GEOPHYSICAL TECHNIQUE FOR GROUNDWATER EXPLORATION: A CASE STUDY USING VERTICAL ELECTRICAL SOUNDING AT UWASOTA, BENIN CITY, EDO STATE, SOUTHERN NIGERIA.

BY

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PSC2008246

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FACULTY OF PHYSICAL SCIENCES,

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BENIN CITY.

MARCH, 2025

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A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF GEOLOGY, FACULTY OF PHYSICAL SCIENCES, UNIVERSITY OF BENIN,

IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF A BACHELOR OF SCIENCE DEGREE (B.Sc) IN GEOLOGY.

MARCH, 2025

CERTIFICATION

This is to certify that this project was submitted and approved by the department of Geology in partial fulfilment for the requirement for the award of the Bachelor of Science in Geology, University of Benin, Benin City.

_______________________ _______________________

PROJECT SUPERVISOR **DATE**

(Dr. S. A SALAMI)

_______________________ _______________________

HEAD OF DEPARTMENT **DATE**

(Dr. S. A SALAMI)

DEDICATION

I dedicate this work to God, I also dedicate this work to my loving parents, Mr. and Mrs. Fredrick Etumah and to my siblings for their honest support and encouragements. Lastly, I dedicate this work to myself, for being amazing throughout my academic journey.

ACKNOWLEDGEMENT

I express profound gratitude to God Almighty for the success of my academic pursuit. This project would not have been possible without my deepest gratitude to God for his guidance and protection over myself, my family and loved ones.

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I extend heartfelt appreciation to my parents, Mr. and Mrs. Fredrick Etumah, for their unconditional love, unwavering support, prayers and financial assistance, especially through challenging times. Their selfless sacrifices have been a constant source of motivation for me. I am forever grateful for their presence in my life.

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Lastly, a special shout out to my parents once again and to my unborn kids, whom, if not for my love for them, I wouldn’t even be studying to get a degree.

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ABSTRACT

The study of geo-electrical resistivity provides critical insights into subsurface characteristics and aquifer dynamics, particularly in regions with varying geological formations. This research investigates the efficiency of Vertical Electrical sounding (VES), a geophysical technique, for groundwater exploration within the hydrological setting of Uwasota Benin city, southern Nigeria. The primary aim of this study is to characterize the geo-electrical layers, assess aquifer thickness and resistivity. A total of 4 VES was acquired using Schlumberger electrode array. The data was interpreted quantitatively using the partial curve matching and computer iteration techniques to generate the first order geo-electric parameters and to also delineate subsurface lithological variations and identify potential aquifer zones.

CHAPTER ONE

INTRODUCTION

1.1 General Statement

Water symbolizes the essence of life on our planet and holds tremendous significance across the globe. It exists in various forms, such as rain, snow, and subsurface aquifers, with groundwater being a crucial source of fresh water. Groundwater is defined as the water located beneath the Earth's surface, trapped in the pores of soil and the fractures in rock formations (USGS, 2023; Freeze & Cherry, 1979). An aquifer is categorized as a geological layer or loose sediment that can provide a substantial quantity of water (Todd & Mays, 2005; Winter et al., 1998). The water table is the depth at which the pores in the soil or the fractures in the rock are fully saturated with water (Alley et al., 1999). Groundwater is commonly extracted for agricultural, municipal, and industrial uses through the construction of operational extraction wells. It is also heavily relied upon for drinking water and irrigation in food production (Zekster and Everett, 2004). In fact, approximately 53% of the world's population relies on groundwater for their drinking needs, with this figure being even higher in rural areas (Jasechko et al., 2024). The electrical resistivity method is often viewed as the favored technique for evaluating groundwater potential among geophysical methods (Oladapo et al., 2022). Vertical Electrical Sounding (VES) is a frequently applied geo-electrical technique that assesses vertical variations in electrical resistivity. This method has been recognized as particularly suitable for hydrogeological surveys in sedimentary basins (Aizebeokhai et al., 2023).

The electrical resistivity method Involves measuring the apparent resistivity of soils and rocks depending on their depth or location. Vertical electrical soundings (resistivity sounding) are the most widely employed electrical technique in hydrogeological and environmental research (Zhou et al., 2023). The increasing global depletion of groundwater makes such geophysical methods essential in identifying viable groundwater sources, especially in arid and semi-arid regions where groundwater recharge is slow and aquifer depletion rates are accelerating (Jasechko et al., 2024). During resistivity surveys, an electric current is injected into the ground using a pair of current electrodes, while the voltage difference is logged between another pair of potential electrodes (Dobrin & Savit, 1988). The arrangement of the current and potential electrodes is typically linear.

Common configurations include the dipole-dipole array, pole-pole array, Schlumberger array, and Wenner array (Telford, Geldart, & Sheriff, 1990). To find the overall average resistivity of the various soils and rocks affecting the current, the measured potential difference is divided by the input current and then multiplied by a geometric factor corresponding to the specific array used and the spacing between the electrodes (Reynolds, 2011).

