COMPARATIVE ANALYSIS OF TECHNIQUES FOR ESTIMATING AQUIFER HYDRAULIC PARAMETERS: CASE STUDY OF EZZA AND IKWO AREAS SOUTHEASTERN NIGERIA.

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THESIS

SUBMITTED TO

THE DEPARTMENT OF GEOLOGY

SCHOOL OF PHYSICAL SCIENCES

FEDERAL UNIVERSITY OF TECHNOLOGY OWERRI

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

DECEMBER, 2021

CERTIFICATION

This is to certify that this work "Comparative Analysis of Techniques for Estimating Aquifer Hydraulic Parameters: Case Study of Ezza and Ikwo Areas Southeastern Nigeria" was carried out by Oli Ifeanyi C. with Registration Number 20174077808 in partial fulfillment for the award of the degree of M.Sc. in Hydrogeology in the Department of Geology of Federal University of Technology, Owerri.

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DEDICATION

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

ACKNOWLEDGEMENTS

This research would not have been possible if not for the support of so many people too numerous to mention.

Firstly, I will love to thank my Supervisors Prof. A.I. Opara and Prof. O.C Okeke for their Fatherly support, help and encouragement. Their input made this work possible thank you Sirs, God bless you.

I also wish to thank 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.

Furthermore, I am eternally grateful to my family; my dad; Chief Sir Emmanuel Chukwudi Oli; Chidimma & Ifeoma, my sisters; Pst. K.C Ahaiwe, whose call was always to remind me the need to be strong and Finish, my awesome friend In-laws, my friend Everestus for vetting the work, may God bless you all. I love you all.

Finally, I thank my colleagues Chidimma, Harry, Ifeanyi and others too numerous to mention who supported me with all the needed information necessary to having a finished work. I pray for you all that my heavenly Father will bless you all awesomely in Jesus's name Amen.

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ABSTRACT

Aquifer hydraulic parameters (Hydraulic conductivity and transmissivity) plays an important role in the assessment and management of groundwater. Conventionally, these parameters are best estimated by means of a pumping test, which is expensive and time consuming. The integration of data from the electrical resistivity survey and the pumping test provides a cost-effective and efficient alternative. A total of Thirty-five (35) Vertical Electrical Sounding with a maximum current electrode spacing of 150m using Schlumberger array, with parametric sounding performed in the vicinity of the five (5) wells where the pumping test was conducted for comparative purposes. The empirical relationship between the hydraulic conductivity derived from the pumping test and the aquifer resistance were established for the different Formations (Ebonyi and Abakaliki Formation) and, in turn, used to estimate aquifer hydraulic parameters in areas away from wells. Aquifer hydraulic conductivity varies from 0.49m/day to 1.5735m/day with a mean value of 0.9205m/day for the Ebonyi Formation, while those underlain by the Abakaliki Formation have hydraulic conductivity values that varies from 0.0775m/day to 1.3023m/day, with a mean value of 0.2883m/day. The Transmissivity values ranges between 0.29m^2/day to 57.27m^2/day with a mean value of 6.59m^2/day. Transmissivity values obtained were compared with Krásný's Transmissivity classifications and the result used to delineate the area into three aquifer potential zones; very low, low and intermediate zones. The study shows that the areas underlain by the Ebonyi Formation have a higher groundwater potential than those underlain by the Abakaliki Formation. This is also supported by the geology of the area, with the Abakaliki Formation dominated by shales that have very low permeability, while the Ebonyi Formation consists of shales with alternations of sandstones, which supports good aquifer conditions. Statistical analysis of the different model equations used in estimating hydraulic conductivity of the study area shows that the New Model proved to be a better substitute in the absence of pumping test data.

Keywords: Aquifer potential, Hydraulic conductivity, Pumping test, Transmissivity, Vertical Electrical Sounding.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND INFORMATION

Groundwater resources is a major source of freshwater and its essential for reliable and economic provision of safe water supplies in both the urban and rural environments for sustainable development of any economy (Adelena et al, 2008). Most developing nations of the world like Nigeria are challenged with acute shortage of water leading to serious inconveniences to the local people (Mgbeojed et al, 2018). The major source of freshwater (87%) is locked as ice; Groundwater, accounting for 12% of the world's freshwater reserve, while 1% of the world's freshwater reserves are represented by surface water (Gleick, 2011). It is obvious that humanity will have to rely heavily on sustainable groundwater development as population values are predicted to skyrocket in the next decade. Groundwater is not easily susceptible to pollution when compared with other water sources. However, its occurrence and distribution is basically controlled by geological factors such as lithology, texture and structure of the rocks as well as hydrological/meteorological factors like stream flow and rainfall (Nwankwola, 2015). Due to the increased need for water and scarcity of surface water in the study area, groundwater provides a viable option. None of the surface water is as hygienic or as economical for exploitation as the groundwater (Singh, 2007). Groundwater is recommended for its natural biological quality and its general chemical quality for most uses (McDonald et al, 2002). Disease related to unsafe drinking water, sanitation and hygiene conditions are a huge burden to developing countries (Adams et al., 2009). Every year, about 1.8 million children die of diarrhea and other diseases caused by unclean water (WHO, 2009). The Guinea worm infestations in some parts of Ebonyi state are attributed to ignorance and lack of safe drinking water (Okoronkwo, 2003). The people that live in the study area lack a good number of functional boreholes and depend on ponds and other existing contaminated surface sources which are open to physical, chemical and biological contaminations (Obiora et al, 2016). Limited access to safe water in Nigeria has been attributed to the enormous socioeconomic development and poor planning (Oluwasanya, 2009). Efficient management and development of groundwater in such areas necessitate knowledge of the physical parameters of the hydrogeological system. These parameters include transmissivity and hydraulic conductivity. Therefore, it is vital to establish sustainable limits to the exploitation of groundwater (Juandi et al, 2017). Pumping tests are commonly used to evaluate these parameters. Pumping tests are considered the most reliable method for determining well capacity or yield, in comparison to estimates made by a driller at the time of well construction, or empirical pumping 'runs' in which water is pumped from the well at a desired rate without measuring the change in water level (BCMELP, 1999).

The normal practice in a pumping test is to pump a borehole at a specified discharge rate and observe the drawdown recovery in an observation well and the drawdown data so obtained can be used to estimate aquifer parameters such as transmissivity and storativity by employing procedures such as Theis, Cooper-Jacob's and Chow's methods (Venkatarao et al,2015). However, pumping test is too expensive and time consuming to be used to ascertain aquifer parameters. Also various formulas available for calculating the aquifer characteristics from pumping test data analysis are valid only if various assumptions about aquifer continuity, thickness, homogeneity, isotropy, well storage and nature of fluid flow are valid under field conditions (Freeze and Cherry 1979), hence the need for a reasonable alternative. This gives way for a non- invasive method of evaluating aquifer parameters which is provided by surface geoelectric methods. Vertical electrical sounding (VES) which determines the vertical variation of subsurface resistivity with depth has been very efficient in delineating subsurface layering, overburden thickness and depth of fractured aquifer (Eyankware, 2020). According to Ekwe et al (2006), the method is cost and time effective and is used to predict the parameters for even those areas where there are no existing wells. Electric current flow influences the physical state of the water flow in a porous medium. The major hydraulic parameters of interest in aquifer investigation and characterization are hydraulic conductivity and transmissivity. Integration of hydraulic parameters determined by borehole and aquifer resistivity parameters estimated by geoelectrical methods has been suggested and successfully achieved by various authors (Heigold et al.,1979; Ponzini et al., 1984; Kelly and Frohlich, 1985; Mbonu et al., 1991; Kalinski et al., 1993; Frohlich et al., 1996; Dasargues, 1997; Purvance and Andricevic, 2000; Chen et al 2001; Sinha, Israil and Singhal (2009); Nwosu et al., 2013; Ugada et al., 2013, Harry, Ushie and Agbasi, 2018; Ekwe et al., 2020; Hasan et al., 2020). Ugada et al. (2013) made use of Dar Zarrouk parameters to estimate aquifer properties of Umuahia. Ngwoke (2013) determined aquifer parameters in Ishiagu, Ebonyi state, using geolectric methods. Ekwe et al (2020) determined aquifer parameters from geosounding data in parts of Afikpo sub-basin, southeastern Nigeria. This proves that relationship between hydraulic and geoelectric parameters of the aquifer can be deduced practically. However, such relationship depends on specific areas and may have limited application in other areas (Rehfeldt et al.,1992; Salem, 1999; Purvance and Andricevic, 2000; Hasan et al., 2019). Based on these results, one can set limits to the amount of groundwater that can sustainably be extracted from an aquifer and thus avoid over exploitation (Juandi et al, 2017).

1.2 STATEMENT OF PROBLEM

Due to the major challenge of water availability and quality in the study area, groundwater is the only viable option for portable water, given that the wells usually dry up during dry seasons and the surface waters are easily susceptible to contamination, with the villagers having to trek long distances to get it. Bearing this is in mind, there is need for a good groundwater resource management policy which can be not be developed without analyzing the aquifer hydraulic parameters of the area in the scope. Pumping test have proved to be very expensive and time consuming, therefore there is a need to introduce a faster, less invasive and less expensive way of determining aquifer hydraulic parameters.

1.3AIM AND OBJECTIVES

The aim of this research work is to carry out a comparative analysis of various techniques for estimating aquifer hydraulic characteristics of the study area using geophysical and hydrogeological data.

In achieving the stated aim, the following objectives were to be utilized:

1) To determine aquifer geometrical and layer parameters (aquifer resistivity, depth, thickness) of the study area using vertical electrical sounding data.
2) To evaluate hydraulic parameters of the aquifer such as transmissivity and hydraulic conductivity from pumping test.
3) To estimate aquifer hydraulic conductivity and transmissivity of aquifers in the study area using different models from vertical electrical sounding.

4) To compare and asses the reliability of the various geophysical models used in estimating aquifer hydraulic parameters of the study area using geostatistical data.
5) To use the estimated aquifer hydraulic characteristics to determine the groundwater potentials of the study area for effective groundwater exploration and management.

1.4 JUSTIFICATION OF STUDY

Due to the high expense and length of time needed in conducting pumping tests to estimate aquifer hydraulic characteristics, a less expensive and non-invasive technique that has been used all over the world with excellent results. This technique unlike the others is constrained by the geology of the area, thereby eliminating the error of under estimation or overestimation This study will also provide much needed data on the groundwater potential of the area that will help reduce the rate of failed or abortive boreholes in the study area.

1.5 SCOPE OF STUDY

The scope of the study is to compare techniques used in estimating aquifer hydraulic parameters in parts of Ezza South and Ikwo L.G. A's in Ebonyi State, Southeastern Nigeria.

CHAPTER TWO

LITERATURE REVIEW

2.1.1 Groundwater

In the study area, groundwater is a critical natural resource. It is utilized in industry and agriculture, and it provides about 100 percent of the drinking water supply in the study area's rural areas. Groundwater is simply water that originates from the earth. Groundwater, in more precise terms, is water that fills gaps and crevices between soil and rock particles. The saturated zone is formed when water fills all of the pores and open areas. Contrary to popular belief, groundwater does not often comprise of subterranean lakes or streams, but rather fills the uneven space inside rock cracks or between sand, gravel, or clay particles (Mayooran et al. 2011). The water then dissolves some of the naturally existing minerals it comes into touch with as it travels through the earth. Chemical properties of groundwater are influenced by the dissolved minerals, which in turn affects the hardness and flavor.

Sodium, calcium, magnesium, potassium, chloride, bicarbonate, and sulfate are the most frequent dissolved mineral compounds. Groundwater recharge occurs when surface water percolates from land areas or streams via permeable soils into water-holding rocks that offer subterranean storage (Longe, 2011; Amos-Uhegbu, 2013). Rainwater that infiltrates from forests and surface water features such as marshes, lakes, and streams can replenish groundwater. For groundwater recharge regions, woodlands, wetlands, and floodplains act as a filtering mechanism. An aquifer is formed when water-bearing soil or rock yields substantial volumes of water to wells or springs.

2.1.2 Aquifer

An aquifer is a water-bearing stratum of rock or unconsolidated sediments that will produce water in a useful amount to a well or spring. An aquifer can be a layer of gravel or sand, a layer of sandstone or limestone, or even a huge body of rock like shattered granite. There are two types of aquifers: confined and unconfined. Water-bearing strata in confined aquifers are separated by impermeable soil barriers above and below. Because the water in these aquifers is under pressure, when a well is constructed in a restricted aquifer, the water level in the well casing rises over the aquifer's top. Unconfined aquifers, also known as water table aquifers, are the saturated parts of the soil profile that are accessible to the atmosphere via permeable material positioned above an impermeable soil barrier (Obiora and George, 2016). The presence of salt, methane gas, hydrogen sulfide, and other dissolved minerals can change the quality of groundwater in the bedrock from acceptable drinking water to unusable water.

2.1.3 Unconfined Aquifers

If water only partially fills the aquifer materials and water easily rises and falls along the unsaturated/saturated zone boundary, the aquifer is termed unconfined. These unconfined aquifers are also known as water table aquifers, and wells opened to these unconfined aquifers show the position of the water table (Hassan et. al, 2020)

2.1.4 Confined Aquifers

When water fully fills the aquifer materials and is overlain by a restricting bed, the aquifer is said to be confined. An artesian aquifer is a typical name for a restricted aquifer. The water level from a well that only allows water from a restricted aquifer to enter the well will be higher than the top of the confined aquifer but not necessarily higher than the land surface. The water level in a well open to a restricted aquifer is equal to the potentiometric surface. If the potentiometric surface is above ground, the well is sometimes referred to as a free-flowing artesian well.

2.1.5 Confining Bed

A confining bed is a layer of rock or unconsolidated sediments that slows the passage of water in and out of an aquifer and has a very low hydraulic conductivity. According to these criteria, all such rocks are either aquifers or confining beds.

2.2 AQUIFER HYDRAULIC PROPERTIES

Transmissivity and hydraulic conductivity are essential hydrogeological variables for managing groundwater resources because they represent an aquifer's overall capacity to transport water (across the whole saturated thickness for transmissivity and over a unit thickness for hydraulic conductivity). To verify the validity of the hydrologic assumptions and interpretations employed in regional water plans, representative transmissivity and hydraulic conductivity data are necessary. Storativity is the change in volume of water caused by a unit change in water level per unit area.

It is critical to have a publicly available database of transmissivity, hydraulic conductivity, and storage coefficient (storativity) for constructing local and regional water plans and numerical groundwater flow models to anticipate future groundwater availability. Aquifer testing are costly to do, and historical test data, while available, is labor demanding to assemble and assess (see for example**,** Razack and Huntley, 1991; Huntley and Steffey., 1992; Mace, 1997).

2.2.1. Aquifer Transmissivity (T)

Aquifer hydraulic conductivity (also known as permeability) and unit thickness are the two factors that determine transmissivity. This is expressed as a meter square per day (m^2/d). Under a hydraulic gradient of 1 ft/ 1 ft, the transmissivity (T) is the volume of water flowing through an aquifer's cross-sectional area multiplied by its thickness (b) (usually a day).

2.2.2 Hydraulic Conductivity (K)

This is a key aquifer characteristic that provides a quantitative assessment of a geologic formation's ability to transport a certain fluid (groundwater). This parameter influences the flow rate through a porous material (Bouvwer, 1978). While hydraulic conductivity dimensions have velocity (distance / time) units, it is really a flux expressing a discharge of water per unit area under a hydraulic gradient of 1, with full units of $m^3/day/m^2$ (Rae, 1998). In other terms, it is the amount of water that passes through an aquifer's square cross-sectional area in a particular period.

2.3 WATER TABLE AND PIEZOMETRIC SURFACE

2.3.1 Water Table

The level at which water will stand in a well dug in an unconfined aquifer is referred to as the water table. In other words, is the surface at which the water pressure head equals the atmospheric pressure (gauge pressure = 0). (Freeze and Cherry, 1979). Where there is recharge or outflow from the aquifer infant, the water table varies. The water table is continuously moving and changing its surface to create a balance between recharge and outflow.

Water seeps into the ground and flows downhill in reaction to gravity until the rock is no longer porous. The zone of saturation is the subsurface zone in which all holes in the rock are filled with water. The water table is the top surface of the zone of saturation. To be successful, a well must be dug into the saturation zone. The speed at which water travels underground is determined by the permeability of the rock or the size and connectivity of the holes. In general, the water table follows geographic characteristics, being high beneath ridges and low beneath valleys. However, the topographic crest and the water table ridge may not always coincide, resulting in movement from one aquifer to the other, a phenomenon known as watershed leakage (Hughes and Thackray, 1999). A seepage surface or spring is created whenever the water table contacts the ground surface. Water can also escape from the earth through cracks. The permeability of the aquifer material has a large impact on water flow in aquifers.

Permeable materials have linked fractures or spaces that are large enough and frequent enough to allow water to flow freely. Groundwater can travel many meters in a day in some porous materials; in others, it can move only a few millimeters in a year.

Groundwater flows at a glacial pace through relatively impermeable rocks such as clay and shale. Water slowly flows into an aquifer and ultimately releases from the aquifer as springs, seeps into streams, or is extracted from the earth via wells. Water may be trapped under pressure in aquifers between layers of impermeable rock, such as clay or shale. When a well is drilled into such a restricted aquifer, water rises above the aquifer's surface and may even flow from the well onto the land surface.

2.3.2 Piezometric and Potentiometric Surfaces

A piezometric surface is a hypothetical surface to which the water level would rise if piezometers were placed in an aquifer. This is the fictitious surface to which groundwater rises within an aquifer due to hydrostatic pressure It is occasionally high enough to induce water to rise in a well and pour out. This represents the pressure of water in the aquifer

As previously stated, water in a restricted aquifer is under pressure. When a well is drilled in a restricted aquifer, the water level in the well rises above the aquifer's surface. As a result, a potentiometric surface is the imaginary plane where a given reservoir of fluid will "equalize out to" if permitted to flow.

A potentiometric surface, also known as a piezometric surface, is an imaginary surface that defines the height to which water in a restricted aquifer would rise if it were entirely perforated with wells (Younger, 2007).

The piezometric surface (or potentiometric surface, as the case may be) is the level of water in an aquifer within a piezometric well. On maps, it is shown as a line connecting the walls of a well (US Geological Survey, 2014). An engineer or hydro geologist can calculate recharge and discharge rates, as well as groundwater flow direction and rates, when numerous piezometric surface observations are available.

The level of water within a piezometeric well in an aquifer (as in cased well) are usually measured using the water level meter. A water level meter uses a flat measuring tape to transmit a signal buzzer when water is encountered. It is commonly mounted on a hand-cranked and a powered supply reel that contains a space for batteries and some device (indicator) for signaling when the circuit is closed. The amount of water in the well is best assessed at static (non-pumping) ground water level since it best mimics the surrounding aquifer conditions (Sea Grant Oregon, 2016). A graded steel tape, an existing airline, or an electric sounding instrument are among more techniques for monitoring ground water level. A water level meter is seen in Figure 2.1.

Figure 2.1: Dip meter

2.4 Previous Works

The relationship between aquifer geoelectric properties and their hydraulic parameters such as hydraulic conductivity and transmissivity has been investigated in several studies. Those instances include those of Archie (1942), Kelly (1977), Niwas and Singhal (1985), Salem (1999), Purvance, and Andricevic (2000). The experiments were specific area but the methods can be applied under various geological conditions.

According to Ngwoke (2013), three types of relationships have been derived between geoelectric and hydraulic properties:

i. Relation between Formation factor (F) and Hydraulic properties

ii. Relation between Formation resistivity

and Hydraulic conductivity (K)

iii. Relation between Transverse resistance (R) and Transmissivity (T)

Croft (1971) developed a relationship between the aquifer intrinsic permeability and the Formation factor to estimate the transmissivity from measurements of borehole resistivity. Kosinski and Kelly (1981) did a job of predicting aquifer properties on geoelectrical soundings. On the one hand, Niwas and Singhal (1981) identified an empirical relationship between aquifer transmissivity and transverse resistance, and on the other, transmissivity and longitudinal conductance. Niwas and Singhal (1985) noted that it is easier to use an "adjusted transverse resistivity" rather than transverse resistance where the consistency of the groundwater quality varies considerably. In a complex aquifer of glacial outwash deposits, Frohlich and Kelly (1985) studied the relationship between hydraulic transmissivity and transverse resistance Mazac et al. (1985) focused on the correlation of aquifer and geoelectric parameters in both the aquifers ' saturated and unsaturated zones Ako and Osondu (1986) conducted groundwater investigations at Darazo on the Kerri-Kerri Formation; concluded that Dar-Zarouk parameters are related to borehole characteristics and noted that the highest transverse resistance (T) corresponds to the zone with the highest borehole yield.

Mbonu, et al (1991) used geoelectric sounding to determine aquifer properties in parts of Nigeria's Umuahia region. McDonald et al (1999) used a geoelectric approach to estimate the transmissivity of aquifers in the Thames gravels in the basement complex area of Jos, Plateau State. De Lima and Niwas, (2000) derived hydraulic parameters for shaly sandstone aquifers from geoelectrical measurements. Amadi (2006) carried out a hydrogeophysical survey of Ebonyi South-Eastern Nigeria, including Ishiagu and Ohaozara. Akaolisa (2006) used geoelectric investigation involving twenty-six vertical electrical soundings, to investigate the aquifer potential of the underlying bedrock as well as the transmissivity of aquifers in the Jos Plateau area. In the majority of the previous studies carried out, the concept of Da- Zarouk parameters was applied in sandstone aquifers

Nevertheless, Ekwe et al (2010) used the same approach to estimate aquifer hydraulic characteristics of low permeability (shaly) formation in the town of Oduma, Enugu State where the aquifer hydraulic conductivity was estimated to fall between 0.624 m/day and 5.5091 m/day and transmissivity to range from 14.17m^2/day to 174.89 m^2/day. The geology and hydrogeology of the Oduma region are close to those of the current study area, where shale is the main lithology underlying the area. Opara et al (2012) also used geophysical sounding for the determination of aquifer hydraulic characteristic from Dar-Zarrock parameters. case study of Ngor-Okpala, Imo River Basin Southeastern Nigeria. Ngwoke (2013) used the geoelectric method of Vertical Electrical Sounding (VES) to characterize important aquifer parameters where he determined the hydraulic conductivity and transmissivity and groundwater potential of

Ishiagu area to be between 0.02 m/day to 4.4 m/day. Analytical models based on the integrated surface geophysical technique and pumping test data were utilized to estimate aquifer hydraulic characteristics across Nigeria. Opara et al., 2020; Emberga et al., 2021; Urom et al., 2021; Israil and Singhal (2009) presented a hydrogeological model of the connection between an anisotropic aquifer's geoelectric and hydraulic characteristics. However, such relationship depends on specific areas and may have limited application in other areas (Rehfeldt et al., 1992; Salem, 1999; Purvance and Andricevic, 2000; Hasan et al., 2019; Urom et al., 2021). Amos-Uhegbu, (2013), 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 some parts of Umuahia, Southeastern Nigeria. Hasan et al. (2020) estimated hydraulic parameters in hard rock aquifer using integrated surface geophysical method and pumping test data in southeast Guangdong, China, and were able to delineate aquifer potential zones. Ibeneme et al (2020) with the aid of surface resistivity methods (VES) estimated the aquifer hydraulic parameters of Isiukwuato and Environs in Umuahia Southeastern Nigeria. The hydraulic conductivity values range from 0.5 m/day to 6.5 m/day, while the transmissivity values range from 19.86 m^2/day and 830.98 m^2/day. They were able to delineate areas that will bear high yield. Opara et al., 2020 estimated aquifer hydraulic parameters in parts of Afikpo basin Sub-basin, Southeastern Nigeria, with the hydraulic conductivity values ranging from 1.344m/day to 2.792m/day with a mean value of 2.068m/day, while the transmissivity values were from 28.18m^2/day to 31.73m^2/day and a mean value of 29.96m^2/day.

CHAPTER THREE

MATERIALS AND METHODS

3.1 PUMPING TEST

Pumping tests was carried out in 2 boreholes locations within Ezza South and 3 boreholes locations in Ikwo LGA's in Ebonyi State which were part of projects embarked on by the Federal Ministry of Water Resources through its executing agency; Anambra Imo River Basin Development Authority in which I was part of the team as shown in Fig 3.1. Materials used for the work were;

i) 1.5hp Pump (Submersible)

ii) Water level probe (dipper)

iii) Risers

iv) Stopwatch

v) Power Source (Generator)

vi) Calibrated bucket

vii) GPS (global positioning system)

3.1.1 Methodology

Constant rate pumping method with single well was adopted, and the following steps were undertaken:

i) This process consists of two stages – the pumping phase and the non-pumping phase.

ii) Before the start of the pumping test, the static water level was measured using the electrical water level probe (dipper) and a submersible pump was mounted and the water level increase was noted.

iii) The water pumped during the pumping process was measured and registered with a dipper and stopwatch at a constant rate from suitable local datum (top case).

iv) The flow rate was calculated shortly after the test started, and at intervals during the test using a defined container volume.

v) Dynamic water levels in the boreholes were measured at stop watch intervals.

vi) The second phase which was the non-pumping or recovery process started when the pump was turned off at the end of the pumping phase.

vii) The stopwatch was restarted and the recovery of the water level was assessed at the same intervals as the drawdown to the pre-test level.

Figure 3.1: Pumping test ongoing

3.1.2 Data Analysis of Pumping Test

The Cooper and Jacob solution method was used to determine the aquifer-derived parameters (transmissivity, hydraulic conductivity and specific capacity). This was achieved using a computer software (Aquifer Win32) by plotting drawdown against their respective time data acquired in semi-log format during the pumping test. 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 determined and then incorporated into Cooper and Jacob well flow equation (for single well) as stated below for the computation of the transmissivity and specific capacity (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.

(Freeze and cherry 1979) developed several equations used in estimating transmissivity and hydraulic conductivity, given in equation 3.1 and 3.2

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

Where T = Transmissivity in m^2/day, Q = Discharge Rate in m^3/day, ΔS = Change in drawdown over one logarithmic cycle and

$$\boldsymbol{K = \frac{T}{b}} \qquad (3.2)$$

Where K = Hydraulic conductivity in m/day, b = Aquifer thickness in m, T = Transmissivity in m^2/day.

