulo, et al. 2017). It is often expressed as the product of the hydraulic conductivity and the full saturated thickness of the aquifer. The estimated aquifer transmissivity values of the study area (from newly generated model) varies between 25.70 m^2/day and 2767.81 m^2/day with a mean value of 500.05 m^2/day (Table 4.5). The highest aquifer transmissivity value was identified in the Nsukka Formation whereas the minimum value were recorded within the Nkporo Formation (See Table 4.5). The eaquifer transmissivity values of the area (from Niwas and Singhal model 1982, varies from 5.65 m^2/day to 426993.46m^2/day with a mean value of 27017.54m^2/day) while (from Heigold model 1979, ranges from 0.89m^2/day to 12303.76m^2/day with a mean value of 502.33m^2/day), The spatial distribution map of transmissivity across the study area (from newly generated model) is shown in (Fig. 4.12). Based on the Krasny, (1993) classification, the generated values of transmissivity across the area shows that the groundwater potential of the area ranged from very high, high to moderate potential zones with the northern and north-western parts of the study area lies within the class of very high groundwater potential (See fig. 4.12). The study's findings are similar to those of previous research conducted worldwide (Fatoba, Omolayo and Adigun (2014); Ebong, Akpan and Onwuegbuche (2014); Kazakis, Vargemezis and Voudouris (2016); Joel, Olasehinde, De, Omeje and Adewoyin (2016); Ibout, Obiora, Ekpa and Okoroh (2017); Hassan, Shang, Akhter and Jin (2018); Oyeyemi, Aizebeokhai, Ndambuki, Sanuade, Olofinnade, Adagunodo, Olaojo and Adeyemi (2018); Rabeh, Ali, Bedar, Sadik and Ismail (2019); Ejiogu, et al. (2019); Oli, et al. 2020)). Therefore, low hydraulic conductivity and transmissivity values are often indicative of clay/shale aquifer materials, according to Akhter and Hassan (2016). High values are commonly as a result of presence of sand/gravel materials.

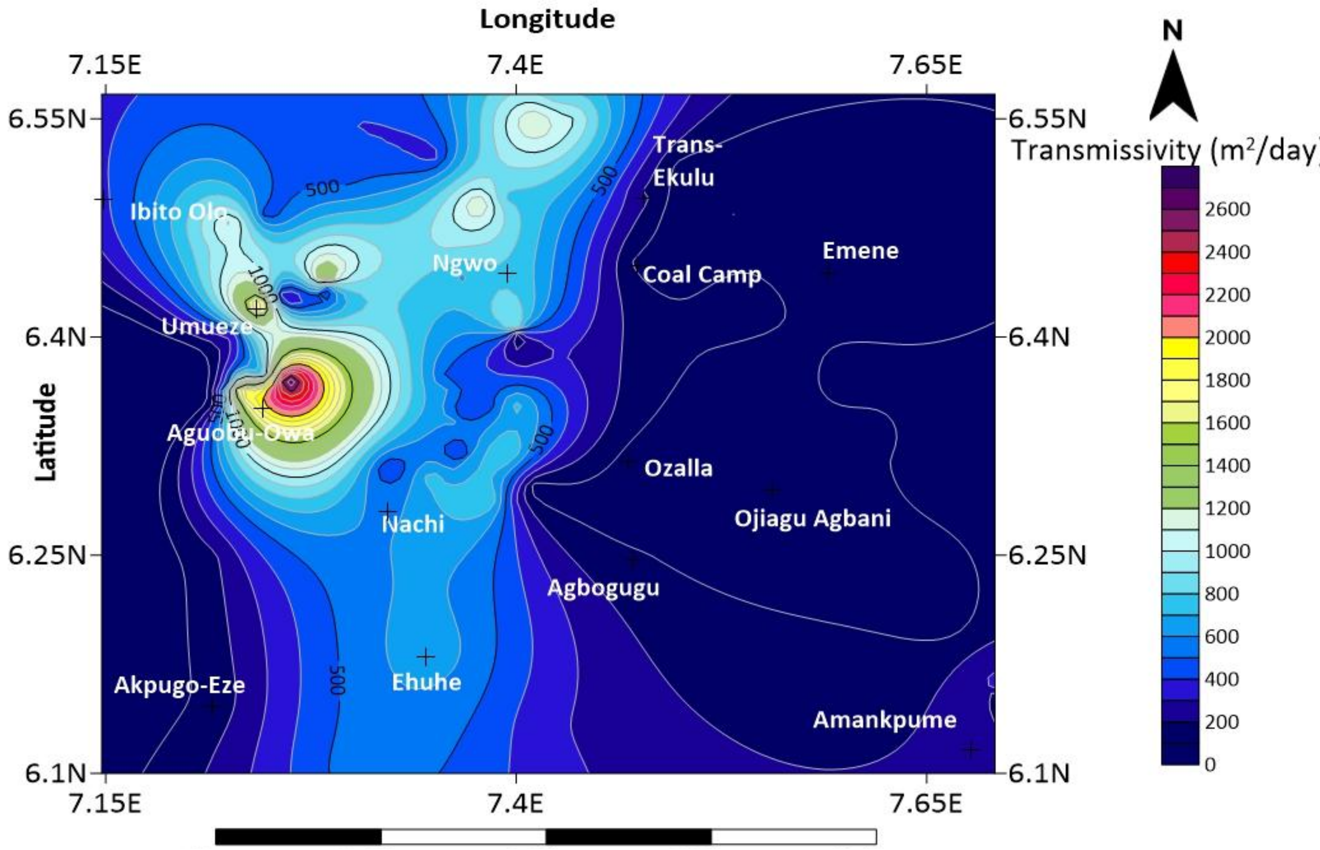


Fig 4.12 Spatial Distribution Map of Transmissivity (m/^{2}day) of the study area

4.6 Statistical Analysis between k-Values from different Models and Pumping Test

Statistical analysis was carried out to determine the dependability of the different models in estimating hydraulic conductivity in relation to pumping tests. This was achieved by applying the following methods; Paired t Test, Analysis of Variance (ANOVA) and Multiple Regression Analysis

4.6.1 Paired t Test

The Paired t Test between the New Model and Pumping Test results showed a t Stat value lower than the t Critical and a $P > 0.05$, (Table 4.6a), which therefore accepts the Null Hypothesis (There is no difference in the mean) and rejects the Alternative Hypothesis (There is a difference in the mean).

The same Paired Test was conducted between the Niwas and Singhal models and the pumping test. The t Stat value is lower than the t Critical and the $P > 0.05$, (Table 4.6b), which therefore accepts the Null Hypothesis (there is no difference in the mean) and rejects the Alternative Hypothesis (there is a difference in the mean).

Finally, the Heigold model and pumping test results were analyzed with the Paired t Test. The t Stat value is higher than the t Critical and the $P > 0.05$, (Table 4.6c), which therefore rejects the Null Hypothesis (there is no difference in the mean) and accepts the Alternative Hypothesis (there is a difference in the mean).

Table 4.6a: t-Test: Paired Two Sample for Means (New Model and Pumping test)

	K-Value (m/day) from New model	*k (m/day) from pumping test*
Mean	3.155974195	3.156747368
Variance	2.359170895	2.360657635
Observations	19	19
Pearson Correlation	0.998858574	
Hypothesized Mean Difference	0	
Df	18	
t Stat	-0.045915283	
P(T<=t) one-tail	0.481941673	
t Critical one-tail	1.734063607	
P(T<=t) two-tail	0.963883346	
t Critical two-tail	2.10092204	

Table 4.6b: t-Test: Paired Two Sample for Means (Niwas and Singhal model and Pumping test)

	K-Value from Niwas and Singhal	*k (m/day) from pumping test*
Mean	31.36815091	3.156747368
Variance	10755.39195	2.360657635
Observations	19	19
Pearson Correlation	0.515468918	
Hypothesized Mean Difference	0	
Df	18	
t Stat	1.194764045	
P(T<=t) one-tail	0.123842579	
t Critical one-tail	1.734063607	
P(T<=t) two-tail	0.247685158	
t Critical two-tail	2.10092204	

Table 4.6c: t-Test: Paired Two Sample for Means (Heigold model and Pumping test)

	K- Value from Heigold (m/day)	*k (m/day) from pumping test*
Mean	17.09054935	3.156747368
Variance	1130.013516	2.360657635
Observations	19	19
Pearson Correlation	-0.134431101	
Hypothesized Mean Difference	0	
Df	18	
t Stat	1.793927002	
P(T<=t) one-tail	0.044820507	
t Critical one-tail	1.734063607	
P(T<=t) two-tail	0.089641014	
t Critical two-tail	2.10092204	

4.6.2 ANOVA

The ANOVA test was conducted on the various models with the Pumping Test. For the ANOVA analysis between the Pumping test and the new model, the F stat < F critical, which shows that there is no significant difference, while the P > 0.05 (Table 4.7a), therefore, accepting the null hypothesis that there is no difference in the variance and rejecting the alternative hypothesis that there is a difference in the variance. For the ANOVA between the Niwas and Singhal model and the Pumping test, the F stat < F critical, which shows that there is no significant difference, while the P > 0.05 (Table 4.7b), therefore, accepts the null hypothesis and rejects the alternative hypothesis. Finally, the ANOVA between the Heigold model and pumping test result shows that the F stat < F critical, which shows that there is no significant difference, while the P > 0.05 (Table 4.7c), therefore, accepting the null hypothesis.

Table 4.7a: ANOVA (Pumping test and New model)

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
k (m/day) from pumping test	19	59.9782	3.156747	2.360657635		
K-Value (m/day) from New model	19	59.96351	3.155974	2.359170895		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5.67907E-06	1	5.68E-06	2.40647E-06	0.998770822	4.113165
Within Groups	84.95691353	36	2.359914			
Total	84.95691921	37				

Table 4.7b: ANOVA (Pumping test and Niwas & Singhal)

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
k (m/day) from pumping test	19	59.9782	3.156747	2.360657635		
K-Value from Niwas and Singhal	19	595.9949	31.36815	10755.39195		
ANOVA						
Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7560.891	1	7560.891	1.405663717	0.243545	4.113165
Within Groups	193639.5	36	5378.876			
Total	201200.4	37				

Table 4.7c: ANOVA (Pumping test and Heigold)

Anova: Single Factor						
SUMMARY						
Groups	***Count***	***Sum***	***Average***	***Variance***		
k (m/day) from pumping test	19	59.9782	3.15674737	2.360657635		
K- Value from Heigold (m/day)	19	324.72044	17.0905493	1130.013516		
ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	1844.433	1	1844.43296	3.257638685	0.079462	4.113165
Within Groups	20382.74	36	566.187087			
Total	22227.17	37				

4.6.3 Multiple Regression Analysis

A multiple regression analysis was carried out on the various models, with the pumping test results serving as the independent factor, while the different models became the dependent factors. The R^2 value, which determines how accurate and reliable the model is, shows a value of 0.99 (Table 4.8), which means that 99% of the variability of pumping test results can be explained by the different models. The significance F value was shown to be 4.60E-20, which is less than 0.05. This shows that the analysis is reliable. Therefore, rejecting the null hypothesis and accepting the alternative hypothesis. The Null Hypothesis is that there is no useful relationship between the independent and dependent factors, while the alternative hypothesis is that there is at least one useful relationship between the independent and dependent factors.

The coefficients of the various models were shown in Table 4.8 to be 1.00, -8.28E-05, and -7.24E-05 for the New model, the Niwas and Singhal model, and the Heigold model, respectively. The positive value depicted by the new model shows that there is a positive relationship between the model and the pumping test results, while the negative values presented by the Niwas and Singhal models and the Heigold models show a downward negative relationship between the models and pumping test results.

The P value plays an important role in assessing the predictive ability of the models. When $P < 0.05$, the coefficients predict the outcome of the pumping test results, rejecting the null hypothesis and accepting the alternative hypothesis. The P values of the new model, the Niwas and Singhal model, and the Heigold model are shown to be 3.028E-20, 0.704, and 0.900, respectively, with only the new model meeting the requirements of rejecting the null hypothesis and accepting the alternative hypothesis.

In general, from the different statistical analysis of the models, the New model is found to more reliable and accurate in predicting hydraulic conductivity in the study area, followed by the Niwas and Singhal model and lastly the Heigold model.

Table 4.8: Multiple Regression Analysis of the Models

Regression Statistics								
Multiple R	0.998870538							
R Square	0.997742352							
Adjusted R Square	0.997290823							
Standard Error	0.079971496							
Observations	19							
ANOVA								
	Df	***SS***	***MS***	***F***	***Significance F***			
Regression	3	42.39590583	14.13196861	2209.694463	4.60E-20			
Residual	15	0.095931602	0.00639544					
Total	18	42.49183743						
	Coefficients	***Standard Error***	***t Stat***	***P-value***	***Lower 95%***	***Upper 95%***	***Lower 95.0%***	***Upper 95.0%***
Intercept	-0.001295528	0.047976025	-0.02700365	0.978812811	-0.103554005	0.100962949	-0.103554005	0.100962949
K-Value (m/day) from New model	1.001870839	0.014400296	69.57293445	3.0287E-20	0.971177335	1.032564343	0.971177335	1.032564343
K-Value from Niwas and Singhal	-8.28485E-05	0.000213692	-0.38770001	0.703684187	-0.000538323	0.000372626	-0.000538323	0.000372626
K- Value from Heigold (m/day)	-7.23683E-05	0.000568198	-0.12736458	0.90034359	-0.001283453	0.001138717	-0.001283453	0.001138717

4.7 Estimation of Aquifer Vulnerability of the study area Using DRASTIC and GOD Model

4.7.1 DRASTIC Model

The aquifer vulnerability study using the DRASTIC model clearly showed that the study area is characterized by three vulnerability zones; low, moderate and high zones (Table 4.9 and Figure 4.13). The estimated DRASTIC Index of the study area ranged between 80 and 144 with a mean value of 109.3. About 31% of the study area are within the low class of groundwater vulnerability to contamination, with DRASTIC Index (Di) values ranging from 80 to 100, 67% are within the class of moderate zones with DRASTIC Index (Di) values ranged between 101 and 140 while 2 % of the study area are within the high class of vulnerability zones with DRASTIC Index (Di) values ranging from 141 to 144 (See Figure 4.13). In the high zones, aquifer is less protected from pollution because of its shallow depth from the surface. Therefore, the low vulnerability index in these areas may be attributed to deep water table. The class of classification of DRASTIC Index was based on Oroji, 2018 (See table 3.4 above).

Table 4.9 Summary of Aquifer Vulnerability of the study area Based on DRASTIC Model

VES POINTS	LOCATION	D		R		A		S		T		I		C		DRASTIC INDEX	VULNERABILITY RATING
VES 1 *	OJIAGU TOWN HALL AGBANI NKANU WEST	1	5	9	4	6	3	9	2	10	1	3	5	1	3	105	MODERATE
VES 2	SPECIAL SCI GIRLS SEC. SCH. AGBANI NKANU	1	5	9	4	6	3	9	2	10	1	6	5	1	3	120	MODERATE
VES 3 *	OGBASHI VILLAGE SQ NDIUNO AKPUGO NKANU	1	5	9	4	6	3	6	2	10	1	6	5	1	3	114	MODERATE
VES 4	EZEMEZUOBODO IKORO UMUOIKA NKEREFI NKANU EAST	1	5	9	4	6	3	3	2	10	1	3	5	1	3	93	LOW
VES 5*	GIRLS SEC. SCH. UMUOIKA ENUOGU NKEREFI NKANU EAST	1	5	9	4	6	3	3	2	10	1	3	5	1	3	93	LOW
VES 6	AMANKPUME NKEREFI NKANU EAST	1	5	9	4	6	3	3	2	10	1	3	5	1	3	93	LOW
VES 7	AMAOFU NKANU EAST	1	5	9	4	6	3	3	2	10	1	3	5	1	3	93	LOW
VES 8*	OBODO EBUNABO NKEREFI NKANU EAST	1	5	9	4	6	3	3	2	10	1	3	5	1	3	93	LOW
VES 9	UMUOVUDU 1 UMUOIKA NKEREFI NKANU EAST	1	5	9	4	6	3	3	2	10	1	3	5	1	3	93	LOW
VES 10	OBUOHIA NKANU EAST/ WEST FED.	1	5	9	4	6	3	9	2	10	1	3	5	1	3	105	MODERATE
VES 11	ONUACHI AGBANI NKANU WEST	1	5	9	4	6	3	9	2	10	1	3	5	1	3	105	MODERATE
VES 12 *	NARA NKANU EAST	1	5	9	4	6	3	3	2	10	1	3	5	1	3	93	LOW
VES 13	OBINAGU UWANI AKPUGO NKANU WEST	1	5	9	4	6	3	6	2	10	1	6	5	1	3	114	MODERATE
VES 14	OBINAGU UWANI NKANU	1	5	9	4	6	3	6	2	10	1	6	5	1	3	114	MODERATE
VES 15	OBINAGU UWANI NKANU	1	5	9	4	6	3	6	2	10	1	6	5	1	3	114	MODERATE
VES 16 *	AFOR PRIMARY SCH ABC	1	5	9	4	8	3	6	2	9	1	6	5	2	3	122	MODERATE
VES 17	OBINAGU UDI	1	5	9	4	8	3	9	2	9	1	6	5	2	3	128	MODERATE
VES 18	AMAGU UMUENE IBITE OKPATU, UDI	1	5	9	4	8	3	9	2	9	1	6	5	2	3	128	MODERATE
VES 19	OGENE OJEBE, UDI	1	5	9	4	8	3	9	2	9	1	6	5	2	3	128	MODERATE
VES 20	EKE-UDI SQUARE UDI	1	5	9	4	8	3	3	2	9	1	6	5	2	3	116	MODERATE
VES 21 *	NACHI, UDI	1	5	9	4	8	3	6	2	9	1	6	5	1	3	119	MODERATE
VES 22	OFF NACHI, UDI	1	5	9	4	8	3	6	2	9	1	6	5	1	3	119	MODERATE
VES 23	NACHI BY AMOKWE RD, U	1	5	9	4	8	3	6	2	9	1	6	5	1	3	119	MODERATE
VES 24	AMOKWE, UDI	1	5	9	4	8	3	6	2	9	1	6	5	1	3	119	MODERATE