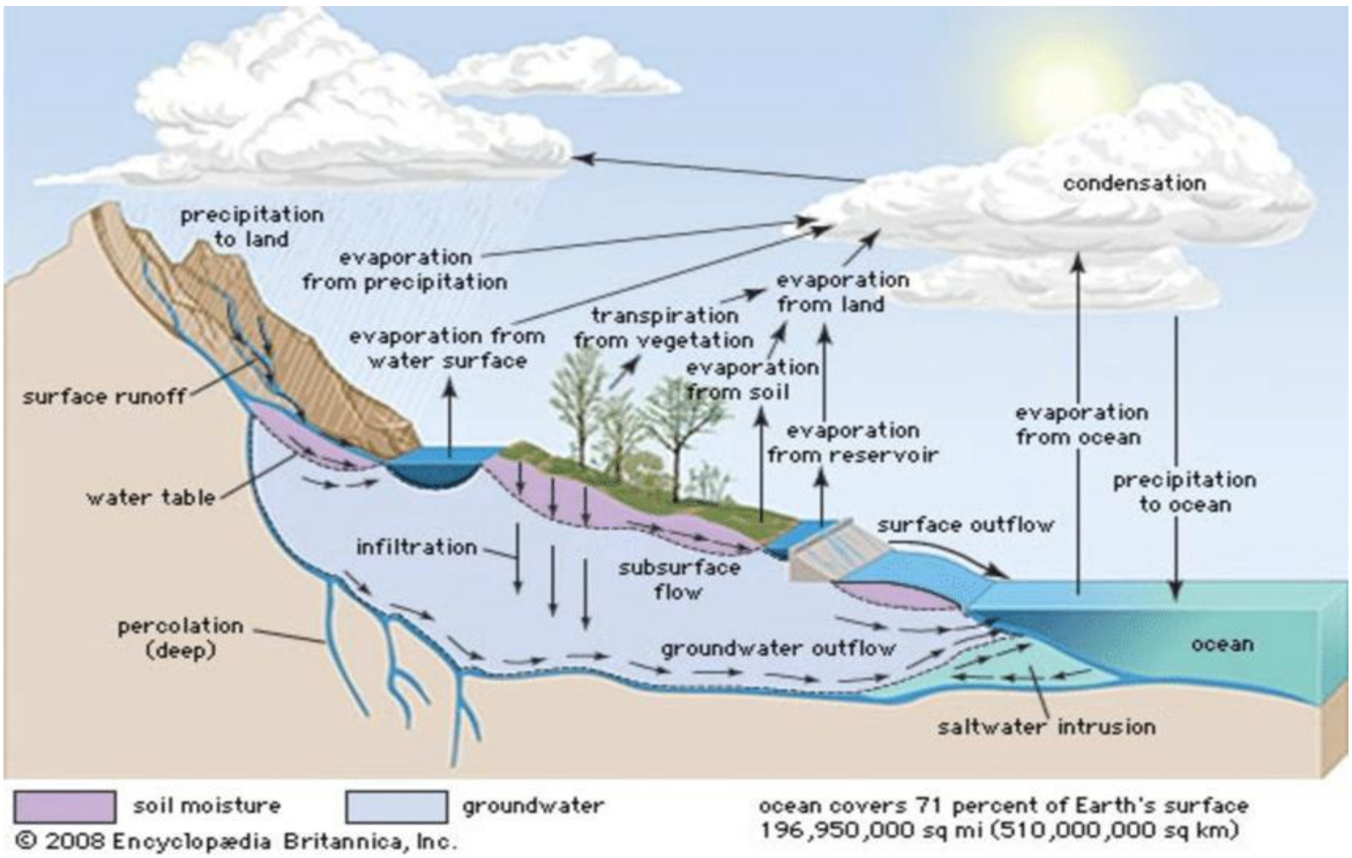

Figure 1: Hydrological cycle (Encyclopedia Britannica (2008).

1.2 Aim and Objectives

The aim of this research project is to explore the groundwater potential of the area by employing the vertical electrical sounding (VES) method. The objectives are as follows:

1. To delineate the lithology based on variations in resistivity values.
2. To assess the groundwater prospects within the area being studied.

1.3 Location of Study Area

The study area is located at Uwasota and environ, Egor Local Government Area of Edo State. It falls within the geographical location of Latitude N 6°22’50”- N 6°22’39” and Latitude E 5°35’30”- E 5°35’44” (fig 2)