(Cooper and Jacob, 1946) used equation 3.3 to estimate Specific capacity in m^2/day

$$\boldsymbol{Sc = \frac{Q}{\Delta S}} \qquad (3.3)$$

Where Sc = Specific capacity in m^2/day, Q = Discharge Rate in m^3/day, ΔS = Change in drawdown over one logarithmic cycle

3.2 GEOELECTRIC INVESTIGATION

During the exercise (Fig 3.3) the following materials and field equipment were used to gather the data;

(i) The ABEM 4000 model Terrameter. This equipment displays apparent resistivity values digitally as computed by Ohm's law. It has a 12.5V DC battery as its power source.

Other accessories to this equipment included:

(ii) Four metal electrodes (two potentials and two current)

(iii) Connecting cables, for current and potential electrodes

(iv) GPS (Global Positioning System).

Thirty-five (35) sounding points were selected with one parametric sounding performed at each of the wells where the pumping test had already been completed and the sounding points being geo-referenced using a GPS held by hand. VES used the Schlumberger array. This configuration involves attaching four electrodes to the terrameter using the connecting cables and spacing them linearly, with the potential electrodes between the sounding station at the end of the spread and the current electrode as illustrated in Fig. 3.2.

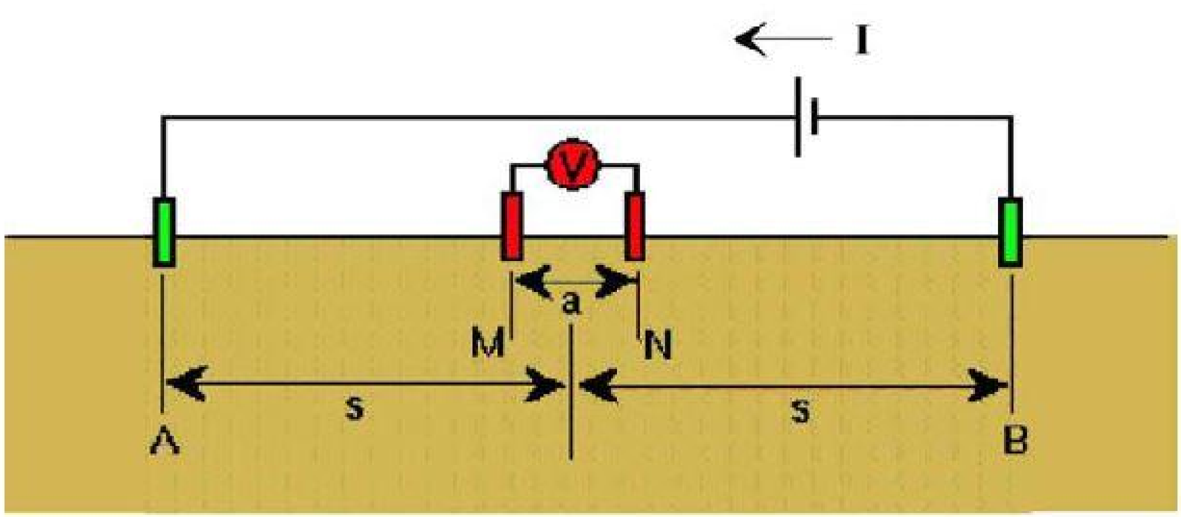

Figure 3.2: Illustration of the Schlumberger Array A and B = Current Electrodes, M, and N= Potential Electrodes (Source: Milson 2003)

On the terrameter's digital screen the computed resistance for the investigated subsurface was shown. At each sounding point the record of the displayed value was taken, while the position and elevation of each of the sounding points were also recorded using a GPS. A maximum half current 150 m spacing of the electrode "AB/2" was used.

Figure 3.3: Geophysical Study of the area using direct current resistivity method

For each of the sampled VES sites, the above processes had been replicated. The data was further interpreted using IPI2Win computer software using iterative / inversion approach. An initially created field curve was compared with adjustable theoretical curve until a good match was obtained which yielded true values of resistivity, depth and thickness.

3.3 DATA ANALYSIS OF GEOELECTRIC SOUNDING

Aquifer parameters (transmissivity and hydraulic conductivity) will be determined from the interpreted vertical electrical sounding tests, for all sounding points including those points without existing borehole data. To accomplish this, various methods can be used, and they include;

3.3.1 Estimation from Niwas and Singhal.,1981

The determination of aquifer hydraulic characteristics can be accomplished by using parameters of transverse resistance and longitudinal conductance from Dar-Zarrock. Niwas and Singhal (1981) developed, on the one hand, an empirical 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

$$Q = KIA \qquad (3.4)$$

And from ohm's law

$$J = \delta E \qquad (3.5)$$

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 (3.4) and (3.5) to get

$$T = K\delta R = \frac{KL}{\delta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (3.6)$$

Where T= aquifer transmissivity, R= Transverse resistance and L= longitudinal conductance

Quantitative interpretations of vertical electrical sounding data often lead to the generation of geoelectric layers. The information from these geoelectric layers enhances the identification of layer parameters which include aquifer depth and thickness. This layer parameters thus obtained will be used to evaluate the Dar-Zarrock parameters. 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.

$$R = h\rho \qquad (3.7)$$

$$L = h/\rho \qquad (3.8)$$

$$K_{NS} = k\delta\rho \qquad (3.9)$$

Where K_{NS} = Hydraulic conductivity from Niwas and Singhal, (1981), and Kδ= Diagnostic constant

In areas of similar geologic setting and water quality the product Kδ remains 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.

3.3.2 Estimation from Heigold et al.,1979

The Heigold et al model leverages the relationship between hydraulic conductivity (K) obtained from other methods and aquifer resistance to produce an equation that allows us to estimate hydraulic conductivity using aquifer resistance. The equation is;

$$K_{HG}=386.40Rw^{-0.93283} \qquad (3.10)$$

where K_{HG} is hydraulic conductivity from Heigold et al (1979) and Rw is the resistivity of the aquifer.

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

$$Tt=k\delta T=ks/\delta=kh \qquad (3.11)$$

Where δ is the electrical conductivity (inverse of resistivity),

S is the longitudinal conductance

and T is the transverse resistance.

3.3.3 Estimation using New Model from the study area

This model, clouts on understanding the relationship between Hydraulic conductivity and Aquifer resistivity, and the relationship between Transmissivity and Transverse resistance. This makes it possible to produce a new model that is more specific to the geology of the study area. Hydraulic conductivities and Transmissivity obtained from the wells where pumping tests were conducted on was plotted against aquifer resistivity and Transverse resistance values respectively, obtained from parametric soundings on the well locations in the different Formations as shown in Fig. 3.4, Fig. 3.5, Fig 3.6 and Fig 3.7.

Table 3.1: Hydraulic conductivity from pumping test and corresponding aquifer resistivity from VES in Ebonyi Formation.

Hydraulic Conductivity k (m/day) from pumping test	**Aquifer Resistivity (Ohm-m)**
1.007	84.6
0.6909	275.6

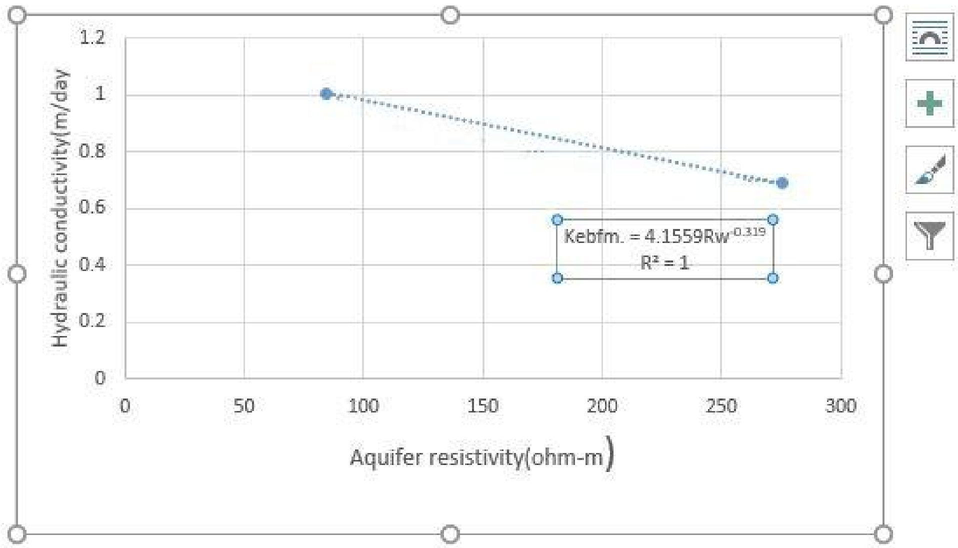

Figure 3.4: Hydraulic conductivity plotted against Aquifer resistivity for Ebonyi Formation

A new equation of K for Ebonyi Formation is formed which is;

$\mathbf{K^{ebfm}}. = 4.1559Rw^{-0.319}$ …………………………………………………………. (3.12)

Where $\mathbf{K^{ebfm}}$ = hydraulic conductivity for Ebonyi Formation

Rw= Aquifer resistivity

Table 3.2: Transmissivity from Pumping test and corresponding Transverse resistance from VES in Ebonyi Formation

Transmissivity (m^2/day) from pumping test	**Transverse resistance (Ohm^2)**
9.0662	84.6
4.1457	275.6

Likewise, Transmissivity was plotted against Transverse resistance and a new equation for Transmissivity (T) was derived for Ebonyi Formation.

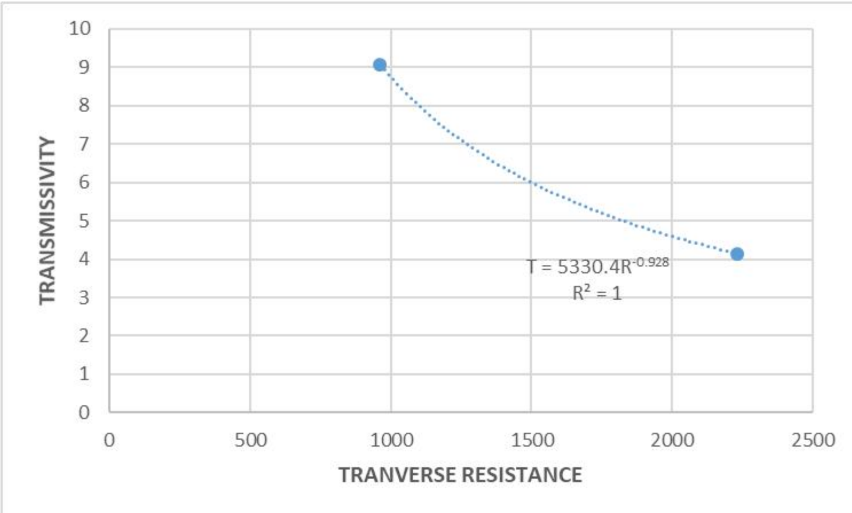

Figure 3.5: Transmissivity plotted against Transverse resistance for Ebonyi Formation

$\mathbf{T}^{ebfm}$. = 5.3304$R^{-0.928}$ …………………………………………………………… (3.13)

Where $\mathbf{T}^{ebfm}$ = hydraulic conductivity for Ebonyi Formation

R= Transverse resistance

The coefficient of correlation for equations 3.12 and 3.13 was 1 showing a positive relationship between both parameters.

While for Abakaliki formation a new equation for K and T was also developed with the same concept

Table 3.3: Hydraulic conductivity from pumping test and corresponding Aquifer resistivity from VES in Abakaliki Formation.

Hydraulic Conductivity k (m/day) from pumping test	**Aquifer Resistivity (Ohm-m)**

0.6289	172.9
0.5976	160
1.019	319

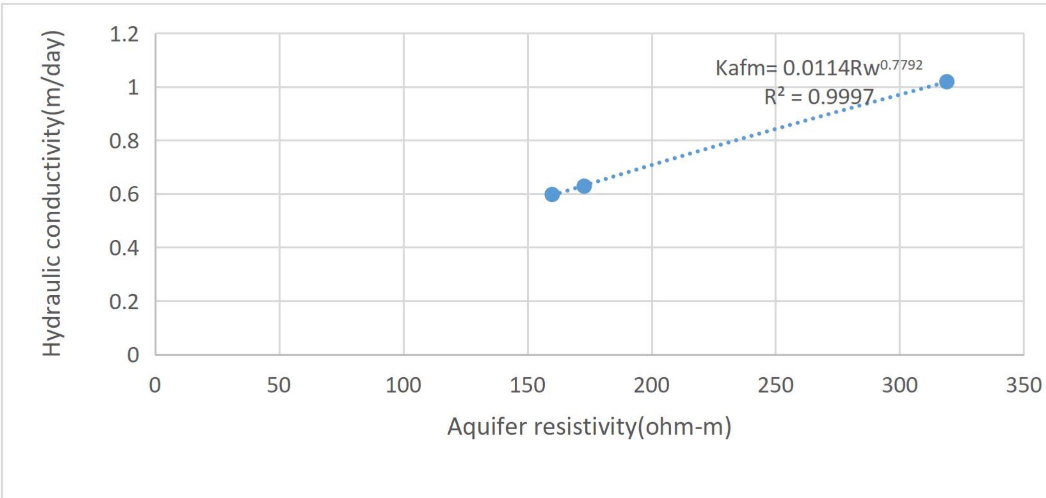

Figure 3.6: Hydraulic conductivity plotted against Aquifer resistivity for Abakaliki Formation

The new equation of K for Abakaliki Formation is;

$\mathbf{K^{afm}}. = 0.0114Rw^{0.7792}$ ……………………………………………………………. (3.14)

Where $\mathbf{K^{afm}}$ = hydraulic conductivity for Abakaliki Formation

Rw= Aquifer resistivity

Table 3.4: Transmissivity from pumping test and corresponding Transverse resistance from VES in Abakaliki Formation.

Transmissivity (m^2/day) from pumping test	**Transverse resistance (Ohm^2)**

5.6585	2749.11
5.3789	2576 5.3789
9.1713	4976.4

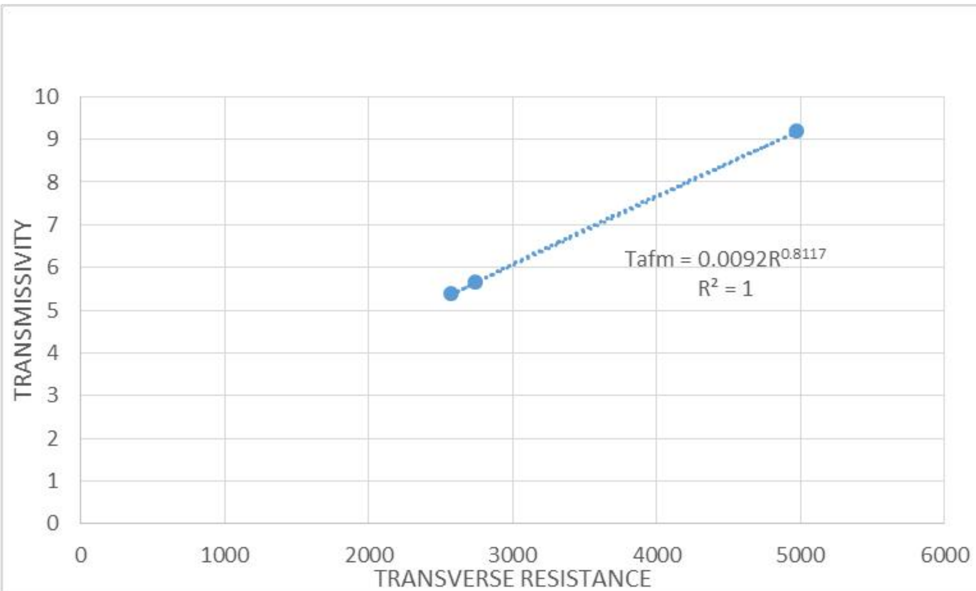

Figure 3.7: Transmissivity plotted against Transverse resistance for Abakaliki Formation

$\mathbf{T^{afm}}$. = 0.0092$R^{0.8117}$ ……………………………………………………………. (3.15)

Where $\mathbf{T^{afm}}$ = Transmissivity for Abakaliki Formation

R = Transverse resistance

The coefficient of correlation for equations 3.14 and 3.15 was 0.9 and 1 respectively, showing a positive relationship between both parameters.

3.4 LOCATION AND ACCESSIBILITY OF THE STUDY AREA

The study area lies between Latitude 6˚ 4' 76''N and 6˚ 11' 94''N of the equator and Longitude 7˚ 58' 32''E and 8˚ 9' 99''E and covers an area of 442.57 sq. km. It overlaps two Local

Government Areas in Ebonyi state, Southeastern Nigeria, which are Ezza South and Ikwo LGA's with a population of 133,625 and 214,969 as at 2006 census. The location and accessibility map is shown in Fig. 3.8.

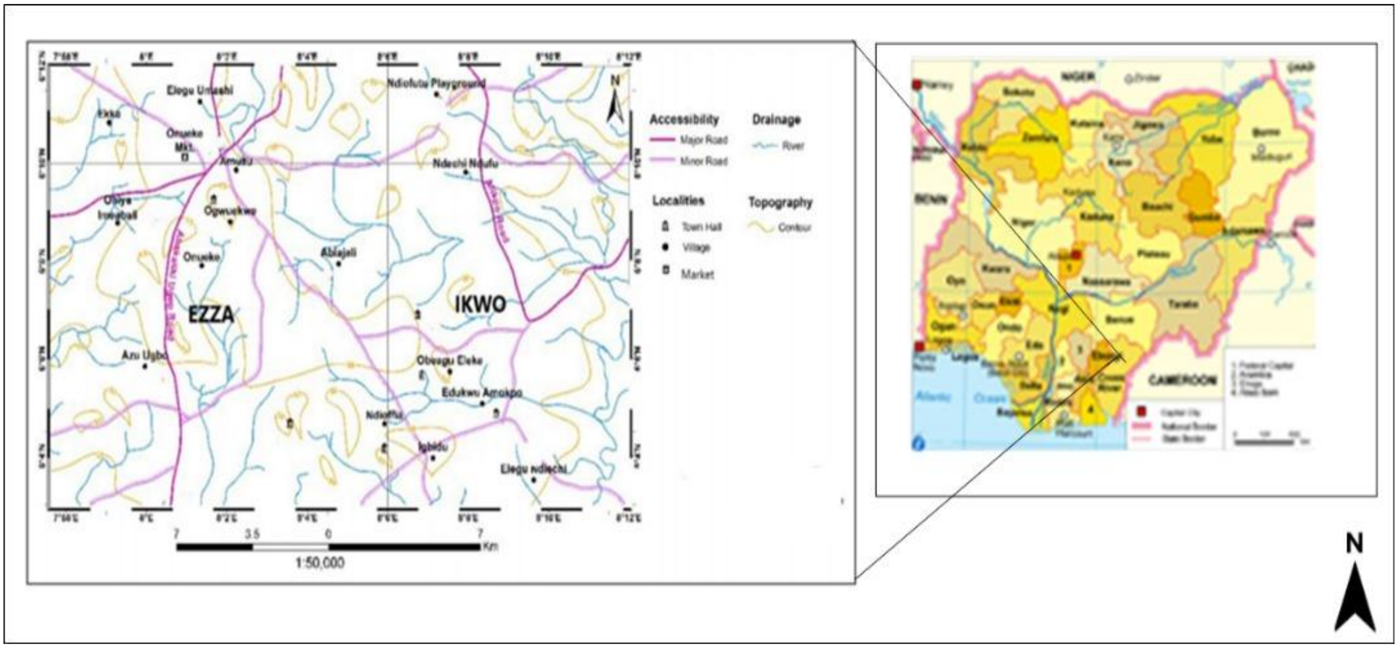

Figure 3.8: Accessibility and Drainage map of the study area

3.5 DRAINAGE, CLIMATE AND VEGETATION

The Ebonyi River is the major drainage system in the area. The average annual temperature range is between 25˚C and 31˚C while an average annual rainfall of about 1500mm to 2400mm is prevalent (Aroh et al 2006, Akintola, 1986,). The drainage map is shown above (Fig.3.8). The area is categorized by two distinctive climatic seasons, which are; the rainy season which generally starts on April and ends in October, while the dry season prevails between November and March. A period of extreme coldness and dryness called the harmathan dots the dry season from around the months of December to January (Iloeje, 1981).

The vegetation of the area is Parkland; this is characterized by stunted trees and pockets of derelict woodland and secondary forests consisting of few shrubs with dispersed large trees and climbers (Aghamelu et al, 2011)

3.6 GEOLOGY OF THE STUDY AREA

The study area is located in the lower Benue Trough of Nigeria which is part of the Benue depression as discussed by Wright (1968), Benkhelil (1967, 1987) and Reyment (1965). The basin began by the separation of the south Atlantic and the marine invasion into the trough in the Cretaceous times. This brought about sedimentation within the South Eastern Nigeria Sedimentary basins (Nwachukwu, 1972). Major transgressive and regressive cycles occasioned by epeirogenic movement controlled the sedimentary fill of the lower Benue basin (Short and Stauble, 1967 Murat, 1970). Cretaceous successions in the Basin include over 5000m of sediments ranging from Aptian /Albian to Maastrichtian (Ngwoke, 2013). The sediments consist of three unconformity confined sedimentary cycles extending from Albian- Cenomanian, Turonian – Coniacian to Campanian – Maastrichtian sedimentary cycles. The regional geologic map of the area is shown in Fig. 3.9.

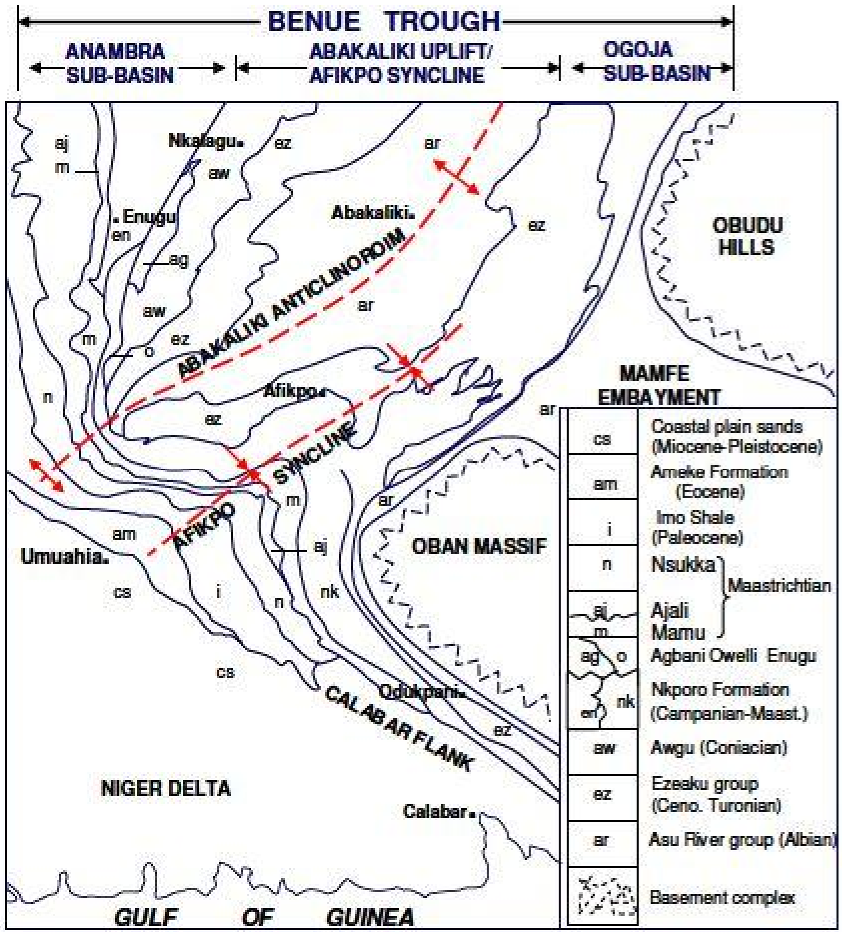

Figure 3.9: Regional Stratigraphic Map of Study Area (Modified after Akande et al 2011).

The oldest Aptian – Cenomanian successions are the Asu River Group consisting of arkosic sandstones, volcaniclastics, marine shales, siltstones and limestone which overlie the Pre-Cambrian to Lower Paleozoic crystalline basement rocks. The arkosic sediments were derived principally from the extensive weathering of the basement rocks which were invaded by alkaline basaltic rocks prior to the initial rapid marine flooding of the Middle Albian times. Because the Asu River Group sediments are dominated by shale, they are not good aquifers except in areas where they are weathered, fractured or at points of sandstone intercalations. The Albian – Cenomanian successions are overlain by the Eze-Aku and Awgu Formations (Turonian-Coniacian) consisting predominantly of marine shales, calcareous siltstones, limestone and marls which share similar aquifer characteristics as the Asu River Group. Orogenic and tectonic activities occurred in the Santonian times leading to compressional folding, faulting, uplift and magmatic intrusion of Pre-Santonian sediments of the first and second depositional cycle (Akande, et al 2011). Sagging of the lips of the trough led to the formation of the Anambra basin on one axis and the Afikpo syncline on the other axis both of which became major depocenters for Campanian – Maastrichtian sediments.

The uplifted part of the fold became known as the Abakaliki anticlinorium. The Campanian – Maastrichtian sediments are made up of the marine Nkporo / Enugu Formations (lateral equivalents) overlain by the deltaic successions of the Mamu Formation (Fig.3.9). The Nkporo / Enugu Formations consist of a sequence of bluish to dark grey shale and mudstone locally with sandy shales, thin sandstones and shaly limestone beds. The deltaic facies of Mamu Formation consist of sandstones, shales, siltstones and mudstones and interbedded coal seams which grade laterally into the overlying marginal marine sandstones of the Ajali and Nsukka Formations (Etuk et al, 2008). Marine incursions in the south western side of the Anambra Basin resulted in the deposition of the Paleocene to Eocene shales of the Imo Formation which succeeded the deltas of the Mamu Formation. The Imo Formation is overlain by the regressive sandstones succession of the Ameki Formation and the overlying sandstones, shales and lignite beds of the Oligocene / Miocene Ogwashi – Asaba Formation. The Anambra basin Formations of the lower Benue trough have proven better aquifer units than the Abakaliki Asu River Group sediments obviously as a result of the presence of more sandstone units' notable among which is the Ajali sandstone. The Ajali Sandstone unit has been studied extensively by various researchers and is without doubt the most prolific and extensive aquifer in the lower Benue trough.