VES 25	AMOKWE BY NACHI RD, U	1	5	9	4	8	3	6	2	9	1	6	5	2	3	122	MODERATE
VES 26	EKEAGU OBELEAGU, EZEA	1	5	9	4	8	3	6	2	9	1	6	5	2	3	122	MODERATE
VES 27	UMUGHU OBELEAGU, EZE	1	5	9	4	8	3	6	2	10	1	6	5	2	3	123	MODERATE
VES 28	UMANA OBELEAGU, EZEA	1	5	9	4	8	3	6	2	9	1	6	5	2	3	122	MODERATE
VES 29	OBELEAGU BY AMOKWE ROAD, EZEAGU	1	5	9	4	6	3	6	2	9	1	6	5	2	3	116	MODERATE
VES 30	UDI BY AMOKWE RD, UDI	1	5	9	4	8	3	6	2	9	1	6	5	2	3	122	MODERATE
VES 31	AMOKWE, UDI	1	5	9	4	8	3	6	2	9	1	6	5	1	3	119	MODERATE
VES 32 *	AMOKWE, UDI	1	5	9	4	8	3	6	2	9	1	6	5	2	3	122	MODERATE
VES 33	UDI, UDI	1	5	9	4	8	3	6	2	9	1	6	5	2	3	122	MODERATE
VES 34	OBELEAGU UMANA, EZEA	1	5	9	4	8	3	6	2	9	1	6	5	2	3	122	MODERATE
VES 35	NSUDE, UDI	2	5	6	4	6	3	6	2	9	1	6	5	2	3	109	MODERATE
VES 36	AMAOKWE, UDI	1	5	9	4	8	3	6	2	9	1	6	5	2	3	122	MODERATE
VES 37	UMUABI, UDI	1	5	9	4	6	3	6	2	9	1	6	5	2	3	116	MODERATE
VES 38	UMUEZE UMUAGA, UDI	1	5	9	4	6	3	6	2	9	1	6	5	2	3	116	MODERATE
VES 39	NSUDE II, UDI	1	5	9	4	6	3	6	2	9	1	6	5	2	3	116	MODERATE
VES 40	EZIAMA EBE UDI	1	5	9	4	6	3	6	2	9	1	6	5	2	3	116	MODERATE
VES 41	OKPATU II, UDI	1	5	9	4	6	3	9	2	9	1	6	5	2	3	122	MODERATE
VES 42	AMACHALA OBIOMA, UDI	1	5	9	4	6	3	6	2	9	1	3	5	2	3	101	MODERATE
VES 43	AMAOKWE, UDI	1	5	9	4	8	3	6	2	9	1	6	5	2	3	122	MODERATE
VES 44	OBEAGU UKANA, UDI	1	5	9	4	8	3	6	2	9	1	6	5	2	3	122	MODERATE
VES 45	OFF OBIOMA, UDI	1	5	9	4	6	3	6	2	9	1	3	5	2	3	101	MODERATE
VES 46	UMUDIM, UDI	1	5	9	4	6	3	6	2	9	1	6	5	1	3	113	MODERATE
VES 47 *	OBIOMA COMM. HIGH SCI	1	5	9	4	6	3	6	2	9	1	3	5	1	3	98	LOW
VES 48	UMUAJI MGBAGBU OWA, I	1	5	9	4	6	3	3	2	10	1	3	5	4	3	102	LOW
VES 49	AGUAGBAJA UMUNADIAC	1	5	9	4	6	3	3	2	10	1	3	5	2	3	96	LOW
VES 50	IBITO OLO, EZEAGU	1	5	9	4	6	3	3	2	10	1	3	5	2	3	96	LOW
VES 51	IWOLLO TOWN, EZEAGU	1	5	9	4	6	3	9	2	9	1	6	5	2	3	122	MODERATE
VES 52	AGULU OBELEAGU UMANA	1	5	9	4	6	3	3	2	9	1	6	5	2	3	110	MODERATE
VES 53	UMUAJI AGUOBU-OWA, EZ	1	5	9	4	6	3	3	2	10	1	3	5	4	3	102	LOW
VES 54 *	IHUONAYIA CITY OGHE, EZ	1	5	9	4	6	3	6	2	10	1	6	5	1	3	114	MODERATE
VES 55	EZEAMA AGU AGUOBU-O	1	5	9	4	6	3	6	2	10	1	6	5	1	3	114	MODERATE
VES 56	IMEZI .O, EZEAGU	1	5	9	4	8	3	9	2	10	1	6	5	2	3	129	MODERATE
VES 57	AGUOBI IWOLLO, EZEAGU	1	5	9	4	8	3	9	2	10	1	6	5	1	3	126	MODERATE
VES 58 *	OGHE, EZEAGU	1	5	9	4	6	3	9	2	9	1	6	5	2	3	122	MODERATE
VES 59	ANIKE IWOLLO, EZEAGU	1	5	9	4	6	3	9	2	9	1	6	5	2	3	122	MODERATE
VES 60	NDIAGU-UMANA, EZEAGU	1	5	9	4	6	3	3	2	10	1	6	5	4	3	117	MODERATE
VES 61	COMM. SEC SCH OLO, EZE	1	5	9	4	6	3	3	2	10	1	3	5	1	3	93	LOW
VES 62	OGWUOFIA, EZEAGU	1	5	9	4	6	3	9	2	9	1	6	5	2	3	122	MODERATE

VES 63	NGWO, UDI	1	5	9	4	8	3	9	2	9	1	3	5	2	3	113	MODERATE
VES 64	EHUHE ACHI OJI RIVER	1	5	9	4	8	3	9	2	9	1	8	5	2	3	138	MODERATE
VES 65	UMUEKE OZEGU INYI OJI R	1	5	9	4	8	3	9	2	10	1	3	5	2	3	114	MODERATE
VES 66	OBEAGU, AWGU	1	5	9	4	8	3	9	2	9	1	3	5	2	3	113	MODERATE
VES 67*	AKPUGO-EZE, OJI RIVER	1	5	9	4	6	3	9	2	10	1	3	5	1	3	105	MODERATE
VES 68	UGWUOBA OJI RIVER	1	5	9	4	6	3	9	2	10	1	3	5	1	3	105	MODERATE
VES 69	UMUEZE, EZEAGU	1	5	9	4	8	3	6	2	10	1	6	5	6	3	135	MODERATE
VES 70	AMANSIODO EZEAGU	1	5	9	4	8	3	6	2	10	1	9	5	4	3	144	HIGH
VES 71	OKPOGHO, EZEAGU	1	5	9	4	8	3	6	2	9	1	3	5	4	3	113	MODERATE
VES 72	AFOR- UGWU, UDI	1	5	9	4	8	3	6	2	10	1	9	5	4	3	144	HIGH
VES 73	COAL CAMP, ENUGU	1	5	9	4	2	3	3	2	9	1	3	5	1	3	80	LOW
VES 74*	WINNERS ESTATE TRANS-EKULU, ENUGU	1	5	9	4	2	3	3	2	9	1	3	5	1	3	80	LOW
VES 75*	PHASE 6 TRANS-EKULU, E	1	5	9	4	2	3	3	2	9	1	3	5	1	3	80	LOW
VES 76*	OZALLA NKANU, ENUGU	1	5	9	4	2	3	3	2	9	1	3	5	1	3	80	LOW
VES 77	OBODOAKPU AGBOGUGU	1	5	9	4	2	3	3	2	9	1	3	5	1	3	80	LOW
VES 78	EMENE INDUSTRIAL LAYOUT, ENUGU	1	5	9	4	2	3	3	2	10	1	3	5	1	3	81	LOW
VES 79	ENUGU INDEPENDENT LA	1	5	9	4	2	3	3	2	10	1	3	5	1	3	81	LOW
VES 80	UMUGHOKENE IJI-NIKE EN	1	5	9	4	2	3	3	2	10	1	3	5	1	3	81	LOW
VES 81	UMUGHOKENE IJI-NIKE EN	1	5	9	4	2	3	3	2	9	1	3	5	1	3	80	LOW
VES 82	NIKE LAKE ROAD, ENUGU	2	5	9	4	2	3	3	2	9	1	3	5	1	3	85	LOW
VES 83	HARMONY ESTATE NIKE,	1	5	9	4	2	3	3	2	10	1	3	5	1	3	81	LOW
VES 84*	OBEAGU ENUGU SOUTH	1	5	9	4	2	3	3	2	10	1	3	5	1	3	81	LOW
VES 85	9 ABAKALIKI ROAD EMEN	1	5	9	4	2	3	3	2	10	1	3	5	1	3	81	LOW

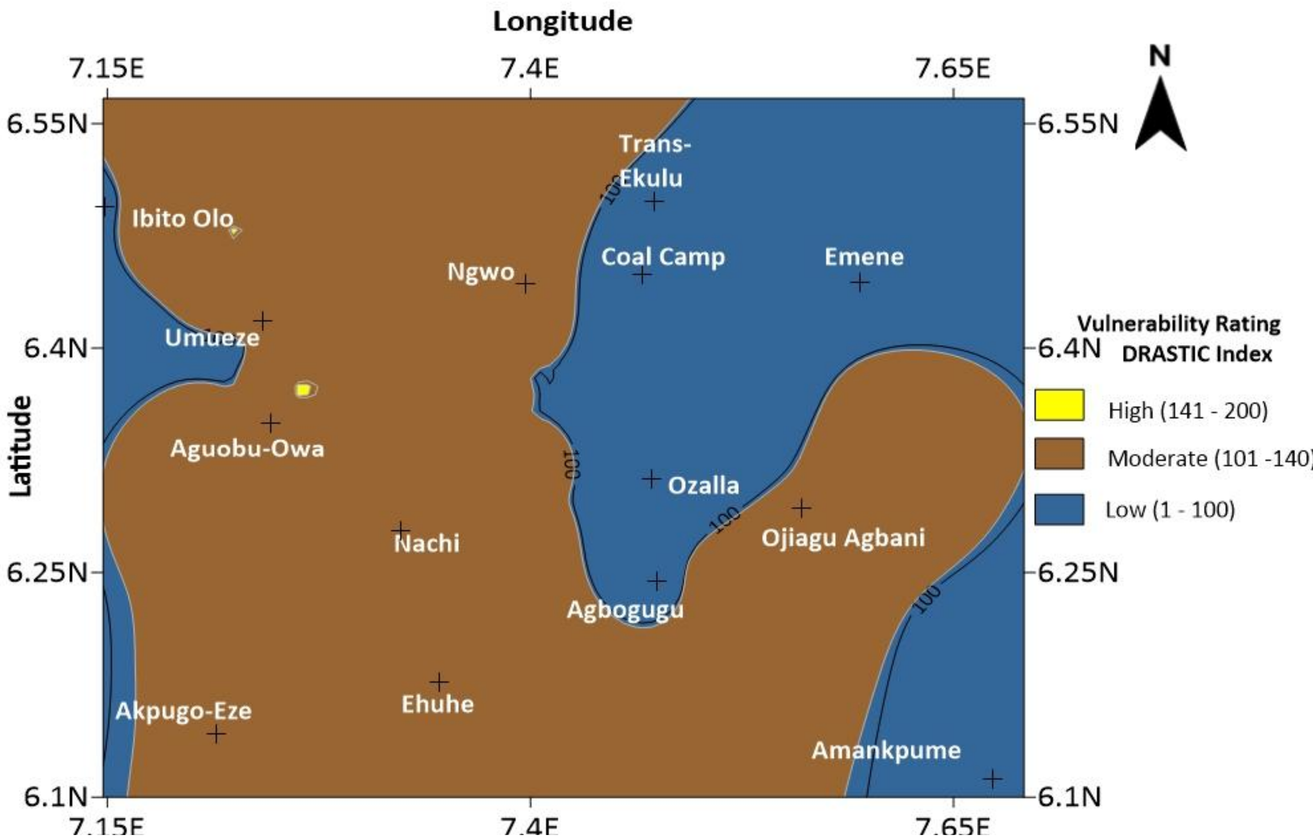


Fig 4.13 Spatial Distribution Map of Aquifer Vulnerability of the study area based on DRASTIC Index

4.7.2 GOD Model

Similarly, overlapping of groundwater confinement, overlying strata, and depth to groundwater was used to generate an intrinsic aquifer vulnerability analysis utilizing the GOD Index vulnerability model. Table 4.10 indicates the summary of GOD Indices for the various hydrogeological settings generated across the study area. The interpreted result of the vulnerability based on the GOD Index clearly revealed that the study area is characterized by three vulnerability zones; extremely low (Negligible), low zones and moderate zones vary from 0.06 in the extremely low vulnerable areas to 0.42 in the moderate vulnerable areas (Table 4.10 and Figure 4.14). The interpreted results revealed that about 60% of the study area are within the class of extremely low groundwater vulnerability to contamination, 33% are within the class of low vulnerability zones while the 7% of the area are within the class of moderate vulnerability. The extremely low vulnerability is essentially due to the deep groundwater, the vadose zone sediments and low permeability and also to add to that the low hydraulic conductivity. The vulnerability pattern is mainly dictated by the variation of the permeability and the vadose zone (Philes, 2004). The two indicators that influencing on vulnerability degrees to pollution are the depth of groundwater and the recharge. The degrees of vulnerability of the contaminant were determined from the GOD Index was based on the classification, Fosteri et al. 2002 (See table 3.5 above).

Table 4.10 Summary of Aquifer Vulnerability of the study area Based on GOD Model

VES POINTS	LOCATION	G		O		D		GOD INDEX	VULNERABILITY RATING
		R	W	R	W	R	W		
VES 1*	OJIAGU TOWN HALL AGBANI NKANU WEST	0.2	1	0.5	1	0.6	1	0.06	NEGLIGIBLE
VES 2	SPECIAL SCI GIRLS SEC. SCH. AGBANI NKANU WEST	0.4	1	0.7	1	0.6	1	0.168	LOW
VES 3*	OGBASHI VILLAGE SQ NDIUNO AKPUGO NKANU WEST	0.4	1	0.7	1	0.6	1	0.168	LOW
VES 4	EZEMEZUOBODO IKORO UMUOIKA NKEREFI NKANU	0.2	1	0.5	1	0.6	1	0.06	NEGLIGIBLE
VES 5	GIRLS SEC. SCH. UMUOIKA ENUOGU NKEREFI NKANU	0.2	1	0.5	1	0.6	1	0.06	NEGLIGIBLE
VES 6	AMANKPUME NKEREFI NKANU EAST	0.2	1	0.5	1	0.6	1	0.06	NEGLIGIBLE
VES 7	AMAOFU NKANU EAST	0.2	1	0.5	1	0.6	1	0.06	NEGLIGIBLE
VES 8	OBODO EBUNABO NKEREFI NKANU EAST	0.2	1	0.5	1	0.6	1	0.06	NEGLIGIBLE
VES 9	UMUOVUDU 1 UMUOIKA NKEREFI NKANU EAST	0.2	1	0.5	1	0.6	1	0.06	NEGLIGIBLE
VES 10	OBUOHIA NKANU EAST/ WEST FED. CONSTITUENCY	0.4	1	0.5	1	0.6	1	0.12	LOW
VES 11	ONUACHI AGBANI NKANU	0.4	1	0.5	1	0.6	1	0.12	LOW
VES 12*	NARA NKANU EAST	0.2	1	0.5	1	0.6	1	0.06	NEGLIGIBLE
VES 13	OBINAGU UWANI AKPUGO NKANU WEST	0.2	1	0.7	1	0.6	1	0.084	NEGLIGIBLE
VES 14	OBINAGU UWANI NKANU	0.4	1	0.7	1	0.6	1	0.168	LOW
VES 15	OBINAGU UWANI NKANU	0.4	1	0.7	1	0.6	1	0.168	LOW
VES 16*	AFOR PRIMARY SCH ABOR UDI	0.2	1	0.7	1	0.6	1	0.084	NEGLIGIBLE
VES 17	OBINAGU UDI	0.6	1	0.7	1	0.6	1	0.252	LOW
VES 18	AMAGU UMUENE IBITE OKPATU, UDI	0.6	1	0.7	1	0.6	1	0.252	LOW
VES 19	OGENE OJEBE, UDI	0.6	1	0.7	1	0.6	1	0.252	LOW
VES 20	EKE-UDI SQUARE UDI	0.2	1	0.7	1	0.6	1	0.084	NEGLIGIBLE

VES 21*	NACHI, UDI	0.2	1	0.7	1	0.6	1	0.084	NEGLIGIBLE
VES 22	OFF NACHI, UDI	0.4	1	0.7	1	0.6	1	0.168	LOW
VES 23	NACHI BY AMOKWE RD, UDI	0.4	1	0.7	1	0.6	1	0.168	LOW
VES 24	AMOKWE, UDI	0.2	1	0.7	1	0.6	1	0.084	NEGLIGIBLE
VES 25	AMOKWE BY NACHI RD, UDI	0.4	1	0.7	1	0.6	1	0.168	LOW
VES 26	EKEAGU OBELEAGU, EZEAGU	0.4	1	0.7	1	0.6	1	0.168	LOW
VES 27	UMUGHU OBELEAGU, EZEAGU	0.4	1	0.7	1	0.6	1	0.168	LOW
VES 28	UMANA OBELEAGU, EZEAGU	0.4	1	0.7	1	0.6	1	0.168	LOW
VES 29	OBELEAGU BY AMOKWE ROAD, EZEAGU	0.2	1	0.7	1	0.6	1	0.084	NEGLIGIBLE
VES 30	UDI BY AMOKWE RD, UDI	0.2	1	0.7	1	0.6	1	0.084	NEGLIGIBLE
VES 31	AMOKWE, UDI	0.2	1	0.7	1	0.6	1	0.084	NEGLIGIBLE
VES 32*	AMOKWE, UDI	0.2	1	0.7	1	0.6	1	0.084	NEGLIGIBLE
VES 33	UDI, UDI	0.2	1	0.7	1	0.6	1	0.084	NEGLIGIBLE
VES 34	OBELEAGU UMANA, EZEAGU	0.2	1	0.7	1	0.6	1	0.084	NEGLIGIBLE
VES 35	NSUDE, UDI	0.2	1	0.7	1	0.7	1	0.098	NEGLIGIBLE
VES 36	AMAOKWE, UDI	0.2	1	0.7	1	0.6	1	0.084	NEGLIGIBLE
VES 37	UMUABI, UDI	0.2	1	0.7	1	0.6	1	0.084	NEGLIGIBLE
VES 38	UMUEZE UMUAGA, UDI	0.2	1	0.7	1	0.6	1	0.084	NEGLIGIBLE
VES 39	NSUDE II, UDI	0.2	1	0.7	1	0.6	1	0.084	NEGLIGIBLE
VES 40	EZIAMA EBE UDI	0.2	1	0.7	1	0.6	1	0.084	NEGLIGIBLE
VES 41	OKPATU II, UDI	0.6	1	0.7	1	0.6	1	0.252	LOW
VES 42	AMACHALA OBIOMA, UDI	0.4	1	0.5	1	0.6	1	0.12	LOW
VES 43	AMAOKWE, UDI	0.4	1	0.7	1	0.6	1	0.168	LOW
VES 44	OBEAGU UKANA, UDI	0.4	1	0.7	1	0.6	1	0.168	LOW
VES 45	OFF OBIOMA, UDI	0.4	1	0.5	1	0.6	1	0.12	LOW
VES 46	UMUDIM, UDI	0.4	1	0.7	1	0.6	1	0.168	LOW
VES 47*	OBIOMA COMM. HIGH SCH, UDI	0.4	1	0.5	1	0.6	1	0.12	LOW
VES 48	UMUAJI MGBAGBU OWA, EZEA	0.2	1	0.5	1	0.6	1	0.06	NEGLIGIBLE
VES 49	AGUAGBAJA UMUNADIAGU, EZ	0.2	1	0.5	1	0.6	1	0.06	NEGLIGIBLE
VES 50	IBITO OLO, EZEAGU	0.2	1	0.5	1	0.6	1	0.06	NEGLIGIBLE
VES 51	IWOLLO TOWN, EZEAGU	0.6	1	0.7	1	0.6	1	0.252	LOW
VES 52	AGULU OBELEAGU UMANA, EZI	0.4	1	0.7	1	0.6	1	0.168	LOW
VES 53	UMUAJI AGUOBU-OWA, EZEAG	0.4	1	0.5	1	0.6	1	0.12	LOW