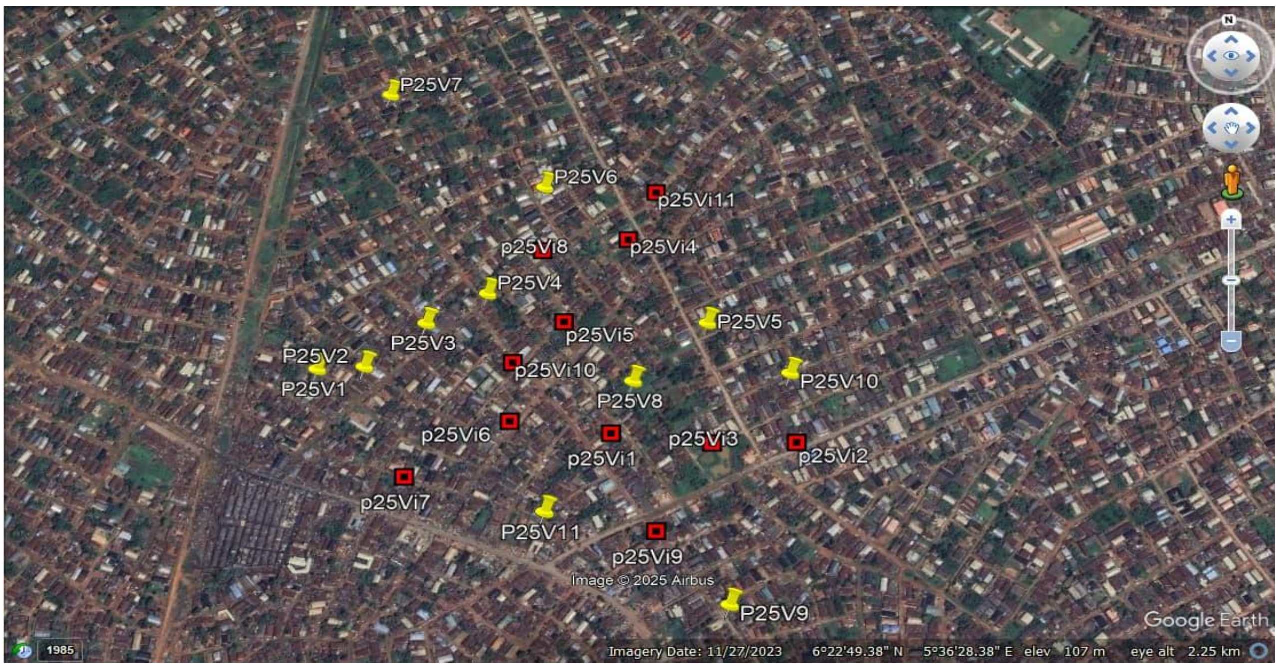

Figure 2: Location map of study area

1.4 Common Methods of Geophysical Investigation

1. Seismic Refraction: This technique assesses the duration it takes for seismic waves to propagate through various layers of the earth. By examining the arrival times of these waves at multiple locations, you can deduce the subsurface structure, including the depth of the bedrock or groundwater.
2. Magnetic method: This approach uses a magnetometer to passively record the earth's magnetic field at specific points along the surface. Irregularities in the magnetic data can reveal areas below the surface with high magnetic susceptibility, and therefore, can be employed for site characterization (Burger et al., 2006; Telford et al., 1990). The magnetic method uses a magnetometer to passively measure the Earth's magnetic field at various locations on the surface. Variations in magnetic data may suggest the presence of subsurface areas with high magnetic susceptibility, making it useful for site characterization (Burger et al., 2006; Telford et al., 1990).
3. In the electrical methods, there are various types utilized, which can be classified as passive—relying on the Earth's natural electric field—or active—utilizing artificial currents. These electrical methods apply direct currents or low-frequency alternating currents to study the electrical characteristics of the subsurface (Kearey et al., 2002).
4. The gravity method entails measuring the variations in Earth's gravity field, which are influenced by local differences in subsurface rock density. This technique is primarily linked with extensive regional geophysical surveys that explore geological structures at significant depths. Gravity measurements can also be conducted from aircraft or maritime locations. Initially, in terrestrial investigations, gravity data was primarily utilized to create contoured maps that identified anomalous areas related to reduced density in the near-surface materials, often due to the presence of cavities or mineshafts. For specific uses, such as detecting near-surface voids, the gradient of the Earth's gravity field can be assessed. In larger engineering surveys, this method has been employed to pinpoint substantial fault zones, deeply buried channels, and rock formations within back-filled quarries.

1.4.1. Electrode Array

This refers to a configuration of electrodes intended for the purpose of measuring electric current or voltage. Some electrode arrays are capable of operating in both directions, allowing them to be used for applying a stimulating pattern of electric current or voltage as well. Examples of electrode arrays include the Schlumberger array, Wenner array, pole-pole array, pole-dipole array, and others. Below are details about the Schlumberger and Wenner arrays.

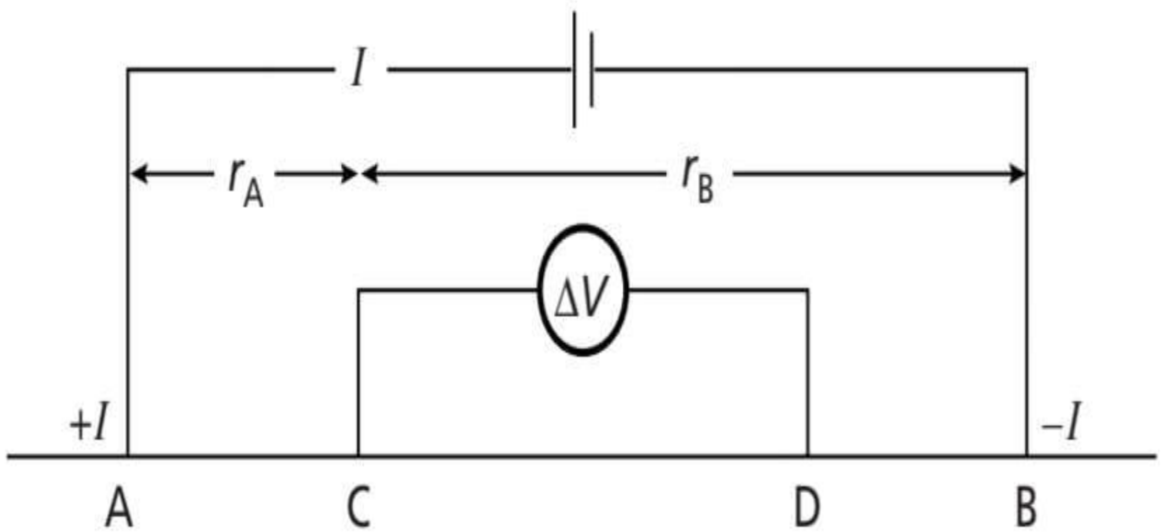

Figure 3: Electrode Array (Kearney et al., 2002).

1.4.2. Schlumberger Array

The Schlumberger array, illustrated in the accompanying figure, consists of four electrodes arranged in a straight line around a central point. The outer electrodes, designated as A and B, function as the current electrodes, while the inner electrodes, M and N, serve as potential electrodes and are positioned close together. Throughout the survey, the current electrodes (A and B) are gradually moved further apart to increase their separation, while the potential electrodes (M and N) remain fixed until the detected voltage drops too low to measure reliably. When that happens, the potential electrodes are moved outward to a new separation. Typically, the distance between M and N should start off as equal to or less than one-fifth of the distance between A and B, with adjustments made based on signal strength, often reducing to one-tenth or one-fifteenth. The geometric factor for the Schlumberger array is determined by multiplying 3.142 by the difference between half the square of the initial separation of A and B and half the square of the initial separation of M and N, which is then divided by the distance between M and N.