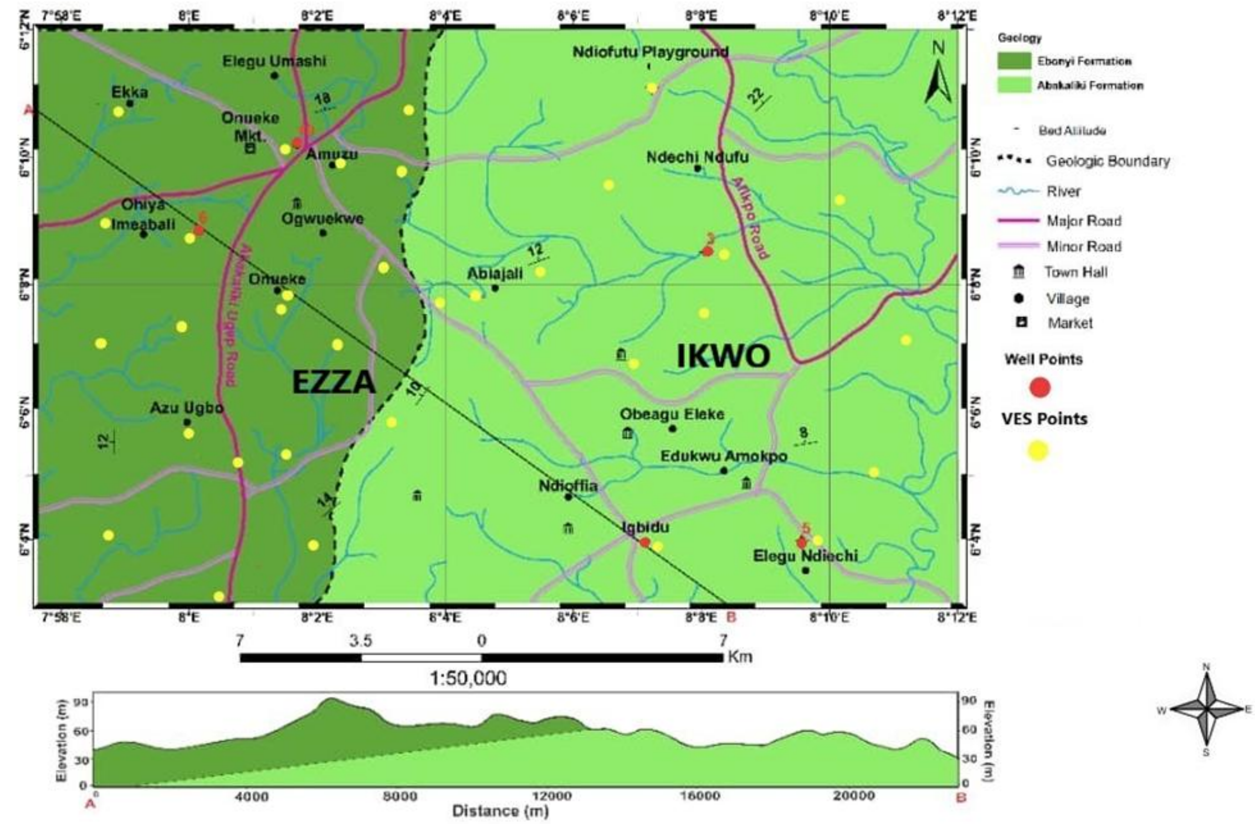

Figure 3.10: Local geologic map of the study area with VES and well locations.

Stratigraphically, the study area falls within the Abakaliki and Ebonyi Formations, which was described by Agumanu (1989) as sub-divisions of the Asu River Group in which the Ebonyi Formation overlies the Abakaliki Formation as shown in Fig. 3.10. It was previously referred to in the literature as “Unknown Formation’’ (Reyment, 1965).

It is now referred to as Ebonyi Formation (Agumanu, 1989). The age and lithology of the Formations are shown in Table 3.5. The western part of the study area falls under the Ebonyi Formation and consists of rapid alternations of sandstone, siltstone, shales, mudstones, oolitic and serpulid grainstones and packstone-wackestone (Agumanu, 1989). The Eastern part of the study area falls under the Abakaliki Formation, which is predominantly shales that are dark-grey to black and mudstones interbedded with black micritic limestone, siltstone, and minor feldspathic sandstones. This depicts an anoxic and reducing depositional environment which falls in line with the description made by Agumanu (1989) about the formation. Sandstones are found as minimal lithofacies or lenses.

Table 3.5: Stratigraphic sequence of the Formations in the study area (After Agumanu, 1989)

Age	**Formation**	**Characteristics**
Mid Albian	Ebonyi	Rapid alterations of sandstones, siltstone, shales, mudstones, oolitic and serpulid grainstones, and packstone-wackestone.
Late Albian – Cenomanian	Abakaliki	Kaolinitic and illitic black shales and mudstones interbedded with black micritic limestone, siltstone, and minor feldspathic sandstones.

3.7 HYDROGEOLOGY

The study area is mostly underlined by the shales of the Albian Asu River, the Ebonyi and Abakaliki Formation in particular. This is a difficult hydro-geological setting, as the dominant rock type (shale) is a poor aquifer. Generally, groundwater availability is limited to fractured or weathered zones of geological units. In most cases, these weathered / fractured zones are not interconnected on a large scale, resulting in groundwater in pockets making the regional groundwater flow in the area unworkable.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results from Pumping Test

The results of aquifer parameters acquired from the five wells are presented in Table 4.1. The pumping test data were analyzed and plotted using Copper-Jacob straight line curve with the aid of Aquiwin 32 software as shown in Fig. 4.1, 4.2, 4.3 and 4.4.

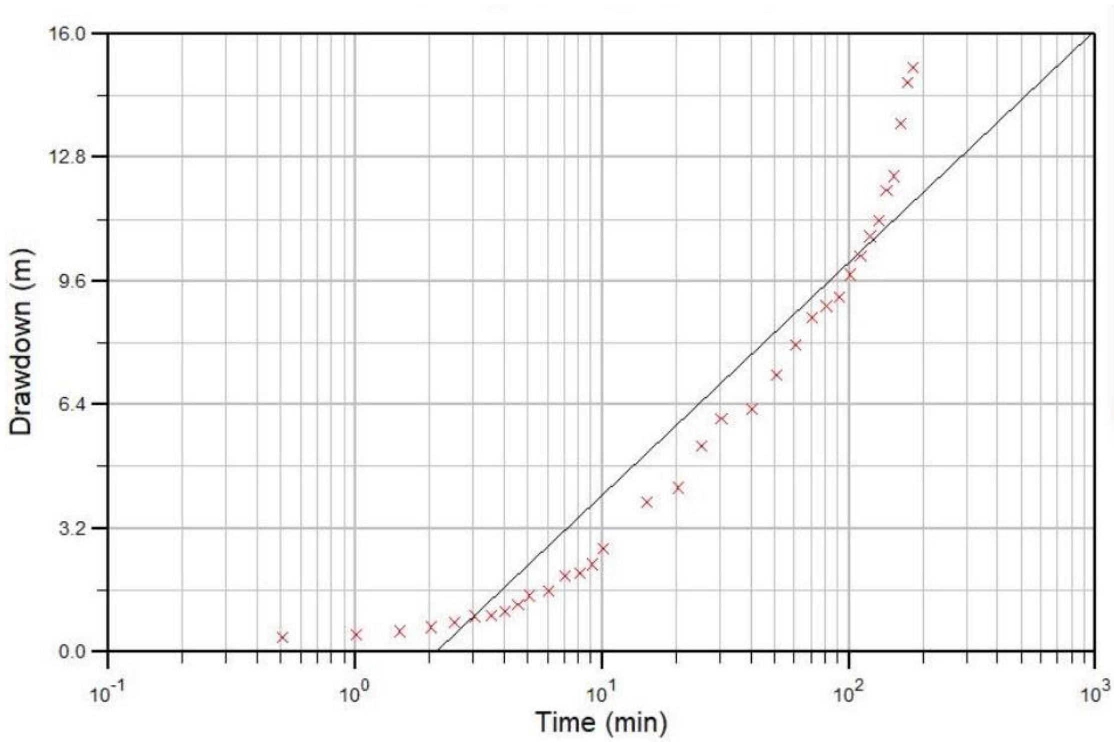

Figure 4.1: Jacob straight line on drawdown versus log (time) graph for Ekka Ezza

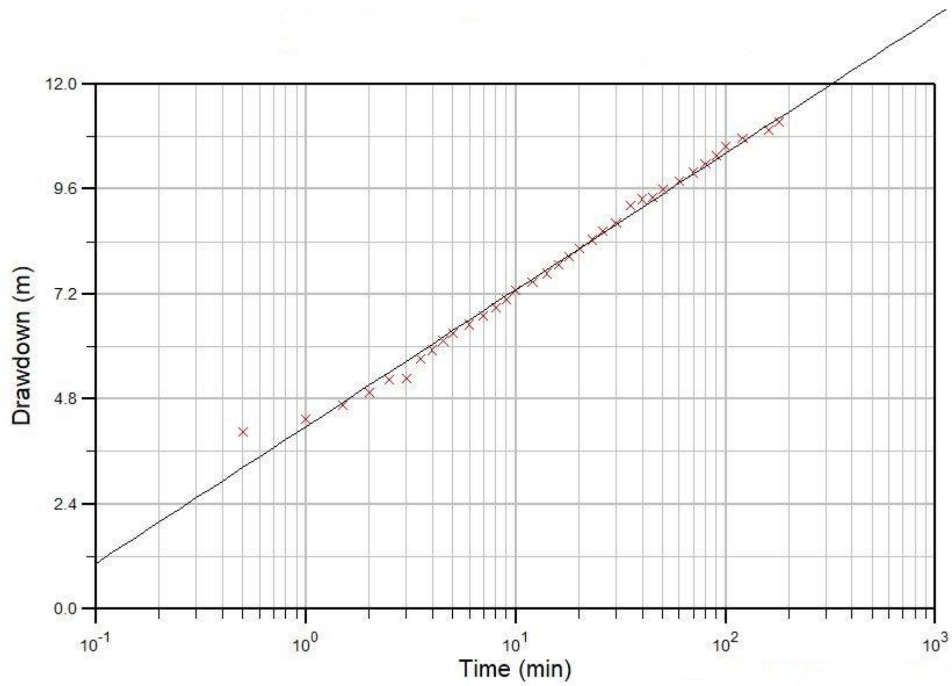

Figure 4.2: Jacob straight line on drawdown versus log (time) graph for Onueke market

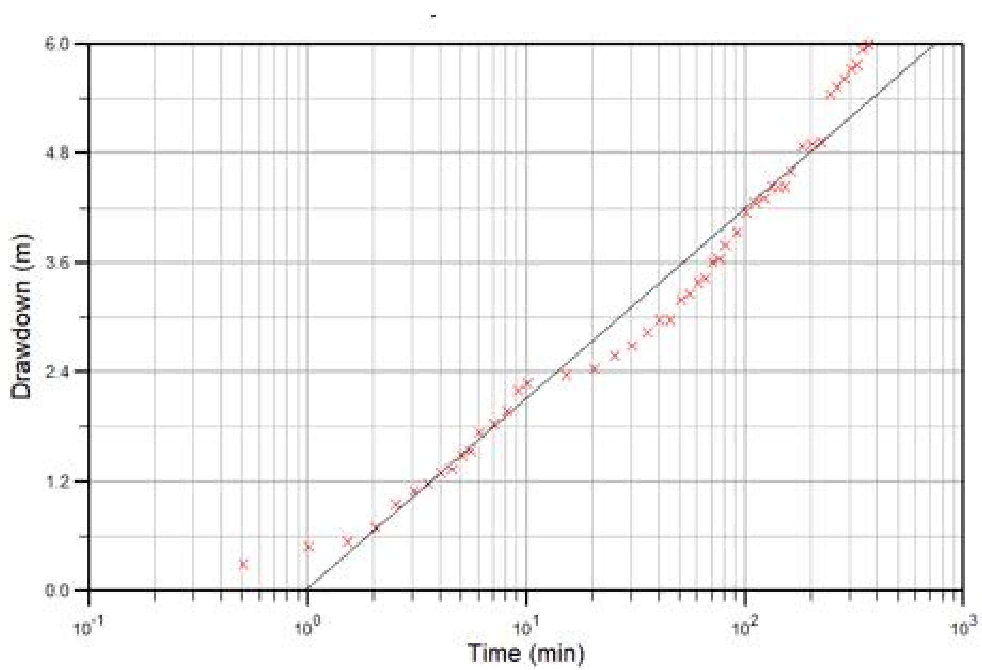

Figure 4.3: Jacob straight line on drawdown versus log (time) graph for Ndiechi Ndufu Achara

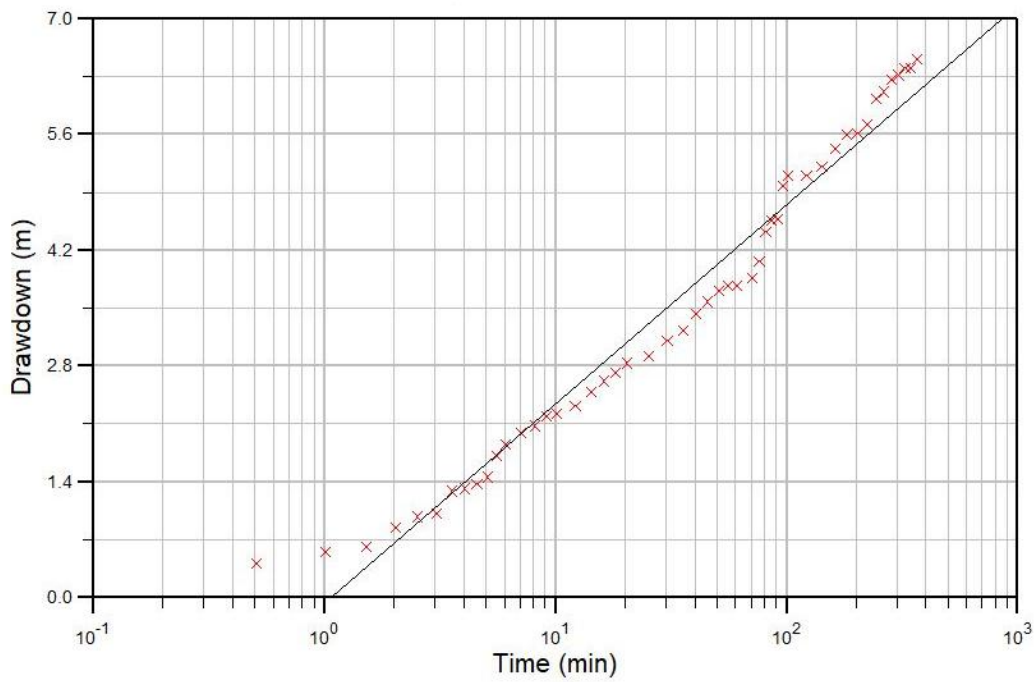

Figure 4.4: Jacob straight line on drawdown versus log (time) graph for Ishieke Ndufu Igbudu

Table 4.1: Summary of Aquifer hydraulic parameters from pumping test data

Well No	Location	Longitude	Latitude	Transmisivity (m^2/day)	Hydraulic conductivity (m/day)	Screen Lenth (m)	Discharge (m^3/day)	Drawdown per log cycle(m)	Specific Capacity (m^2/day)	Static Water Level (m)
1	EKKA (EZZA SOUTH LGA)	7°58'32.21"E	6°10'58.67"N	1.8659	0.2073	9	61.43	6.02	10.2	2
2	ONUEKE MARKET (EZZA SOUTH LGA)	8° 4'31.07"E	6° 7'31.36"N	4.1457	0.6909	6	70.85	3.12	22.71	1.88
3	NDECHI NDUFU ACHARA (IKWO LGA)	8° 8'4.84"E	6° 8'31.50"N	5.6585	0.6287	9	64.37	2.08	30.95	3
4	ISHIEKE, NDUFU IGBUDU (IKWO LGA)	8° 1'17.84"E	6° 2'54.55"N	5.3789	0.5976	9	70.85	2.41	29.39	2.42
5	ELEGU NDIECHI EKPO MAKA (IKWO	8° 9'34.99"E	6° 4'0.76"N	9.1713	1.019	9	114.05	2.28	50.02	2.06

4.2 Qualitative Results of VES

The summary of the results of the vertical electrical sounding data and locations of the sounding points are presented in Table 4.2 and Table 4.3 respectively.

The following curve types were observed QH, QHK, QHKH, QQH, KHK, QHAK and QQHK.

The most prevalent of the curve types are the QH. Which was followed by the QHK curve type which occurred four times, the type QHAK occurred twice and the QHKH, QQHK, HA, KHK, QH types occurred once. A summary of all curve types identified and their occurrences are presented in Table 4.4

Table 4.2: Thickness, Depth, Formations and Resistivity of Layers in Sounding Points

VES POIN	LAYER RESISTIVITY (Ohm̄1)							LAYER DEPTH (m)						LAYER THICKNESS (m)						GEOLOGIC FM.
	p1	p2	p3	p4	p5	p6	p7	d1	d2	d3	d4	d5	d6	t1	t2	t3	t4	t5	t6	
VES 1	662.2	196.9	102.3	84.6	744.3			0.69	11.99	22.92	34.28			0.69	11.3	10.93	11.36			EBONYI FM.
VES 2	915.2	825.5	275.6	850.4				2.9	12.5	20.6				2.9	9.6	8.1				EBONYI FM.
VES 3	780.4	428.8	219.6	944.5				11.4	33.1	42.3				11.4	21.7	9.20				EBONYI FM.
VES 4	830.0	58.1	16.75	50.0	5.4			1.45	1.70	19.7	28.2			1.45	0.25	18.0	8.50			EBONYI FM.
VES 5	300.0	60.0	22.5	130.0	11.4	20.8		1.80	4.14	22.99	31.39	49		1.80	2.34	18.85	8.40	17.6		EBONYI FM.
VES 6	440.0	286.0	36.5	12.0	45.5			2.55	3.70	13.7	220.7			2.55	1.15	10.00	207			EBONYI FM.
VES 7	870.0	60.9	24.5	84.0	116.0	6.6		1.40	1.67	21.83	25.5	30.6		1.40	0.27	20.16	3.67	5.07		EBONYI FM.
VES 8	720.0	360.0	57.0	107.5	65.0			2.00	13.6	44.85	53.75			2.00	11.60	31.25	8.9			EBONYI FM.
VES 9	825.0	330.0	68.0	106.0	65.0			1.90	13.3	56.5	12.3			1.90	11.40	43.20	64.80			EBONYI FM.
VES 10	320.0	48.0	3.85	58.0	24.0			1.90	10.64	11.54	35.77			1.90	8.74	0.9	24.23			EBONYI FM.
VES 11	280.0	560.0	40.0	273.0	210.0			1.75	3.76	22.76	35.26			1.75	2.01	19.0	12.5			EBONYI FM.
VES 12	2151.7	814.0	14.1	35.8				8.25	12.3	31.0				8.25	4.05	18.7				EBONYI FM.
VES 13	345.0	205.0	103.0	36.0	198.0	3125.0		0.5	1.2	4.0	12.0	18.0		0.50	0.7	2.8	8.0	6.0		EBONYI FM.
VES 14	45.0	26.0	25.0	98.0	458.0	4578.0		0.8	1.5	3.0	8.0	18.0		0.80	0.7	1.5	5.0	10.0		EBONYI FM.
VES 15	939.1	443.3	174.8	789.5				9.6	21.3	38.4				9.6	11..8	17.1				EBONYI FM.
VES 16	461.8	365.5	701.5	383.6				2.2	5.6	14.4				2.2	3.4	8.8				EBONYI FM.
VES 17	910.0	974.5	160.0	603.1				3.4	18.0	34.0				3.4	14.6	16.1				EBONYI FM.
VES 18	299.5	21	12.6	256				2.4	8.7	48.9				2.4	6.3	40.2				EBONYI FM.
VES 19	1232.6	1198.5	173.0	765.3				2.4	6.6	105.8				2.4	4.2	99.2				EBONYI FM.
VES 20	1300.0	195	38.0	240				1.8	5.0	77.0				1.8	3.2	72				EBONYI FM.
VES 21	2100.0	630	95.0	150				2.5	9.8	52.0				2.5	7.3	42.2				EBONYI FM.
VES 22	1500.0	105	230.0	3000				2.3	32.0	37.0				2.3	29.7	5				EBONYI FM.
VES 23	983.1	928.8	172.9	1329.3				8.3	17.3	33.2				8.3	9.0	15.9				ABAKALIKI FM.
VES 24	910.0	974.5	160.0	603.1				3.4	18.0	34.0				3.4	14.6	16.1				ABAKALIKI FM.
VES 25	921.1	835	319	839.1				2.9	15.5	31.1				2.9	12.7	15.60				ABAKALIKI FM.
VES 26	2205.0	150	29.1	200	14.3			0.76	6.6	23.0	82.8			0.76	5.84	16.4	59.8			ABAKALIKI FM.
VES 27	733.0	340	32.1	46.9	458			1.8	5.03	22.1	46			1.8	3.23	17.1	23.8			ABAKALIKI FM.
VES 28	84.1	459	17.4	24.5	12.8			0.75	2.15	6.18	17.7			0.75	1.4	4.03	11.6			ABAKALIKI FM.
VES 29	293.0	105	330.0	26.6	279			0.924	2.81	15.8	59.4			0.924	1.88	13	43.7			ABAKALIKI FM.
VES 30	11.5	72.9	51.6	11.7	44.7			1.13	2.76	5.43	40.1			1.13	1.63	2.67	34.6			ABAKALIKI FM.
VES 31	158.1	12.9	4.4	25.2	14.8	127	604	2.18	2.21	6.0	17.67	50	115.4	2.18	0.03	3.81	11.65	32.33	65.40	ABAKALIKI FM.
VES 32	190	184	312	17.7	112	348		1.58	3.16	7.47	25.5	68.5		1.58	1.58	4.31	18.03	43.00		ABAKALIKI FM.
VES 33	129	57.1	831	23.2	141	17.9		1.58	1.83	5.64	51.6	98.4		1.58	0.25	3.81	45.96	46.80		ABAKALIKI FM.
VES 34	749.9	2533	86.24	330	94.1	1448	2617	0.75	2.15	6.055	17.78	51	167.1	0.75	1.40	3.91	11.73	33.20	116.12	ABAKALIKI FM.
VES 35	23.1	270	13.9	20.7	15.4	50		0.75	2.58	14.6	59.4	113		0.75	1.83	12.02	44.80	53.60		ABAKALIKI FM.

Table 4.3: VES locations with coordinates

S/NO	VES POINT	LOCATION	LONGITUDE	LATITUDE
1	VES 1	EKKA (EZZA SOUTH LGA)	7°58'32.21"E	6°10'58.67"N
2	VES 2	ONUEKE MARKET (EZZA SOUTH LGA)	8°01'45.10"E	6°10' 13.13"N
3	VES 3	ABIAJI VILLAGE SQUARE ,NGANGB0-OGELE (EZZA SOUTH LGA)	8° 4'31.07"E	6° 7'31.36"N
4	VES 4	AMUZU PRIMARY SCHOOL (EZZA SOUTH)	8° 4'19.59"E	6°12'20.64"N
5	VES 5	NDIUHU AMANA (EZZA SOUTH)	8° 5'44.10"E	6° 8'19.93"N
6	VES 6	NGANBO NDIAGU AMAGU (EZZA SOUTH)	8° 2'27.72"E	6° 5'51.29"N
7	VES 7	NGANBO AGU	8° 1'11.86"E	6° 7'58.73"N
8	VES 8	SACRED HEART CATHOLIC CHURCH ONUEKE (EZZA SOUTH)	8° 1'18.34"E	6° 7'54.51"N
9	VES 9	NDUFU IDEMBIA COMMUNITY HALL	7°58'11.20"E	6° 7'42.75"N
10	VES 10	NGANBO OHAINYA EZZAMA (EZZA SOUTH)	7°58'37.08"E	6° 9'2.18"N
11	VES 11	NGANBO AMAEZEKWE (EZZA SOUTH)	8° 4'24.74"E	6° 7'34.57"N
12	VES 12	EZEUGWU OKOFIA (EZZA SOUTH)	8° 0'37.27"E	6° 5'40.06"N
13	VES 13	ORIEGU- MARKERT SQUARE 1	7°58'6.48"E	6° 7'1.63"N
14	VES 14	ORIEGU- MARKERT SQUARE 2	7°58'11.45"E	6° 6'59.67"N
15	VES 15	AZU UGBO VILLAGE SQUARE(EZZA SOUTH LGA)	8° 0'14.57"E	6° 5'20.43"N
16	VES 16	OHIYA, IMEABALI	8° 00'06.85"E	6° 08'54.33"N
17	VES 17	ISHIEKE, NDUFU IGBUDU	8° 1'17.84"E	6° 2'54.55"N
18	VES 18	OGWUEKWE VILLAGE HALL	8° 1'43.34"E	6° 9'16.93"N
19	VES 19	OUR LADY FATIMA CATHOLIC CHURCH	7°58'55.33"E	6° 9'19.40"N
20	VES 20	OCHUFUAGBA COMMUNITY PRIMARY SCHOOL	7°59'13.05"E	6° 7'23.66"N
21	VES 21	COMMUNITY PRIMARY SCHOOL UGWUOGO	7°57'48.36"E	6° 7'0.94"N
22	VES 22	AMUZU TOWN HALL	8° 1'19.89"E	6°10'5.03"N
23	VES 23	NDECHI NDUFU ACHARA	8° 8'4.84"E	6° 8'31.50"N
24	VES 24	ISHIEKE, NDUFU IGBUDU	8° 1'17.84"E	6° 2'54.55"N
25	VES 25	ELEGU NDIECHI EKPO MAKA	8° 9'34.99"E	6° 4'0.76"N
26	VES 26	ELEGU ETTEM	8°10'51.80"E	6° 5'50.93"N
27	VES 27	EKPELU	6° 2'52.88"N	8° 8'11.30"E
28	VES 28	NDIOFEKE	6° 9'12.20"N	8°10'7.62"E
29	VES 29	ENYACHARIGNE (NDIAGU AMAGU)	6° 7'11.88"N	8° 7'59.73"E
30	VES 30	NDIAGU AMAGU PRIMARY SCHOOL ENYIBIVHIRI 1	6° 4'30.02"N	8° 5'19.26"E
31	VES 31	EKE ETTAM MARKET SQUARE	6° 8'51.77"N	8° 7'19.04"E
32	VES 32	AMAINYIMA	6°10'14.64"N	8° 8'39.24"E
33	VES 33	NDIAGU AMAGU PRIMARY SCHOOL ENYIBIVHIRI 11	6° 4'30.02"N	8° 5'19.26"E
34	VES 34	NDUFU INYIAMAGU OBEAGU PLAYGROUND (1)	6° 4'36.96"N	8° 3'15.95"E
35	VES 35	NDUFU INYIAMAGU OBEAGU PLAYGROUND (11)	6° 4'39.96"N	8° 3'30.85"E

Table 4.4: Frequency Distribution of Curve Types in Study Area.