VES 54 *	IHUONAYIA CITY OGHE, EZEAG	0.4	1	0.7	1	0.6	1	0.168	LOW
VES 55	EZEAMA AGU AGUOBU-OWA	0.4	1	0.7	1	0.6	1	0.168	LOW
VES 56	IMEZI .O, EZEAGU	1.0	1	0.7	1	0.6	1	0.42	MODERATE
VES 57	AGUOBI IWOLLO, EZEAGU	1.0	1	0.7	1	0.6	1	0.42	MODERATE
VES 58 *	OGHE, EZEAGU	1.0	1	0.7	1	0.6	1	0.42	MODERATE
VES 59	ANIKE IWOLLO, EZEAGU	1.0	1	0.7	1	0.6	1	0.42	MODERATE
VES 60	NDIAGU-UMANA, EZEAGU	0.2	1	0.7	1	0.6	1	0.084	NEGLIGIBLE
VES 61	COMM. SEC SCH OLO, EZEAGU	0.2	1	0.5	1	0.6	1	0.06	NEGLIGIBLE
VES 62	OGWUOFIA, EZEAGU	1.0	1	0.7	1	0.6	1	0.42	MODERATE
VES 63	NGWO, UDI	0.2	1	0.7	1	0.6	1	0.084	NEGLIGIBLE
VES 64	EHUHE ACHI OJI RIVER	1.0	1	0.7	1	0.6	1	0.42	MODERATE
VES 65	UMUEKE OZEGU INYI OJI RIVER	0.2	1	0.7	1	0.6	1	0.084	NEGLIGIBLE
VES 66	OBEAGU, AWGU	0.2	1	0.7	1	0.6	1	0.084	NEGLIGIBLE
VES 67*	AKPUGO-EZE, OJI RIVER	0.4	1	0.7	1	0.6	1	0.168	LOW
VES 68	UGWUOBA OJI RIVER	0.2	1	0.5	1	0.6	1	0.06	NEGLIGIBLE
VES 69	UMUEZE, EZEAGU	0.2	1	0.6	1	0.6	1	0.072	NEGLIGIBLE
VES 70	AMANSIODO EZEAGU	0.2	1	0.6	1	0.6	1	0.072	NEGLIGIBLE
VES 71	OKPOGHO, EZEAGU	0.2	1	0.6	1	0.6	1	0.072	NEGLIGIBLE
VES 72	AFOR- UGWU, UDI	0.2	1	0.6	1	0.6	1	0.072	NEGLIGIBLE
VES 73	COAL CAMP, ENUGU	0.2	1	0.5	1	0.7	1	0.07	NEGLIGIBLE
VES 74*	WINNERS ESTATE TRANS-EKULU, ENUGU EAST	0.2	1	0.5	1	0.6	1	0.06	NEGLIGIBLE
VES 75*	PHASE 6 TRANS-EKULU, ENUG	0.2	1	0.5	1	0.7	1	0.07	NEGLIGIBLE
VES 76*	OZALLA NKANU, ENUGU	0.2	1	0.5	1	0.6	1	0.06	NEGLIGIBLE
VES 77	OBODOAKPU AGBOGUGU, AW	0.2	1	0.5	1	0.6	1	0.06	NEGLIGIBLE
VES 78	EMENE INDUSTRIAL LAYOUT, ENUGU	0.2	1	0.5	1	0.6	1	0.06	NEGLIGIBLE
VES 79	ENUGU INDEPENDENT LAYOUT	0.2	1	0.5	1	0.6	1	0.06	NEGLIGIBLE
VES 80	UMUGHOKENE IJI-NIKE ENUGU	0.2	1	0.5	1	0.7	1	0.07	NEGLIGIBLE
VES 81	UMUGHOKENE IJI-NIKE ENUGU	0.2	1	0.5	1	0.7	1	0.07	NEGLIGIBLE
VES 82	NIKE LAKE ROAD, ENUGU	0.2	1	0.5	1	0.7	1	0.07	NEGLIGIBLE
VES 83	HARMONY ESTATE NIKE, ENUG	0.2	1	0.5	1	0.6	1	0.06	NEGLIGIBLE
VES 84*	OBEAGU ENUGU SOUTH	0.2	1	0.5	1	0.7	1	0.07	NEGLIGIBLE
VES 85	9 ABAKALIKI ROAD EMENE	0.2	1	0.5	1	0.7	1	0.07	NEGLIGIBLE

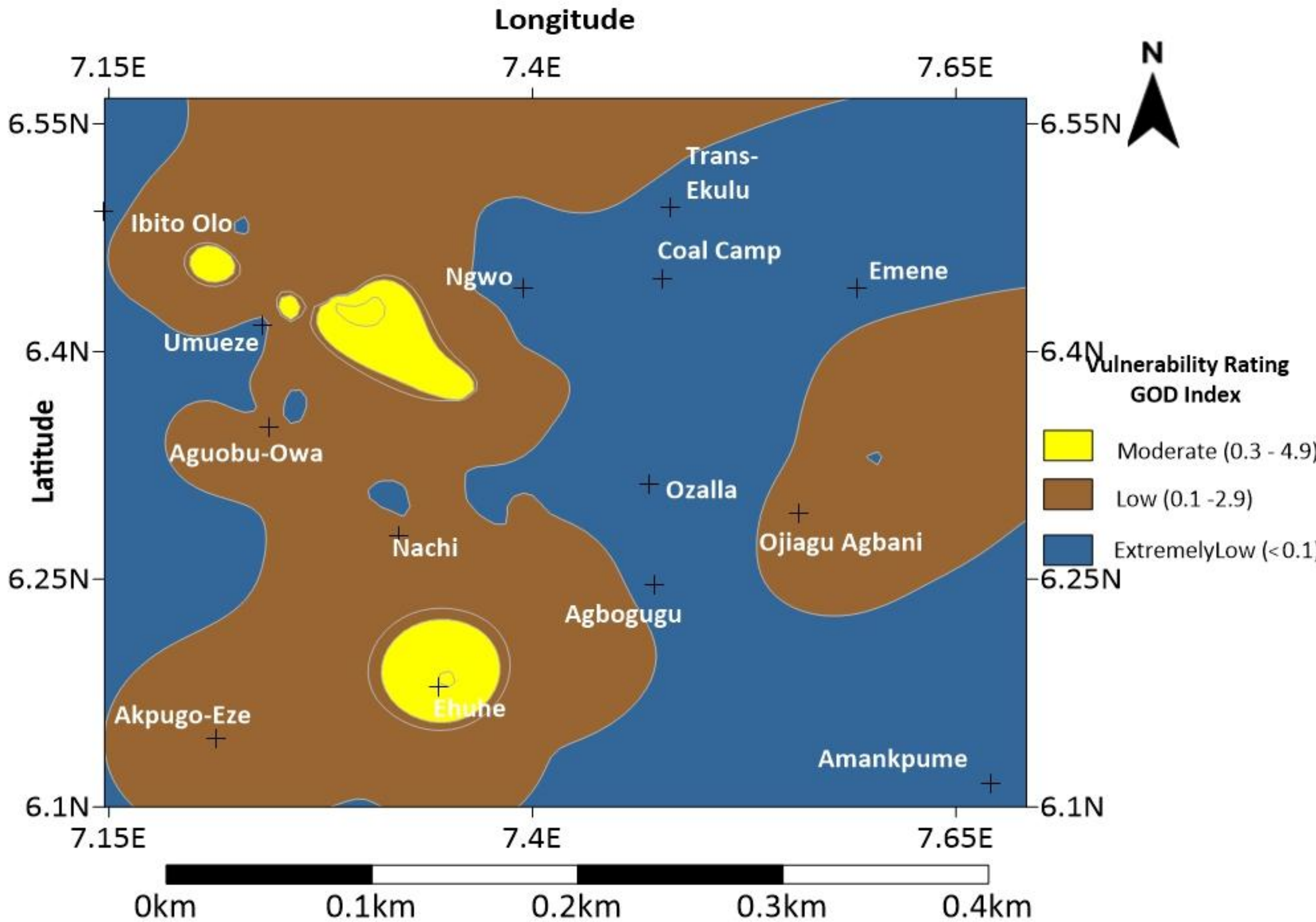


Fig 4.14 Spatial Distribution Map of Aquifer Vulnerability of the study area based on GOD Index

Table 4.11 Description statistics of aquifer geometric and hydraulic characteristics of the study area

Aquifer Parameter	Central Tendency	GEOLOGIC FORMATION						
		IMO	NSUKKA	AJALI	MAMU	NKPORO	AWGU	EZEAKU
Aquifer Resistivity (m)	Min	27.3	82.4	37.5	2.8	3.0	10.7	494.0
	Maxi	1258.0	20000.0	88745.0	23.4	996.3	1628.0	3630.0
	Mean	845.1	3878.0	9843.3	13.7	151.5	311.6	1170.3
Aquifer Depth (m)	Min	76.5	57.9	23.4	40.0	30.0	52.5	149.0
	Maxi	120.0	250.0	300.0	99.2	100.0	143.9	375.0
	Mean	98.8	142.9	150.7	79.4	49.9	83.9	241.7
Aquifer Thickness (m)	Min	50.0	28.6	22.1	32.0	10.0	24.0	22.0
	Maxi	70.0	151.3	195.5	83.2	61.4	104.0	224.0
	Mean	60.3	81.7	113.4	65.7	27.1	52.8	97.7
Aquifer Conductivity (mhos)	Min	0.00079	0.00005	0.00001	0.04274	0.00100	0.00061	0.00028
	Maxi	0.03663	0.01214	0.02667	0.35714	0.33333	0.09346	0.00202
	Mean	0.01274	0.00340	0.00502	0.15551	0.06757	0.03109	0.00141
Transverse Resistance (Ωm2)	Min	1662.57	7341.84	2880	232.96	42	256.8	10956
	Maxi	88060	1200000	8430775	1918.8	61172.82	108913.2	813120
	Mean	50740.857	288160.4629	1051259.93	877.25333	7850.5326	22905.316	185014
Longitudinal Conductance mhos/m	Min	0.04	0.003	0.00107048	2.1333333	0.06162802	0.0410934	0.0441767
	Maxi	2.2307692	1.545454545	3.4	29.714286	4.66666667	4.1294118	0.1372727
	Mean	0.775471	0.323784141	0.63582851	11.783964	1.10611309	1.3236923	0.0928382
Hydraulic Conductivity (m/day) values from Niwas and Singhal model	Min	1.349284	2.40174223	1.8992625	1.5144077	0.57522045	0.235614	1.2809942
	Maxi	62.175798	582.9471431	4494.66802	12.656121	191.030713	35.84856	9.4129739
	Mean	41.768495	122.9037551	498.535917	7.4278092	29.048633	6.8603783	3.0347981
Hydraulic Conductivity (m/day) values from Heigold model	Min	0.4960918	0.03757572	0.00935966	20.407579	0.61666436	0.3900404	0.1846075
	Maxi	17.674271	6.306708192	13.144181	147.88179	138.664119	42.344504	1.1864455
	Mean	6.2231386	1.834788404	2.6047458	66.39611	29.843773	14.68371	0.8384415
Hydraulic Conductivity (m/day) values from New Generated model	Min	2.64	3.708	3.694	2.355	2.454	1.050	1.554
	Maxi	2.691	34.063	8.21	2.750	2.601	1.89	1.594
	Mean	2.671	13.599	5.518	2.513	2.534	1.525	1.583
Transmissivity (m^2/day) values from New Generated Geophysical model	Min	134.986	238.675	122.47	77.848	25.698	45.358	35.071
	Maxi	188.988	2767.81	1229.88	228.787	150.692	125.676	347.987
	Mean	161.573	1049.93	613.184	166.583	68.239	76.554	153.627
IEC Values (mS)	Min	284.92	3.46	0.04	29.60	5.80	2.80	19.47
	Maxi	2140.58	4871.18	1207.34	114.05	15992.67	5752.99	364.26
	Mean	939.06	508.07	61.50	61.39	2294.74	831.53	116.55
DRASTIC Index	Min	93	96	98	80	80	93	93
	Maxi	105	144	138	80	85	120	93
	Mean	101	119	118	80	81.1	109	93
GOD Index	Min	0.06	0.06	0.084	0.06	0.06	0.06	0.06
	Maxi	0.168	0.42	0.42	0.07	0.07	0.168	0.06
	Mean	0.096	0.15	0.15845	0.07	0.065	0.124	0.06

4.8 Evaluation of Soil Corrossivity

Corrosivity described as the ability of a soil to corrode a material buried in it. The investigated area's topsoil resistivity ranged betwween3.0 Ωm and 31001.7 Ωm with mean value of 3189.5 Ωm. The thickness of the layer across the study area ranges between 0.2m and 20.3 m with a mean value of 1.6m (See table 4.12). About 78% of the study area has relatively high topsoil resistivity values with low tendency for corrosivity. The spatial distribution corrossivity map of the study area is shown in (figure 4.15). Based on on Baeckmann and Schenwenk, (1975); Bayowa and Olayiwola,(2015) corrossivity classification rating and competent, the result revealed that 78% of the area are Practically non corrosive (PNC) and it is characteristically sandy-clay, clayey-sand to sand materials which can be rated as moderately competent to highly competent strata; 13% of the area are said to be slightly corrosive and composed of clay to sandy-clay materials which rated as moderately competent to Incompent strata while the 9% are moderately and very strongly corrosive and it composed of sandy-clay and clay material which is an incompenet material to construct on. Consequently, using resistivity data to evaluate soil corrossivity worldwide have previously developed by several authors (Adeniji, et al. 2014; Daku, et al. 2019; Kennedy, 2019).

Table 4.12. Summary of Resistivity values and Corrossivity Rating

VES	LATITUDE	LONGITUDE	LOCATION	RESISTIVITY	THICKNESS	Corrossivity Rating	Competence Rating
VES 1 *	6°17"49.6'N	7°34"39.4'E	OJIAGU TOWN HALL AGBANI NKANU WEST	520.0	1.0	Practically non corrossive	Competent
VES 2	6°17'16.7"N	7°35'18.7"E	SCH. AGBANI NKANU WEST	365.0	1.0	Practically non corrossive	Competent
VES 3 *	6°21'57.35"N	7°35'49.7"E	[illegible] NDIUNO AKPUGO NKANU WEST	1011.1	2.8	Practically non corrossive	Highly Competent
VES 4	6°09'35.89"N	7°41'29.84"E	EZEMEZUOBODO IKORO UMUOIKA NKEREFI NKANU EAST	160.0	2.5	Slightly corrossive	Moderately Competent
VES 5*	6°08'57.20"N	7°41'24.95"E	GIRLS SEC. SCH. UMUOIKA ENUOGU NKEREFI NKANU EAST	158.0	1.9	Slightly corrossive	Moderately Competent
VES 6	6°09'05.67"N	7°41'19.0"E	AMANKPUME NKEREFI NKANU EAST	167.0	1.9	Slightly corrossive	Moderately Competent
VES 7	6°10'40.09"N	7°40'14.00"E	AMAOFU NKANU EAST	164.0	1.7	Slightly corrossive	Moderately Competent
VES 8*	6°10'21.33"N	7°39'45.53"E	OBODO EBUNABO NKEREFI NKANU EAST	240.0	0.5	Practically non corrossive	Moderately Competent
VES 9	6°09'03.38"N	7°41'20.46"E	UMUOVUDU 1 UMUOIKA NKEREFI NKANU EAST	159.0	2.4	Slightly corrossive	Moderately Competent
VES 10	6°18'31.51"N	7°39'19.22"E	OBOUHIA NKANU EAST/ WEST FED. CONSTITUENCY	578.0	0.8	Practically non corrossive	Competent
VES 11	6°18'36"N	7°33'57.60"E	ONUACHI AGBANI NKANU WEST	1112.7	1.5	Practically non corrossive	Highly Competent
VES 12 *	6°13'04.97"N	7°38'53.20"E	NARA NKANU EAST	130.0	0.8	Slightly corrossive	Moderately Competent
VES 13	6°19'38.5"N	7°36'21.5"E	OBINAGU UWANI AKPUGO NKANU WEST	817.0	0.6	Practically non corrossive	Highly Competent
VES 14	6°19'22.2"N	7°36'41.0"E	OBINAGU UWANI NKANU	33.6	1.1	Moderately corrossive	Incompetent
VES 15	6°19'6.0"N	7°37'0.5"E	OBINAGU UWANI NKANU	307.0	0.6	Practically non corrossive	Moderately Competent
VES 16 *	6°29'47"N	7°23'34"E	AFOR PRIMARY SCH ABOR	280.0	0.5	Practically non corrossive	Moderately Competent
VES 17	6°17'19.65"N	7°23'51.36"E	OBINAGU UDI	170.0	3.5	Slightly corrossive	Moderately Competent
VES 18	6°34'0.49"N	7°25'26.7"E	AMAGU UMUENE IBITE OKPATU, UDI	1540.0	0.8	Slightly corrossive	Highly Competent
VES 19	6°33'1.01"N	7°26'12.5"E	OGENE OJEBE, UDI	205.0	0.8	Practically non corrossive	Moderately Competent
VES 20	6°27'28"N	7°21'27"E	EKE-UDI SQUARE UDI	700.0	1.2	Practically non corrossive	Competent