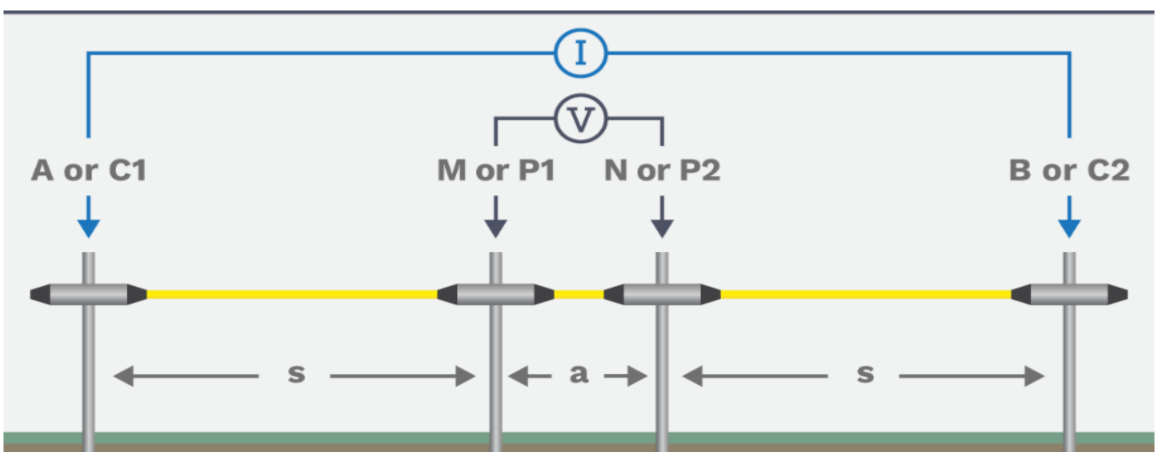

Figure 4: Schlumberger array (Hassan, 2017).

1.4.3 WENNER ARRAY

This configuration of electrodes features four electrodes positioned in a straight line, maintaining equal spacing between the two potential electrodes and between each current electrode and its closest potential electrode. The geometric factor (Kg) for this arrangement is determined by multiplying 2π by the value of a, which varies according to the particular situation.

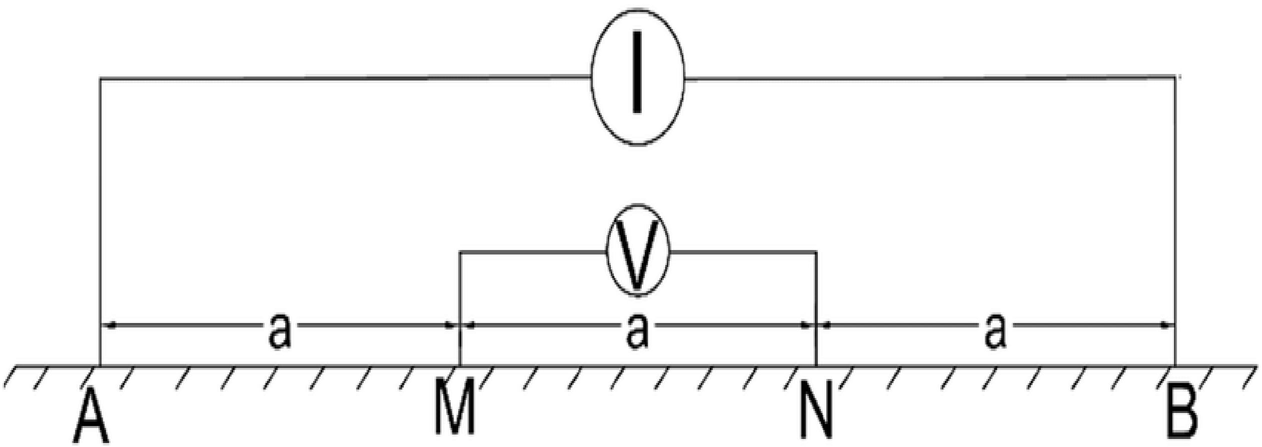

Figure 5: Wenner array (Puttiwongrak and Tesfaldet, 2019).

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

Groundwater is an essential resource for drinking, irrigation, and industrial activities, particularly in urban areas such as Benin City, Nigeria. With the growing demand for clean water in the city and its surrounding areas, it is crucial to adopt effective methods for the exploration and assessment of groundwater resources. One such geophysical method commonly employed to assess subsurface resistivity and identify aquifer formations is Vertical Electrical Sounding (VES). This chapter examines prior research on the implementation of VES in groundwater exploration, with an emphasis on studies carried out in Nigeria.

2.2 Geology of The Study Area

The study area which is the environs of Uwasota is underlined by Benin Formation (information centre, 2010). The geology and hydrogeology of the Benin Formation have been documented (Kogbe, 1976) the area lies between 6°22′N and longitudes 5°35’E. The topography of the area is a plane surface which has the following rock types, topsoil, laterite, clay, sandy clay and clean sand which is in close agreement with the Benin Formation that ranges from miocene to recent. The inhabitant of these survey area earns their sources of livelihood from petit business activities such as trading.

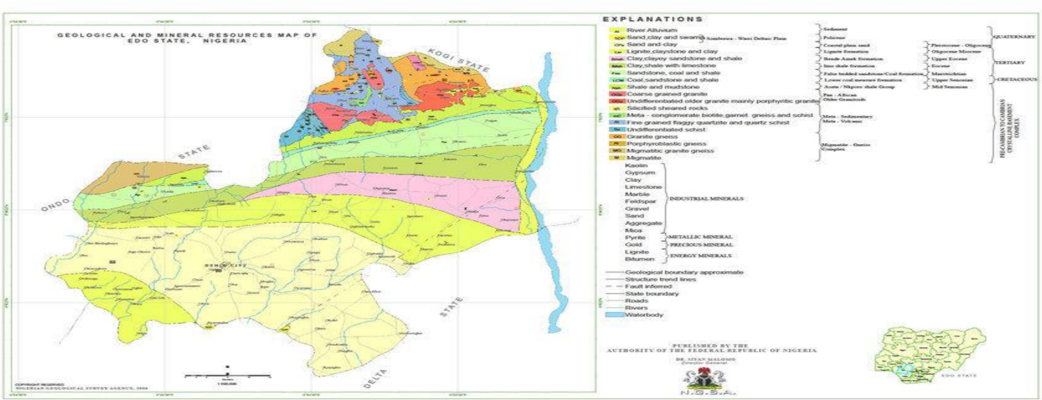

Figure 6: Geological map of Edo state showing benin city and other location (Nigerian Geological Survey Agency, 2006).