Frequency Distribution of Curve Types in the Study Area		
CURVE TYPE	FREQUENCY	PERCENTAGE %
QH	13	37
QHK	8	23
QHKH	1	3
QQH	2	6
KHK	2	6
QHAK	2	6
QQHK	1	3
HA	1	3
HK	3	9
KH	1	3
HKA	1	3

The signatures of some of the curve types are presented in Fig. 4.5 to 4.9.

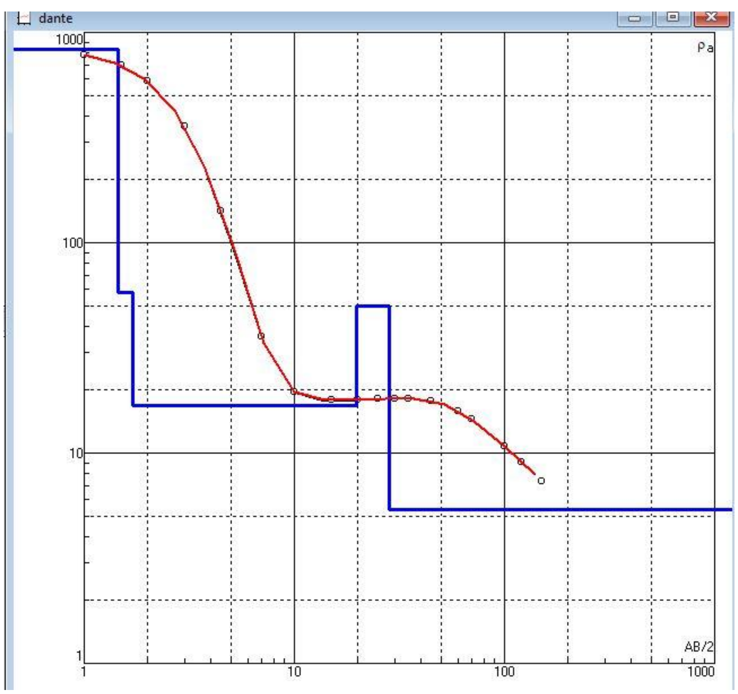

Figure 4.5: VES curve of Amuzu Primary School

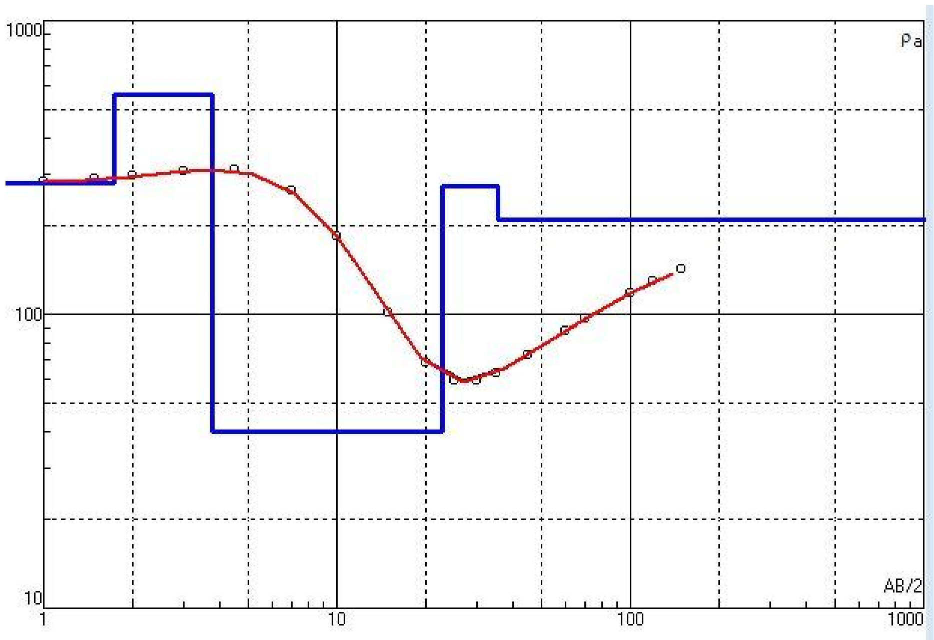

Figure 4.6: VES curve of Amaezekwe

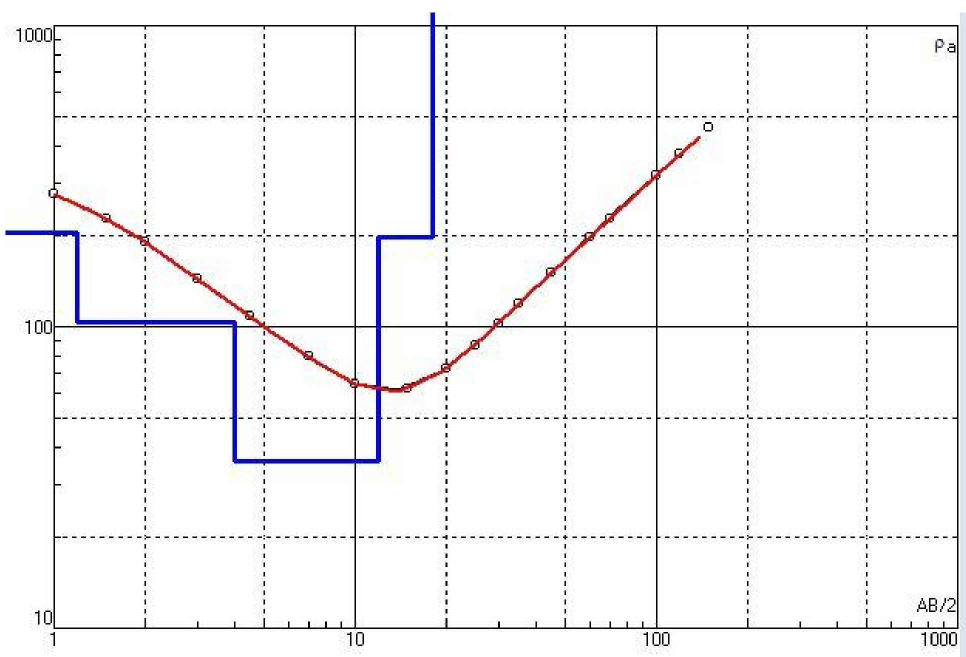

Figure 4.7: VES curve of Oriegu Market Square 1

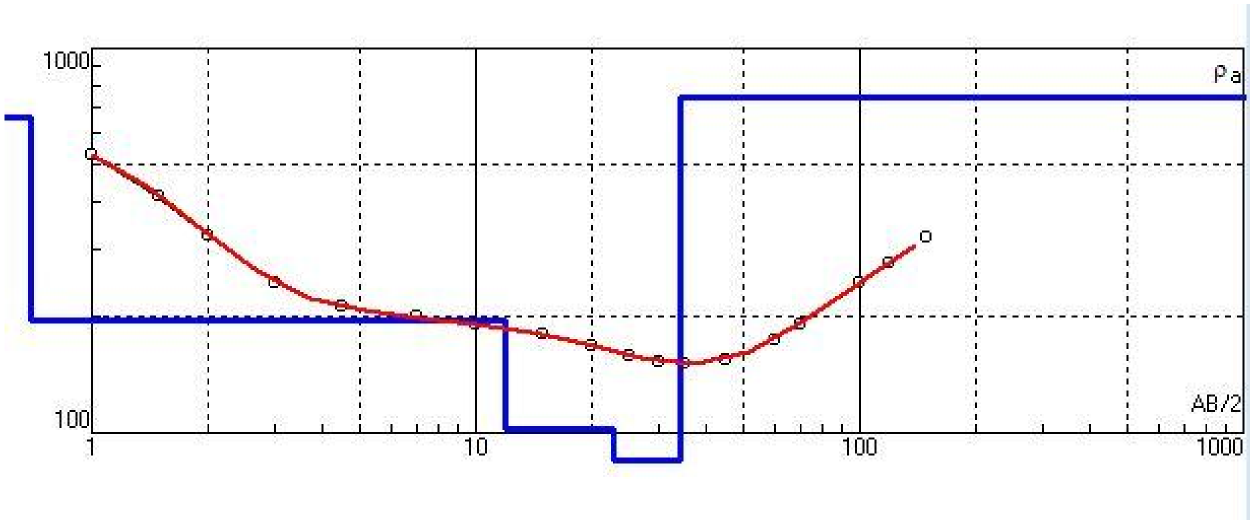

Figure 4.8: VES curve of Ekka

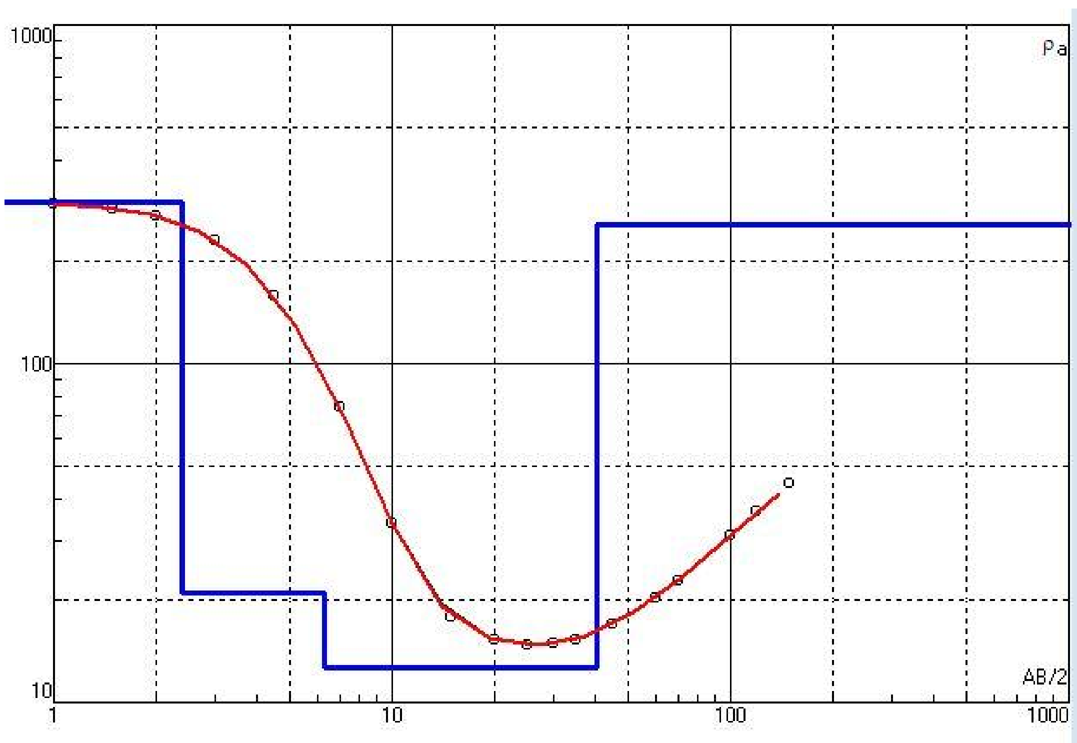

Figure 4.9: VES curve of Ogwuekwe Town Hall

According to (Ngwoke 2016), the occurrence of several curve types show the non-uniformity of resistivity trends across a study area and the non-uniformity of layering and alteration of layer properties as a result of weathering, fracturing and other geologic processes across study locations are factors that can cause variations in resistivity trends across the study area. The predominant curve type is the QH curve type constituting about 37%; QHK 23%; HK 9%; QQH, KHK, QHAK accounts for 6%, while QQHK, KH, HA, and QHK each are represented by 5%.

Four, five, six and seven layer models were identified from the interpreted data from all the sounding locations. The four- and five-layer model were the most prevalent, occurring 13 times; it was trailed by the six-layer model which occurred 7 times and the seven-layer model which occurred twice as shown in Table 4.5.

Table 4.5: Frequency and percentage distribution of different layer models in sounding locations.

Frequency and Percentage Distribution of Different Layers in Sounding			
LOCATION	NO OF LAYERS	LAYER FREQUENCY	PERCENTAGE %
2,3,12,15,16,17,18,19,20,21,22,24,25	4	13	37
1,4,6,8,9,10,11,23,26,27,28,29,30	5	13	37
5,7,13,14,32,33,35	6	7	20
31,34	7	2	6

4.3 Quantitative results of VES

The aquifer horizons present in the area are namely; upper and lower horizons. The upper horizon aquifers are detected between the depths ranges of 1m to 15m (Example VES 6 and VES 12). This aquifer type occurred only in a few number of the sounding points.

This shallow aquifer is predominantly the thick lateritic/ lateritic-shaly- clay layer tapped by hand dug wells that characterize the area. The aquifer has a greater propensity to dry up during the dry season. The lower horizon aquifers were observed at depth greater than 15m (examples of such are VES 2,3,14 and 15). This aquifer is tapped by boreholes in the area and represents a region of weathered/fractured shale with limestone intercalations.

4.4 Iso-Resistivity of the Study Area

Since the effective transmission depth of about 2/3 of half of the current electrode separation (AB/2), well-established assumptions were taken; resistivity depth slices in the study region were used to produce iso-resistivity values (Table 4.6). Several maps with iso resistivity variations at specified AB/2 intervals, from 5 m, 20 m, 80 m, and 150 m, as shown in Fig. 4.10, 4.11, 4.12 and 4.13 respectively, have therefore been made. The resistivity with depth seems to decrease relatively gradually, indicating a strongly resistive overburden and the upper layer, to lower resistive layers at deeper intervals. It should be noted, however, that an iso-resistivity map is a qualitative analysis tool that shows possible variations in resistivity with depth at the given electrode spacing across a region but does not give the true resistivity of a certain geo-electrical layer or unit (Mbonu et al., 1991).

Table 4.7: Iso-resistivity modeling of resistivity across the study area.

VES NO.	LONGITUDE	LATITUDE	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
VES 1	7°58'32.21"E	6°10'58.67"N	72	50	40	45	60	65	73	85	90
VES 2	8°01'45.10"E	6°10' 13.13"N	900	880	820	800	700	500	530	560	610
VES 3	8° 4'31.07"E	6° 7'31.36"N	800	780	770	700	650	450	460	500	550
VES 4	8° 4'19.59"E	6°12'20.64"N	100	28	19	17	18	16	13	12	11
VES 5	8° 5'44.10"E	6° 8'19.93"N	110	51	40	29	26	30	15	12	14
VES 6	8° 2'27.72"E	6° 5'51.29"N	300	160	110	50	30	15	12	14	15
VES 7	8° 1'11.86"E	6° 7'58.73"N	100	32	28	26	25	26	22	18	15
VES 8	8° 1'18.34"E	6° 7'54.51"N	500	400	380	310	250	90	80	82	83
VES 9	7°58'11.20"E	6° 7'42.75"N	500	380	350	280	250	100	80	76	80
VES 10	7°58'37.08"E	6° 9'2.18"N	130	70	58	43	40	38	32	33	35
VES 11	8° 4'24.74"E	6° 7'34.57"N	300	210	180	120	68	70	100	120	140
VES 12	8° 0'37.27"E	6° 5'40.06"N	2100	2000	1800	1300	900	50	26	28	30
VES 13	7°58'6.48"E	6° 7'1.63"N	40	50	60	80	120	250	480	500	700
VES 14	7°58'11.45"E	6° 6'59.67"N	40	58	62	70	120	250	400	500	700
VES 15	8° 0'14.57"E	6° 5'20.43"N	950	900	870	830	670	390	400	450	500
VES 16	8° 00'06.85"E	6° 08'54.33"N	450	430	460	480	500	440	420	400	380
VES 17	8° 1'17.84"E	6° 2'54.55"N	900	910	910	890	830	450	390	400	450
VES 18	8° 1'43.34"E	6° 9'16.93"N	140	50	35	18	15	18	23	32	40
VES 19	7°58'55.33"E	6° 9'19.40"N	5600	2300	1500	700	300	180	190	200	220
VES 20	7°59'13.05"E	6° 7'23.66"N	410	150	130	60	48	42	46	50	60
VES 21	7°57'48.36"E	6° 7'0.94"N	1500	800	710	480	320	130	140	140	150
VES 22	8° 1'19.89"E	6°10'5.03"N	610	260	180	130	120	170	130	200	400
VES 23	8° 8'4.84"E	6° 8'31.50"N	1000	980	970	900	850	500	500	600	700
VES 24	8° 1'17.84"E	6° 2'54.55"N	900	910	910	890	830	450	390	400	450
VES 25	8° 9'34.99"E	6° 4'0.76"N	950	900	880	800	680	400	420	450	500
VES 26	8°10'51.80"E	6° 5'50.93"N	170	130	110	70	52	60	70	80	70
VES 27	6° 2'52.88"N	8° 8'11.30"E	400	240	180	72	49	50	70	80	140
VES 28	6° 9'12.20"N	8°10'7.62"E	170	110	70	40	30	20	22	30	60
VES 29	6° 7'11.88"N	8° 7'59.73"E	180	200	210	230	220	100	60	58	100
VES 30	6° 4'30.02"N	8° 5'19.26"E	28	32	30	28	23	17	19	22	40
VES 31	6° 8'51.77"N	8° 7'19.04"E	52	20	40	12	14	18	22	25	50
VES 32	6°10'14.64"N	8° 8'39.24"E	210	200	190	150	100	40	50	60	100
VES 33	6° 4'30.02"N	8° 5'19.26"E	120	270	280	250	210	48	39	40	45
VES 34	6° 4'36.96"N	8° 3'15.95"E	900	580	380	230	200	190	180	190	300
VES 35	6° 4'39.96"N	8° 3'30.85"E	800	790	770	48	30	18	19	20	25

4.4.1 Iso-resistivity Map (AB/2 = 5 m)

The Iso-resistivity map for AB/2= 5 m in Fig. 4.10 shows that most parts of the study region have relatively low resistivity, except for some sections in the north-west and south-western regions, particularly in the north, east or central areas. These low resistive areas with magenta and deep blue color codes in Fig 4.10 have resistivity values ranging between 0- 1200Ωm. The Iso-resistivity model of the study area at this half current electrode spacing with an effective depth of penetration of 3.33 m (10.87 ft) generally revealed that across the study area, the resistivity values increased from about 200Ωm (magenta) to 5,400Ωm (red). The resistivity values range from 0-1200Ωm for these low-resistive areas with magenta and blue color codes in Fig. 18 On this half-current electrode intersection with an efficient penetration depth of 3.33 m (10.87 ft), the Iso-resistivity model of the study area shows that the resistivity values increased across the study area from about 200Ωm (magenta) to 5.400Ωm (red). A range of resistivities may indicate silt/shale/clay units with the magenta and blue color indicators, while the other colours of the map may reflect areas underlain by sand/sandstone/siltstone.

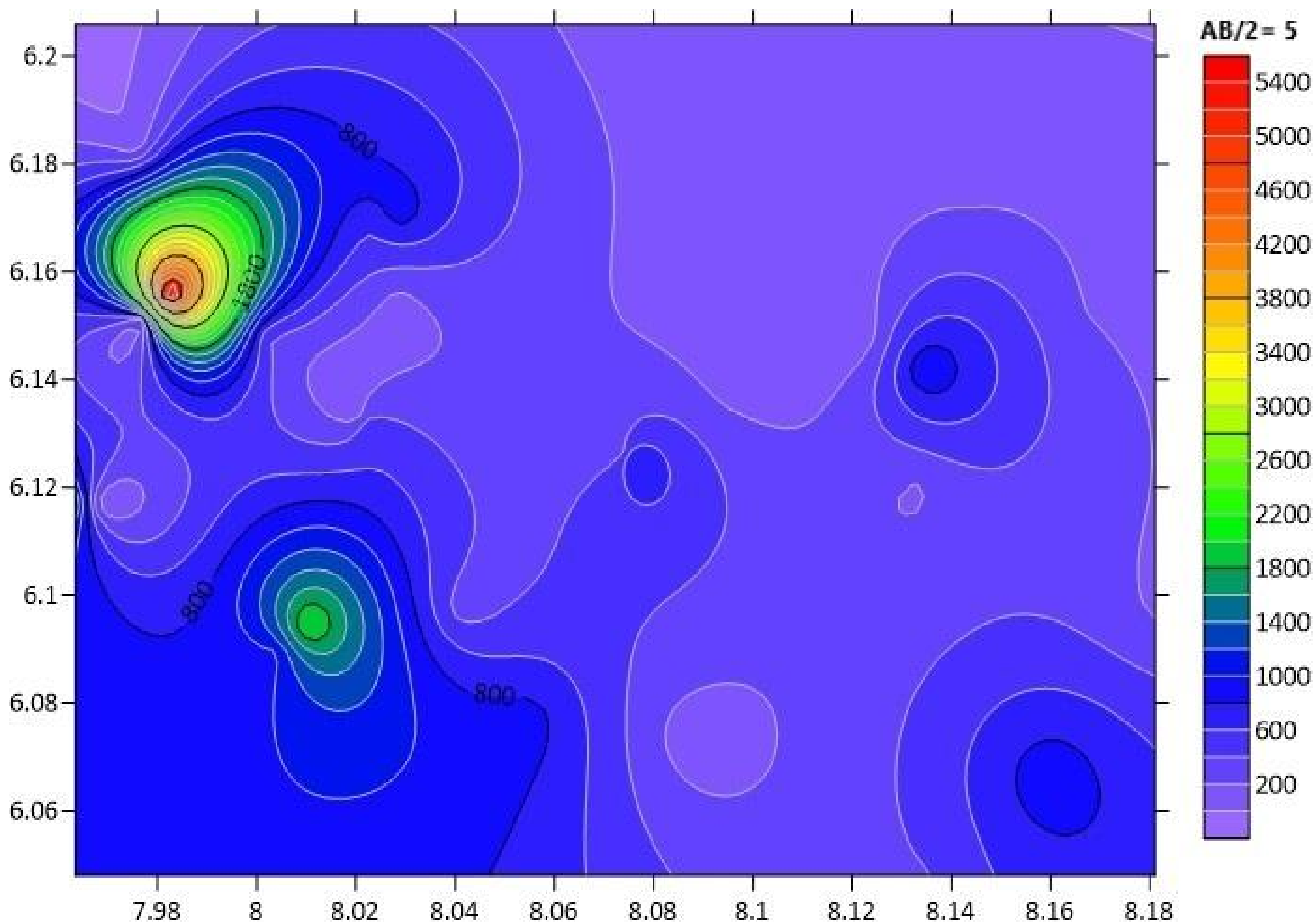

Figure 4.10: Iso resistivity contour map of AB/2 = 5

4.4.2 Iso-resistivity map (AB/2 = 20 m)

The AB/2 contour map of iso-resistivity strength = 20 m in Fig. 4.11 below shows that relatively low resistive materials underlay parts of the study area within the northern, eastern, and southwest axes. The study area's resistivity at this distance with a sufficient penetration depth of 13.33 m indicates that the sound points' resistivity rises from > 0 (magenta) to approximately 900Ωm (red). In the south, eastern, central, and northwestern parts of the study area, low/medium resistivity values between 0 – 150Ωm (in magenta and blue) were observed. The highly resistive areas with values between 500 and 900Ωm were found to be limited to the southwestern and north-east parts of the study area while the green-coloured areas had medium resistivity values between 180 to 350Ωm. The range of resistivities shown by the magenta and blue colours may be an indication of silt/ shale/clay units while the other colors in the map may represent areas underlain by fractured shale or consolidated shale and alternation of shale and sandstone.

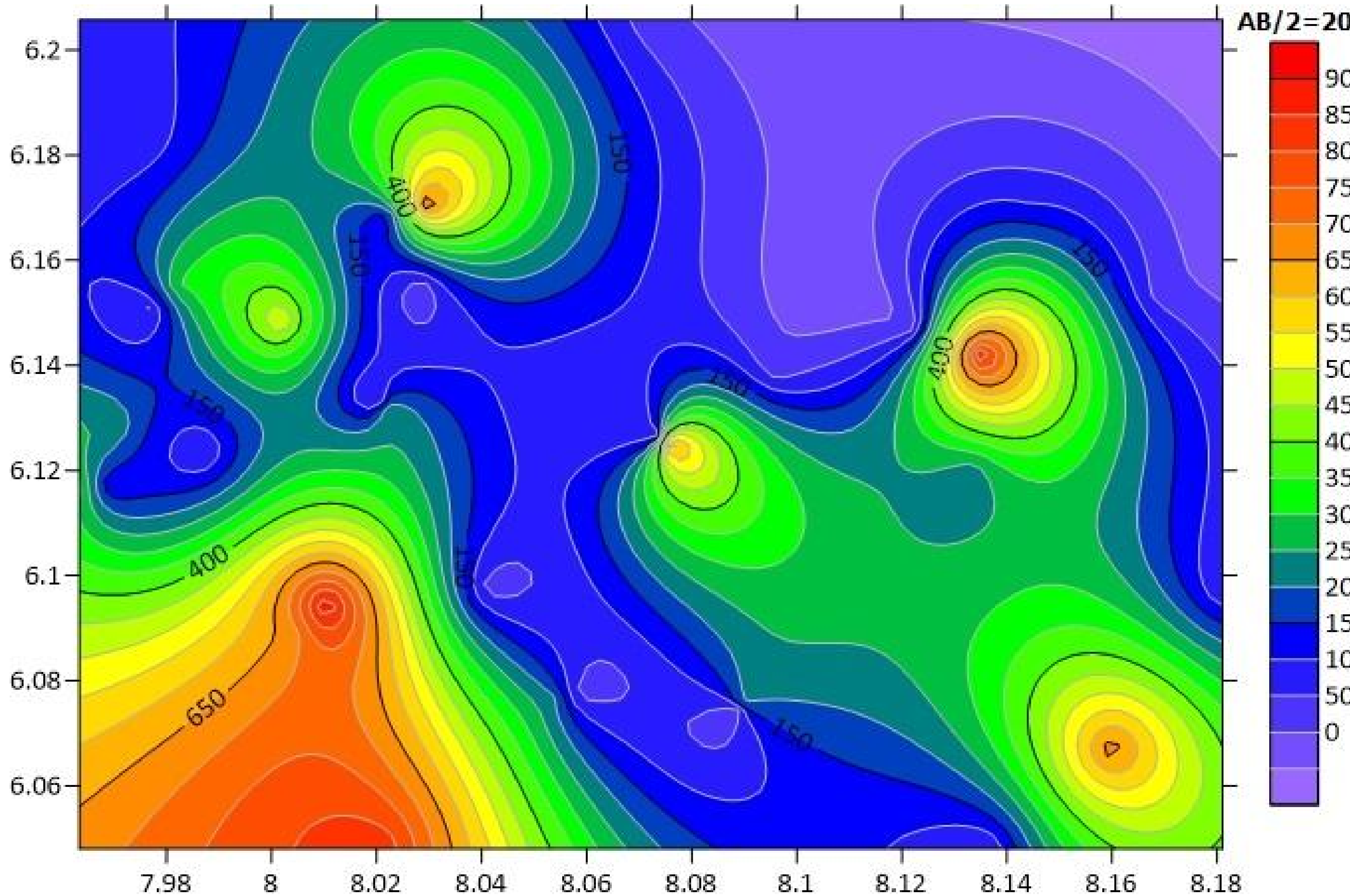

Figure 4.11: Iso resistivity contour map of AB/2 = 20

4.4.3 Iso-resistivity Map (AB/2 = 80 m)

The map of iso-resistivity for AB/2= 80 m in Fig. 4.12 indicates that relatively small resistive materials underlay most of the study area. The resistivity of the study area at this spacing revealed that the sound points of the resistivity values range from 0 to 520Ωm. At this depth range, the study area became shaly as more than 70% of the study area was covered by low to medium resistivities (areas covered by magenta and blue colors) ranging from 0-120Ωm, while very high resistivity values were restricted to the southwestern, northeastern and northwestern portion of the study area. In general, the range of resistivities shown by the magenta and blue colors may be an indication of silt/ shale/clay units while the other colors in the map may generally represent areas underlain by fractured shale or consolidated shale and alternation of shale and sandstone.