VES 21 *	6°17'38.54"N	7°19'26.60"E	NACHI, UDI	6700.0	0.7	Practically non corrossive	Highly Competent
VES 22	6°16'57.23"N	7°19'16.68"E	OFF NACHI, UDI	4800.0	1.4	Practically non corrossive	Highly Competent
VES 23	6°18'18.57"N	7°20'52.30"E	NACHI BY AMOKWE RD, UD	7000.0	0.9	Practically non corrossive	Highly Competent
VES 24	6°19'03.63"N	7°22'04.54"E	AMOKWE, UDI	5600.0	1.0	Practically non corrossive	Highly Competent
VES 25	6°18'52.22"N	7°20'10.39"E	AMOKWE BY NACHI RD, UD	7168.0	1.6	Practically non corrossive	Highly Competent
VES 26	6°23'49.0"N	7°22'15.0"E	EKEAGU OBELEAGU, EZEA	8000.0	1.5	Practically non corrossive	Highly Competent
VES 27	6°21'18.0"N	7°13'06.0"E	UMUGHU OBELEAGU, EZEA	1900.0	1.9	Practically non corrossive	Highly Competent
VES 28	6°20'58.0"N	7°22'01.0"E	UMANA OBELEAGU, EZEA	2500.0	2.0	Practically non corrossive	Highly Competent
VES 29	6°18'35.0"N	7°19'19.0"E	OBELEAGU BY AMOKWE ROAD, EZEAGU	24500.0	1.4	Practically non corrossive	Highly Competent
VES 30	6°19'20.24"N	7°24'01.20"E	UDI BY AMOKWE RD, UDI	4300.0	1.0	Practically non corrossive	Highly Competent
VES 31	6°19'07.53"N	7°22'00.77"E	AMOKWE, UDI	1420.0	1.3	Practically non corrossive	Highly Competent
VES 32 *	6°19'08.34"N	7°21'49.95"E	AMOKWE, UDI	4500.0	0.8	Practically non corrossive	Highly Competent
VES 33	6°19'05.90"N	7°23'31.22"E	UDI, UDI	10000.0	1.8	Practically non corrossive	Highly Competent
VES 34	6°21'54.0"N	7°21'33.0"E	OBELEAGU UMANA, EZEA	22500.0	1.8	Practically non corrossive	Highly Competent
VES 35	6°24'06.23"N	7°23'59.75"E	NSUDE, UDI	3600.0	1.4	Practically non corrossive	Highly Competent
VES 36	6°18'20.3"N	7°21'48.9"E	AMAOKWE, UDI	1057.9	1.0	Practically non corrossive	Highly Competent
VES 37	6°17'19"N	7°23'06"E	UMUABI, UDI	221.3	3.8	Practically non corrossive	Moderately Competent
VES 38	6°26'39"N	7°22'500"E	UMUEZE UMUAGA, UDI	1094.4	1.8	Practically non corrossive	Highly Competent
VES 39	6°24'20"N	7°23'56"E	NSUDE II, UDI	2121.1	0.2	Practically non corrossive	Highly Competent
VES 40	6°29'29"N	7°22'40"E	EZIAMA EBE UDI	31001.7	0.9	Practically non corrossive	Highly Competent
VES 41	6°31'54.3"N	7°24'36.3"E	OKPATU II, UDI	31001.7	0.9	Practically non corrossive	Highly Competent
VES 42	6°22'43.20"N	7°24'38.40"E	AMACHALA OBIOMA, UDI	991.9	2.7	Practically non corrossive	Highly Competent
VES 43	6°19'26.4"N	7°21'00"E	AMAOKWE, UDI	1055.5	1.4	Practically non corrossive	Highly Competent
VES 44	6°30'10.8"N	7°17'49.20"E	OBEAGU UKANA, UDI	520.9	1.5	Practically non corrossive	Competent
VES 45	6°21'17"N	7°23'59"E	OFF OBIOMA, UDI	23500.0	1.5	Practically non corrossive	Highly Competent
VES 46	6°21'05"N	7°23'04"E	UMUDIM, UDI	4000.0	0.8	Practically non corrossive	Highly Competent
VES 47 *	6°22'50"N	7°24' 17"E	OBIOMA COMM. HIGH SCH,	2900.0	0.7	Practically non corrossive	Highly Competent
VES 48	6°22'06.83"N	7°13'26.98"E	UMUAJI MGBAGBU OWA,	462.0	6.5	Practically non corrossive	Competent
VES 49*	6°24'08.92"N	7°13'41.23"E	AGUAGBAJA UMUNADIAG	565.0	20.3	Practically non corrossive	Competent
VES 50	6°29'57.41"N	7°08'51.05"E	IBITO OLO, EZEAGU	1100.0	1.3	Practically non corrossive	Highly Competent
VES 51*	6°25'32.4"N	7°15'54"E	IWOLLO TOWN, EZEAGU	235.5	1.2	Practically non corrossive	Moderately Competent
VES 52	6°20'34.5"N	7°21'48.3"E	AGULU OBELEAGU UMANA	1057.9	1.0	Practically non corrossive	Highly Competent
VES 53	6°21'59"N	7°14'43"E	UMUAJI AGUOBU-OWA, E	821.4	1.0	Practically non corrossive	Highly Competent
VES 54 *	6°29'01.2"N	7°14'52.2"E	IHUONAYIA CITY OGHE, EZ	2574.5	1.5	Practically non corrossive	Highly Competent
VES 55	6°22'29.1"N	7°14'42.5"E	EZEAMA AGU AGUOBU-OV	563.0	0.5	Practically non corrossive	Competent
VES 56	6°27'38.5"N	7°12'46.9"E	IMEZI .O, EZEAGU	13566.0	2.4	Practically non corrossive	Highly Competent
VES 57	6°25'38"N	7°15'20"E	AGUOBI IWOLLO, EZEAGU	718.7	4.8	Practically non corrossive	Competent
VES 58 *	6°26'03"N	7°18'26"E	OGHE, EZEAGU	125.1	0.5	Slightly corrossive	Moderately Competent
VES 59	6°26'05.04"N	7°17'03.9"E	ANIKE IWOLLO, EZEAGU	644.6	0.9	Practically non corrossive	Competent
VES 60	6°21'48.95"N	7°13'55.2"E	NDIAGU-UMANA, EZEAGU	203.0	1.1	Practically non corrossive	Moderately Competent
VES 61*	6°25'04"N	7°10'11"E	COMM. SEC SCH OLO, EZE	3740.0	1.3	Practically non corrossive	Highly Competent
VES 62	6°22'14"N	7°21'29"E	OGWUOFIA, EZEAGU	7000.0	1.1	Practically non corrossive	Highly Competent
VES 63	6°26'38.79"N	7°23'45.16"E	NGWO, UDI	2047.0	0.8	Practically non corrossive	Highly Competent
VES 64	6°11'00.57"N	7°21'00.44"E	EHUHE ACHI OJI RIVER	351.0	0,6	Practically non corrossive	Competent
VES 65	6°06'00.18"N	7°18'00.27"E	UMUEKE OZEGU INYI OJI R	698.0	0.8	Practically non corrossive	Competent
VES 66	6°07'57.25"N	7°25'00.09"E	OBEAGU, AWGU	2406.9	3.6	Practically non corrossive	Highly Competent
VES 67*	6°09'00.18"N	7°12'45.49"E	AKPUGO-EZE, OJI RIVER	42.0	1.0	Moderately corrossive	Incompetent
VES 68	6°15'00.42"N	7°13'00.62"E	UGWUOBA OJI RIVER	3.0	1.0	Very strongly corrossive	Incompetent
VES 69	6°25'17.92"N	7°14'39.42"E	UMUEZE, EZEAGU	4500.0	1.2	Practically non corrossive	Highly Competent
VES 70	6°28'41.42"N	7°16'15.68"E	AMANSIODO EZEAGU	9.1	0.4	Very strongly corrossive	Incompetent
VES 71	6°26'16.54"N	7°17'01.59"E	OKPOGHO, EZEAGU	9.8	0.3	Very strongly corrossive	Incompetent
VES 72	6°22'16.17"N	7°15'35.72"E	AFOR- UGWU, UDI	5.9	0.4	Very strongly corrossive	Incompetent
VES 73	6°27'03.73"N	7°28'23.27"E	COAL CAMP, ENUGU	96.0	1.0	Slightly corrossive	Incompetent
VES 74*	6°29'45.5"N	7°28'43.8"E	WINNERS ESTATE TRANS-	498.7	0.7	Practically non corrossive	Competent
VES 75*	6°29'57"N	7°28'34"E	PHASE 6 TRANS-EKULU, EN	773.5	2.8	Practically non corrossive	Highly Competent
VES 76*	6°19'00.51"N	7°28'33.59"E	OZALLA NKANU, ENUGU	765.0	1.0	Practically non corrossive	Highly Competent
VES 77	6°15'04.03"N	7°28'49.55"E	OBODOAKPU AGBOGUGU,	1036.0	3.0	Practically non corrossive	Highly Competent
VES 78	6°28'00.61"N	7°36'00.37"E	EMENE INDUSTRIAL LAYOU	350.0	0.5	Practically non corrossive	Competent
VES 79	6°25'00.67"N	7°32'00.09"E	ENUGU INDEPENDENT LAY	25.4	1.3	Moderately corrossive	Incompetent
VES 80	6°31'00.12"N	7°30'00.00"E	UMUGHOKENE IJI-NIKE ENU	180.0	1.0	Slightly corrossive	Moderately Competent
VES 81	6°31'01.04"N	7°33'02.00"E	UMUGHOKENE IJI-NIKE ENU	358.0	1.0	Practically non corrossive	Competent
VES 82	6°29'04.53"N	7°30'02.43"E	NIKE LAKE ROAD, ENUGU	40.0	0.8	Moderately corrossive	Incompetent
VES 83	6°29'00.23"N	7°32'09.08"E	HARMONY ESTATE NIKE, E	299.7	1.3	Practically non corrossive	Moderately Competent
VES 84*	6°22'59.07"N	7°32'42.12"E	OBEAGU ENUGU SOUTH	109.2	1.2	Slightly corrossive	Moderately Competent
VES 85	6°27'50.34"N	7°35'09.80"E	9 ABAKALIKI ROAD EMENE	355.0	0.6	Practically non corrossive	Competent

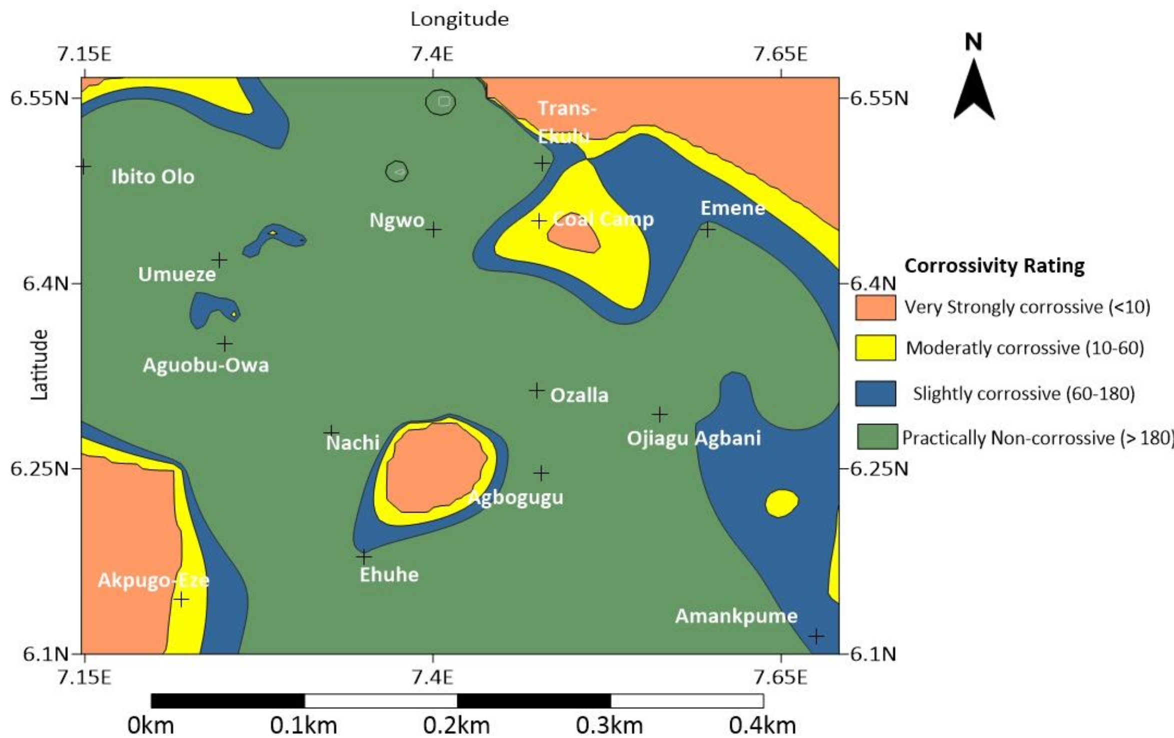


Fig 4.15. Corrossivty Map of the study area

4.9 Estimation of Aquifer Protective Capacity of the study area Using Longitudinal Conductance (Lc) and IEC

4.9.1 Longitudinal Conductance (Lc)

The longitudinal conductance was integrated by dividing the aquifer thickness and by the aquifer apparent resistance (See equation 3.16). However, the longitudinal conductance values across the study area varies between 0.001 mhos/m at Amokwe by Nachi road Udi (VES 63) and 29.714 mhos/m at Obuohia Nkanu (VES 74) with a mean value of 1.073 mhos/m (See Table 4.13), these were used to estimate the overburden protective capacity of the aquifer units in the study area. The values of longitudinal conductance generated from the study area were used to model the spatial distribution map of longitudinal conductance using GIS SURFER 16 Toolkits (See figure 4.16). According to Oladapo and Akintoriwa, 2007; Henriet, 1975, aquifer overburden protective capacity could be zoned into excellent, very good, good, moderate, weak and poor protective capacity. Zones where the conductance is greater than 10 mhos are considered zones of excellence protective capacity, zones where the conductance values varying from 5 to 10 mhos are classified as the zones of very good protective capacity. The area having conductance values varying from 0.7 to 4.9 mhos are considered zones of good protective capacity. Therefore, the region ranging from 0.2 to 0.69 mhos was classified as zone of moderate protective capacity; the area having conductance values ranging from 0.1 to 0.19 mhos are considered as the zones of weak protective capacity and the zone where the conductance value is less 0.1 mhos are considered as zone of poor protective capacity. Therefore, across the study area, the protective capacity is zoned into excellent, very good, good, moderate, weak and poor protective capacity rating (Figure 4.16). Areas marked with purple green coloours is identified as the zone of excellent and very good protective capacity. Moreover, areas marked with a blue colour fall within the zone of good protective capacity occurring towards the eastern western and central parts of the study area. Also, areas marked with a brown colour fall within the zone of moderate protective capacity, areas marked with yellow colour fall within the zone of weak protective capacity and the areas marked with a red colour fall within the zone of poor protective capacity respectively.

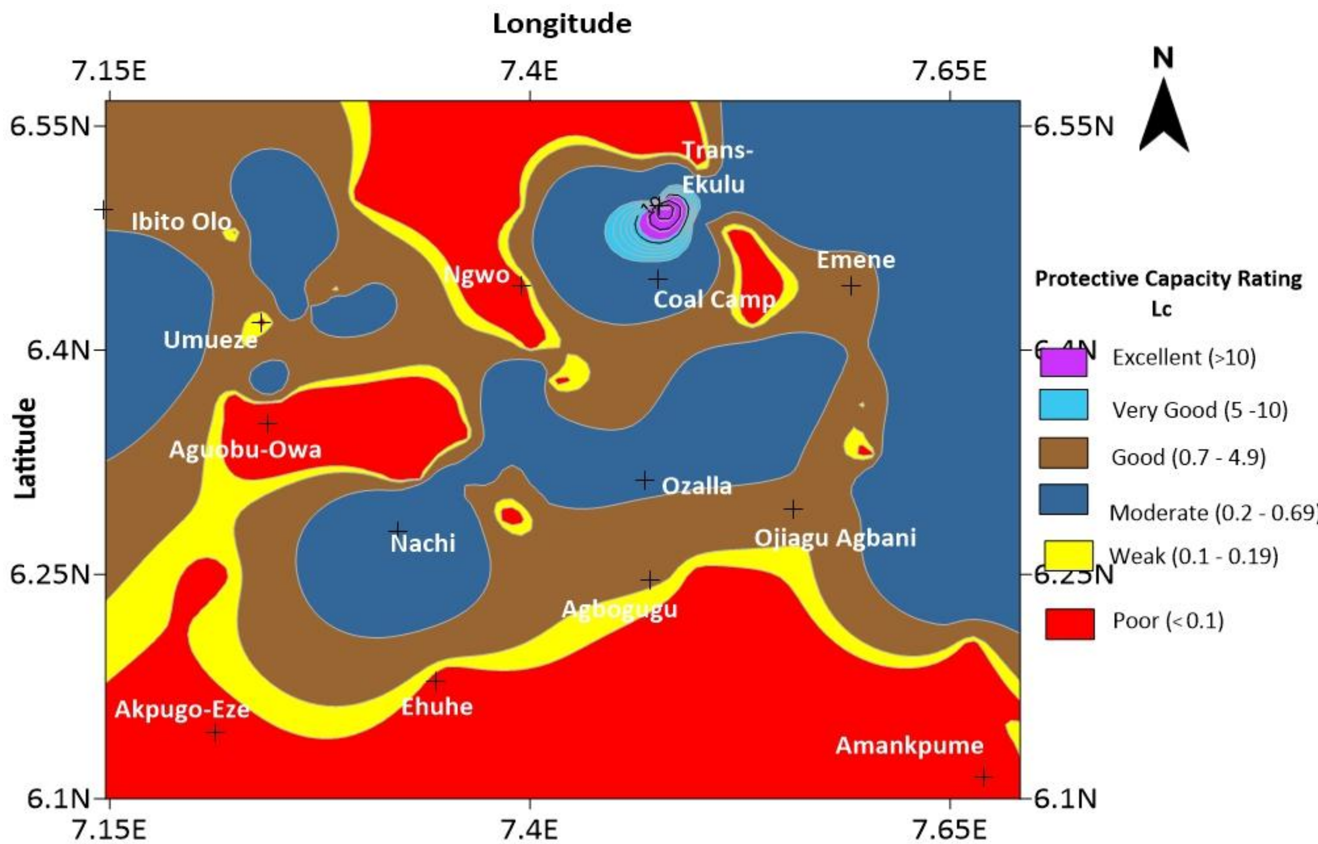


Fig 4.16 Spatial Distribution Map Aquifer Protective Capacity of the study area by Longitudinal Conductance (mhos/m)

Table 4.13 Summary of Aquifer Protective Capacity of the study area by Longitudinal Conductance

VES POINTS	LATITUDE	LONGITUDI	LOCATION	AQUIFER RESISTIVITY (ohm-1)	AQUIFER DEPTH (m)	AQUIFER THICKNESS (m)	AQUIFER CONDUCTIVITY (σ)	TRANVERSE RESISTANCE (R)	LONGITUDNAL CONDUCTANCE (S)	PROTECTIVE CAPACITY RATING	GEOLOGIC FM
VES 1 *	6º17''49.6'N	7º34''39.4'E	OJIAGU TOWN HALL AGBANI NKANU WEST	42.0	85.0	29.0	0.023809524	1218.00	0.69047619	MODERATE	AWGU
VES 2	6'17'16.7''N	7'35'18.7''E	SPECIAL SCI GIRLS SEC. SCH. AGBANI NKANU WEST	250.0	85.0	53.0	0.004	13250.00	0.212	MODERATE	AWGU
VES 3 *	6'21'57.35''N	7'35'49.7''E	OGBASHI VILLAGE SQ NDIUNO AKPUGO NKANU WEST	733.0	143.9	104.0	0.001364256	76232.00	0.141882674	WEAK	AWGU
VES 4	6'09'35.89''N	7'41'29.84''E	EZEMEZUOBODO IKORO UMUOIKA NKEREFI NKANU EAST	3630.0	375.0	224.0	0.000275482	813120.00	0.061707989	POOR	EZEAKU SH
VES 5*	6'08'57.20''N	7'41'24.95''E	GIRLS SEC. SCH. UMUOIKA ENUOGU NKEREFI NKANU EAST	792.0	203.0	87.0	0.001262626	68904.00	0.109848485	WEAK	EZEAKU SH
VES 6	6'09'05.67''N	7'41'19.0''E	AMANKPUME NKEREFI NKANU EAST	508.0	300.0	44.0	0.001968504	22352.00	0.086614173	POOR	EZEAKU SH
VES 7	6'10'40.09''N	7'40'14.00''E	AMAOFU NKANU EAST	1100.0	270.0	151.0	0.000909091	166100.00	0.137272727	WEAK	EZEAKU SH
VES 8*	6'10'21.33''N	7'39'45.53''E	OBODO EBUNABO NKEREFI NKANU EAST	498.0	153.0	22.0	0.002008032	10956.00	0.044176707	POOR	EZEAKU SH
VES 9	6'09'03.38''N	7'41'20.46''E	UMUOVUDU 1 UMUOIKA NKEREFI NKANU EAST	494.0	149.0	58.0	0.002024291	28652.00	0.117408907	WEAK	EZEAKU SH
VES 10	6'18'31.51''N	7'39'19.22''E	OBUOHIA NKANU EAST/ WEST FED. CONSTITUENCY	17.0	76.7	70.2	0.058823529	1193.40	4.129411765	GOOD	AWGU
VES 11	6'18'36''N	7'33'57.60''E	ONUACHI AGBANI NKANU WEST	46.5	70.1	30.4	0.02151926	1412.69	0.654185496	MODERATE	AWGU
VES 12 *	6'13'04.97''N	7'38'53.20''E	NARA NKANU EAST	60.0	85.0	47.0	0.016666667	2820.00	0.783333333	GOOD	AWGU
VES 13	6'19'38.5''N	7'36'21.5''E	OBINAGU UWANI AKPUGO NKANU WEST	1628.0	98.3	66.9	0.000614251	108913.20	0.041093366	POOR	AWGU
VES 14	6'19'22.2''N	7'36'41.0''E	OBINAGU UWANI NKANU	10.7	52.5	24.0	0.093457944	256.80	2.242990654	GOOD	AWGU
VES 15	6'19'6.0''N	7'37'0.5''E	OBINAGU UWANI NKANU	16.8	58.8	50.7	0.05952381	851.76	3.017857143	GOOD	AWGU
VES 16 *	6'29'47''N	7'23'34''E	AFOR PRIMARY SCH ABOR UDI	9000.0	300.0	120.0	0.000111111	1080000.00	0.013333333	POOR	AJALI
VES 17	6'17'19.65''N	7'23'51.36''E	OBINAGU UDI	733.0	260.0	70.0	0.001364238	51310.70	0.095496651	POOR	AJALI
VES 18	6'34'0.49''N	7'25'26.7''E	AMAGU UMUENE IBITE OKPATU, UDI	25178.0	155.0	110.0	3.97172E-05	2769580.00	0.004368893	POOR	AJALI
VES 19	6'33'1.01''N	7'26'12.5''E	OGENE OJEBE, UDI	32587.0	150.0	135.0	3.06871E-05	4399245.00	0.004142756	POOR	AJALI
VES 20	6'27'28.00''N	7'21'27''E	EKE-UDI SQUARE UDI	4500.0	150.0	147.0	0.000222222	661500.00	0.032666667	POOR	AJALI
VES 21 *	6'17'38.54''N	7'19'26.60''E	NACHI, UDI	60.0	154.7	140.5	0.016666667	8430.00	2.341666667	GOOD	AJALI
VES 23	6'18'18.57''N	7'20'52.30''E	NACHI BY AMOKWE RD, UDI	57.5	210.6	195.5	0.017391304	11241.25	3.4	GOOD	AJALI
VES 24	6'19'03.63''N	7'22'04.54''E	AMOKWE, UDI	79.0	162.9	149.0	0.012666244	11763.55	1.887270424	GOOD	AJALI
VES 25	6'18'52.22''N	7'20'10.39''E	AMOKWE BY NACHI RD, UDI	40707.0	115.0	69.0	2.45658E-05	2808783.00	0.00169504	POOR	AJALI
VES 26	6'23'49.0''N	7'22'15.0''E	EKEAGU OBELEAGU, EZEAGU	261.1	130.0	120.0	0.00382995	31332.00	0.459594025	MODERATE	AJALI