2.3 The Niger Delta Stratigraphy

The Niger Delta basin's sedimentary fill has been divided into three (3) broad lithofacies units: Marine shale (Akata Formation), Marginal marine sandstones, shale, and clays (Agbada Formation), and massive continental sandstones (Benin Formation), all of which reflect a gross upward-coarsening clastic wedge. These formations were deposited primarily in marine, deltaic, and fluvial settings. These three geologic formations in the Niger Delta are discussed below:

2.4 Benin Formation

The coastal plain sands found in the Benin-Onitsha area, which stretch north of the present shoreline, represent the upper section of the Niger Delta clastic wedge. The upper boundary of this geological formation is marked by the top surface of the youngest underlying marine shales and reaches a depth of around 1400 meters. This formation is thought to have originated from the Oligocene period up to the current day. The shallow areas of the formation comprise of non-marine sands that formed in alluvial or upper coastal plain environments during the advancement of the delta. As one moves basinward within the formation, it becomes increasingly thinner, ultimately terminating near the shelf's edge. The primary deposits are large, highly porous, freshwater-saturated sandstones, with sporadic clay drapes and minimal shale intercalation, particularly towards the formation's base. It exhibits a fine-grained sandy consistency that is frequently granular. The grains are mostly unconsolidated, exhibiting sub-rounded to well-rounded shapes, and show poor sorting. The sands take on a white or yellowish-brown due to a limonitic layer. In certain regions, one can find traces of vegetation and lignite streaks, along with grains of hematite and feldspar. The age of these sediments spans from the Miocene to the present; however, the limited presence of faunal remains, complicates precise dating. Thickness varies from 0 to 2100 meters, being most substantial in the central delta area where subsidence is most significant. The Benin Formation is described as being partially marine, partially deltaic, partially estuarine, and partially lagoonal, indicating its development within a continental upper deltaic environment.

2.4.1 Agbada Formation

The Agbada Formation is a paralic sequence consisting of interlayers of shale and sand across the Niger Delta clastic wedge. Its shale thickness increases while sand thickness decreases as depth increases. The formation can reach a maximum thickness of approximately 3,900 meters and spans an age range from the Eocene to the Pleistocene. It is found in southern Nigeria, identified as the

Ogwashi-Asaba and Ameki Formations. The lithological composition primarily consists of alternating sands, silts, and shales, exhibiting changes in grain size and bed thickness progressively. The strata are generally understood to have formed in fluvial-deltaic settings, positioned beneath the Benin Formation, the Agbada Formation comprises interbedded fluvio-marine sands, sandstones, and siltstones in varying proportions and thicknesses that depict a cyclical sequence of off lap units. The sandstone textures range from coarse to fine, it varies from poorly sorted to very well sorted, and it transition from unconsolidated to slightly consolidated stratas. Some fragments of shells and glauconites are noted to have a limonite streak and coating. The shales are characterized by medium to dark grey coloration, good consolidation, and a silty composition, with scattered glauconites present throughout. The formation transitions gradually into the Akata Formation as the shale content increases. The Agbada Formation consists of a complex series of deposits that formed in at least five distinct environments: holomarine, barrier bar, barrier foot, tidal coastal plain, and lower deltaic floodplain. Its thickness varies from 0 to 4,500 meters.

2.4.2 Akata Formation

In the central area of this clastic wedge, lies the Akata Formation, characterized by prodeltaic dark grey shales and silts. This is the lowest unit of the modern delta. Near the contact between the overlying Agbada Formation, there are also sandstone lenses. It ranges from Eocene to Recent and is thought to have been deposited in front of the advancing delta. It is over 4,000ft thick. (fig 7) shows the stratigraphy of the Niger delta basin.

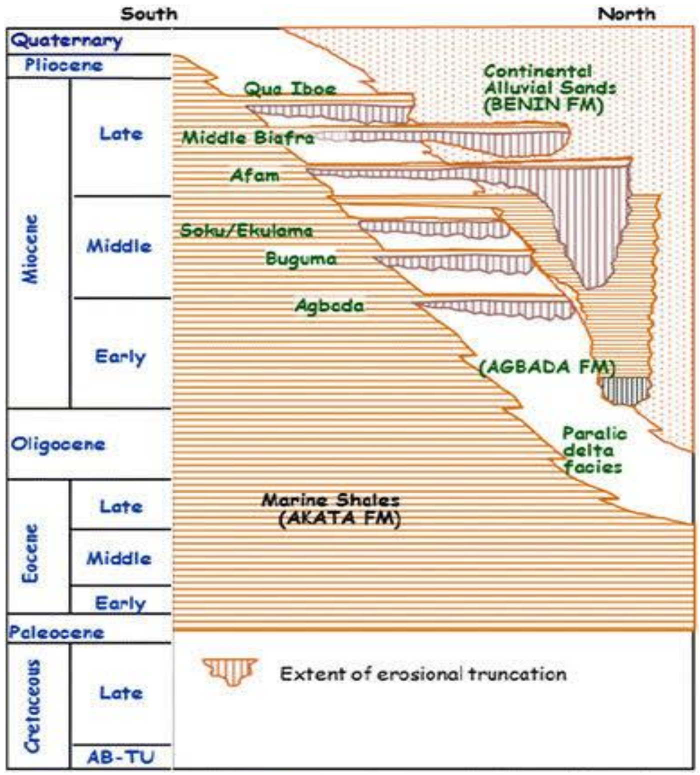

Figure 7: The regional Stratigraphy of the Niger Delta (Corridor et al.)