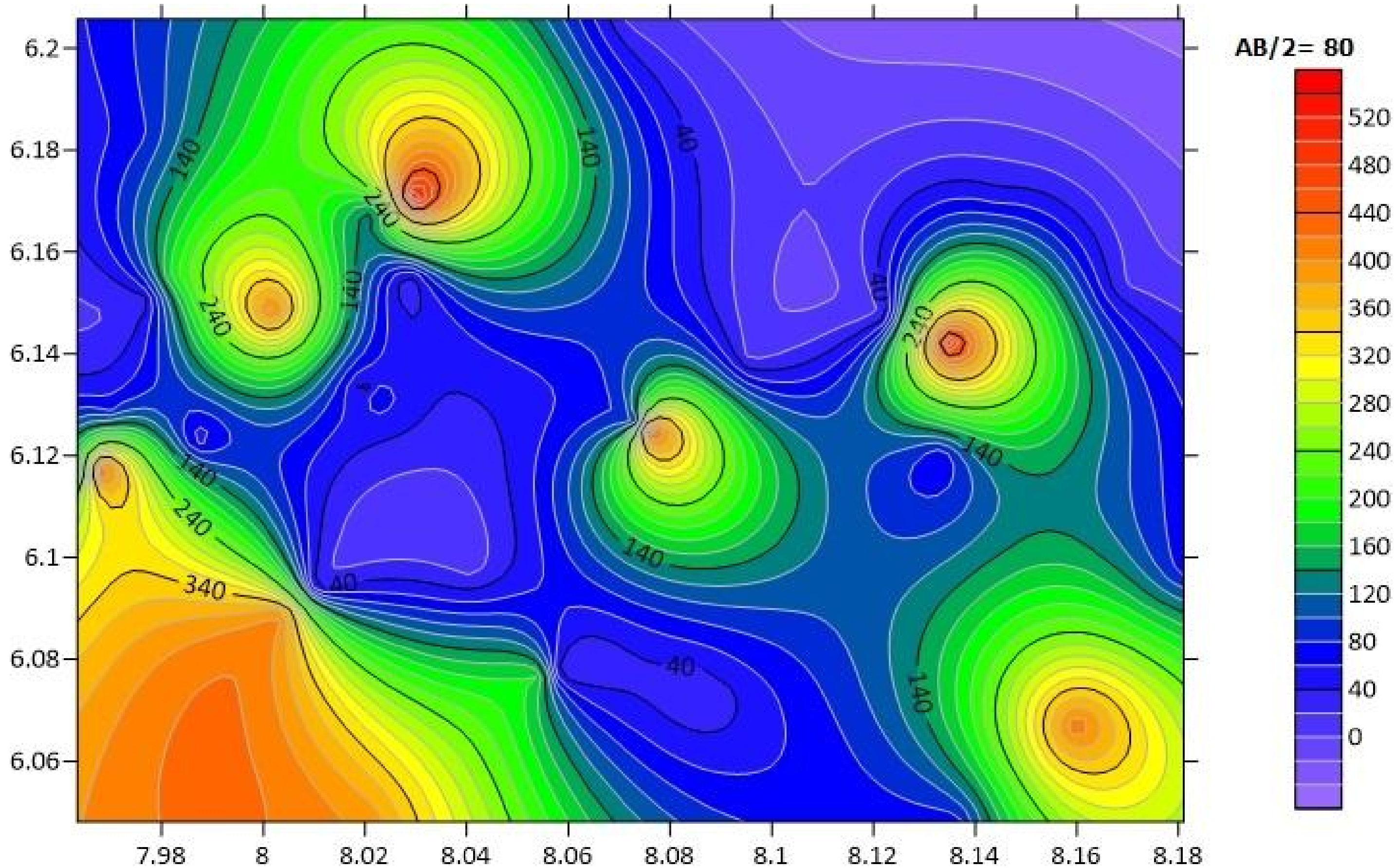

Figure 4.12: Iso resistivity contour map of AB/2 = 80

4.4.4 Iso-resistivity Map (AB/2 = 150 m)

The AB/2= 150 m iso-resistivity map in Fig. 4.13 showed that most parts of the study region in the northern, eastern, western, and southeastern axes are underlined by relatively low resistive materials. The study area's resistivity at this spacing with effective penetration depth given as 100 m (326 ft) revealed that the degree of shaliness increased throughout the region as the areas covered by magenta and blue colors (representing low-medium resistivity) increased. The magenta and blue coloured areas have resistivity values ranging between 0-200Ωm. High resistivities ranging from 250 to 700 Ωm are found mostly within the study area's southwestern axis, with pockets of it located in the northwestern and northeastern portions. Generally, the range of resistivities displayed by the magenta and blue color may be an indicator of silt/limestone/shale/clay units while the other colors on the map may generally reflect underlying areas of fractured shale or consolidated shale and shale and sandstone alternation.

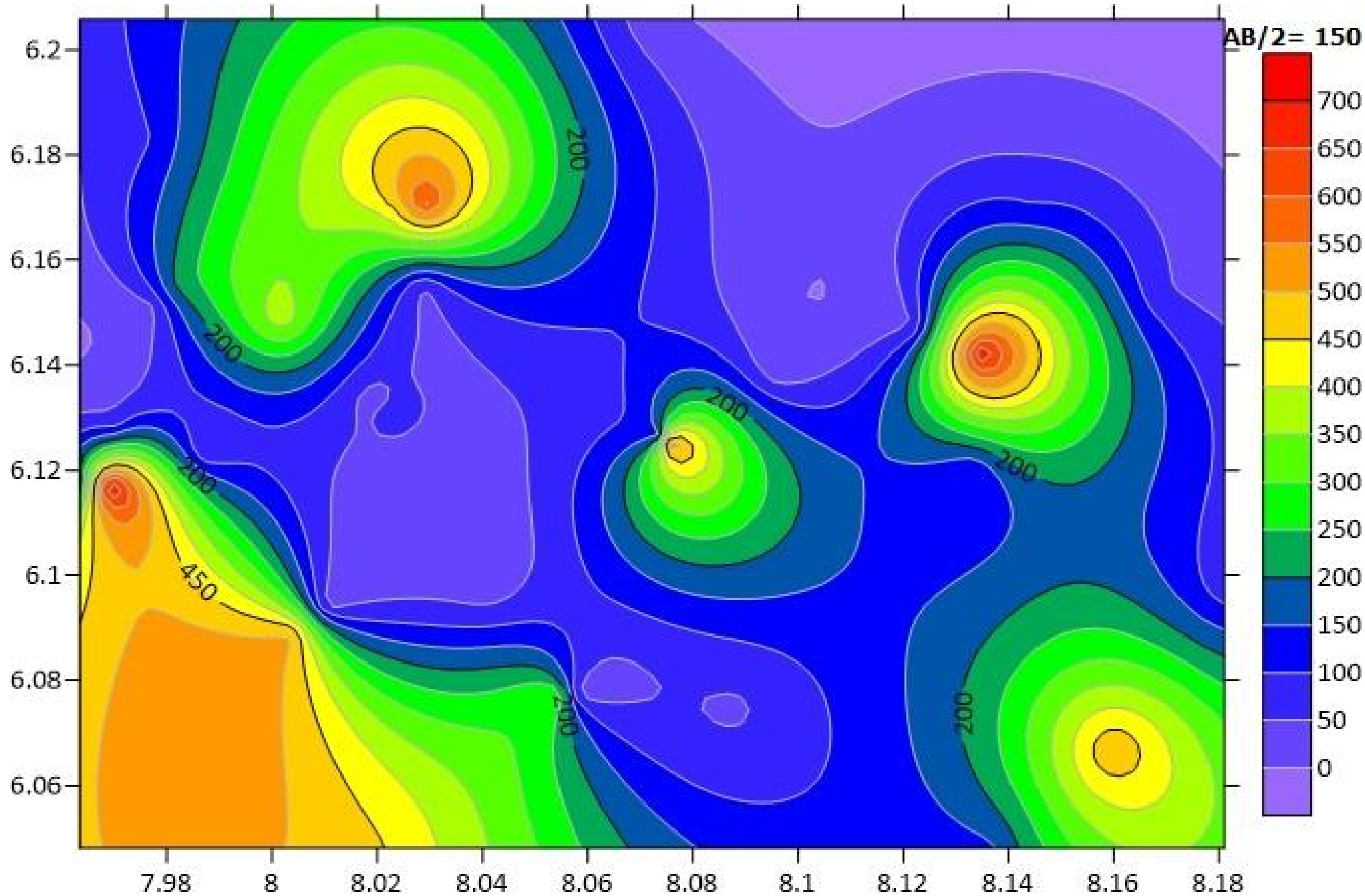

Figure 4.13: Iso resistivity contour map of AB/2 = 150

4.5 Aquifer Geometric Properties

4.5.1 Resistivity of Aquiferous Layer

The resistivity map of the study area is shown in Fig. 4.14. The aquifer resistivity was evaluated from the VES curves and ranges from 11.7 Ωm at Enyibivhiri (VES 30) to 814 Ωm at Ezeugwu Okoffia (VES 12) with a mean value of 141.7Ωm. From the map in Fig.4.14 the western part of the study area which is mostly underlain by the Ebonyi Formation seems to have higher resistivity values when compared to the eastern part of the study area which is underlain by the Abakaliki Formation. This might be due to the fact that the Ebonyi Formation according to Agumanu (1989) have alternations of sandstones making it have more resistivity when compared to the Abakaliki Formation which are predominantly shales that have lower resistivity values.

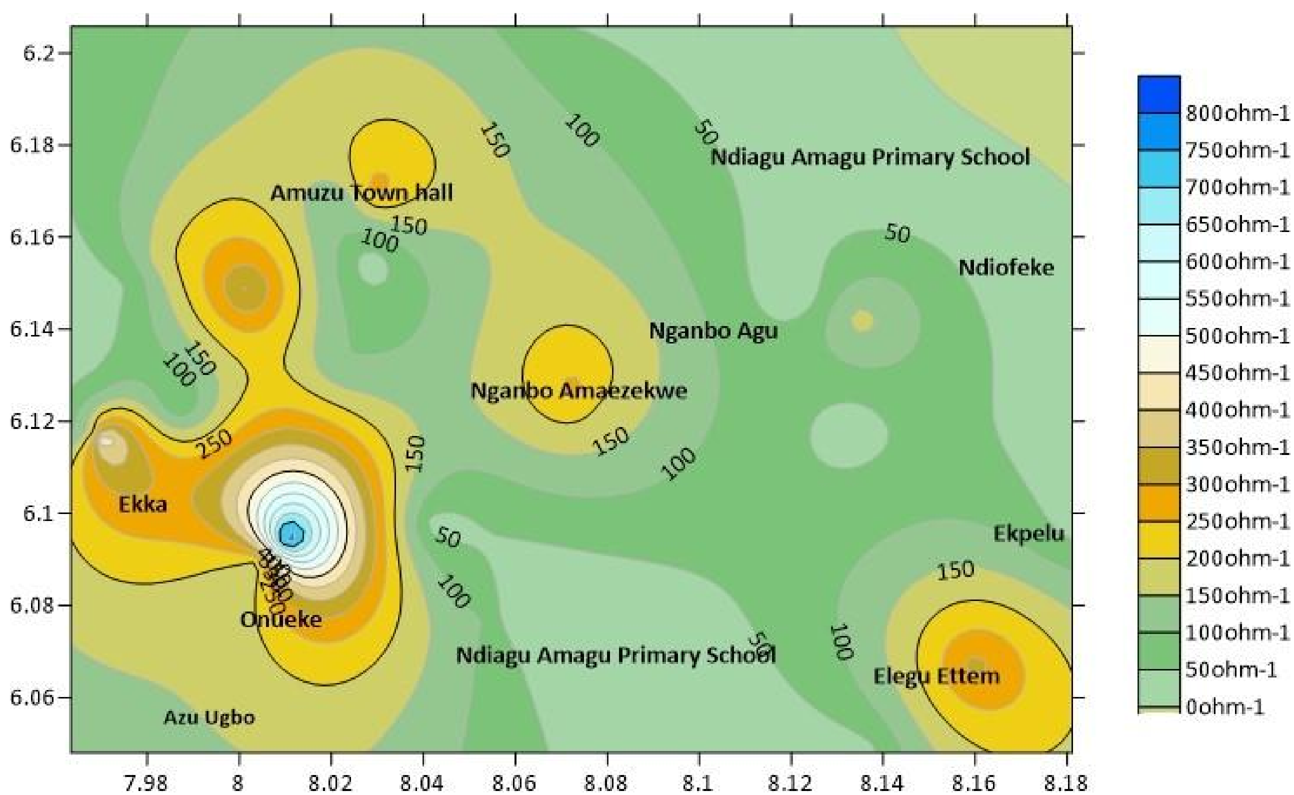

Figure 4.14: Aquifer resistivity map of the study area

4.5.2 Aquifer Depth

The aquifer depth was deduced from VES sounding results, with the depth to water table highest at Our Lady Fatima Catholic Church (VES 19) at the depth of 105.8m and lowest at Ogwuekwe Village Hall (VES 18) with the depth of 8.7m, with a mean depth of 37.6m. Upon comparing the geological map of the study area (Fig. 1.3) and the map of the study area showing the aquifer depth (Fig. 4.15), it can be observed that areas underlain by the Abakaliki Formation has lesser depth to aquifers (shallow aquifers) than the Ebonyi Formation.

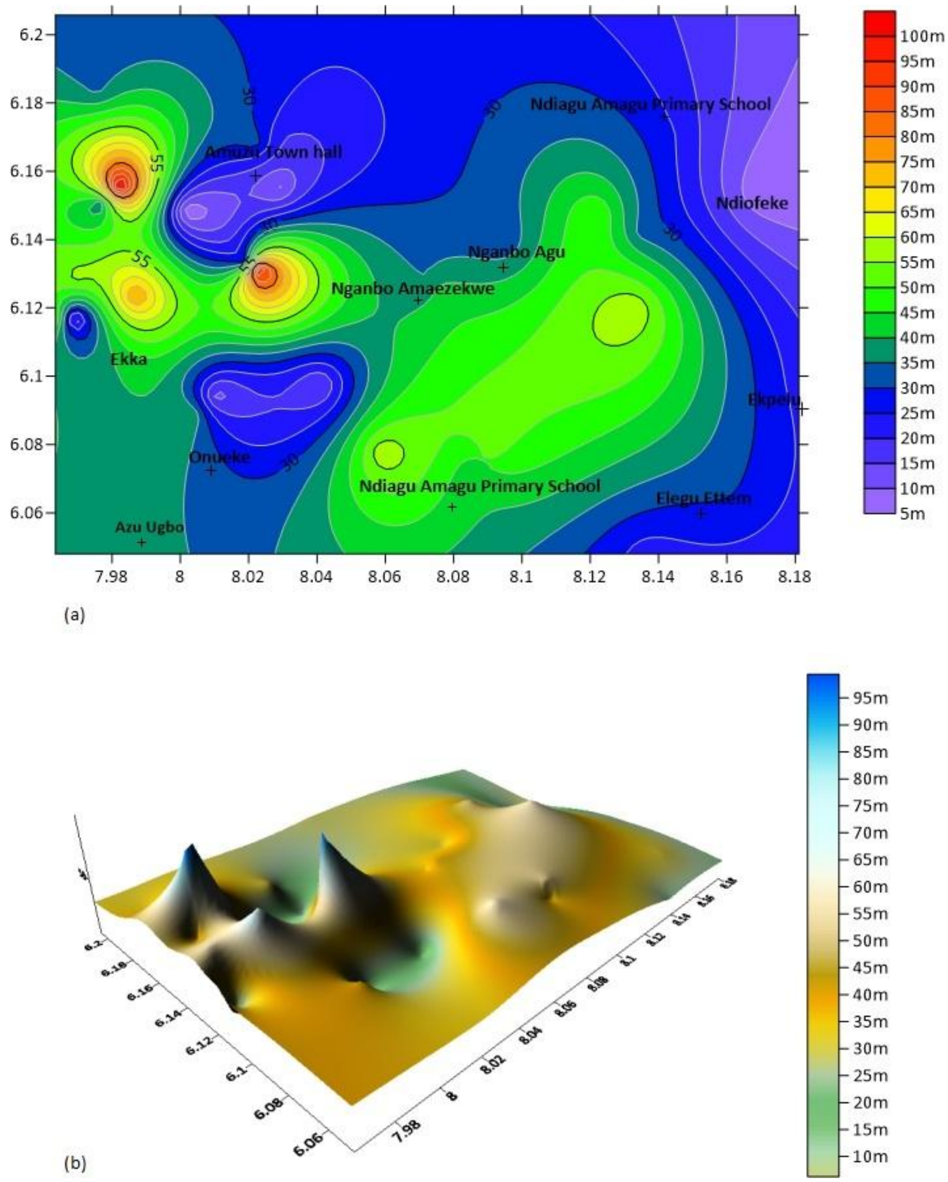

Figure 4.15: Aquifer depth maps: (a) 2D contour map of aquifer depth of the study area (b) 3D model of aquifer depth of the study area

4.5.3 Aquifer Thickness

The aquifer thickness of the area ranges from 99.2m at Our Lady Fatima Catholic Church (VES 19) to 3.4m at Ohiya Imeabali (VES 16) with a mean value of 23.9m. The aquifer thickness map is shown in Fig. 4.16.

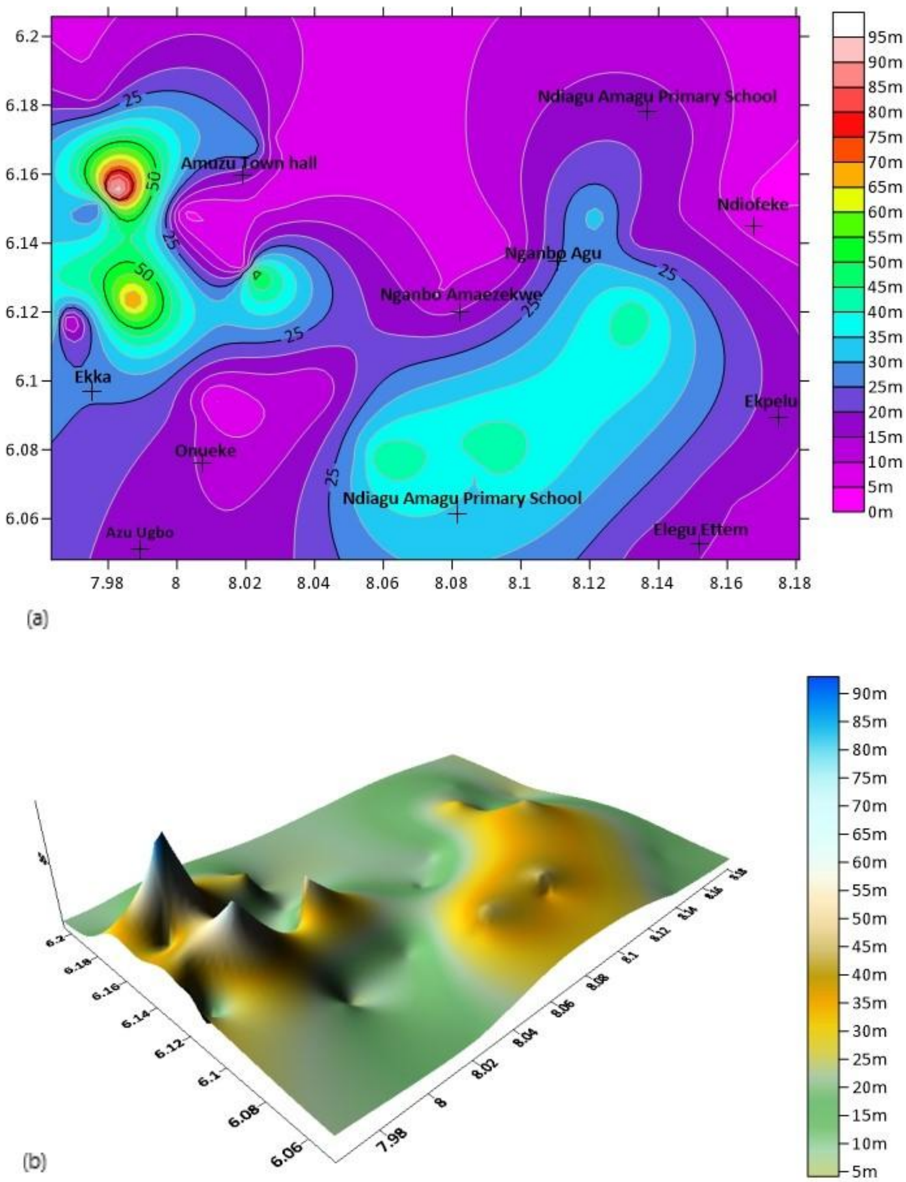

Figure 4.16: Aquifer thickness maps: (a) 2D contour map of aquifer thickness of the study area (b) 3D model of aquifer thickness of the study area

4.5.4 Transverse Resistance

Transverse resistance is usually estimated by finding the product of aquifer resistivity (Ωm) and aquifer thickness (m). The transverse resistance (T) of the study area varies from 70.1 to 17,161.6 Ωm^2 with an average value of 2380.2 Ωm^2. The distribution of the aquifer transverse resistance is shown in Fig. 4.17. Maximum transverse resistance is observed in the northwestern part of the study area which is underlain by the Ebonyi Formation. This indicates that the northwestern part of the area has a high thickness as can be seen from the isopach map (Fig.4.17), and it can be assumed that these areas may likely have high transmissivity and high yield of aquifer units (Agbasi and Edet, 2016). The areas with magenta colours are likely to be unproductive since their transverse resistance values are low.

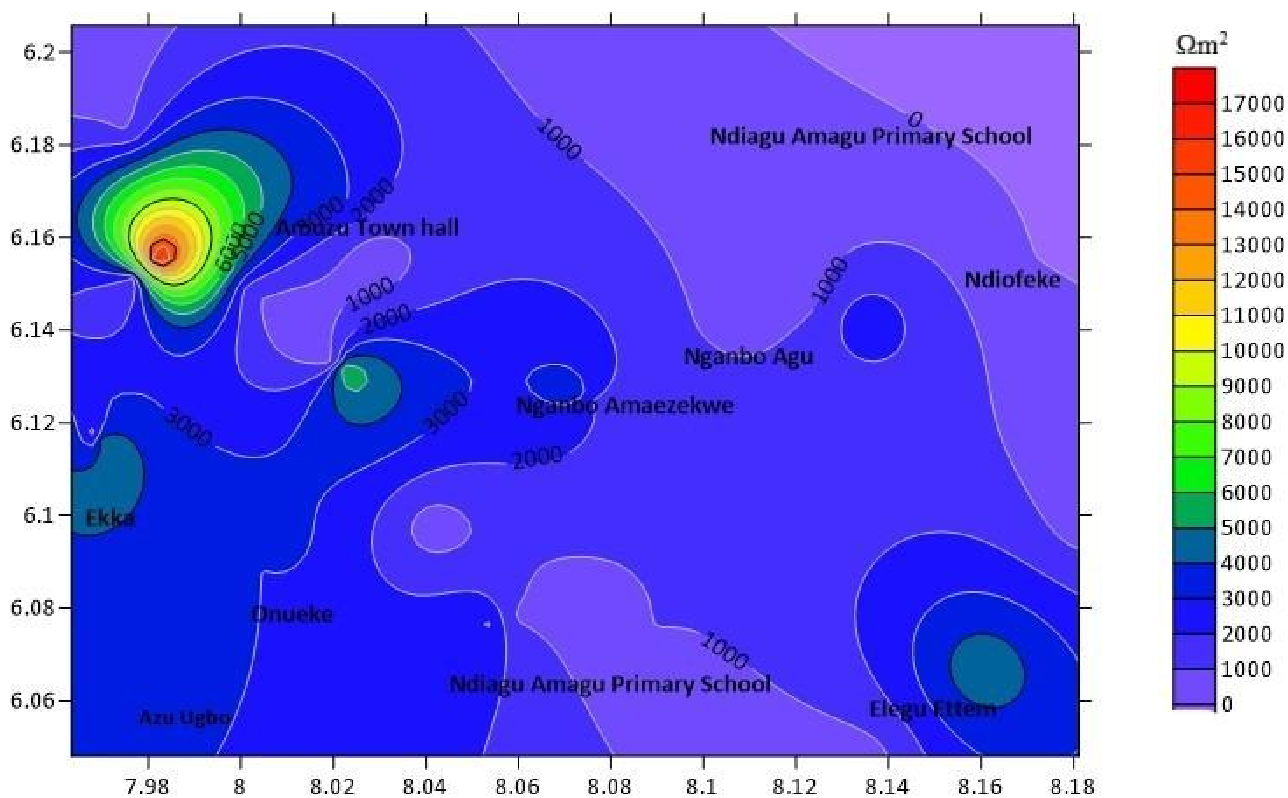

Figure 4.17: Transverse resistance map of the study area

4.6 AQUIFER HYDRULIC PARAMETERS OF THE STUDY AREA

Aquifer hydraulic parameters (Hydraulic conductivity and transmissivity) in the area was evaluated as shown in Table 4.8.