VES 27	6'21'18.0"N	7'13'06.0"E	UMUGHU OBELEAGU, EZEAGU	347.4	57.9	36.0	0.002878775	12505.32	0.103635893	WEAK	NSUKKA
VES 28	6'20'58.0"N	7'22'01.0"E	UMANA OBELEAGU, EZEAGU	293.7	112.0	88.0	0.003405067	25843.84	0.299645873	MODERATE	AJALI
VES 29	6'18'35.0"N	7'19'19.0"E	OBELEAGU BY AMOKWE ROAD,	357.9	103.1	83.3	0.002794155	29812.24	0.232753081	MODERATE	AJALI
VES 30	6'19'20.24"N	7'24'01.20"E	UDI BY AMOKWE RD, UDI	115.8	216.0	180.0	0.008635579	20844.00	1.554404145	GOOD	AJALI
VES 31	6'19'07.53"N	7'22'00.77"E	AMOKWE, UDI	60.0	126.0	95.0	0.016666667	5700.00	1.583333333	GOOD	AJALI
VES 32 *	6'19'08.34"N	7'21'49.95"E	AMOKWE, UDI	105.3	127.8	100.0	0.009500285	10526.00	0.950028501	GOOD	AJALI
VES 33	6'19'05.90"N	7'23'31.22"E	UDI, UDI	705.9	181.8	162.0	0.001416651	114354.18	0.229497514	MODERATE	AJALI
VES 34	6'21'54.0"N	7'21'33.0"E	OBELEAGU UMANA, EZEAGU	777.7	153.3	123.0	0.001285843	95657.10	0.158158673	WEAK	AJALI
VES 35	6'24'06.23"N	7'23'59.75"E	NSUDE, UDI	1938.4	23.4	22.1	0.000515889	42838.64	0.011401156	POOR	AJALI
VES 36	6'18'20.3"N	7'21'48.9"E	AMAOKWE, UDI	5961.2	118.2	100.3	0.000167751	597908.36	0.016825471	POOR	AJALI
VES 37	6'17'19"N	7'23'06"E	UMUABI, UDI	18693.2	136.2	114.7	5.34954E-05	2144110.04	0.006135921	POOR	AJALI
VES 38	6'26'39"N	7'22'500"E	UMUEZE UMUAGA, UDI	13542.4	123.5	100.2	7.38422E-05	1356948.48	0.007398984	POOR	AJALI
VES 39	6'24'20"N	7'23'56"E	NSUDE II, UDI	22838.5	152.3	133.8	4.37857E-05	3055791.30	0.005858528	POOR	AJALI
VES 40	6'29'29"N	7'22'40"E	EZIAMA EBE UDI	26372.6	171.0	169.7	3.79181E-05	4475430.22	0.006434709	POOR	AJALI
VES 41	6'31'54.3"N	7'24'36.3"E	OKPATU II, UDI	26372.6	171.0	169.7	3.79181E-05	4475430.22	0.006434709	POOR	AJALI
VES 42	6'22'43.20"N	7'24'38.40"E	AMACHALA OBIOMA, UDI	4479.2	143.1	54.2	0.000223254	242772.64	0.012100375	POOR	AJALI
VES 43	6'19'26.4"N	7'21'00"E	AMAOKWE, UDI	27453.4	103.0	49.2	3.64254E-05	1350707.28	0.001792128	POOR	AJALI
VES 44	6'30'10.8"N	7'17'49.20"E	OBEAGU UKANA, UDI	7284.5	177.1	79.4	0.000137278	578389.30	0.010899856	POOR	AJALI
VES 45	6'21'17"N	7'23'59"E	OFF OBIOMA, UDI	170.0	191.0	171.9	0.005882353	29223.00	1.011176471	GOOD	AJALI
VES 46	6'21'05"N	7'23'04"E	UMUDIM, UDI	71.1	133.0	117.0	0.014074595	8312.85	1.646727657	GOOD	AJALI
VES 47 *	6'22'50"N	7'24' 17"E	OBIOMA COMM. HIGH SCH, UDI	37.5	93.5	76.8	0.026666667	2880.00	2.048	GOOD	AJALI
VES 48	6'22'06.83"N	7'13'26.98"E	UMUAJI MGBAGBU OWA, EZEAGU	3560.0	125.0	28.6	0.000280899	101816.00	0.008033708	POOR	NSUKKA
VES 49*	6'24'08.92"N	7'13'41.23"E	AGUAGBAJA UMUNA-NDIAGU, EZEAG	326.0	178.0	53.2	0.003067485	17343.20	0.163190184	WEAK	NSUKKA
VES 50	6'29'57.41"N	7'08'51.05"E	IBITO OLO, EZEAGU	200.0	250.0	70.0	0.005	14000.00	0.35	MODERATE	NSUKKA
VES 51*	6'25'32.4"N	7'15'54"E	IWOLLO TOWN, EZEAGU	107.2	123.0	69.9	0.009328358	7493.28	0.652052239	MODERATE	NSUKKA
VES 52	6'20'34.5"N	7'21'48.3"E	AGULU OBELEAGU UMANA, EZEAGU	5961.2	118.2	100.3	0.000167751	597908.36	0.016825471	POOR	AJALI
VES 53	6'21'59"N	7'14'43"E	UMUAJI AGUOBU-OWA, EZEAGU	5627.1	100.9	84.6	0.000177711	476052.66	0.015034387	POOR	NSUKKA
VES 54 *	6'29'01.2"N	7'14'52.2"E	IHUONAYIA CITY OGHE, EZEAGU	47.9	142.1	115.8	0.020876827	5546.82	2.417536534	GOOD	AJALI
VES 55	6'22'29.1"N	7'14'42.5"E	EZEAMA AGU AGUOBU-OWA	97.9	165.7	151.3	0.010214505	14812.27	1.545454545	GOOD	NSUKKA
VES 56	6'27'38.5"N	7'12'46.9"E	IMEZI .O, EZEAGU	271.0	179.3	149.1	0.003690037	40406.10	0.550184502	MODERATE	NSUKKA
VES 57	6'25'38"N	7'15'20"E	AGUOBI IWOLLO, EZEAGU	82.4	97.5	89.1	0.012135922	7341.84	1.08131068	GOOD	NSUKKA
VES 58 *	6'26'03"N	7'18'26"E	OGHE, EZEAGU	192.6	228.4	192.6	0.005192108	37094.76	1	GOOD	AJALI
VES 59	6'26'05.04"N	7'17'03.9"E	ANIKE IWOLLO, EZEAGU	104.4	119.8	106.9	0.009578544	11160.36	1.02394636	GOOD	AJALI
VES 60	6'21'48.95"N	7'13'55.2"E	NDIAGU-UMANA, EZEAGU	7344.0	91.4	84.9	0.000136166	623505.60	0.011560458	POOR	NSUKKA
VES 61*	6'25'04"N	7'10'11"E	COMM. SEC SCH OLO, EZEAGU	27.3	76.5	60.9	0.036630037	1662.57	2.230769231	GOOD	IMO SHALE
VES 62	6'22'14"N	7'21'29"E	OGWUOFIA, EZEAGU	529.0	108.0	94.9	0.001890359	50202.10	0.179395085	WEAK	AJALI
VES 63	6'26'38.79"N	7'23'45.16"E	NGWO, UDI	88745.0	130.0	95.0	1.12682E-05	8430775.00	0.001070483	POOR	AJALI
VES 64	6'11'00.57"N	7'21'00.44"E	EHUHE ACHI OJI RIVER	14320.0	158.0	98.0	6.98324E-05	1403360.00	0.006843575	POOR	AJALI
VES 65	6'06'00.18"N	7'18'00.27"E	UMUEKE OZEGU INYI OJI RIVER	9786.0	130.0	85.0	0.000102187	831810.00	0.008685878	POOR	AJALI
VES 66	6'07'57.25"N	7'25'00.09"E	OBEAGU, AWGU	3200.3	178.2	55.6	0.000312471	177936.68	0.017373371	POOR	AJALI
VES 67*	6'09'00.18"N	7'12'45.49"E	AKPUGO-EZE, OJI RIVER	1250.0	100.0	50.0	0.0008	62500.00	0.04	POOR	IMO SHALE
VES 68	6'15'00.42"N	7'13'00.62"E	UGWUOBA OJI RIVER	1258.0	120.0	70.0	0.000794913	88060.00	0.055643879	POOR	IMO SHALE

VES 69	6°25'17.92"N	7°14'39.42"E	UMUEZE, EZEAGU	20000.0	103.2	60.0	0.00005	1200000.00	0.003	POOR	NSUKKA
VES 70	6°28'41.42"N	7°16'15.68"E	AMANSIODO EZEAGU	3723.9	192.3	66.5	0.000268536	247639.35	0.017857622	POOR	NSUKKA
VES 71	6°26'16.54"N	7°17'01.59"E	OKPOGHO, EZEAGU	6176.6	200.1	72.1	0.000161901	445332.86	0.011673089	POOR	NSUKKA
VES 72	6°22'16.17"N	7°15'35.72"E	AFOR- UGWU, UDI	6428.0	136.0	128.5	0.000155569	825998.00	0.019990666	POOR	NSUKKA
VES 73	6°27'03.73"N	7°28'23.27"E	COAL CAMP, ENUGU	15.0	40.0	32.0	0.066666667	480.00	2.133333333	GOOD	MAMU
VES 74*	6°29'45.5"N	7°28'43.8"E	WINNERS ESTATE TRANS-EKULU, ENU	2.8	98.9	83.2	0.357142857	232.96	29.71428571	EXCELLENT	MAMU
VES 75*	6°29'57"N	7°28'34"E	PHASE 6 TRANS-EKULU, ENUGU	23.4	99.2	82.0	0.042735043	1918.80	3.504273504	GOOD	MAMU
VES 76*	6°19'00.51"N	7°28'33.59"E	OZALLA NKANU, ENUGU	22.0	38.0	18.0	0.045454545	396.00	0.818181818	GOOD	NKPORO
VES 77	6°15'04.03"N	7°28'49.55"E	OBODOAKPU AGBOGUGU, AWGU	156.0	100.0	40.0	0.006410256	6240.00	0.256410256	MODERATE	NKPORO
VES 78	6°28'00.61"N	7°36'00.37"E	EMENE INDUSTRIAL LAYOUT, ENUGU	28.0	40.0	20.0	0.035714286	560.00	0.714285714	GOOD	NKPORO
VES 79	6°25'00.67"N	7°32'00.09"E	ENUGU INDEPENDENT LAYOUT	996.3	67.69	61.4	0.001003714	61172.82	0.061628024	POOR	NKPORO
VES 80	6°31'00.12"N	7°30'00.00"E	UMUGHOKENE IJI-NIKE ENUGU	100.0	36.0	24.0	0.01	2400.00	0.24	MODERATE	NKPORO
VES 81	6°31'01.04"N	7°33'02.00"E	UMUGHOKENE IJI-NIKE ENUGU 2	3.0	36.0	14.0	0.333333333	42.00	4.666666667	GOOD	NKPORO
VES 82	6°29'04.53"N	7°30'02.43"E	NIKE LAKE ROAD, ENUGU	10.0	30.0	10.0	0.1	100.00	1	GOOD	NKPORO
VES 83	6°29'00.23"N	7°32'09.08"E	HARMONY ESTATE NIKE, ENUGU	160.1	63.3	42.7	0.006246096	6829.87	0.266458463	MODERATE	NKPORO
VES 84*	6°22'59.07"N	7°32'42.12"E	OBEAGU ENUGU SOUTH	9.6	47.7	23.4	0.104166667	224.64	2.4375	GOOD	NKPORO
VES 85	6°27'50.34"N	7°35'09.80"E	9 ABAKALIKI ROAD EMENE	30.0	40.0	18.0	0.033333333	540.00	0.6	MODERATE	NKPORO

4.9.2 Integrated Electrical Conductivity

The Integrated Electrical Conductivity (IEC) of the study area was integrated and generate from the resistivity parameters of the vadose zone by applying equation (3.19) above as shown in table (4.14) and is expressed in (S) and milli- siemens (mS). The IEC values ranged between 0.04 mS and 15993 mS with a mean value of 514 mS. Extremely high vulnerability zones was recorded with IEC values ranging from 0.04 mS to 500 mS. Similarly, high vulnerability zones was recorded with IEC values varies between 500 mS and 1ooo mS, Moderate zones were identified with IEC ranging from 1000 mS to 2000 mS, low vulnerability zones with IEC values ranging between 2000 mS and 4000 mS and extremely low zones were detected with IEC ranging from 4000 mS to 15993 mS were delineated in parts of the study area covering of about 88%, 5%, 5%, 1% and 1% of the areas respectively. The IEC technique that was used to evaluate the degrees of vulnerability and percolation time of the contamination from anthropogenic sources, based on the method used by Madi et al. (2016) (See table 3.3). In most areas of the study area, extremely high vulnerability index values of less than 500 mS with a percolation period of several months were discovered, as illustrated in figure (4.17). Because 88% of the area falls within the category of extremely high vulnerability, this implies it will take months for surface effluent or any other liquid waste to reach the groundwater in the research area