2.5 The Principle Of Vertical Electrical Sounding

Vertical Electrical Sounding (VES) is a geophysical method that evaluates the resistivity of the underground by passing an electrical current into the earth using a pair of current electrodes, while simultaneously recording the potential difference with a set of potential electrodes. The resistivity of various subsurface layers changes according to the type of material, water content, and other parameters, which makes VES effective in differentiating between various geological formations, including groundwater aquifers. As noted by Telford et al. (1990), VES is commonly utilized in environmental and hydrogeological research due to its non-invasive characteristics, allowing for broad profiling of underground conditions without the necessity of drilling.

Recent developments in the interpretation of VES data, including inversion methodologies and 2D/3D resistivity imaging (Loke, 2010), have greatly enhanced the precision and detail of the technique, facilitating improved detection of groundwater zones in both shallow and deep aquifers. These progressions make VES particularly useful in intricate urban settings like Benin City, where subsurface conditions are often inconsistent.

2.6 Application Of Ves In Groundwater Exploration In Nigeria

VES has been effectively deployed in different regions of Nigeria for groundwater exploration, offering crucial insights into subsurface conditions and potential water supplies. Research conducted in southwestern Nigeria, Delta State, and other locations illustrates the effectiveness of VES in aquifer mapping and groundwater availability assessment.

2.6.1 Southwestern Nigeria

In southwestern Nigeria (Olayinka et al 1999) employed VES to examine groundwater availability, utilizing the technique to pinpoint water-bearing formations at varying depths. The findings indicated that VES was highly proficient at mapping both shallow and deep aquifers, particularly in areas characterized by sedimentary basins. Their results highlight that VES is a suitable method for evaluating groundwater resources in areas like Benin City, which shares similar geological attributes, including sedimentary rocks and diverse resistivity profiles.

2.6.2 Warri, Nigeria

(Atakpo, E.O 2013) carried out VES surveys in Warri, an urban area in southern Nigeria, to evaluate groundwater potential. The research indicated that VES could effectively pinpoint aquifers even amidst the urban challenges posed by infrastructure, contamination, and human activities. His study illustrated the relevance of VES in urban environments, where subsurface conditions are frequently influenced by both artificial and natural factors. His study has provided an insight to the subsurface disposition of the aquifer systems and delineated areas for groundwater development programme in Deghele community. The findings from Warri are pertinent for Benin City, considering the urban expansion and growing demand for water resources in both locations.

2.6.3 Ves Research Pertaining To Benin City, Nigeria

Although numerous studies on VES have been conducted in Nigeria, research specifically targeting Benin City is still fairly sparse. Nonetheless, investigations carried out in adjacent regions, such as Warri and southwestern Nigeria, offer valuable insights that can be relevant to Benin City. For example, (Egwebe, and Braimah, 2007) carried a geo-electric investigation in the city of Benin, examining groundwater availability and potential water extraction. They discovered that VES could efficiently delineate both shallow and deep aquifers, aiding in the identification of prospective groundwater sources for the city.

2.7 Advances In Ves Interpretation

Recent developments in the interpretation of VES data have markedly improved its precision and dependability in groundwater studies (Loke and Barker 1996) presented rapid inversion methods, enabling the swift and effective interpretation of VES data. These methods utilize computational models to generate 2D resistivity profiles, offering a more transparent view of subsurface conditions.

In addition, 2D and 3D resistivity imaging, as outlined by (Loke 2010), has become increasingly prevalent in contemporary geophysical surveys. These techniques facilitate more intricate imaging of subsurface formations, enhancing the resolution of aquifers and other geological features. This is particularly vital for urban areas like Benin City, where shallow and deep groundwater layers may be separated by low-resistivity materials such as clay.

These advancements have enhanced the accuracy of VES in mapping intricate geological formations and are anticipated to boost the reliability of groundwater investigations in Benin City, where the geology and hydrology can be complex.

2.8 Limitations In The Research

While there is a substantial body of literature concerning VES applications for groundwater exploration in Nigeria, certain considerable gaps remain. Most research has concentrated on rural settings or areas with simpler geological structures. In contrast, Benin City, as a prominent urban center experiencing rapid population increase, poses distinctive challenges for groundwater exploration. These issues entail the influence of urbanization on subsurface conditions and the risk of contamination of shallow aquifers. VES can also serve as a valuable instrument for groundwater exploration in Benin City, especially in understanding the depth and distribution of aquifers beneath the urban area.

CHAPTER THREE

MATERIALS AND METHODS

3.1 List of Equipment

The equipment used for the field work comprise of:

1 The ABEM digital Terrameter, shown in Plate 1, is a signal averaging device known as the SAS300. It operates in various modes and completes four cycles. In the resistivity mode, it features a battery-operated deep penetrating resistivity meter capable of supporting current electrode separations of up to 2 km under optimal surveying conditions. The system automatically computes the ratio of the resulting potential (V) to the supplied current (I), averages this over a chosen number of cycles, and presents the result digitally in milliohms, ohms, or kiloohms. The measurement range spans from 0.5 milliohm to 1999 kiloohms. The SAS300 consists of three compact units contained within a single casing: the transmitter, the receiver, and the microprocessor. These units collaborate as one to generate the displayed reading. The voltage signal produced by the transmitted current is picked up by the receiver after filtering out noise from the actual signal. The microprocessor manages and oversees all measurements to guarantee high accuracy, performing a comprehensive check on the circuit and switch position every second.