4.6.1 Hydraulic Conductivity

Hydraulic conductivity, which is the measure of the ease with which a fluid will pass through a medium (Heigold et al. 1979) was estimated using Niwas and Singhal model, Heigold model and the newly generated geophysical model (Table 4.8).

4.6.1.1 Hydraulic Conductivity from Heigold Model

Hydraulic conductivity was estimated from the Heigold model for the two (2) Formations in the study area, which are the Ebonyi and Abakaliki Formation. Hydraulic conductivity of the Ebonyi Formation ranges from 0.75 m/day to 22.6 m/day, with a mean value of 5.84m/day, while that of the Abakaliki Formation ranges from 1.78m/day to 39m/day, and has a mean value of 17.8 m/day. From the hydraulic conductivity map (Fig. 4.18), areas underlain by the Abakaliki Formation (Eastern axis) has a higher value when compared with those underlain by the Ebonyi Formation (Western axis). This is not fitting for the geology of the study region according to Agumanu (1989), as shales dominate the Abakaliki Formation, having a lower hydraulic conductivity when compared with the Ebonyi Formation, which has alternating sandstones, siltstones and shales.

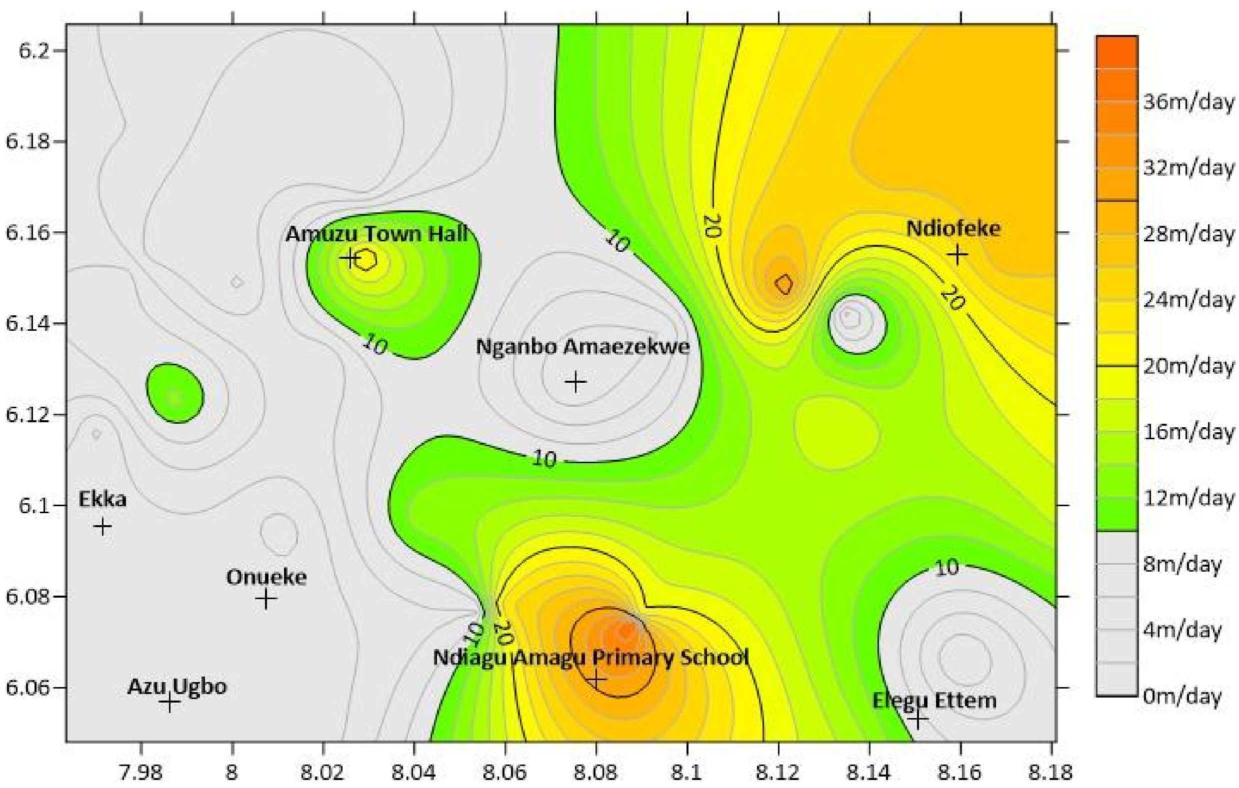

Figure 4.18: Hydraulic conductivity map of the study area from Heigold Model

4.6.1.2 Hydraulic Conductivity from Niwas and Singhal Model

For the Niwas and Singhal Model, aquifer hydraulic conductivity was estimated by establishing the product of the diagnostic constant (kδ) and aquifer resistivity (ρ) as shown in Equ. 9. The average diagnostic parameter of 0.00721 was used for areas under the Ebonyi Formation, while areas under the Abakaliki Formation have a mean of diagnostic parameter of 0.00352. The Niwas and Singhal Model estimated hydraulic conductivity of the Formations in the study area with Ebonyi Formation ranging from 0.15 m/day to 5.87 m/day, with a mean value of 1.32 m/day. Whereas the Abakaliki Formation ranges from 0.04 m/day to 0.61 m/day, with an average from 0.25 m/day. From Fig. 4.19, the model assumes that the areas majorly underlain by the Ebonyi Formation (Western axis) has a higher hydraulic conductivity when compared with the areas underlain by the Abakaliki Formation (Eastern axis).

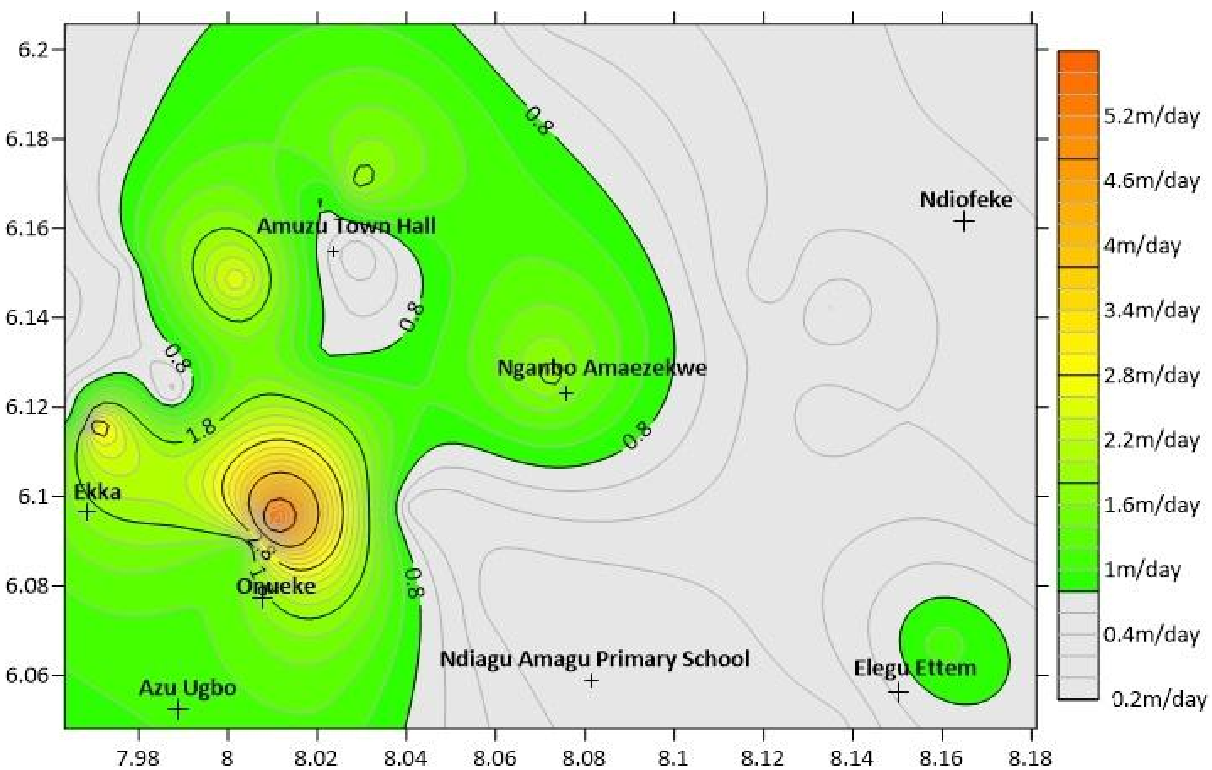

Figure 4.19: Hydraulic conductivity map of the study area from Niwas and Singhal Model

4.6.1.3 Hydraulic Conductivity from the Newly Generated Model

With the aid of the newly generated geophysical model, hydraulic conductivity was estimated in the Ebonyi and Abakaliki Formations. Hydraulic conductivity values of areas underlain by the Ebonyi Formation estimated from the new model varies from 0.49m/day to 1.5735m/day with a mean value of 0.9205m/day while those underlain by the Abakaliki Formation have hydraulic conductivity values that ranges from 0.0775m/day to 1.3023m/day, with a mean value of 0.2883m/day.

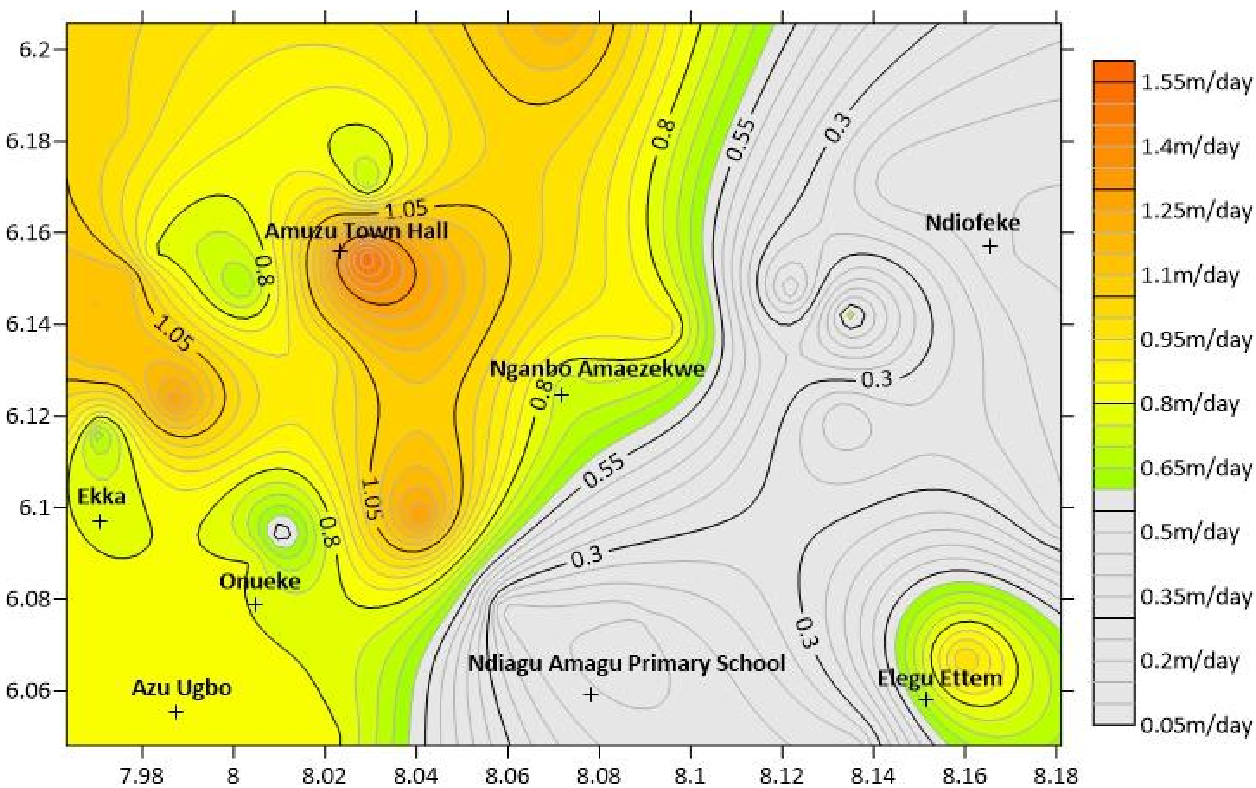

Figure 4.20: Hydraulic conductivity map of the study area from the Newly Generated Geophysical Model.

From Table 4.8, there is a greater level of agreement between hydraulic conductivity evaluated from pumping test and that from the New model when compared with Niwas and Singhal model and Heigold model. This shows that the new model is more effective in estimating aquifer hydraulic parameters in the study area. From the hydraulic conductivity map of the study area (Fig. 4.20), there exists a hydrogeological divide with the Ebonyi Formation in the western axis of the study area having higher hydraulic conductivity values and therefore a more prolific aquifer than the Abakaliki Formation which is in the eastern part of the study area with lower hydraulic conductivity values. This goes in correspondence with studies on the Formation (Agumanu, 1989, Ekwe et al., 2015 and Oli et al., 2020). Within the Abakaliki Formation, areas with hydraulic conductivity greater than the surrounding Formation are identified as highly fractured zone which encourages porosity and permeability.

4.6.2 Transmissivity

Transmissivity, which is the rate of flow of under a unit hydraulic gradient though a unit width of aquifer of thickness was also estimated via the various models (Heigold Model, Niwas and Singhal Model and The Newly Generated Model).

4.6.2.1 Transmissivity from Heigold Model

Transmissivity was estimated using the Heigold model with that of the Ebonyi Formation ranging from 3.01 m^2/day and 934 m^2/day with a mean value of 142 m^2/day while that of the Abakaliki Formation ranges from 50.2 m^2/day to 1347 m^2/day with a mean value of 507 m^2/day, with the map shown in Fig. 4.21.

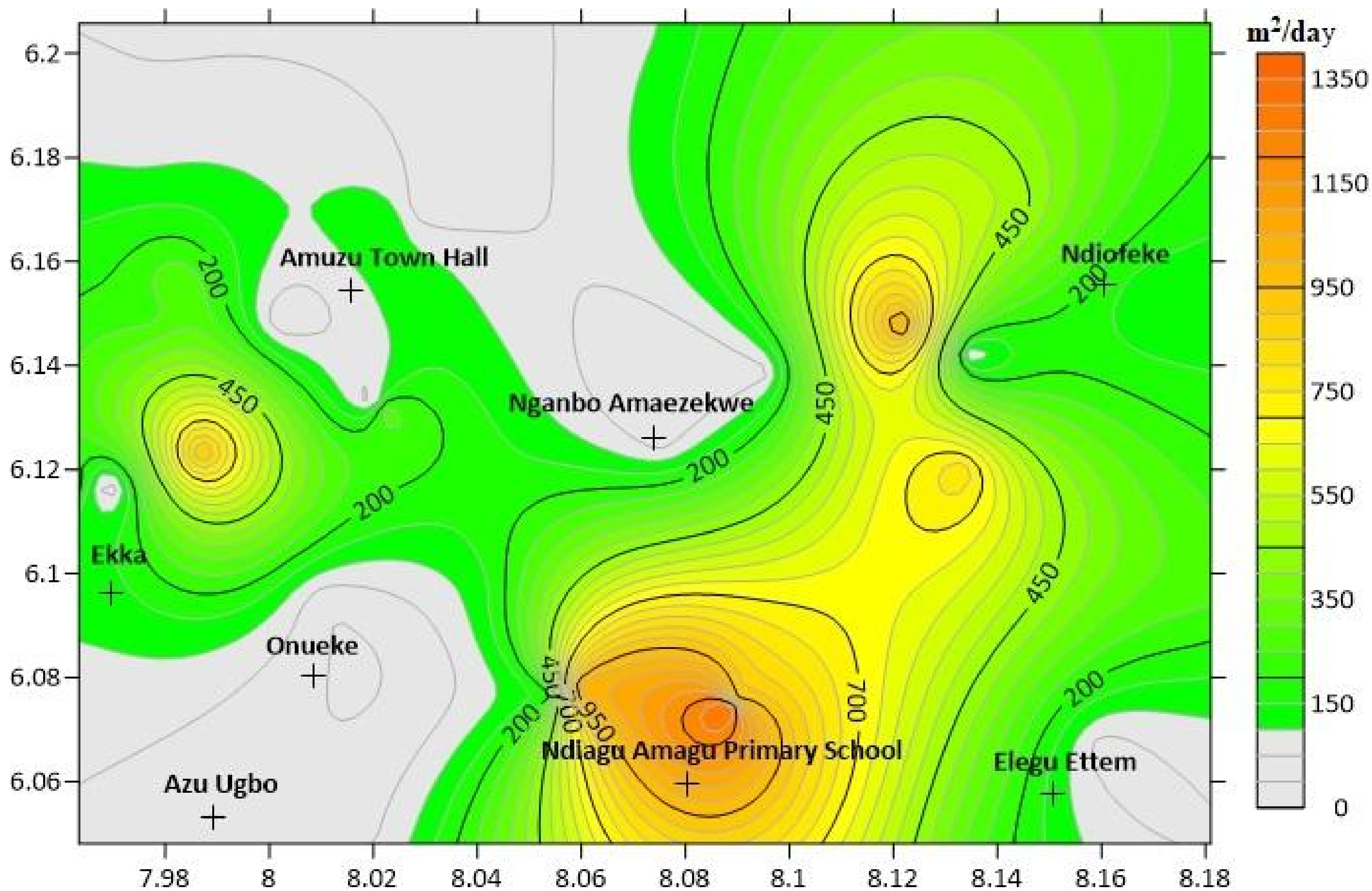

Figure 4.21: Transmissivity map of the study area from the Heigold Model.

4.6.2.2 Transmissivity from Niwas and Singhal Model

Niwas and Singhal model was used to estimate transmissivity in the Ebonyi and Abakaliki Formations. The values for the Ebonyi Formation ranges from 0.95 m^2/day to 124 m^2/day with a mean, while the Abakaliki Formation ranges from 0.25 m^2/day to 17.5 m^2/day. The Ebonyi Formation having greater transmissivity values than the Abakaliki Formation as shown in Fig. 4.22.

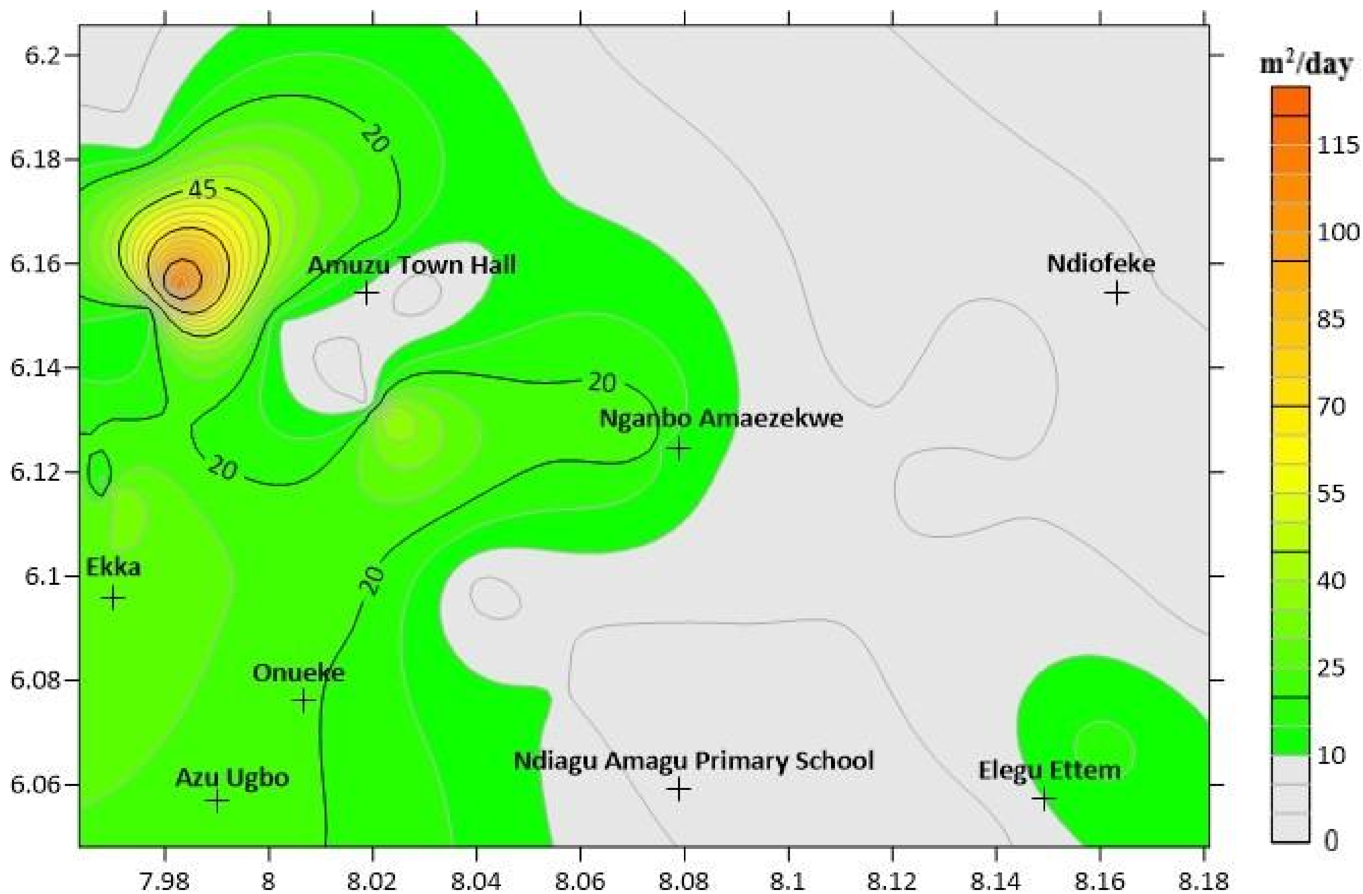

Figure 4.22: Transmissivity map of the study area from the Niwas and Singhal Model.

4.6.2.3 Transmissivity from The New Model

The aquifer transmissivity values from the new model ranges from 0.29m^2/day to 57.27m^2/day with a mean value of 6.59m^2/day. The transmissivity values of the Ebonyi Formation vary from 0.63 m^2/day to 57.27 m^2/day with a mean value of 8.61m^2/day, while that of Abakaliki Formation ranges from 0.29 m^2/day to 9.22 m^2/day with a mean value of 3.17 m^2/day. The transmissivity map is shown in Fig. 4.23.