Table 4.15 Summary of Aquifer Protective Capacity of the study area by IEC

VES POINTS	LATIITUDE	LONGITUDE	LOCATION	h_1 (m)	h_2 (m)	h_3 (m)	σ_1 (mhos)	σ_2 (mhos)	σ_3 (mhos)	$\sigma_1 h_1$	$\sigma_2 h_2$	$\sigma_3 h_3$	$IEC = \sum_i \sigma_i h_i$ (SEIMENS)	IEC (mS)	PERCOLATION TIME	VULNERABILITY RATING
VES 1*	6°17"49.6'N	7°34"39.4'E	OJIAGU TOWN HALL AGBANI NKANU WEST	1.0	0.5	2.5	0.001923	0.001176	0.000114	0.001923	0.000588	0.000286	0.002797	3	SEVERAL MONTHS	EXTREMELY HIGH
VES 2	6°17'16.7"N	7°35'18.7"E	SCH. AGBANI NKANU WEST	1.0	0.5	3.5	0.002740	0.001961	0.000397	0.002740	0.000980	0.001390	0.005110	5	SEVERAL MONTHS	EXTREMELY HIGH
VES 3*	6°21'57.35"N	7°35'49.7"E	OGBASHI VILLAGE SQ NDIUNO AKPUGO NKANU WEST	2.8	5.1	32.0	0.000989	0.000661	0.007704	0.002769	0.003373	0.246533	0.252675	253	SEVERAL MONTHS	EXTREMELY HIGH
VES 4	6°09'35.89"N	7°41'29.84"E	EZEMEZUOBODO IKORO UMUOIKA NKEREFI NKANU EAST	2.5	1.7	8.1	0.006250	0.003106	0.011765	0.015625	0.005280	0.095294	0.116199	116	SEVERAL MONTHS	EXTREMELY HIGH
VES 5	6°08'57.20"N	7°41'24.95"E	GIRLS SEC. SCH. UMUOIKA ENUOGU NKEREFI NKANU EAST	1.9	1.4	8.3	0.006329	0.003521	0.009709	0.012025	0.004930	0.080583	0.097537	98	SEVERAL MONTHS	EXTREMELY HIGH
VES 6	6°09'05.67"N	7°41'19.0"E	AMANKPUME NKEREFI NKANU EAST	1.9	1.2	5.7	0.005988	0.004219	0.005682	0.011377	0.005063	0.032386	0.048827	49	SEVERAL MONTHS	EXTREMELY HIGH
VES 7	6°10'40.09"N	7°40'14.00"E	AMAOFU NKANU EAST	1.7	1.2	6.5	0.006098	0.004566	0.005714	0.010366	0.005479	0.037143	0.052988	53	SEVERAL MONTHS	EXTREMELY HIGH
VES 8	6°10'21.33"N	7°39'45.53"E	OBODO EBUNABO NKEREFI NKANU EAST	0.5	0.7	2.7	0.004167	0.010000	0.003846	0.002083	0.007000	0.010385	0.019468	19	SEVERAL MONTHS	EXTREMELY HIGH
VES 9	6°09'03.38"N	7°41'20.46"E	UMUOVUDU 1 UMUOIKA NKEREFI NKANU EAST	2.4	1.9	24.8	0.006289	0.003484	0.013812	0.015094	0.006620	0.342541	0.364256	364	SEVERAL MONTHS	EXTREMELY HIGH
VES 10	6°18'31.51"N	7°39'19.22"E	WEST FED. CONSTITUENCY	0.8	2.4	3.3	0.001730	0.000708	0.024390	0.001384	0.001699	0.080488	0.083570	84	SEVERAL MONTHS	EXTREMELY HIGH
VES 11	6°18'36"N	7°33'57.60"E	ONUACHI AGBANI NKANU WEST	1.5	2.4	3.8	0.000899	0.002199	0.001576	0.001366	0.005278	0.005990	0.012634	13	SEVERAL MONTHS	EXTREMELY HIGH
VES 12*	6°13'04.97"N	7°38'53.20"E	NARA NKANU EAST	0.8	0.7	5.0	0.007692	0.010204	0.022222	0.006154	0.007143	0.111111	0.124408	124	MONTHS	EXTREMELY HIGH
VES 13	6°19'38.5"N	7°36'21.5"E	OBINAGU UWANI AKPUGO NKANU WEST	0.6	11.0	9.1	0.001224	0.014104	0.110619	0.000734	0.155148	1.006637	1.162520	1163	3 - 10 YEARS	MODERATE
VES 14	6°19'22.2"N	7°36'41.0"E	OBINAGU UWANI NKANU	1.1	27.4		0.029762	0.208768	-	0.032738	5.720251	-	5.752989	5753	>25 YEARS	EXTREMELY LOW
VES 15	6°19'6.0"N	7°37'0.5"E	OBINAGU UWANI NKANU	0.6	7.5	-	0.003257	0.011351	-	0.001954	0.085131	-	0.087085	87	SEVERAL MONTHS	EXTREMELY HIGH
VES 16*	6°29'47"N	7°23'34"E	AFOR PRIMARY SCH ABO	0.5	0.5	8.0	0.003571	0.001000	0.001299	0.001786	0.000500	0.010390	0.012675	13	SEVERAL MONTHS	EXTREMELY HIGH
VES 17	6°17'19.65"N	7°23'51.36"E	OBINAGU UDI	3.5	49.5	67.0	0.005882	0.005050	0.002500	0.020588	0.249987	0.167487	0.438063	438	SEVERAL MONTHS	EXTREMELY HIGH
VES 18	6°34'0.49"N	7°25'26.7"E	AMAGU UMUENE IBITE OKPATU, UDI	0.8	1.2	2.0	0.000649	0.000755	0.000737	0.000519	0.000906	0.001475	0.002900	3	SEVERAL MONTHS	EXTREMELY HIGH
VES 19	6°33'1.01"N	7°26'12.5"E	OGENE OJEBE, UDI	0.8	0.7	2.5	0.004878	0.004000	0.002222	0.003902	0.002800	0.005556	0.012258	12	SEVERAL MONTHS	EXTREMELY HIGH
VES 20	6°27'28.00"N	7°21'27"E	EKE-UDI SQUARE UDI	1.2	1.8	-	0.001429	0.010000	-	0.001714	0.018000	-	0.019714	20	SEVERAL MONTHS	EXTREMELY HIGH
VES 21*	6°17'38.54"N	7°19'26.60"E	NACHI, UDI	0.7	13.5	-	0.000149	0.000597	-	0.000109	0.008060	-	0.008169	8	SEVERAL MONTHS	EXTREMELY HIGH
VES 22	6°16'57.23"N	7°19'16.68"E	OFF NACHI, UDI	1.4	21.0	-	0.000208	0.000625	-	0.000281	0.013125	-	0.013406	13	SEVERAL MONTHS	EXTREMELY HIGH
VES 23	6°18'18.57"N	7°20'52.30"E	NACHI BY AMOKWE RD, U	0.9	14.3	-	0.000143	0.000571	-	0.000121	0.008171	-	0.008293	8	SEVERAL MONTHS	EXTREMELY HIGH
VES 24	6°19'03.63"N	7°22'04.54"E	AMOKWE, UDI	1.0	12.9	-	0.000179	0.000536	-	0.000179	0.006911	-	0.007089	7	SEVERAL MONTHS	EXTREMELY HIGH
VES 25	6°18'52.22"N	7°20'10.39"E	AMOKWE BY NACHI RD, U	1.6	1.4	43.5	0.000140	0.000005	0.000127	0.000218	0.000007	0.005536	0.005761	6	SEVERAL MONTHS	EXTREMELY HIGH
VES 26	6°23'49.0"N	7°22'15.0"E	EKEAGU OBELEAGU, EZEA	1.5	8.5	-	0.000125	0.000390	-	0.000193	0.003312	-	0.003504	4	SEVERAL MONTHS	EXTREMELY HIGH
VES 27	6°21'18.0"N	7°13'06.0"E	UMUGHU OBELEAGU, EZE	1.9	20.0	-	0.000526	0.000123	-	0.001000	0.002456	-	0.003456	3	SEVERAL MONTHS	EXTREMELY HIGH
VES 28	6°20'58.0"N	7°22'01.0"E	UMANA OBELEAGU, EZEA	2.0	22.0	-	0.000400	0.000123	-	0.000800	0.002702	-	0.003502	4	SEVERAL MONTHS	EXTREMELY HIGH

VES 30	6°19'20.24"N	7°24'01.20"E	UDI BY AMOKWE RD, UDI	1.0	25.0	-	0.000233	0.000349	-	0.000233	0.008721	-	0.008953	9	SEVERAL MONTHS	EXTREMELY HIGH
VES 31	6°19'07.53"N	7°22'00.77"E	AMOKWE, UDI	1.3	5.3	24.0	0.000704	0.000176	0.000045	0.000915	0.000933	0.001086	0.002935	3	SEVERAL MONTHS	EXTREMELY HIGH
VES 32 *	6°19'08.34"N	7°21'49.95"E	AMOKWE, UDI	0.8	27.0	-	0.000222	0.000413	-	0.000178	0.011143	-	0.011321	11	SEVERAL MONTHS	EXTREMELY HIGH
VES 33	6°19'05.90"N	7°23'31.22"E	UDI, UDI	1.8	18.0	-	0.000100	0.000186	-	0.000180	0.003343	-	0.003523	4	SEVERAL MONTHS	EXTREMELY HIGH
VES 34	6°21'54.0"N	7°21'33.0"E	OBELEAGU UMANA, EZEA	1.8	28.5	-	0.000044	0.000133	-	0.000080	0.003800	-	0.003880	4	SEVERAL MONTHS	EXTREMELY HIGH
VES 35	6°24'06.23"N	7°23'59.75"E	NSUDE, UDI	1.4	-	-	0.000278	-	-	0.000375	-	-	0.000375	0.4	SEVERAL MONTHS	EXTREMELY HIGH
VES 36	6°18'20.3"N	7°21'48.9"E	AMAOKWE, UDI	1.0	9.4	7.5	0.000945	0.001728	0.000434	0.000945	0.016240	0.003256	0.020441	20	SEVERAL MONTHS	EXTREMELY HIGH
VES 37	6°17'19"N	7°23'06"E	UMUABI, UDI	3.8	17.7	-	0.004519	0.000331	-	0.017171	0.005863	-	0.023034	23	SEVERAL MONTHS	EXTREMELY HIGH
VES 38	6°26'39"N	7°22'500"E	UMUEZE UMUAGA, UDI	1.8	21.5	-	0.000914	0.000643	-	0.001645	0.013821	-	0.015466	15	SEVERAL MONTHS	EXTREMELY HIGH
VES 39	6°24'20"N	7°23'56"E	NSUDE II, UDI	0.2	2.8	15.5	0.000471	0.000581	0.000379	0.000094	0.001627	0.005869	0.007590	8	SEVERAL MONTHS	EXTREMELY HIGH
VES 40	6°29'29"N	7°22'40"E	EZIAMA EBE UDI	0.9	0.4	-	0.000032	0.000037	-	0.000029	0.000015	-	0.000044	0.04	SEVERAL MONTHS	EXTREMELY HIGH
VES 41	6°31'54.3"N	7°24'36.3"E	OKPATU II, UDI	0.9	0.4	-	0.000032	0.000037	-	0.000029	0.000015	-	0.000044	0.04	SEVERAL MONTHS	EXTREMELY HIGH
VES 42	6°22'43.20"N	7°24'38.40"E	AMACHALA OBIOMA, UDI	2.7	5.9	11.3	0.001008	0.000632	0.000251	0.002682	0.003732	0.002838	0.009252	9	SEVERAL MONTHS	EXTREMELY HIGH
VES 43	6°19'26.4"N	7°21'00"E	AMAOKWE, UDI	1.4	21.1	31.3	0.000947	0.000031	0.000840	0.001345	0.000658	0.026278	0.028282	28	SEVERAL MONTHS	EXTREMELY HIGH
VES 44	6°30'10.8"N	7°17'49.20"E	OBEAGU UKANA, UDI	1.5	4.9	29.0	0.001920	0.001323	0.000155	0.002918	0.006484	0.004496	0.013898	14	SEVERAL MONTHS	EXTREMELY HIGH
VES 45	6°21'17"N	7°23'59"E	OFF OBIOMA, UDI	1.5	17.6	-	0.000043	0.000241	-	0.000063	0.004244	-	0.004307	4	SEVERAL MONTHS	EXTREMELY HIGH
VES 46	6°21'05"N	7°23'04"E	UMUDIM, UDI	0.8	15.2	-	0.000250	0.000375	-	0.000208	0.005701	-	0.005909	6	SEVERAL MONTHS	EXTREMELY HIGH
VES 47 *	6°22'50"N	7°24' 17"E	OBIOMA COMM. HIGH SC	0.7	16.1	-	0.000345	0.001379	-	0.000228	0.022207	-	0.022434	22	SEVERAL MONTHS	EXTREMELY HIGH
VES 48	6°22'06.83"N	7°13'26.98"E	UMUAJI MGBAGBU OWA,	6.5	10.4	32.5	0.002165	0.000233	0.003058	0.014069	0.002419	0.099388	0.115876	116	SEVERAL MONTHS	EXTREMELY HIGH
VES 49	6°24'08.92"N	7°13'41.23"E	AGUAGBAJA UMUNADIA(	20.3	25.5	50.6	0.001770	0.000089	0.000943	0.035929	0.002277	0.047736	0.085942	86	SEVERAL MONTHS	EXTREMELY HIGH
VES 50	6°29'57.41"N	7°08'51.05"E	IBITO OLO, EZEAGU	1.3	33.7	45.0	0.000909	0.100000	0.033333	0.001182	3.370000	1.500000	4.871182	4871	>25 YEARS	EXTREMELY LOW
VES 51	6°25'32.4"N	7°15'54"E	IWOLLO TOWN, EZEAGU	1.2	1.1	3.4	0.004246	0.013552	0.024213	0.005223	0.014907	0.082324	0.102455	102	SEVERAL MONTHS	EXTREMELY HIGH
VES 52	6°20'34.5"N	7°21'48.3"E	AGULU OBELEAGU UMAN	1.0	9.4	7.5	0.000945	0.001728	0.000434	0.000945	0.016240	0.003256	0.020441	20	SEVERAL MONTHS	EXTREMELY HIGH
VES 53	6°21'59"N	7°14'43"E	UMUAJI AGUOBU-OWA, E	1.0	2.8	12.5	0.001217	0.000626	0.000491	0.001217	0.001752	0.006140	0.009109	9	SEVERAL MONTHS	EXTREMELY HIGH
VES 54 *	6°29'01.2"N	7°14'52.2"E	IHUONAYIA CITY OGHE, E	1.5	7.5	17.3	0.000388	0.001820	0.068966	0.000583	0.013651	1.193103	1.207337	1207	3 - 10 YEARS	MODERATE
VES 55	6°22'29.1"N	7°14'42.5"E	EZEAMA AGU AGUOBU-O	0.5	5.3	8.6	0.001776	0.001492	0.059880	0.000888	0.007909	0.514970	0.523767	524	SEVERAL MONTHS - 3	HIGH
VES 56	6°27'38.5"N	7°12'46.9"E	IMEZI .O, EZEAGU	2.4	8.9	18.9	0.000074	0.000121	0.001736	0.000177	0.001074	0.032801	0.034052	34	SEVERAL MONTHS	EXTREMELY HIGH
VES 57	6°25'38"N	7°15'20"E	AGUOBI IWOLLO, EZEAGU	4.8	3.6	89.1	0.001391	0.034965	0.012136	0.006679	0.125874	1.081311	1.213864	1214	3 - 10 YEARS	MODERATE
VES 58 *	6°26'03"N	7°18'26"E	OGHE, EZEAGU	0.5	0.5	34.8	0.007994	0.001126	0.007994	0.003997	0.000563	0.278177	0.282737	283	SEVERAL MONTHS	EXTREMELY HIGH
VES 59	6°26'05.04"N	7°17'03.9"E	ANIKE IWOLLO, EZEAGU	0.9	12.0	-	0.001551	0.001914	-	0.001396	0.022962	-	0.024358	24	SEVERAL MONTHS	EXTREMELY HIGH
VES 60	6°21'48.95"N	7°13'55.2"E	NDIAGU-UMANA, EZEAGU	1.1	0.9	1.1	0.004926	0.000129	0.000061	0.005419	0.000116	0.000067	0.005602	6	SEVERAL MONTHS	EXTREMELY HIGH
VES 61	6°25'04"N	7°10'11"E	COMM. SEC SCH OLO, EZI	1.3	2.8	11.5	0.000267	0.003788	0.185185	0.000342	0.010606	2.129630	2.140578	2141	10 - 25 YEARS	LOW
VES 62	6°22'14"N	7°21'29"E	OGWUOFIA, EZEAGU	1.1	12.0	-	0.000143	0.000231	-	0.000157	0.002769	-	0.002927	3	SEVERAL MONTHS	EXTREMELY HIGH
VES 63	6°26'38.79"N	7°23'45.16"E	NGWO, UDI	0.8	1.7	1.0	0.000489	0.000299	0.000333	0.000391	0.000507	0.000333	0.001231	1	SEVERAL MONTHS	EXTREMELY HIGH
VES 64	6°11'00.57"N	7°21'00.44"E	EHUHE ACHI OJI RIVER	0.6	0.6	2.8	0.002849	0.001923	0.000994	0.001709	0.001154	0.002783	0.005647	6	SEVERAL MONTHS	EXTREMELY HIGH
VES 65	6°06'00.18"N	7°18'00.27"E	UMUEKE OZEGU INYI OJI R	0.8	0.7	3.5	0.001433	0.001022	0.000221	0.001146	0.000716	0.000773	0.002635	3	SEVERAL MONTHS	EXTREMELY HIGH

VES 66	6'07'57.25"N	7'25'00.09"E	OBEAGU, AWGU	3.6	7.1	21.2	0.000415	0.001887	0.008048	0.001479	0.013472	0.170624	0.185575	186	SEVERAL MONTHS	EXTREMELY HIGH
VES 67	6'09'00.18"N	7'12'45.49"E	AKPUGO-EZE, OJI RIVER	1.0	0.5	3.5	0.023810	0.022222	0.071429	0.023810	0.011111	0.250000	0.284921	285	SEVERAL MONTHS	EXTREMELY HIGH
VES 68	6'15'00.42"N	7'13'00.62"E	UGWUOBA OJI RIVER	1.0	0.5	0.5	0.333333	0.066667	0.050000	0.333333	0.033333	0.025000	0.391667	392	SEVERAL MONTHS	EXTREMELY HIGH
VES 69	6'25'17.92"N	7'14'39.42"E	UMUEZE, EZEAGU	1.2	10.0	12.0	0.000222	0.000167	0.000143	0.000267	0.001667	0.001714	0.003648	4	SEVERAL MONTHS	EXTREMELY HIGH
VES 70	6'28'41.42"N	7'16'15.68"E	AMANSIODO EZEAGU	0.4	1.2	3.8	0.109769	0.000146	0.000089	0.043908	0.000168	0.000338	0.044414	44	SEVERAL MONTHS	EXTREMELY HIGH
VES 71	6'26'16.54"N	7'17'01.59"E	OKPOGHO, EZEAGU	0.3	1.2	3.6	0.102354	0.000151	0.000117	0.030706	0.000175	0.000417	0.031298	31	SEVERAL MONTHS	EXTREMELY HIGH
VES 72	6'22'16.17"N	7'15'35.72"E	AFOR- UGWU, UDI	0.4	1.1	2.9	0.169492	0.000156	0.000109	0.067797	0.000179	0.000313	0.068289	68	SEVERAL MONTHS	EXTREMELY HIGH
VES 73	6'27'03.73"N	7'28'23.27"E	COAL CAMP, ENUGU	1.0	1.0	2.0	0.010417	0.008929	0.005128	0.010417	0.008929	0.010256	0.029602	30	SEVERAL MONTHS	EXTREMELY HIGH
VES 74*	6'29'45.5"N	7'28'43.8"E	TRANS-EKULU, ENUGU EAST	0.7	15.0		0.002005	0.002608		0.001404	0.039113		0.040517	41	SEVERAL MONTHS	EXTREMELY HIGH
VES 75*	6'29'57"N	7'28'34"E	PHASE 6 TRANS-EKULU, E	2.8	14.4	-	0.001293	0.007669	-	0.003620	0.110429	-	0.114049	114	SEVERAL MONTHS	EXTREMELY HIGH
VES 76*	6'19'00.51"N	7'28'33.59"E	OZALLA NKANU, ENUGU	1.0	1.2	7.8	0.001307	0.000905	0.002000	0.001307	0.001086	0.015600	0.017993	18	SEVERAL MONTHS	EXTREMELY HIGH
VES 77	6°15'04.03"N	7°28'49.55"E	OBODOAKPU AGBOGUGU	3.0	5.0	52.0	0.000965	0.002899	0.100000	0.002896	0.014493	5.200000	5.217389	5217	>25 YEARS	EXTREMELY LOW
VES 78	6°28'00.61"N	7°36'00.37"E	EMENE INDUSTRIAL LAYO	0.5	1.0	1.3	0.002857	0.004785	0.015152	0.001429	0.004785	0.019697	0.025910	26	SEVERAL MONTHS	EXTREMELY HIGH
VES 79	6°25'00.67"N	7°32'00.09"E	ENUGU INDEPENDENT LA	1.3	2.8	2.3	0.039386	0.083822	0.011027	0.049626	0.230511	0.025692	0.305829	306	SEVERAL MONTHS	EXTREMELY HIGH
VES 80	6°31'00.12"N	7°30'00.00"E	UMUGHOKENE IJI-NIKE EN	1.0	1.0	3.0	0.005556	0.003497	0.003623	0.005556	0.003497	0.010870	0.019922	20	SEVERAL MONTHS	EXTREMELY HIGH
VES 81	6°31'01.04"N	7°33'02.00"E	UMUGHOKENE IJI-NIKE EN	1.0	1.0	0.8	0.002793	0.001404	0.002000	0.002793	0.001404	0.001600	0.005798	6	SEVERAL MONTHS	EXTREMELY HIGH
VES 82	6°29'04.53"N	7°30'02.43"E	NIKE LAKE ROAD, ENUGU	0.8	0.7	1.5	0.025000	0.021739	0.007576	0.020000	0.015217	0.011364	0.046581	47	SEVERAL MONTHS	EXTREMELY HIGH
VES 83	6°29'00.23"N	7°32'09.08"E	HARMONY ESTATE NIKE,	1.3	5.8	13.5	0.003337	0.001823	0.093985	0.004204	0.010611	1.267857	1.282672	1283	3 - 10 YEARS	MODERATE
VES 84*	6'22'59.07"N	7'32'42.12"E	OBEAGU ENUGU SOUTH	1.2	2.3	20.8	0.009154	0.001424	0.769112	0.011351	0.003235	15.978080	15.992666	15993	>25 YEARS	EXTREMELY LOW
VES 85	6'27'50.34"N	7'35'09.80"E	9 ABAKALIKI ROAD EMEN	0.6	1.1	1.8	0.0028169	0.00442478	0.014492754	0.001690	0.004867	0.026087	0.032644	33	SEVERAL MONTHS	EXTREMELY HIGH