Plate 1: The Terrameter

2 Cable reels: These instruments are used to connect the electrodes to the terrameter which gives reading.

3 Connecting cables: They are used to connect the terrameter to the cable reels.

4 Connecting cables: They are used to connect the terrameter to the cable reels.

5 Hammer: The instrument was used to nail electrodes into the ground
6 Electrodes: The instrument is used to collect data and also marking points.
7 Measuring tapes: The instrument is used to measure distance in the field.
8 GPS: The instrument is used to get GPS coordinates and take the elevation of the aeas were readings were taken from.
9 Battery (Backup): This is used to power the terrameter instrument on the field

Plate 2: Cable reels

Plate 3: Connecting cables

Plate 4: Hammer

Plate 5: Electrodes

Plate 6: Measuring tapes

Plate 7: GPS

Plate 8: Battery (Backup)

3.2. Field Procedure

Field operations involved performing VES traverses at specific locations within the research zone. Each VES traverse began with the establishment of a central point where an electrode was inserted as a reference for measuring the array spread. The electrode configuration employed was the Schlumberger array, which necessitated placing potential and current electrodes at equal distances from the center point. These electrodes were connected to the appropriate reels and inserted into the ground. The reels were then attached to a Terrameter, which was turned on to capture resistance measurements by pressing a button. Once a measurement was acquired, the current electrodes were systematically moved further away from the center, followed by another reading. This process was repeated until the resistance was too low to detect, at which point the potential electrodes were also moved apart, and the current intensity was increased to obtain larger readings. This cycle continued until the predetermined endpoint of the spread was achieved. The exact positioning of the electrodes from the center was determined using the point-per-decade technique, with the study applying the 6-point-per-decade method.

3.3. Data Acquisition

Various surface geophysical techniques are available for groundwater exploration, but the Electrical Resistivity Method is the most widely used. This method measures the apparent resistivity of the subsurface, aiding in the identification of bedrock fractures, contaminants, and groundwater. Variations in electrical resistivity can indicate changes in rock composition, layer thickness of the weathered zone, or overburden (Fajana, 2020). The resistivity of subsurface materials such as rocks and minerals, is influenced by factors like lithology, porosity, water saturation, and the presence of voids in the rock. Soil electrical resistivity reflects the soils ability to conducts electrical currents and serves as a key indicator of permeability, helping to predict its water-bearing capacity (Ibuot et al., 2022). In this study, the Electrical resistivity method was employed using the Schlumberger configuration. A direct current (D.C.) was passed into the soil through a pair of current electrodes, while the potential difference (Δv) resulting from this current flow was measured using a second pair of electrodes (potential electrodes). Figure 4 provides a systematic representation of the field data acquisition process and subsurface current interactions.

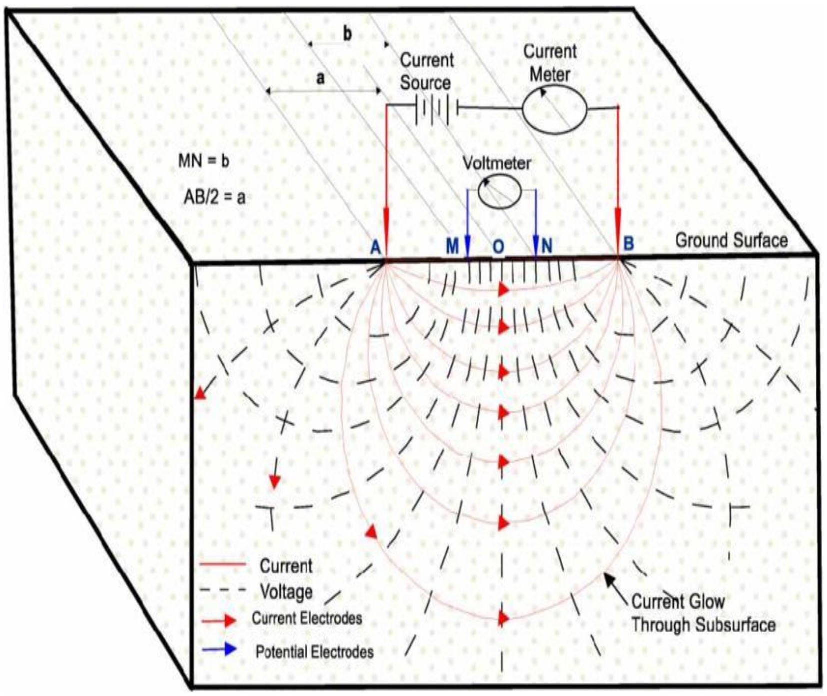

Figure 8: Electrical resistivity measurements (Akiang et al. 2024)

Plate 9: Picture of our data acquisition on the field.

3.4 Field Precautions

The following measures were implemented to minimize errors during data acquisition:

1. Proper contact between the reel wires and electrodes was ensured.
2. The electrodes were securely hammered into the ground to establish good contact.
3. Care was taken to avoid proximity to power lines to prevent distortion in resistance readings.
4. It was ensured that reels were disconnected from the terrameter while they were rotating to prevent tangling.
5. Precautions were taken to avoid the crossing of potential and current reel wires to prevent tangling.

3.5 Adjusted Data

The adjusted data results from the data reduction process, which includes plotting the apparent resistivity values on the vertical axis against the current electrode spacing (AB/2) on a log-log graph, either manually or electronically. After this step, the curve is examined to determine its smoothness, and corrections can be applied to enhance the smoothness of the resistivity curve. Adjusting these values to create a more uniform curve leads to the generation of the adjusted values

3.6 Interpretation Technique

In this section, the Quantitative interpretation technique is utilized. The observed apparent resistivity values are graphed against the current electrode position AB/2 (m), where A and B represent the two positions of the current electrodes, on standard double logarithmic paper with a scale of 62.5mm per decade. While employing this method, focus is placed on the configuration of the field curve, particularly the nature of the connections between adjacent sections in cases involving three layers. Four prevalent relationships or curves labeled H, K, A, and Q correspond to Bowl type, Bell type, ascending type, and Descending type curves, respectively, which have been identified for the apparent resistivity field curves. The process of determining the number of layers along with their specific thicknesses from the curve is referred to as quantitative interpretation. Geo-electric parameters were manually extracted from the adjusted resistivity values after applying smoothing techniques using Microsoft Excel. For the final stages of interpretation related to identifying lithology, analyzing groundwater depth, and constructing a

Geo-electric section that illustrates the various lithologies, IX1D and Surfer software were employed.