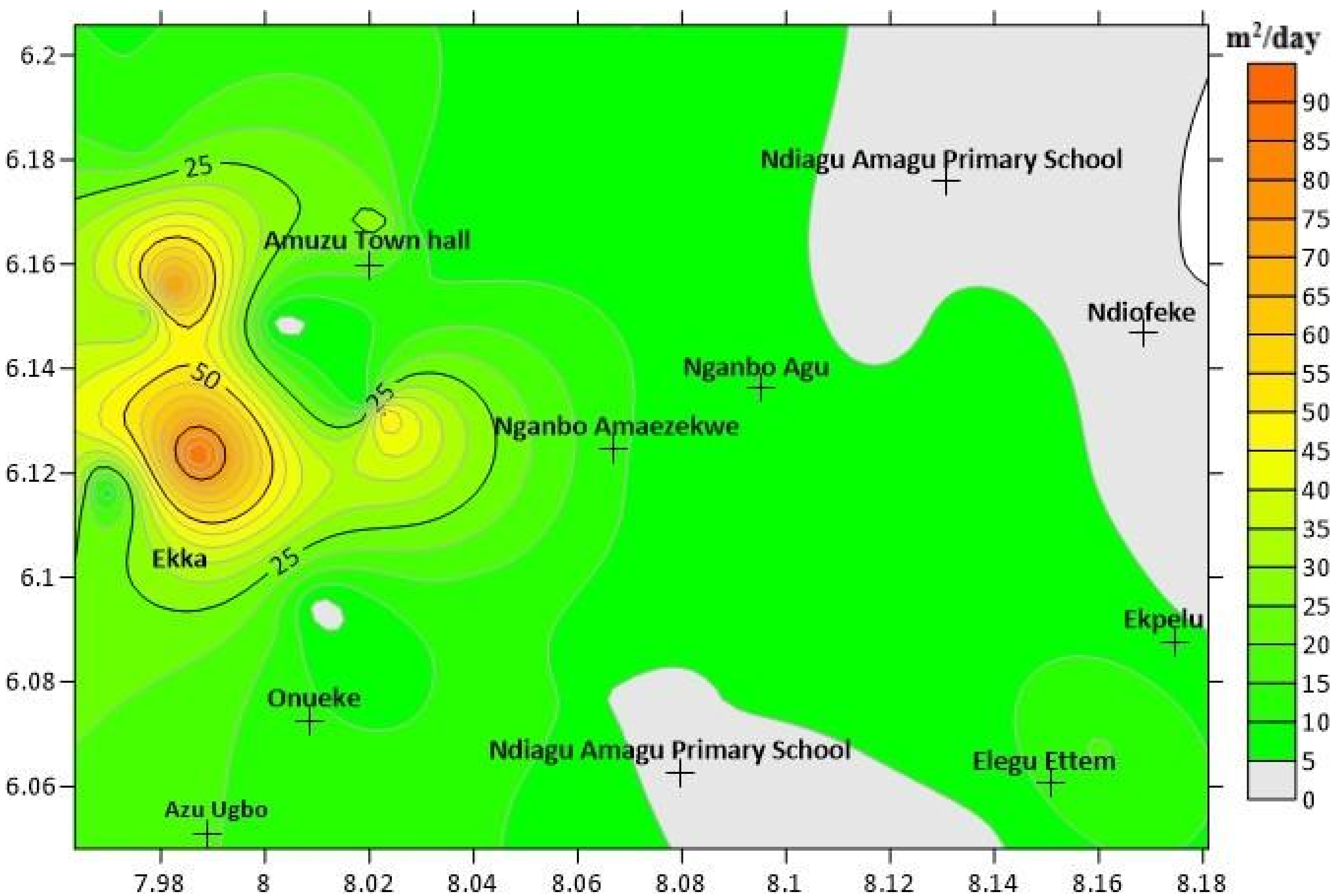

Figure 4.23: Transmissivity map of the study area from The New Geophysical Model

Table 4.8: Aquifer hydraulic parameters of the study area

VES Point	Location	K From Pumping Test m/day	K from New Model m/day	K from Niwas and Singhal m/day	K'' from Heigold m/day	Transmissivity (T) From Pumping Test m^2/day	Transmissivity (T) From Heigold (m^2/day)	Transmissivity (T) From New Model (m^2/day)	Transmissivity From Niwas Singhal (T) (m^2/day)	Geologic Formation
VES 1 *	Ekka	1.01	1.01	0.61	6.15	9.0662	69.9	9.09	6.93	Ebonyi Fm.
VES 2 *	Onueke Market	0.69	0.69	1.99	2.04	4.1457	16.6	4.16	16.09	Ebonyi Fm.
VES 3	Abiaji Village Square,Nganbo-Ogele		0.74	1.58	2.53		23.3	4.56	14.56	Ebonyi Fm.
VES 4	Amuzu Primary School		1.19	0.36	10.05		85.4	19.39	3.06	Ebonyi Fm.
VES 5	Ndiuhu Amana		0.88	0.94	4.12		34.6	8.08	7.87	Ebonyi Fm.
VES 6	Nganbo Ndiagu Amagu		1.32	0.26	13.48		134.8	22.33	2.63	Ebonyi Fm.
VES 7	Nganbo Agu		0.91	0.84	4.58		23.2	14.34	4.24	Ebonyi Fm.
VES 8	Sacred Heart Catholic Church Onueke		0.93	0.77	4.92		272.8	1.67	42.95	Ebonyi Fm.
VES 9	Ndufu Idembia Community Hall		1.08	0.49	7.54		325.9	3.22	21.17	Ebonyi Fm.
VES 10	Nganbo Ohainya Ezzama		1.14	0.42	8.75		212.0	6.39	10.13	Ebonyi Fm.
VES 11	Nganbo Amaezekwe		0.69	1.97	2.06		25.8	2.81	24.60	Ebonyi Fm.
VES 12	Ezeugwu Okofia		0.49	5.87	0.74		3.0	2.90	23.76	Ebonyi Fm.
VES 13	Oriegu- Market Square 1		0.77	1.43	2.78		16.7	7.47	8.56	Ebonyi Fm.
VES 14	Oriegu- Market Square 11		0.59	3.30	1.27		12.7	2.14	33.01	Ebonyi Fm.
VES 15	Azu Ugbo Village Square		0.80	1.26	3.13		53.5	3.17	21.54	Ebonyi Fm.
VES 16	Ohiya Imeabali		0.63	2.63	1.57		5.3	7.16	8.96	Ebonyi Fm.
VES 17	Ishieke Ndufu Igbudu		0.82	1.15	3.40		54.7	3.64	18.57	Ebonyi Fm.
VES 18	Oguwekwe Village Hall		1.57	0.15	22.58		142.2	57.27	0.95	Ebonyi Fm.
VES 19	Uur Lady Fatima Catholic Church		0.80	1.25	3.16		313.2	0.63	123.69	Ebonyi Fm.
VES 20	ochufuagba community primary		1.30	0.27	12.98		934.8	3.44	19.72	Ebonyi Fm.
VES 21	Community Primary School Ugwuogo		0.93	0.68	5.52		233.1	2.42	28.89	Ebonyi Fm.
VES 22	Amuzu Town hall		0.94	0.76	5.03		149.4	3.05	22.48	Ebonyi Fm.
VES 23*	Ndechi Ndufu achara	0.63	0.63	0.61	3.16	5.6585	50.2	5.69	9.68	Abakaliki Fm.
VES 24*	Ishieke, Ndufu Igbudu	0.60	0.59	0.56	3.40	5.3789	54.7	5.40	9.07	Abakaliki Fm.
VES 25*	Elegu Ndiechi Ekpomaka	1.02	1.02	1.12	1.78	9.1713	27.8	9.22	17.52	Abakaliki Fm.
VES 26	Elegu Ettem		0.16	0.10	16.65		273.1	1.37	1.68	Abakaliki Fm.
VES 27	Ekpelu		0.17	0.11	15.20		259.8	1.54	1.93	Abakaliki Fm.
VES 28	Ndiofeke		0.11	0.06	26.90		108.4	0.29	0.25	Abakaliki Fm.
VES 29	Enyacharigne (Ndiagu Amagu)		0.15	0.09	18.11		791.3	2.83	4.09	Abakaliki Fm.
VES 30	Ndiagu Amagu Primary School Enyibivhiri 1		0.08	0.04	38.96		1348.0	1.20	1.42	Abakaliki Fm.
VES 31	Eke Ettam Market Square		0.09	0.05	32.29		1043.0	1.38	1.68	Abakaliki Fm.
VES 32	Amainyima		0.11	0.06	26.48		477.4	0.99	1.12	Abakaliki Fm.
VES 34	Ndiagu Amagu Primary School Enyibivhiri 11		0.13	0.08	20.57		945.5	2.64	3.75	Abakaliki Fm.
VES 34	Ndufu Inyiamagu Obeagu playground (1)		0.39	0.33	5.57		185.0	6.32	11.00	Abakaliki Fm.
VES 35	Ndufu Inyiamagu Obeagu playground (11)		0.12	0.07	22.88		1025.0	2.36	3.26	Abakaliki Fm.

4.7 COMPARISON OF SURFICIAL RESISTIVITY MODELS WITH PUMPING TEST

Several Statistical analysis was carried out to ascertain the reliability of the different models in estimating hydraulic conductivity in relation to pumping test, which includes the Paired t-Test, ANOVA and Multiple regression analysis

4.7.1 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 4.9), 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 4.10), 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 4.11), 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 4.9: Paired t-Test Two for Means (New Model and Pumping test)

	K New Model	**K Pumping Test**
Mean	0.7891284	0.78872
Variance	0.043145744	0.043137957
Observations	5	5
Pearson Correlation	0.999938017	
Hypothesized Mean Difference	0	
df	4	
t Stat	0.394872745	
P(T<=t) one-tail	0.356543915	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.713087829	
t Critical two-tail	2.776445105	

Table 4.10: Paired t-Test Two for Means (Niwas and Singhal model and Pumping test)

	K Niwas & Singhal Model	K Pumping Test
Mean	0.978154931	0.78872
Variance	0.370468383	0.043137957
Observations	5	5
Pearson Correlation	-0.01466853	
Hypothesized Mean Difference	0	
df	4	
t Stat	0.655711871	
P(T<=t) one-tail	0.273904578	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.547809156	
t Critical two-tail	2.776445105	

Table 4.11: Paired t-Test Two for Means (Heigold model and Pumping test)

	K Heigold Model	K Pumping Test
Mean	3.30751504	0.78872
Variance	3.011254259	0.043137957
Observations	5	5
Pearson Correlation	0.278796752	
Hypothesized Mean Difference	0	
df	4	
t Stat	3.33422159	
P(T<=t) one-tail	0.014495679	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.028991359	
t Critical two-tail	2.776445105	

4.7.2 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 4.12), therefore, accepting the null hypothesis that there is no difference in the mean and rejecting the alternative hypothesis that there is a difference in the mean. 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 4.13), 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 a significant difference, while the P <0.05 (Table 4.14), therefore, rejecting the null hypothesis and accepting the alternative hypothesis.

Table 4.12: ANOVA (Pumping test and New model)

Anova: Single Factor						
SUMMARY						
Groups	***Count***	***Sum***	***Average***	***Variance***		
k from Pumping test	5	3.9436	0.78872	0.043138		
k from New model	5	3.945642	0.789128	0.043146		

ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	4.17E-07	1	4.17E-07	9.67E-06	0.997596	5.317655
Within Groups	0.345135	8	0.043142			
Total	0.345135	9				

Table 4.13: ANOVA (Pumping test and Niwas & Singhal)

Anova: Single Factor						
SUMMARY						
Groups	***Count***	***Sum***	***Average***	***Variance***		
k from Pumping test	5	3.9436	0.78872	0.043138		
k from Niwas and	5	4.890775	0.978155	0.370468		

Singhal model						
ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.089714	1	0.089714	0.433813	0.52862	5.317655
Within Groups	1.654425	8	0.206803			
Total	1.744139	9				

Table 4.14: ANOVA (Pumping test and Heigold)

Anova: Single Factor						
SUMMARY						
Groups	***Count***	***Sum***	***Average***	***Variance***		
k from Pumping	5	3.9436	0.78872	0.043138		

Test						
K From Heigold model	5	16.53758	3.307515	3.011254		
ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	15.86082	1	15.86082	10.38558	0.01219	5.317655
Within Groups	12.21757	8	1.527196			
Total	28.07839	9				

4.7.3 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 4.15), 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 0.01, 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 4.15 to be 1.00, -0.001, and -0.0006 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 0.006, 0.79, and 0.76, respectively, with only the new model meeting the requirements of rejecting the null hypothesis and accepting the alternative hypothesis.

Table 4.15: Multiple Regression Analysis of the Models

Regression Statistics						
Multiple R	0.999946823					
R Square	0.999893649					
Adjusted R Square	0.999574594					

Standard Error	0.004283822					
Observations	5					
Anova						
	Df	***Ss***	***Ms***	***F***	***Significance F***	
Regression	3	0.172533477	0.057511	3133.93	0.013130283	
Residual	1	1.83511e-05	1.84e-05			
Total	4	0.172551828				
	Coefficients	***Standard Error***	***T Stat***	***P-Value***	***Lower 95%***	***Upper 95%***
Intercept	0.002147817	0.01045483	0.205438	0.871009	-0.130693387	0.134989022
K New Model	1.001285487	0.010968295	91.28907	0.006973	0.861920083	1.140650891
K Niwas & Singhal Model	-0.0014955	0.004479218	-0.33388	0.794856	-0.058409363	0.055418353
K Heigold Model	-0.00063727	0.001636972	-0.3893	0.763655	-0.021436972	0.020162423

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.

4.8 GROUNDWATER POTENTIAL

The groundwater potential of the study area was assessed based on transmissivity of the aquifer in each sounding point extracted from the new model. Transmissivity analysis was done using two methods as reflected in Mayooran et al (2011). The methods include; Descriptive statistical testing for identification of background transmissivity and anomalies, while the other method is based on Krasny's transmissivity classification scheme for groundwater appraisal.

4.8.1 Statistical Testing

Using this method, all transmissivity values acquired were assembled and the Transmissivity index (Ý) which relates to transmissivity through the equation stated below:

T (m^2 / day) = $10^{Y-8.96} x 86400$ …………………………………………………...(4.1)

The Transmissivity index (Y), is calculated by modifying the above stated equation thus:

Y = Log (T / 86400) + 8.96 ………………………………………………………… (4.2)

Where T = Transmissivity (m^2/day)

The calculated transmissivity index is shown in Table 4.9

Table 4.10: Transmissivity Index Evaluation

LOCATION	TRANSMISSIVITY (M^2/DAY)	TRANSMISSIVITY INDEX (Y)
Ekka	9.09	4.98
Onueke Market	4.16	4.64
Abiaji Village Square,Nganbo-Ogele	4.56	4.68
Amuzu Primary School	19.39	5.31
Ndiuhu Amana	8.08	4.93
Nganbo Ndiagu Amagu	22.33	5.37
Nganbo Agu	14.34	5.18
Sacred Heart Catholic Church Onueke	1.67	4.25
Ndufu Idembia Community Hall	3.22	4.53
Nganbo Ohainya Ezzama	6.39	4.83
Nganbo Amaezekwe	2.81	4.47
Ezeugwu Okofia	2.90	4.49
Oriegu- Market Square 1	7.47	4.90
Oriegu- Market Square 11	2.14	4.35
Azu Ugbo Village Square	3.17	4.52
Ohiya Imeabali	7.16	4.88
Ishieke Ndufu Igbudu	3.64	4.58
Oguwekwe Village Hall	57.27	5.78
Uur Lady Fatima Catholic Church	0.63	3.82
Ochufuagba community primary school	3.44	4.56
Community Primary School Ugwuogo	2.42	4.41
Amuzu Town hall	3.05	4.51
Ndechi Ndufu achara	5.69	4.78
Ishieke, Ndufu Igbudu	5.40	4.76
Elegu Ndiechi Ekpomaka	9.22	4.99
Elegu Ettem	1.37	4.16
Ekpelu	1.54	4.21
Ndiofeke	0.29	3.49
Enyacharigne (Ndiagu Amagu)	2.83	4.48
Ndiagu Amagu Primary School Enyibivhiri 1	1.20	4.10
Eke Ettam Market Square	1.38	4.16
Amainyima	0.99	4.02
Ndiagu Amagu Primary School Enyibivhiri 11	2.64	4.44
Ndufu Inyiamagu Obeagu playground (1)	6.32	4.82
Ndufu Inyiamagu Obeagu playground (11)	2.36	4.40
MINIMUM		3.49
MAXIMUM		4.98
MEAN		4.59
STANDARD DEVIATION		0.45

The process for the analysis of the transmissivity of the study area on the criteria of transmissivity index classification for identification of anomalies and background transmissivity is shown in Table 4.10.

Table 4.11: Transmissivity Analysis based on Transmissivity Index (Y) classification (modified from Diloha et al, (2018)

Transmissivity Analysis based on Transmissivity Index (Y) classification		
Classification	**Description**	**Range of 'Y' of The Studied Area**
Negative extreme anomalies	Less than[mean – (2 *standard deviation)]	< 3.69
Negative anomalies	Between (mean - standard deviation) and [mean - (2*standard deviation)]	Between 4.14 and 3.69
Background anomalies	Between (mean – standard deviation) and (mean + standard deviation)	Between 4.14 and 5.04
Positive anomalies	Between (mean + standard deviation) and mean + (2*standard deviation)	Between 5.04 and 5.49
Positive extreme anomalies	Greater than [mean + (2*standard deviation)	> 5.49

From Table 4.11, background transmissivity represents the interval between (mean - standard deviation) and (mean + standard deviation) of the index transmissivity values. The prospective and less prospective areas are represented by the positive and negative anomalies respectively. Higher groundwater supply prospect is correlated to extreme positive anomalies while areas with negligible groundwater supply prospect are linked to extreme negative anomalies. The mean value and standard deviation of the logarithmic transmissivity index (Y) of the Study Area were obtained as 4.59 and 0.45 respectively as shown in Table 4.9, while the transmissivity index classification of the area is shown in Table 4.11. The standard deviation value indicates that the study area is fairly heterogeneous.

Table 4.12: Transmissivity Index Classification

LOCATION	TRANSMISSIVITY (M^2/DAY)	TRANSMISSIVITY INDEX (Y)	TRANSMISSIVITY INDEX (Y) CLASSIFICATION
Ekka	9.09	4.98	Background anomalies
Onueke Market	4.16	4.64	Background anomalies
Abiaji Village Square,Nganbo-Ogele	4.56	4.68	Background anomalies
Amuzu Primary School	19.39	5.31	Positive anomalies
Ndiuhu Amana	8.08	4.93	Background anomalies
Nganbo Ndiagu Amagu	22.33	5.37	Positive anomalies
Nganbo Agu	14.34	5.18	Positive anomalies
Sacred Heart Catholic Church Onueke	1.67	4.25	Background anomalies
Ndufu Idembia Community Hall	3.22	4.53	Background anomalies
Nganbo Ohainya Ezzama	6.39	4.83	Background anomalies
Nganbo Amaezekwe	2.81	4.47	Background anomalies
Ezeugwu Okofia	2.90	4.49	Background anomalies
Oriegu- Market Square 1	7.47	4.90	Background anomalies
Oriegu- Market Square 11	2.14	4.35	Background anomalies
Azu Ugbo Village Square	3.17	4.52	Background anomalies
Ohiya Imeabali	7.16	4.88	Background anomalies
Ishieke Ndufu Igbudu	3.64	4.58	Background anomalies
Oguwekwe Village Hall	57.27	5.78	Positive extreme anomalies
Uur Lady Fatima Catholic Church	0.63	3.82	Negative extreme anomalies
Ochufuagba community primary school	3.44	4.56	Background anomalies
Community Primary School Ugwuogo	2.42	4.41	Background anomalies
Amuzu Town hall	3.05	4.51	Background anomalies
Ndechi Ndufu achara	5.69	4.78	Background anomalies
Ishieke, Ndufu Igbudu	5.40	4.76	Background anomalies
Elegu Ndiechi Ekpomaka	9.22	4.99	Background anomalies
Elegu Ettem	1.37	4.16	Background anomalies
Ekpelu	1.54	4.21	Background anomalies
Ndiofeke	0.29	3.49	Negative extreme anomalies
Enyacharigne (Ndiagu Amagu)	2.83	4.48	Background anomalies
Ndiagu Amagu Primary School Enyibivhiri 1	1.20	4.10	Negative anomalies
Eke Ettam Market Square	1.38	4.16	Background anomalies
Amainyima	0.99	4.02	Negative anomalies
Ndiagu Amagu Primary School Enyibivhiri 11	2.64	4.44	Background anomalies
Ndufu Inyiamagu Obeagu playground (1)	6.32	4.82	Background anomalies
Ndufu Inyiamagu Obeagu playground (11)	2.36	4.40	Background anomalies

From the Table 4.12, 77% of the area falls under background anomalies; 6% under negative extreme anomalies; 3% under positive extreme anomalies; 6% is under negative anomalies and 9% under positive anomalies.

4.8.2 Krasny Classification

The classification of transmissivity and variation based on transmissivity magnitude and standard deviation of transmissivity index respectively were proposed by Jiri Krasny (1993). The classification methods for transmissivity magnitude and variation are in Tables 4.13 and 4.14 respectively. Based on the standard deviation value from the study area which is 0.45, the area has a moderate transmissivity variation, which implies a fairly heterogeneous environment. This means that aquiferous conditions vary moderately over a short lateral distance.

Table 4.13: Krasny's Classification of Transmissivity Variation (Krasny, 1993)

Standard Deviation of Transmissivity	Class of Transmissivity Variation	Designation of Transmissivity Variation	Hydrogeological Environment
<0.2	A	Insiginificant	Homogenous
0.2-0.4	B	Small	Slightly Homogenous
0.4-0.6	C	Moderate	Fairly Heterogenous
0.6-0.8	D	Large	Considerably Heterogenous
0.8-1.0	E	Very Large	Very Heterogenous
>1	F	Extremely Large	Extremly Hetergenous

Table 4.14: Classification of Transmissivity Magnitude (Krasny, 1993)

Magnitude of Transmissivity (m^3/day)	Class	Designation	Specific Capacity(m^2/ day)	Groundwater Supply Potential
> 1000	I	Very High	>864	Regional importance
100-1000	II	High	86.4- 864	Lesser Regional Importance
10-100	III	Intermediate	8.64- 86.4	Local water supply
1–10	IV	Low	0.864- 8.64	Private consumption
0.1-1	V	Very Low	0.0864- 0.864	Limited consumption
< 0.1	VI	Imperceptible	<0.0864	Very difficult to utilize for local water supply

Table 4.15: Transmissivity classification based on data collected in the Study Area

LOCATION	TRANSMISSIVITY (m^2/day)	DESIGNATION OF TRANSMISSIVITY MAGNITUDE	GROUNDWATER SUPPLY POTENTIAL
Ekka	9.09	Low	Private consumption
Onueke Market	4.16	Low	Private consumption
Abiaji Village Square,Nganbo-Ogele	4.56	Low	Private consumption
Amuzu Primary School	19.39	Intermediate	Local water supply
Ndiuhu Amana	8.08	Low	Private consumption
Nganbo Ndiagu Amagu	22.33	Intermediate	Local water supply
Nganbo Agu	14.34	Intermediate	Local water supply
Sacred Heart Catholic Church Onueke	1.67	Low	Private consumption
Ndufu Idembia Community Hall	3.22	Low	Private consumption
Nganbo Ohainya Ezzama	6.39	Low	Private consumption
Nganbo Amaezekwe	2.81	Low	Private consumption
Ezeugwu Okofia	2.90	Low	Private consumption
Oriegu- Market Square 1	7.47	Low	Private consumption
Oriegu- Market Square 11	2.14	Low	Private consumption
Azu Ugbo Village Square	3.17	Low	Private consumption
Ohiya Imeabali	7.16	Low	Private consumption
Ishieke Ndufu Igbudu	3.64	Low	Private consumption
Oguwekwe Village Hall	57.27	Intermediate	Local water supply
Uur Lady Fatima Catholic Church	0.63	Low	Private consumption
Ochufuagba community primary school	3.44	Low	Private consumption
Community Primary School Ugwuogo	2.42	Low	Private consumption
Amuzu Town hall	3.05	Low	Private consumption
Ndechi Ndufu achara	5.69	Low	Private consumption
Ishieke, Ndufu Igbudu	5.40	Low	Private consumption
Elegu Ndiechi Ekpomaka	9.22	Low	Private consumption
Elegu Ettem	1.37	Low	Private consumption
Ekpelu	1.54	Low	Private consumption
Ndiofeke	0.29	Very low	limited consumption
Enyacharigne (Ndiagu Amagu)	2.83	Low	Private consumption
Ndiagu Amagu Primary School Enyibivhiri 1	1.20	Low	Private consumption
Eke Ettam Market Square	1.38	Low	Private consumption
Amainyima	0.99	Very low	limited consumption
Ndiagu Amagu Primary School Enyibivhiri 11	2.64	Low	Private consumption
Ndufu Inyiamagu Obeagu playground (1)	6.32	Low	Private consumption
Ndufu Inyiamagu Obeagu playground (11)	2.36	Low	Private consumption

From Table 4.15, it was observed that aquifers in two (2) of the locations representing 6% of the entire sounding locations have groundwater potential which can only sustain limited consumption; twenty-nine (29) of the locations which represents 83% of the total locations can serve for private consumption while the remaining four (4) locations representing 11% of the total sounding locations holds a groundwater potential that can serve as a local water supply. The aquifer potential map of the study area is shown in Fig. 4.24.

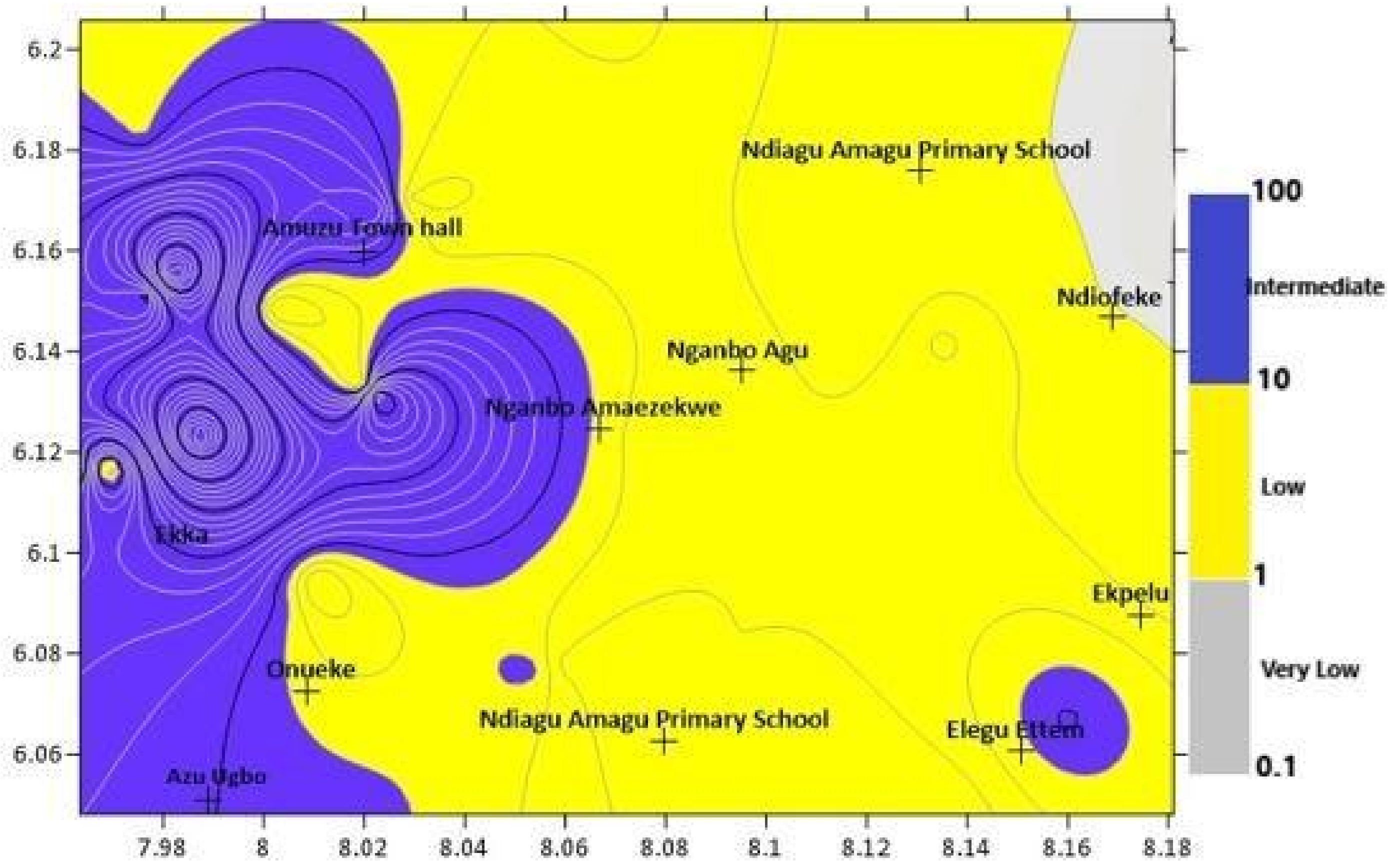

Figure 4.24: Groundwater potential map of the study area

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

This study has shown that surface geophysical methods are not only useful in delineation of aquifers, but can also be useful in estimating aquifer hydraulic parameters and this can help reduce the huge expenses involved in carrying out pumping tests. The estimated aquifer parameters revealed aquifer thickness and depth to water table varying from 3.4m - 99.2m and 8.7m – 105.8m. The resistivity of the aquiferous zone within the study area varied from 11.7Ωm - 814 Ωm with a mean resistivity value of 141.7Ωm. Hydraulic conductivity (K) were determined using Niwas and Singhal,1982, Heigold, 1979 and the New model. Hydraulic conductivity values using Niwas and Singhal varied from 0.04m/day- 5.87m/day, the hydraulic conductivity values obtained from Heigold, 1979 varied from 0.744m/day – 38.96m/day and those from the New Model varied from 0.08m/day – 1.57m/day. The New Model in this study also compared favorably with pumping test data. This was confirmed by statistical analysis of the various models to determine their dependability, with the New model coming out on top. From the study, the Ebonyi Formation was found to be more productive in terms of hydraulic conductivity and transmissivity when compared with Abakaliki Formation. Based on Krasny's classification of transmissivity magnitude, the area falls under intermediate, low and very low and groundwater potential, which is characteristic of fractured/shaly environments, which is the case in the study area. The places like Amuzu Primary School, Nganbo-Ndiagu Amagu, Nganbo Agu and Oguwekwe Village Hall have intermediate groundwater supply potential which is suitable to site a local water supply scheme. Also, places like Onueke Market, Ndiuhu Amana and Ekka with background transmissivity have groundwater supply potential for private consumption, while places like Ndiofeke and Ndiagu Amagu Primary School Enyibivhiri 11 should be avoided as they have groundwater supply potential for limited consumption.