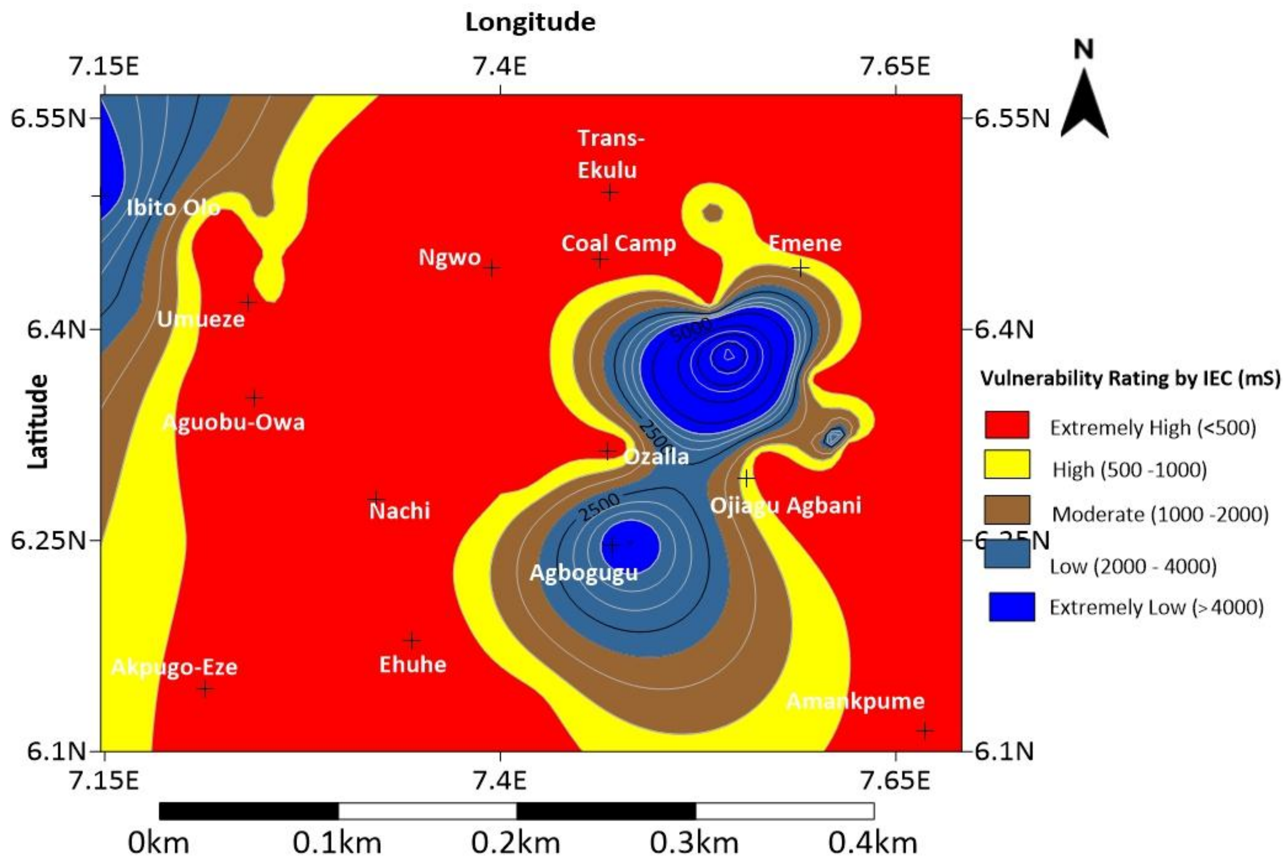


Fig 4.17 Spatial Distribution Map of Aquifer Protective Capacity of the study area by Integrated Electrical Conductivity (S)

CHAPTER FIVE

CONCLUSION, RECOMMENDATIONS AND CONTRIBUTION TO KNOWLEDGE

5.4 Conclusion

The focus of this research was designed to use hydrogeophysical data to assess the aquifer system's vulnerability as well as the soil corrosivity of Enugu and environs. This study has showcased how effective geo-electric methods can be when applied to the prediction of parameters for areas where there are no existing wells. It has been shown that a dependable method of pumping test results can be used with the surface geo-electric method to estimate aquifer parameters in areas where there are no existing wells. This will give a less expensive method of carrying out pumping tests. This research has also shown that the geophysical method is not only important in the delineation of aquifer zones but also useful in evaluating the soil corrosivity of an area. This will help to map the zones that are non-corrosive for burying utilities and pipes. The characteristics of aquifer layer parameters were interpreted from the results of the 85 vertical electrical soundings (VES) data which showed the presence of three to nine geo-electrical layers model with the aquifer zone lying mainly between the fourth and sixth layers. Twenty-five geo-electric curve types were encountered in the study area, with the QH-type being the most prevalent, which occurred fifteen times. The aquifer resistivity ranges from a value of 2.8 Ωm to 88745.0 Ωm with a mean value of 5434.61 Ωm. Aquifer conductivity ranged between a value of 1.12682E-05 mhos and 0.357142857 mhos with a mean value of 0.02019914 mhos. The aquifer depth of the area varies between 23.4 m to 375.0 m with a mean value of 132.53 m. Similarly, the aquifer thickness in the area is highly variable with values varies between 10.0 m to 224.0 m with a mean value of 86.96m while the transverse resistance vary between 42.0 Ωm^2 and 8,430,775.0 Ωm^2 with a mean value of 560,402.8 Ωm^2.

The aquifer hydraulic characteristics of the area were determined from the newly generated geophysical model. The result shows hydraulic conductivity of the area varied between 1.05m/day and 34.06 m/day with a mean value of 5.59 m/day while transmissivity values ranged from 25.70 m^2/day to 2767.81 m^2/day with a mean value of 500.05 m^2/day. Generally, based on the Krasny, (1993) classification, the groundwater potentials of the study area are classified into three category, from moderate, high and very high potential zones.

From the different statistical analysis of the models, the New model is found to more reliable and accurate in predicting hydraulic conductivity in the study area, followed by the Niwas and Singhal model and lastly the Heigold model.

The aquifer vulnerability of the study area were determined using DRASTIC and GOD models. The obtained DRASTIC and GOD models were used together to develop vulnerability map. Results based on the DRASTIC model revealed that the study area ranges from zone of low class of vulnerability zone, moderate zones and high class of vulnerability zones whereas GOD model clearly showed that the study area are within the class of extremely low, class of low vulnerability zones and class of moderate vulnerability zones.

The evaluated soil corrossivity of the study area were determined and the result showed that 78% of the area are Practically non corrosive (PNC) and can be rated as moderately competent to highly competent strata; 13% of the area are said to be slightly corrosive which rated as moderately competent to Incompent strata while the 9% are moderately and very strongly corrosive which rated as an incompenet material to construct on. The aquifer protective capacity of the study area were determined using longitudinal conductance technique.

The longitudinal conductance in the study area varies from 0.001 mhos/m to 29.714 mhos/m with a mean value of 1.073 mhos/m. According to Henriet, (1975) classification, the protective capacity of the area is zoned into excellent, very good, good, moderate, weak and poor protective capacity rating. Similarly, Integrated Electrical Conductivity technique was also used to determine the protective capacity of the area, the result indicates that the aquifer system in the study area has low protective capacity and the areas are susceptible to contamination based on the IEC technique

5.5 Recommendations

The followings recommendations are made based on the results obtained from the studies.

i. A thorough hydro-chemical evaluation should be carried out to determine the water quality of the aquifer system in the areas with a susceptibility risk
ii. The relevant authorities should monitor the manner in which industrial and domestic wastes are disposed in the areas that has high vulnerability.
iii. Areas with a susceptibility risk should be carefully handled by implementing current garage disposal techniques in that particular location.
iv. Areas with low resistivity values, corrosion-resistant materials such as polyvinyl chloride (PVC) pipes and galvanized metals should be used to prevent rapid corrosion.

5.6 Contribution to Knowledge

The research work carried out in the study area has offered the following contribution to knowledge;

i. New model equations controlled by geology was established and used in this study.

ii. This study successfully generated a Aquifer protective capacity, Vulnerability and Corrosivity maps of the study area.

iii. The sensitive areas against pollution were recognized and delineated in the study area

iv. This study also created a data repository for government and water sectors, as well as a framework for the study area's groundwater management strategy.

REFERENCES

Abbasi, S., Mohammadi, K., Kholghi, M. and Howard, K., (2013). Aquifer vulnerability assessment using GRASTIC, weights of Evidence and Analytic Element Mothod. *Hydrological Sciences Journal*

Adeigbe, OC and Salufu, A.E., (2009). Geology and Depositional environment of Campano-Maastrichtian Sediments in the Anambra basin, Southeastern Nigeria: Evidence from field Relationship and Sedimentological Study. *Earth Sciences Research Journal Vol (13), p.p 148-166.*

Adelana, S.M.A., Olasehinde, P.I., Bale, R.B., Vrbka, P., Edet, A.E. and Goni, I.B., (2008). An overview of the geology and hydrogeology of Nigeria. *Applied groundwater studies in Africa.*

Adeniji, A.E, Omonona, O.V., Obiora1 D.N and Chukudebelu, J.U., (2014). Evaluation of soil corrosivity and aquifer protective capacity using geoelectrical investigation in Bwari basement complex area, Abuja. *J. Earth Syst. Sci.* 123, No. 3,pp. 491–502.

Agunloye, O., (1984). Soil aggressivity along Steel Pipeline Route at Ajaokuta, South-western Nigeria. Nigerian Journal of Mining and Geology, Vol. 21 (1 and 2), pp. 97-101.

Akhter, G. and Hassan, M. (2016). Determination of aquifer parameters using geo-electrical sounding and pumping test data in Khanewal District. *Pakistan, Open Geoscience, 8, 630– 638.*

Akintorinwa O J and Abiola O (2011). Sub-soil evaluation for pre-foundation study using geophysical and geotechnical approach; *J. Emerging Trends Eng. Appl. Sci.* 2(5) 858–863

Akpan, A.E., Ebong, E.D. and Emeka, C.N., (2015). Exploratory assessment of groundwater vulnerability to pollution in Abi, southeastern Nigeria, using geophysical and geological techniques. *Environ Monit Assess*. 187: 156

Al-Abadi, A.M., Al-Shamma'a, A.M. and Aljabbari, M.H., (2014). A GIS-based DRASTIC model for assessing intrinsic groundwater vulnerability in northeastern Missan governorate southern Iraq. *Applied water Science.*

Aller, L., Bennet, T., Lehr, J.H. and Petty, R.J., (1987). DRASTIC: A Standardized System for Evaluating Ground Water Pollution Using Hydrological Settings. *US EPA document no.EPA/600/2-85-018.*

Aller, L., Bennet, T., Lehr, J.H. and Petty, R.J., (1985). DRASTIC: A standardized system for evaluating ground water pollution potential using hydrogeologic settings. *NWWA/EPA Series EPA-600/2-85/035.*

Al Hallaq, A. and Abu Elaish, B. (2008). Determination of Mean Areal Rainfall in the Gaza Strip Using Geographic Information System (GIS) Technique. *Journal of Pure & Applied Sciences, University of Sharjah, UAE, Vol. 5 No. 2, pp. 105-126.*

Al- Mallah, I.A.R. and Al- Qurnawi, W.S., (2018). Intrinsic vulnerability assessment for the Quaternary aquifer in Baghdad area using DRASTIC model. *Applied Water Science*.8:139

Al-Qurnawi WS (2014) Groundwater vulnerability assessment and well head protection zones of Alton Kopry Basin, Kirkuk Governorate Northeast of Iraq. Ph.D. thesis. *Basrah Unv. Collage of Science, (216).*

Amos-Uhegbu, A.C. (2013) Bridging the Gap between Available Aquifer Test Data and Missing Aquifer Hydraulic Characteristics Using a Simple Graphical Approach. *Pacific Journal of Science and Technology (14)2.*

Aweto, K.E and Akpoborie I.A. (2014). Estimating Aquifer Parameters with Geoelectri Soundings: Case Study from the Shallow Benin Formation at Orerokpe, Western Niger Delta, Nigeria. British *Journal of Applied Science & Technology Vol 6(5): pp 486-49.*

Baeckmann,W.V and W. Schwenk, (1975). Handbook of Cathodic Protection: The Theory and Practice of Electrochemical Corrosion Protection Technique; Surrey Protucullin Press.

Balsubramanian, A. (2017). Methods of Groundwater Exploration Centre for Advanced Studies in Earth Science. *University of Mysore, Mysore-6.*

Bayowa, O.G and N.S. Olayiwola, (2015). Electrical Resistivity Investigation for Topsoil Thickness, Competence and Corrosivity. Department of Earth Science Ladoke Akintola University, pp. 53.

Benson A K, Payne K L and Stubben M A (1997). Mapping groundwater contamination using dc resistivity and VLF geophysical methods – a case study; *Geophysics* 62(1) 80–86.

Bhattacharya, P.K. and Patra, H.P., (1968). Direct Current Geoelectric Sounding Methods in Geochemistry and Geophysics. Elsevier, Amsterdam, pp. 135p.

Braga A O, Filho W M and Dourado J C (2006). Resistivity (DC) method applied to aquifer protection studies; *Revista Brasileira Geofisica* 24(4) 513–581.

Chukwuma, E.C., Orakwe, L.C., Anizoba, D.C., Amaefule, D.O., Odoh, C.C., Nzediegwu, C., (2015). Geo-electric Groundwater Vulnerability Assessment of Overburden Aquifer at Awka in Anambra State, Southeastern Nigeria. *European Journal of Biotechnology and Bioscience*, 3(1): pp29-34.

Cooper, H.H. and Jacob, C.E., (1946). A generalized graphical method for evaluating formation constants and summarizing well-field history. Trans. *Amer. Geophys. Union, 27: (526-534).*

Daku S.S., Diyelmak V.B., Otitolaiye O.A. and Abalaka I.E. (2019). evaluation of soil corrosivity using electrical resistivity method: a case study of part of the university of jos permanent site. *Scientific Research Journal (SCIRJ), Volume VII.*

Daly, D. and Warren, W.P., (1998). Mapping groundwater vulnerability: the Irish perspective. *Geol Soc Spec Publ (130:179).*

Daniel N.O*,* Adeolu E.A and Johnson C.I., (2015). Evaluation of aquifer protective capacity of overburden unit and soil corrosivity in Makurdi, Benue state, Nigeria, using electrical resistivity method. *Journal of Earth System Science.*

Diloha II, Udom G.J and Nwankwoala H.O., (2018). Application of Aquifer Parameters in Evaluating Groundwater Potential of Logo Area, Benue State, Nigeria. *Int J Environ Sci Nat Res. 11(5)*

Draskovits, P., Mayar, B. and Pattantyus, A.M., (1995). Geophysical methods in groundwater prospecting and environmental protection*. Fisica de la Tierra,* pp. 53-86.

Duijvenbooden, W. van and Waegeningh, H.G. van (1987). Vulnerability of soil and groundwater to pollutants. In: *Proceedings and information no. 38 of the international conference, The Netherlands: TNO Committee on Hydrological Research*

Ebong, D. E., Akpan, A. E. and Onwuegbuche, A. A. (2014). Estimation of geohydraulic parameters from fractured shales and sandstone aquifers of Abi (Nigeria) using electrical resistivity and hydrogeological measurements. *Journal of African Earth Sciences, 96, 99–109.*

Egboka, B. C. E. and Ezeonu, F. C. (1990). Nitrate and Nitrite pollution and contamination in parts of SE Nigeria*.Water Resources, **2**, 101–110*

Ejiogu, B. C., Opara, A. I., Nwofor, O.k. and Nwosu, E. I. (2017). Geochemical and bacteriological analysis of water resources prone to contamination from solid waste dumpsites in Imo state, southeastern Nigeria. *Journal of Environmental Science and Technology*, 10, 325–343.

Ejiogu, B. C., Opara, A. I., Nwosu, E. I., Nwofor, O. K., Onyema, J. C. and Chinaka, J. C., (2019). Estimates of aquifer geo-hydraulic and vulnerability characteristics of Imo State and environs, Southeastern Nigeria, using electrical conductivity data*. Environ Monit Assess* 191:238.

Ekwe A.C.,Onuoha K.M. and Onu N.N. (2006). Estimation of aquifer hydraulic characteristics from electrical sounding data: The case of middle Imo River basin aquifers, Southeastern Nigeria. *Journal of spatial hydrology, Vol. 6, No. 2. pp 121 –126.*

Ekwe, A.C and Opara, A.I., (2012). Aquifer Transmissivity from Surface Geoelectrical Data: A case study of Owerri and Environs, Southeastern Nigeria. *Journal of the Geological Society of India: (355-378).*

Ekwe, A.C., Opara, A.I., Okeugo, C.G., Azuoko, G., Nkitnam, E.E., Abraham, E.M., Chukwu, C.G. and Mbaeyi, G., (2020). Determination of aquifer parameters from geosounding data in parts of Afikpo Sub-basin, southeastern Nigeria. *Arabian Journal of Geosciences.* 13: (189)

Engel, B., Navular, K. and Cooper, B. L. (1996). Estimating groundwater vulnerability to non-point source pollution from nitrates and pesticides on a regional scale. *International Association of Hydrological Science* Publ., 235, 521–526.

Ezeh, C.C. and Ugwu, G.Z., (2010). Geoelectrical sounding for estimating groundwater potential in Nsukka LGA, Enugu State, Nigeria. *International Journal of Physical Sciences*, 5(5), 415-420.

Ezeh, C.C., (2012). Hydrogeophysical studies for the delineation of potential groundwater zones in Enugu state, Nigeria. *International Research Journal of Geology and Mining,* 2(5), pp.103-112.

Ezeh, C.C., Ugwu, G.Z., Okonkwo, A. and Okamkpa, J., (2013). Using the relationships between g eoelectrical and hydrogeological parameters to assess aquifer productivity in Udi LGA, Enugu State, Nigeria. *International Journal of Geology and Mining (IRJGM) (2276-6618) Vol. 3(1) pp. 9-18.*

Fatoba, J. O., Omolayo, D. D., and Adigun, E. O. (2014). Using geoelectric sounding for the estimation of hydraulic characteristics of aquifers in coastal areas of Lagos, South western Nigeria. *International letters Natural Science, 11, 30–39.*

Fetter, C.W., (1993). *Contaminant Hydrogeology, Waveland press incorporate Long Grove, illinoise*, 500.

Foster SSD (1987). Fundamental concepts in aquifer vulnerability, pollution risk and protection strategy. In: van Duijvenbooden W, van Waegeningh HG (eds) Proceedings and information in vulnerability of soil and ground-water to pollutants, vol 38. *TNO Committee on Hydrological Research, The Hague, pp 69–8.*

Foster, S. S. D., Hirata, R., Gomes, D., D'Elia, M., and Paris, M. (2002). Groundwater quality protection: a guide for water utilities, municipal authorities and environment agencies (secondth ed.). Washington, DC: World Bank.

Freeze, R.A, (1972). *The Mechanism of natural Groundwater Recharge and Discharge*

Freeze A., and Cheery J.A., (1979). *Groundwater. Prentice-Hall Inc., Engle Wood Cliffs, New Jersey.* (491).