5.2 RECOMMENDATIONS

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

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

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

iii. Down the hole log should be carried out to facilitate screening and pumping installation.

iv. Care should be taken in choosing the kind of pump to be installed. Hand pumps may be effective in areas where the groundwater supply potential can only sustain limited consumption. This will help prevent excessive drawdown, while in places that can sustain local water supply, motorized pumps will be more effective.

5.3 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 proposed and used in this study.

ii. This study successfully generated a Groundwater potential map of the study area.

iii. Created a data repository for government and water specialists, as well as a framework for the study area's groundwater management strategy.

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APPENDICES

Appendix 1: Pumping test data from Ekka Ezza

SWL: 2.14 m

TYPE OF PUMP: ASTRA- 1.5hp SUBMERSIBLE PUMP

DEPTH OF PUMP: 40.60m

Time since pumping started (m)	Dynamic water level (m)	Drawdown (m)	Pumping rate (lit/min)
0.5	4.36	2.22	79.2Lit/min
1.0	4.55	2.41	
1.5	4.74	2.6	
2.0	4.93	2.79	
2.5	5.13	2.99	
3.0	5.32	3.18	
3.5	5.47	3.33	
4.0	5.62	3.48	
4.5	5.76	3.62	
5.0	5.91	3.77	
6.0	6.06	3.92	
7.0	6.21	4.07	
8.0	6.36	4.22	
9.0	6.5	4.36	
10.0	6.65	4.51	
12.0	6.81	4.67	
14.0	6.96	4.82	
16.0	7.1	4.96	
18.0	7.25	5.11	
20.0	7.4	5.26	
23.0	7.55	5.41	
30.0	7.69	5.7	
35.0	7.84	5.7	
40.0	7.99	5.85	
45.0	8.14	6	
50.0	8.29	6.15	
60.0	8.44	6.3	
70.0	8.59	6.45	
80.0	8.74	6.6	
90.0	8.89	6.75	
100.0	9.04	6.9	
120.0	9.18	7.04	
140.0	9.33	7.19	

Time since pumping started (m)	Dynamic water level (m)	Drawdown (m)	Pumping rate (lit/min)
160.0	9.63	7.49	
180.0	9.78	7.64	

Appendix 2: Pumping test data from Onueke

SWL: 1.88m

TYPE OF PUMP: ASTRA- 1.5hp SUBMERSIBLE PUMP

DEPTH OF PUMP: 40.60m

Time since pumping started (m)	Dynamic water level (m)	Drawdown (m)	Pumping rate (lit/min)
0.5	5.92	4.04	49.2Lit/min
1.0	6.23	4.35	
1.5	6.53	4.65	
2.0	6.84	4.96	
2.5	7.13	5.25	
3.0	7.14	5.26	
3.5	7.61	5.73	
4.0	7.8	5.92	
4.5	8.01	6.13	
5.0	8.19	6.31	
6.0	8.38	6.5	
7.0	8.58	6.7	
8.0	8.77	6.89	
9.0	8.96	7.08	
10.0	9.16	7.28	
12.0	9.35	7.47	
14.0	9.55	7.67	
16.0	9.74	7.86	
18.0	9.93	8.05	
20.0	10.13	8.25	
23.0	10.32	8.44	
26.0	10.51	8.63	
30.0	10.7	8.82	
35.0	11.11	9.23	
40.0	11.25	9.37	
45.0	11.28	9.4	
50.0	11.48	9.6	
60.0	11.67	9.79	
70.0	11.86	9.98	
80.0	12.06	10.18	
90.0	12.25	10.37	
100.0	12.45	10.57	
120.0	12.64	10.76	

Time since pumping started (m)	Dynamic water level (m)	Drawdown (m)	Pumping rate (lit/min)
160.0	12.83	10.95	
180.0	13.02	11.14	

Appendix 3: Pumping test data from Ndiechi Ndufu Achara

SWL: 3.00m

TYPE OF PUMP: ASTRA- 1.5hp SUBMERSIBLE PUMP

DEPTH OF PUMP: 41.5m

Time since pumping started (m)	Dynamic water level (m)	Drawdown (m)	Pumping rate (lit/min)
0.5	3.28	0.28	44.7Lit/min
1.0	3.47	0.47	
1.5	3.52	0.52	
2.0	3.68	0.68	
2.5	3.94	0.94	
3.0	4.08	1.08	
3.5	4.16	1.16	
4.0	4.28	1.28	
4.5	4.32	1.32	
5.0	4.47	1.47	
5.5	4.52	1.52	
6.0	4.72	1.72	
7.0	4.82	1.82	
8.0	4.96	1.96	
9.0	5.18	2.18	
10.0	5.26	2.26	
15.0	5.36	2.36	
20.0	5.42	2.42	
25.0	5.57	2.57	
30.0	5.67	2.67	
35.0	5.82	2.82	
40.0	5.92	2.96	
45.0	5.96	2.96	
50.0	6.18	3.18	
55.0	6.24	3.24	
60.0	6.37	3.37	
65.0	6.42	3.42	
70.0	6.59	3.59	
75.0	6.63	3.63	
80.0	6.78	3.78	
90.0	6.92	3.92	
100.0	7.14	4.14	
110.0	7.24	4.24	
120.0	7.29	4.29	

Time since pumping started (m)	Dynamic water level (m)	Drawdown (m)	Pumping rate ( )
130.0	7.42	4.42	
140.0	7.42	4.42	
150.0	7.42	4.42	
160.0	7.59	4.59	
180.0	7.86	4.86	
200.0	7.89	4.89	
220.0	7.91	4.91	
240.0	8.43	5.43	
260.0	8.51	5.51	
280.0	8.61	5.61	
300.0	8.71	5.71	
320.0	8.76	5.76	
340.0	8.92	5.92	
360.0	8.98	5.98	

Appendix 4: Pumping test data from Ishieke Igbudu

SWL: 2.42m

TYPE OF PUMP: PEDROLLO- 1.5hp SUBMERSIBLE PUMP

DEPTH OF PUMP: 40.0m

Time since pumping started (m)	Dynamic water level (m)	Drawdown (m)	Pumping rate (lit/min)
0.5	2.81	0.39	49.2Lit/min
1.0	2.95	0.53	
1.5	3.02	0.6	
2.0	3.25	0.83	
2.5	3.38	0.96	
3.0	3.42	1	
3.5	3.69	1.27	
4.0	3.72	1.3	
4.5	3.78	1.36	
5.0	3.86	1.44	
5.5	4.12	1.7	
6.0	4.26	1.84	
7.0	4.39	1.97	
8.0	4.48	2.06	
9.0	4.59	2.17	
10.0	4.63	2.21	
12.0	4.72	2.3	
14.0	4.89	2.47	
16.0	5.02	2.6	
18.0	5.12	2.7	
20.0	5.24	2.82	
25.0	5.32	2.9	
30.0	5.51	3.09	
35.0	5.63	3.21	
40.0	5.84	3.42	
45.0	5.98	3.56	
50.0	6.11	3.69	
55.0	6.17	3.75	
60.0	6.18	3.76	
70.0	6.27	3.85	
75.0	6.47	4.05	
80.0	6.82	4.4	
85.0	6.96	4.54	
90.0	6.98	4.56	
95.0	7.38	4.96	
100.0	7.51	5.09	

Time since pumping started (m)	Dynamic water level (m)	Drawdown (m)	Pumping rate ( )
120.0	7.51	5.09	
140.0	7.62	5.2	
160.0	7.83	5.41	
180.0	8	5.58	
200.0	8.02	5.6	
220.0	8.13	5.71	
240.0	8.43	6.01	
260.0	8.52	6.1	
280.0	8.67	6.25	
300.0	8.72	6.3	
320.0	8.81	6.39	
340.0	8.81	6.39	
360.0	8.92	6.5	

Appendix 5: Pumping test data from Elegu

Ndiechi Ekpomaka

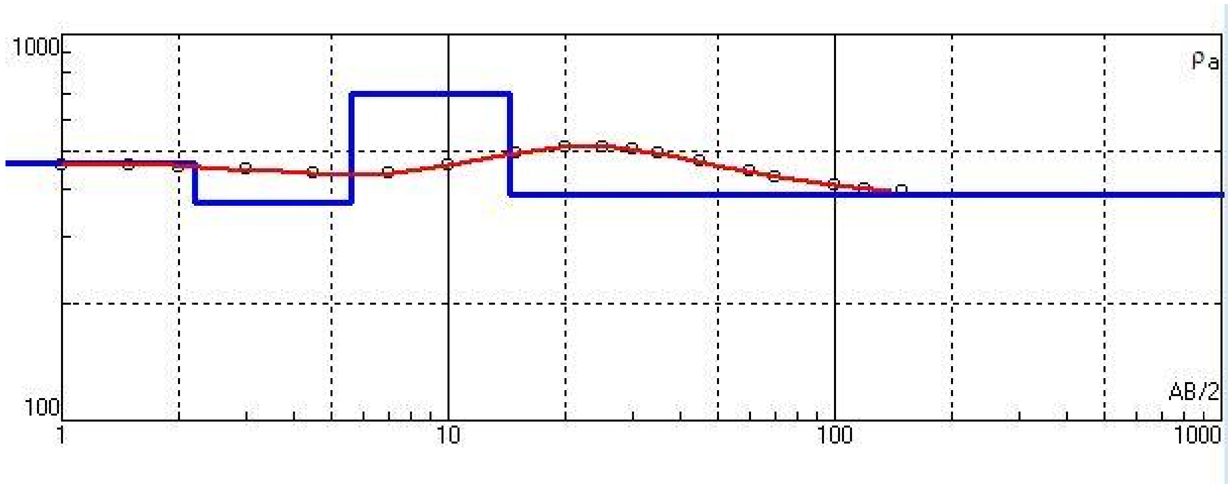
SWL: 2.06 m

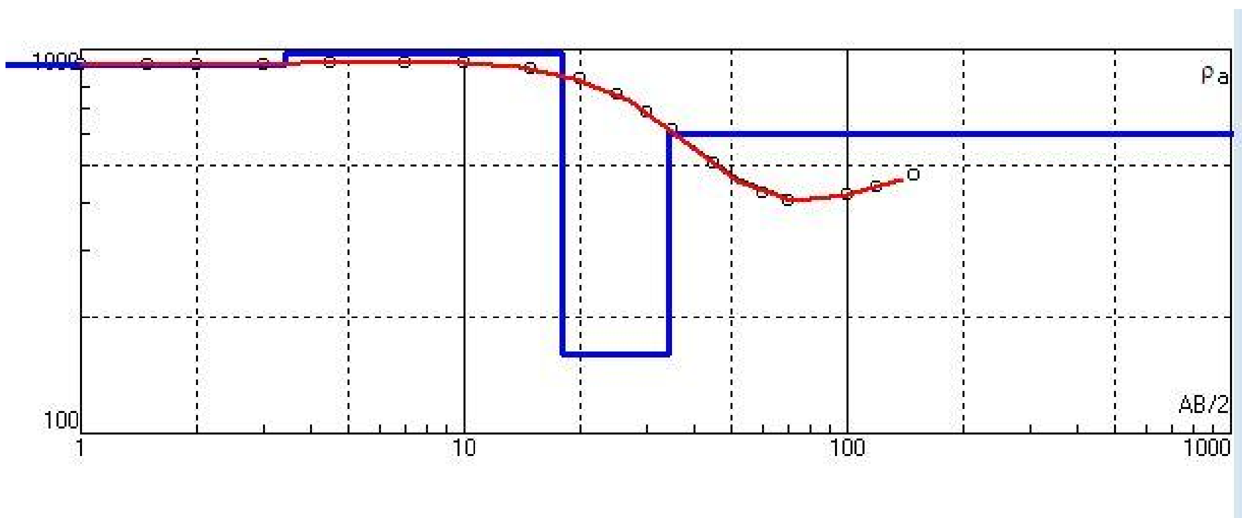
TYPE OF PUMP: ASTRA- 1.5hp SUBMERSIBLE PUMP

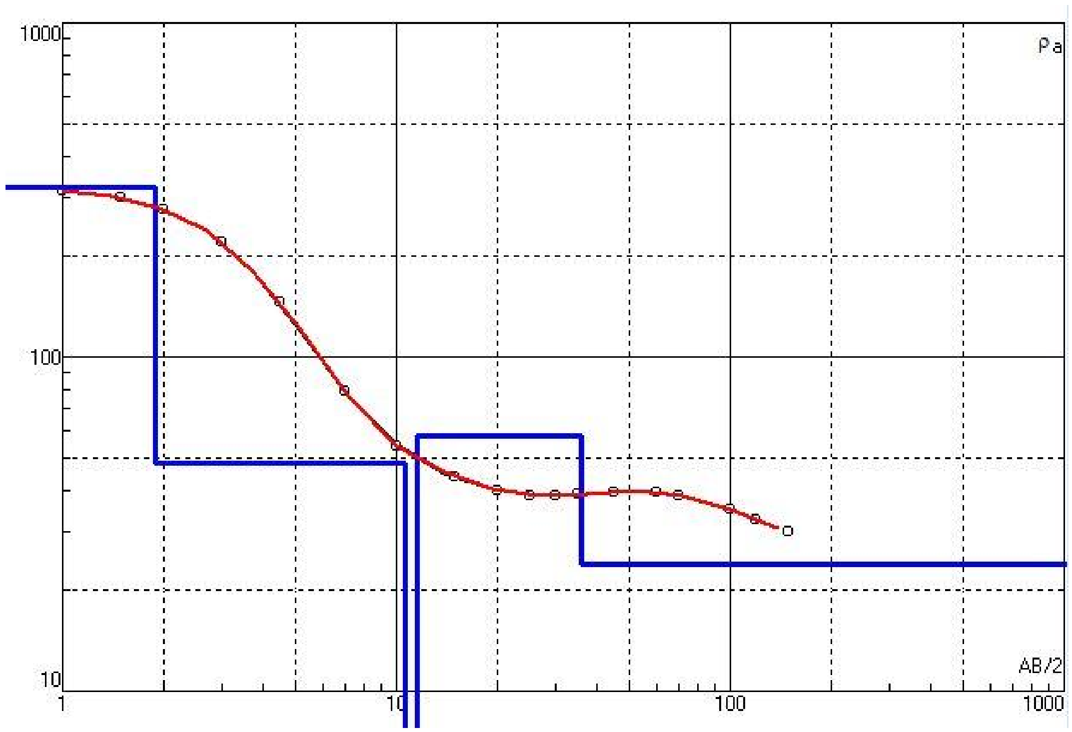
DEPTH OF PUMP: 42.87m

Time since pumping started (m)	Dynamic water level (m)	Drawdown (m)	Pumping rate (lit/min)
0.5	3.94	1.88	79.2Lit/min
1.0	3.98	1.92	
1.5	4.01	1.95	
2.0	4.11	2.05	
2.5	4.28	2.22	
3.0	4.36	2.3	
3.5	4.54	2.48	
4.0	4.83	2.77	
4.5	4.91	2.85	
5.0	4.95	2.89	
6.0	5.01	2.95	
7.0	5.23	3.17	
8.0	5.41	3.35	
9.0	5.57	3.51	
10.0	5.62	3.56	
12.0	5.81	3.75	
14.0	5.92	3.86	
16.0	5.99	3.93	
18.0	6.18	4.12	
20.0	6.21	4.15	
23.0	6.38	4.32	
26.0	6.42	4.45	
30.0	6.51	4.45	
35.0	6.8	4.74	
40.0	7.01	4.95	
45.0	7.12	5.06	
50.0	7.41	5.35	
60.0	7.52	5.46	
70.0	8.12	6.06	
80.0	8.2	6.14	
90.0	8.3	6.24	
100.0	8.4	6.34	
120.0	8.5	6.44	
140.0	8.6	6.54	
160.0	8.7	6.64	
180.0	8.8	6.74	

Appendix 6: Some VES curve types in the study area







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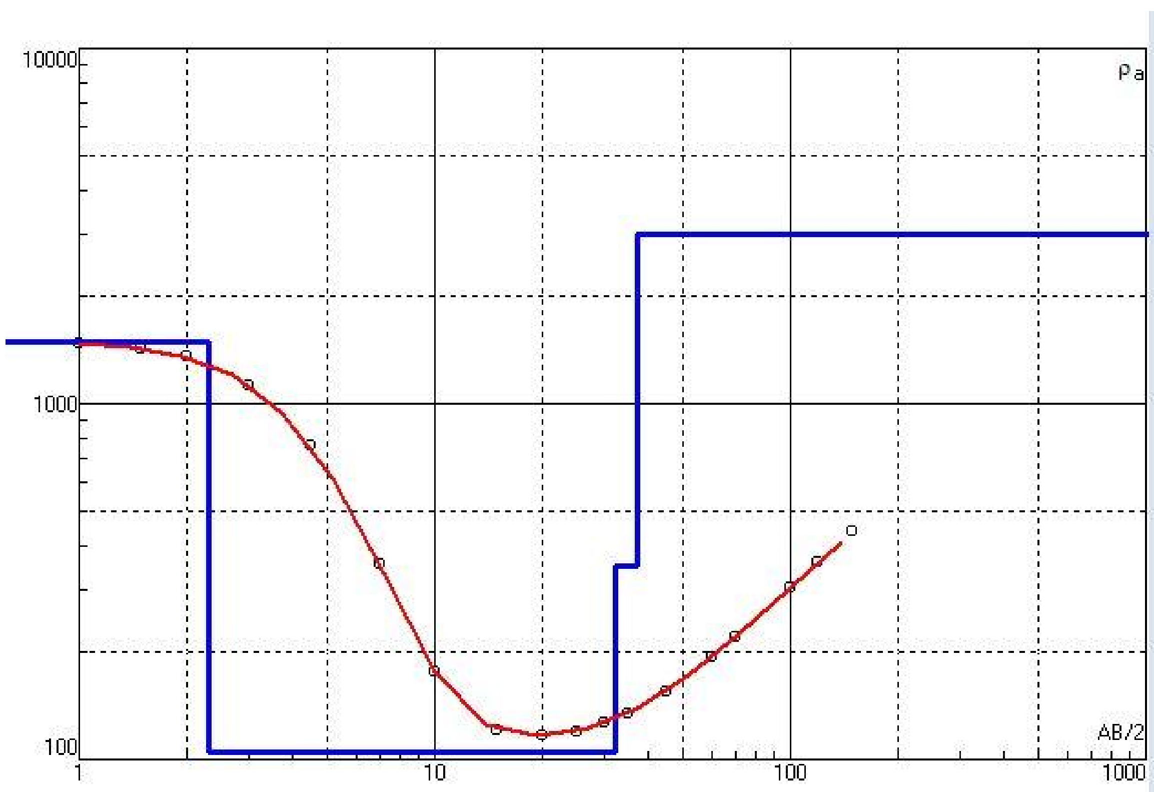

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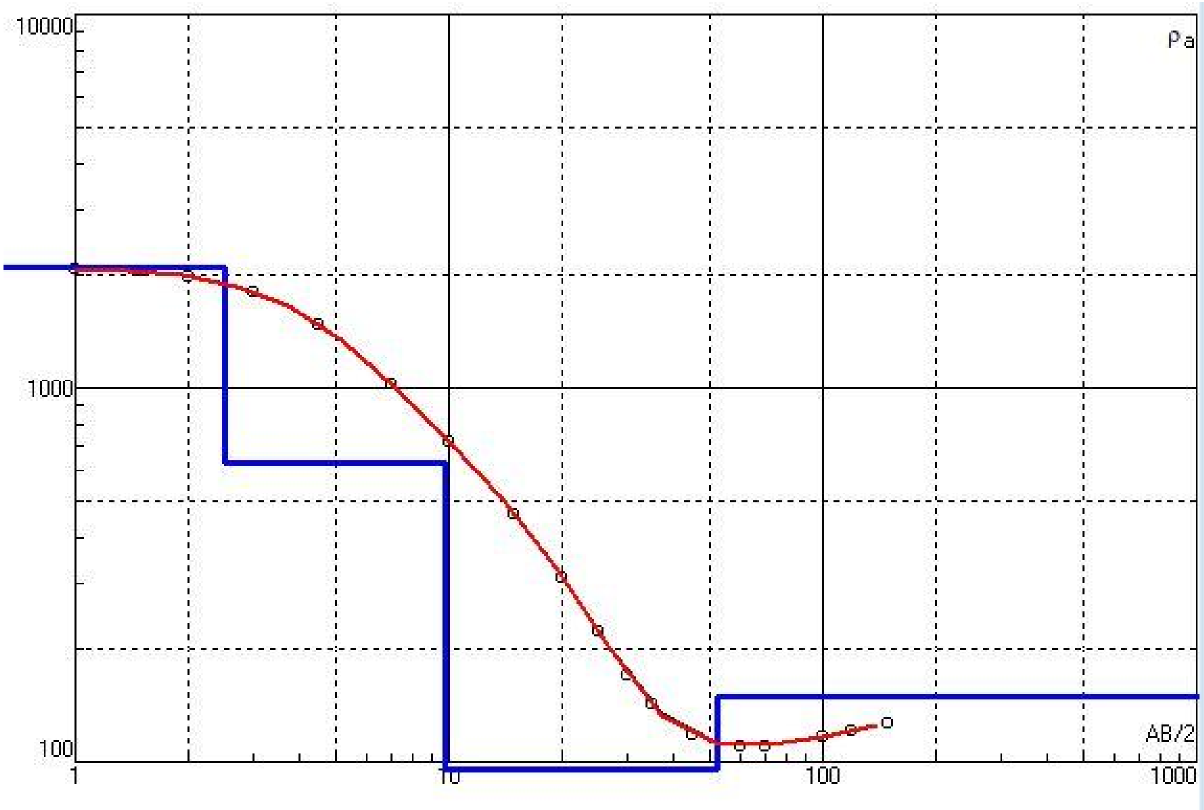
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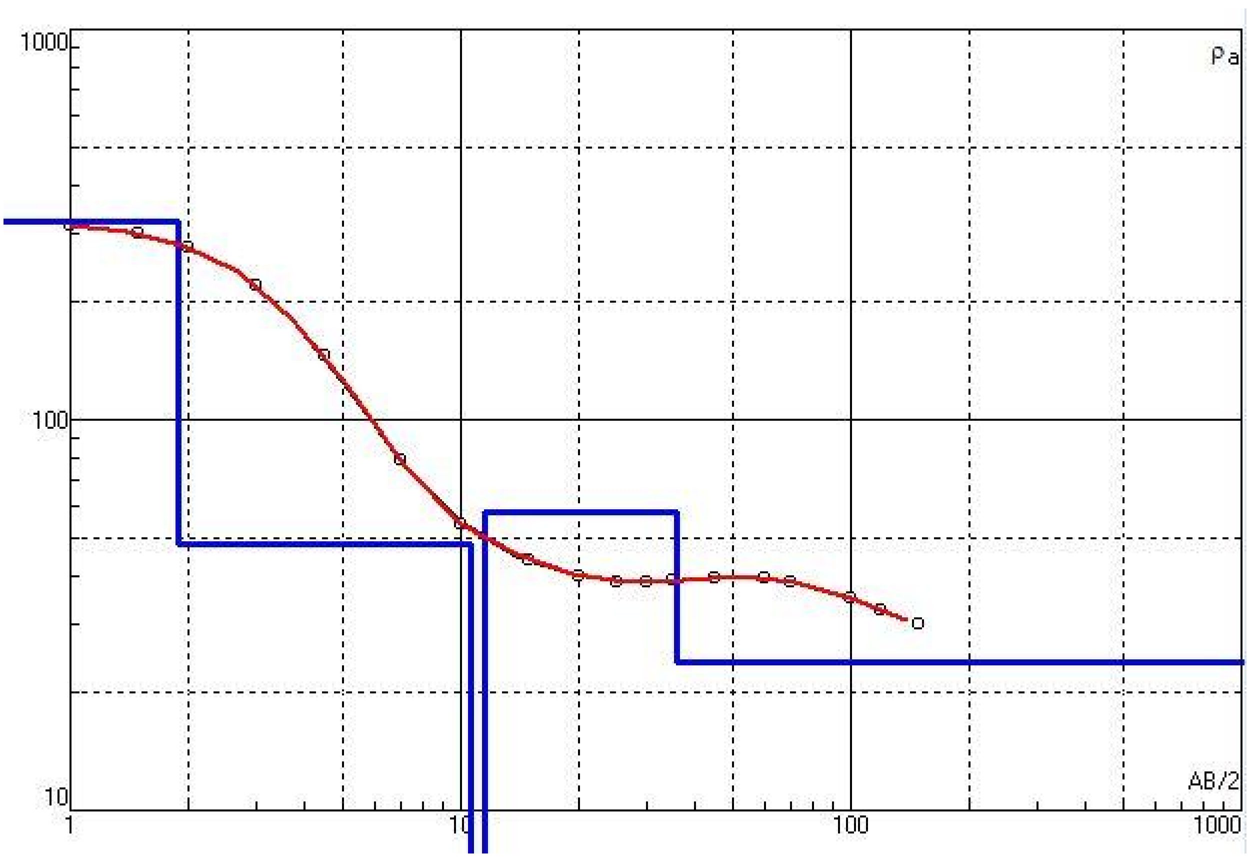
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