George N, Obianwu V. and Udofia K (2011) Estimation of aquifer hydraulic parameters via complimenting surficial geophysicalmeasurement by laboratory measurements on the aquifer core samples. *Int Rev Phys* 5(2):88–96

George NJ, Emah J.B and Ekong UN (2015) Geohydrodynamic properties of hydrogeological units in parts of Niger Delta, southern Nigeria. *J Afr Earth Sci* 105:55–63.

Ghazavi, R. and Ebrahimi, Z., (2015). Assessing groundwater vulnerability to contamination in an arid environment using DRASTIC and GOD models. *Int. J. Environ. Sci. Technol*. 12:2909–2918.

Gogu RC, Dassargues A (2000). Current trends and future challenge in ground-water vulnerability assessment using overlay and index methods. Environ Geol 39(6):549–559.

Gupta, N., (2014). Groundwater Vulnerability Assessment using DRASTIC method in Jabalpur District of Madhya Pradesh. *International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-3*

Hamamin, D.F., (2011). Hydrogeological assessment and groundwater vulnerability map of Basara Basin, Sulaimani Governorate, Iraq, Kurdistan Region. *Unpublished Ph.D. thesis, College of Science, University of Sulaimani, Sulaymaniyah*

Harter, T., (2003). Basic Concepts of Groundwater Hydrology. *University of California, Division of Agriculture and Natural Resources.*

Hasan, M., Shang, Y., Akhter, G. and Jin, W. (2018). Geophysical assessment of groundwater potential: a case study from Mian Channu Area, Pakistan. Groundwater, *56(5), 783–796.*

Hashimoto, T., Stedinger, J.R. and Loucks, D.P., (1982). Reliability, resiliency, and vulnerability criteria for water resources system performance evaluation. *Water Resources Research, 18: (14–20).*

Heigold, P. C., Gilkeson, R. H., Cartwright, K. and Reed, P. C. (1979). *Aquifer transmissivity from surficial electrical methods. Ground Water,* 17(4), 338–345.

Henriet, J. P., (1977). *Direct application of the Dar Zarrouk parameters in groundwater surveys. Geophysical Prospecting. 24.*

Ibuot J.C, Akpabio G.T and George N.J (2013) A survey of repository of groundwater potential and distribution using geoelectrical resistivity method in Itu L.G.A., Akwa Ibom State, Southern Nigeria. *Central Eur J Geosci* 5(4):538–547.

Ibuot, J. C., Obiora, D. N., Ekpa, M.M. and Okoroh, D. O. (2017). Geo-electrohydraulic investigation of the surficial aquifer units and corrosivity in parts of Uyo L. G. A., Akwa Ibom State, Southern Nigeria. *Applied Water Science, 7, 4705– 4713.*

Igbokwe, M.U., Okwueze, E.E. and Okereke, C.S., (2006). Delineation of Aquifer Zones from Geoelectric Soundings in Kwa Ibo River Watershed, Southeastern Nigeria. *Journal of Engineering and Applied Sciences* 1(4): pp. 410-421

Iloeje, N.P. (1981). A new geography of Nigeria (new revised edition*). Longman Nig. Ltd., Lagos, Nigeria. pp 201.*

Inyang, G.E., Opara, A.I., Ibechu, B.O., Nwachukwu, H.G., Eluwa, N., Amadi, C.C., Emberga, T.T and Eke, D.R., (2017). Geophysical Appraisal of the Aquifer Geomaterials of Ugep and Environs, Southeastern, Nigeria using Resistivity Data. *Journal of Geography, Environment and Earth Science International 9(2): 1-24.*

Javadi, S. and Mohammadi, K., (2008). Calibrating groundwater vulnerability potential to pollution using statistical method. *Proceedings of 36th IAH congress,Toyama, Japan.*

Joel, E.S. Olasehinde, P.I. De, D.K., Omeje, M. and Adewoyin, O.O. (2016). Estimation of aquifer transmissivity from geophysical data: a case study of Covenant University and environs, southwesthern Nigeria. *Science International, 28, 3379–3385.*

Kazakis, N., Vargemezis, G., and Voudouris, K. S. (2016). Estimation of hydraulic parameters in a complex porous aquifer system using geo-electrical methods. *The Science of the Total Environment, 550, 742–750.*

Keller, G. V. and Frischnechk, F.C., 1979. Electrical methods in geophysical prospecting. Pergamon Press, New York, (91-135).

Kelly, W.E (1976). Geoelectric sounding for delineating groundwater contamination; *Groundwater* 14 6–10.

Kennedy, G.W., (2019). Potential Corrosivity of Groundwater in Nova Scotia and its Association with Lead in Private Well Water.

Kirsch, R, Sengpiel K.P and Voss, W., (2003). The use of electrical conductivity mapping in the definition of an aquifer vulnerability index. Near Surface Geophysics 1:3–20.

Kogbe, C.A., (1976): Paleogeographic History of Nigeria from Albian times, In Kogbe, C.A., (Ed), Geology of Nigeria: *Elizabeth Publishers, Lagos pp. 237-282.*

Kogbe, C. A. (1989). *Geology of Nigeria*. Rock View (Nigeria) Limited. Jos, Nigeria.

Krasny, J. (1993) Classification of Transmissivity Magnitude and Variation Groundwater. 31(32): pp230-236.

Kruseman, G.P and Ridder NA (1994) Analysis and evaluation of pumping test data, 3rd edn, vol 11. *International Institute for Land Reclamation and Development*, *Wageningen.*

Lashkarripour, G.R (2003). An investigation of groundwater condition by geoelectrical resistivity method*: A case study in Korin aquifer, southeast Iran. J. Spatial Hydrol.,* 3(1): pp. 1-5.

Lathamani, R., Janardhana, M. R., Mahalingam, B. and Sureshad, S. (2015). Evaluation of aquifer vulnerability using Drastic model and GIS*: a case study of Mysore City, Karnataka. Aquatic Procedia,* 4, 1031–1038

Lenkey, L., Hamori, Z. and Mihalffy, P. (2005). *Investigating the hydrogeology of a water-supply area using direct-current vertical electrical soundings*. Geophy.70 (4): H1-H19

Lowrie, W. (1997).Fundamentals of Geophysics. Cambridge University Press, New York.

Ma´ dl-Szonyi, J., and Fu¨ le, L., (1998). Groundwater vulnerability assessment of the SW Trans-Danubian Central Range, Hungary. *Environmental Geology 35 (1), (9–18).*

Madi, M., Meddi, M., Boutoutaou, D. and Pulido-Bosch, A. (2016). Assessment of aquifer vulnerability using a geophysical approach in hyper-arid zones. A case study (in Salah region, Algeria). *Arabian Journal of Geosciences, 9.*

Mailet, R. (1974). The Fundamental Equations of Electrical Prospecting. Geophysics, (12)4, pp. 529- 556.

Mendoza, J. and Barmen G (2006). Assessment of groundwater vulnerability in the Río Artiguas basin, Nicaragua. *Environ Geol 50: pp. 569–580.*

Mogaji, K A, Adiat K A N and Oladapo M I (2007) Geoelectric investigation of the Dape Phase 111 Housing Estate FCT Abuja Northcentral Nigeria; *J. Earth Sci.* 1(2) 76–84.

Monanu, S. and Inyang, F. (1975) Climatic regimes. In: *Nigeria in Maps* (ed. by G E. K. Ofomata), 27-29. *Ethiope House, Benin.*

Mondal, N. C., Adike, S., Singh, V. S., Ahmed, S. and Jayakumar, K. V. (2017). Determining shallow aquifer vulnerability by the DRASTIC model and hydrochemistry in granitic terrain, southern India. *Journal of Earth System Science,*126.https://doi.org/10.1007/s12040-017-0870-7.

Murat, R. C. (1972). Stratigraphy and Paleogeography of the Cretaceous and LowerTertiary in Southern Nigeria. In: T. F. L. Dessavuagie & A. J. Whiteman (eds,). *African Geology, Ibadan, Geol. Dept. Univ. Ibadan, Nigeria, 251–266.*

Murat, R.C., (1972). Stratigraphy and Paleogeography of the Cretaceous and LowerTertiary in Southern Nigeria. *African Geology, Ibadan, Geol. Dept. Univ. Ibadan, Nigeria, pp. 251–267.*

NWRI, (2012). National Water Resources Institute-Rural Water Supply and Sanitation Centre, Kaduna. RWSSC Course 2.

Niwas, S. and Singhai, D. C., 1981. Estimation of aquifer transmissivity from Dar-Zarrouk Parameters in porous media. *Journal of Hydrology*, 50, 393-399.

Nwosu, I.E. and Iwuoha, H.N., (2018). Geoelectric Exploration for Groundwater in Mbaitoli L.G.A. Imo State Nigeria using Resistivity Data. *International of Journal of Zambrut*

Nwobodo, T.N., Anikwe, M.A.N. and Chukwu, K.E., (2015). Assessment of Spatio-Temporal Variation of Groundwater Quality in Udi-Ezeagu Watershed, Enugu Area Southeastern Nigeria. *International Journal of Environmental Monitoring and Analysis*

Obi, G.C., Okogbue, C.O., and Nwajide, C.S. (2001). Evolution of the Enugu Cuesta: A tectonically driven erosional process. *Global Journal Pure Applied Sciences.* Vol. 7(2): 321-330

Obi, C.G. (2000). Depositional model for the Campanian-Maastrichtian succession, Anambra basin, Southeastern Nigeria. Unpublished Ph.D Thesis University of Nigeria, Nsukka. (291).

Obiadi, I.I., Obiadi, C.M., Akudinobi, B.E.B., Maduewesi, U.V. and Ezim, E.O., (2016). Effects of coal mining on the water resources in the communities hosting the Iva Valley and Okpara Coal Mines in Enugu State, Southeast Nigeria

Obiora, D. N., Ajala, A. E. and Ibuot, J. C. (2015). Evaluation of aquifer protective capacity of overburden unit and soil corrosivity in Makurdi, Benue state, Nigeria, using electrical resistivity method. *Journal of Earth System Science,* 124(1), 125–135.

Obiora, D. N., Alhassan, U. D., Ibuot, J. C. and Okeke, F. N. (2016a). Geoelectric evaluation of aquifer potential and vulnerability of Northern Paiko, Niger State, Nigeria. *Water Environment Research, 7(88), 644–651.*

Obiora, D. N., Ibuot, J. C., and George, N. J. (2016b). Evaluation of aquifer potential, geoelectric and hydraulic parameters in Ezza North, southeastern Nigeria, using geoelectric sounding. *International journal of Environmental Science and Technology, 13(2), 435–444*.

Odunzeakasiugwu, S., Obi, G.C. and Yuan, W., (2013). Sedimentology and sequence stratigraphy of the Nkporo Group (Campanian–Maastrichtian), Anambra Basin, Nigeria.

Offodile, M.E. (2002). Groundwater study and development in Nigeria *(Mecon geology and Engineering services Ltd, Jos, Nigeria*, 2nd Edition,).

Offodile M. E. (2014*).*). Groundwater study and development in Nigeria *(Mecon geology and Engineering services Ltd, Jos, Nigeria*, 3rd Edition,).

Okeke, J.P., Ezeh, C.C. and Okonkwo, A.C., (2017). Geoelectrical Sounding for the Determination Of Groundwater Prospects In Awgu And Its Environs, Enugu State, Southeastern Nigeria. *Journal of Applied Geology and Geophysics* Vol. (5), pp. 14-22.

Okereke, C.S. and Edet, A.E., (2002). Delineation of Shallow Groundwater Aquifers in the Coastal Plain Sands of Calabar Area (Southern Nigeria) using Surface Resistivity and Hydrogeological Data. Journal of African Earth Sciences. 35: (433–443).

Okoli, F.U., Johnson, N.G.and Ejikeme, J.O., (2017). Mapping Groundwater Potential Zonesin Enugu State using Remote Sensing and GIS Techniques. *International Journal of Innovative Environmental Studies Research* 5(1).

Okonkwo, A.C., Ezeh, C.C. and Amoke, A.I (2016). Evaluation of Ground Water Potential Status in Nkanu-West Local Government Area, Enugu State, Nigeria: *Journal of Applied Geology and Geophysics. Vol. 4 pp 58-66.*

Okonkwo, A.C., Ezeh, C.C. and Akaerue, E., (2017). Estimation of Aquifer Hydraulic Properties and Protective Capacity of Overburden units From Geoelectrical Sounding: *Case of Groundwater Aquifers, Nkanu-West LGA, Enugu, Nigeria.* 107, 47366-47370

Olawuyi, A.K and Abolarin S.B (2013) Evaluation of vertical electrical sounding method for groundwater development in basement complex terrain of west-central Nigeria. *Niger J Technol Dev* 10(2):22–28

Oladapo M I, Mohammed M Z, Adeoye O O and Adetola O O (2004). Geoelectric investigation of the Ondo-State Housing Corporation Estate IjapoAkure southwestern Nigeria; *J. Mining Geol.* 40(1) 41–48.

Oli, I.C., Ahairakwem, C.A., Opara, A.I., Ekwe, A.C., Osi-Okeke, I., Urom, O.O. Udeh, H.M. and Ezennubia, V.C. (2020). Hydrogeophysical assessment and protective capacity of groundwater resources in parts of Ezza and Ikwo areas, southeastern Nigeria. *International Journal of Energy and Water Resources*.

Omosuyi, G.O., Ojo, J.S. and Olorunfemi, M.O. (2008). Geoelectric Sounding to Delineate Shallow Aquifers in the Coastal Plain Sands of Okitipupa Area, South Western Nigeria. *The Pacific Journal of Science and Technology, 562-577.*

Onuoha, K. M., and Mbazi, F. C. C. (1988). Aquifer transmissivity from electrical sounding data of the case of Ajali sandstone aquifers, south east of Enugu, Nig. In C. O. Ofoegbu (Ed.), *Groundwater and mineral resources of Nig* (pp. 17–29). Berlin: Fried-Vieweg and Sohn.

Onwe, I.M., Akudinobi, B.E.B. and Aghamelu, O.P., (2016). Estimating the Hydraulic Conductivity of the Ajali Sandstone in the Udi Area of South Eastern Nigeria from Pumping Test and Grain Size Based Empirical Analysis. *Journal of Hydrogeology & Hydrologic Engineering*

Onyekuru, S.O., Akiang, F., Ohenhen, L. and Ibeneme, I., (2019). Integrating Geoelectrical and Hydrogeological Data in Determining Aquifer Hydraulic Parameters of Ikeduru Area, Southeastern Nigeria. *International Journal of Geology and Earth Sciences. Vol. 5, No.*

Opara, A. I., Onu, N .N. and Okereafor, D.U. (2012). Geophysical Sounding for the Determination of Aquifer Hydraulic Characteristic from Dar-Zarrock parameters: Case Study of Ngor-Okpala, Imo River Basin Southeastern Nigeria. *The Pacific Journal of Science and Technology 13(1), pp. 590-603*

Opara, A.I, Inyang, G.E, Onyekuru, S.O, Emberga, T.T., Ekwe A.C, and Eke, D.R. (2015). Estimates of Aquifer Hydraulic Characteristics and Vulnerability from Surface Resistivity Data: Case Study of Ugep and Environs, Southeastern Nigeria. *International Journal of Scientific & Engineering Research,* Volume 6.

Oroji, B. (2018). Groundwater vulnerability assessment using GIS-based DRASTIC and GOD in the Asadabad Plain. *Journal of Materials and Environmental Sciences, 9(6), 1809–1816.*

Osemeikhian, J.E and Asokhia, M.B., (1982). Applied Geophysics for Engineers and Geologists; Mc-Graw Hill.

Osi-Okeke, I., Opara, A.I., Oli, I.C., Udeh, H.M. and Abiahu, C.M., (2021). Hydrogeophysical and Aquifer Protective Capacity of Abakaliki/Afikpo Area and Environs, Southeastern Nigeria using Geo-Sounding Data*. International Journal of Advanced Academic Research. ISSN: 2488-9849 Vol. 7*

Oyeyemi, K.D., Aizebeokhai, A.P., Ndambuki, J.M., Sanuade, O.A., Olofinnade, O.M., Adagunodo, T.A., Olaojo, A.A and Adeyemi, G.A. (2018). Estimation of aquifer hydraulic parameters from surficial geophysical methods: a case study of Ota, Southwestern Nigeria. IOP Conference Series: *Earth and Environmental Science 173(1): 1–9.*

Philes, C.J. (2004). *University Pierre et Marie Curie.* 71.

Popescu, I.C., Gardin, N.N., Brouye're, S. and Dassargues, A. (2008). *IAHS Publication* 320.

Rabeh, T., Ali, K., Bedar, S., Sadik, M. A. and Ismail, A. (2019). Exploration and evaluation of potential groundwater aquifers and subsurface structures at BeniSuef Area in Southern Egypt. *Journal of African Earth Sciences.*

Rahman, A. (2008). A GIS based DRASTIC model for assessing Ground Water Vulnerability in Shallow aquifer in Aligarh India .Applied Geography, 28, 32-53

Reyment, R. A. and Barber, W. M. (1956). Nigeria and Cameroons. In Lexique Stratigraphique International, 4, 35 – 39.

Reyment, R.A. (1964) Review of Nigerian Cretaceous Cenozoic Stratigraphy, Jour. Nig., Min. Geol. Metal. *Soc. Vol. 1. No 2. Pp 61-80.*

Reyment, R.A., (1965). Aspects of the geology of Nigeria. *The Stratigraphy of the Cretaceous and Cenozoic deposits. Ibadan University Press*. *pp145*.

Röttger, B., Kirsch, R., Scheer,W., Thomsen, S., Friborg, R. and Voss, W. (2005).Multi-frequency airborne EM surveys—a tool for aquifer vulnerability mapping. In: D.K. Butler (ed.): Near surface geophysics, investigations in geophysics no. 13. Society of Engineering Geophysicists, 643–651.

Simpson, A. (1954). The Nigerian Coal Field: The geology of parts of Onitsha, Owerri and Benue Provinces. Geological survey of Nigeria Bulletin, 24, 67.

Tattam, C. M. (1944). A review of Nigeria stratigraphy: Geological survey of Nigeria Report, 27 515 – 46.

Tesoriero, A.J., Inkpen, E.L. and Voss, F.D., (1998). Assessing groundwater vulnerability using logistic regression. *Proceedings for the Source Water Assessment and Protection 98 Conference, Dollas, (157-165).*

Ugada, U., Ibe, K.K., Akaolisa, C.Z. and Opara, A.I., (2013). Hydrogeophysical evaluation of aquifer hydraulic characteristics using surface geophysical data: A case study of Umuahia and environs, Southeastern Nigeria. *Arabian Journal of Geosciences.*

USEPA. (1985). DRASTIC: *a standard system for evaluating groundwater potential using hydrogeology settings (p. 163). Ada: Oklahoma WA/EPA series.*

Venkatarao, G., Kalpana, P. and Srinivasa Rao, R. (2015). Estimation of Aquifer Properties Using Pumping Tests: Case Study of Pydibhimavaram IndustrialArea, Srikakulam, India. *International Journal of Environmental and Ecological Engineering Vol:9, No:9. pp 1170-1174.*

Vrba, J., Zaporozec, A. (1994). Guidebook on mappingg roundwater vulnerability. *International contributions to hydrogeology Nr. 16, Hannover, (112)*.

Ward, R.C. and Robinson. M. (2000). *Principles of Hydrology. 4th edition. McGraw-Hill.*