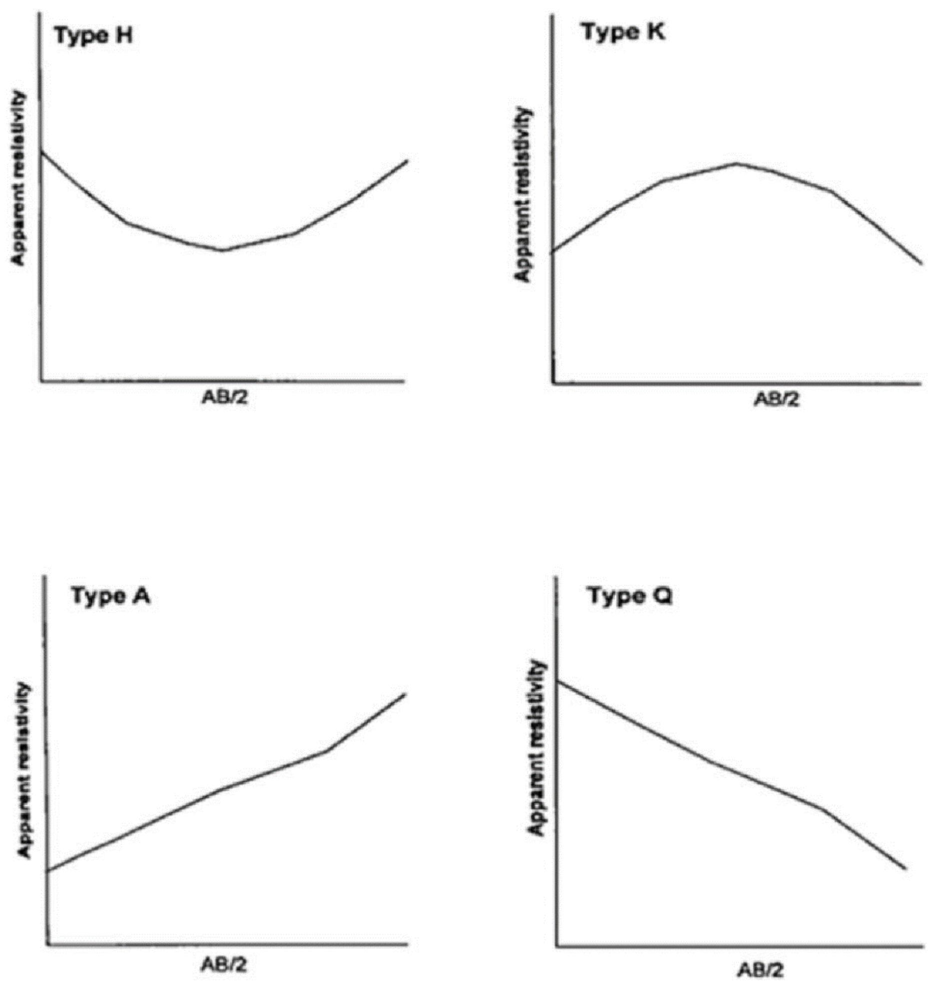

Figure 9: Resistivity curves (after Gopinath & Seralathan, 2003)

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Results

The study results are presented in the form of Geo-Electric pseudo-sections, tables and resistivity curves. Figures display the results of the four VES curves (Vertical Electrical Sounding) which were obtained from the adjusted values of apparent resistivity acquired from the field. Geo-Electric Layers (GL) were generated using computer interpretation operations.

VERTICAL ELECTRICAL SOUNDING [VES] SCHLUMBERGER ARRAY FIELD RECORD

COORDINATES: N 6°22’46.33” E 5° 35’4”

SOUNDING NUMBER: GHV1

Table 1: Results for GHV1

AB/2[m]	MN/2[m]	Adj. Resistivity [Ωm]
1.00	0.4	65.95
1.47	0.4	57.03
2.15	0.4	49.95
3.16	0.4	62.98
4.64	0.4	80.80
6.81	0.4	114.58
10.00	4.00	142.53
14.70	4.00	191.13
21.50	4.00	232.89
31.60	4.00	348.17
46.40	20.00	457.13
68.10	20.00	567.77
100.00	20.00	636.77
147.00	80.00	650.56
215.00	80.00	589.40

316.00	80.00	550.10

VERTICAL ELECTRICAL SOUNDING [VES] SCHLUMBERGER ARRAY FIELD RECORD

COORDINATES: N 6°22’42.74” E 5° 35’35.76”

SOUNDING NUMBER: GHV2

Table 2: Results for GHV2

AB/2[m]	MN/2[m]	Adj. Resistivity [Ωm]
1.00	0.4	105.91
1.47	0.4	96.01
2.15	0.4	99.51
3.16	0.4	101.55
4.64	0.4	117.57
6.81	0.4	122.93
10.00	4.00	157.79
14.70	4.00	182.96
21.50	4.00	244.90
31.60	4.00	355.11
46.40	20.00	491.75
68.10	20.00	584.72
100.00	20.00	693.12
130.00	80.00	797.76

VERTICAL ELECTRICAL SOUNDING [VES] SCHLUMBERGER ARRAY FIELD RECORD

COORDINATES: N 6°22’45.1” E 5° 35’48.81”

SOUNDING NUMBER: GHV3

Table 3: Results for GHV3

AB/2[m]	MN/2[m]	Adj. Resistivity [Ωm]
1.00	0.4	333.51
1.47	0.4	274.76
2.15	0.4	237.63
3.16	0.4	237.01
4.64	0.4	253.83
6.81	0.4	317.42
10.00	4.00	388.67
14.70	4.00	447.99
21.50	4.00	523.80
31.60	4.00	575.75
46.40	20.00	654.94
68.10	20.00	691.61
100.00	20.00	708.92
147.00	80.00	681.62
215.00	80.00	583.42

VERTICAL ELECTRICAL SOUNDING [VES] SCHLUMBERGER ARRAY FIELD RECORD

COORDINATES: N 6°22’37” E 5° 35’44”

SOUNDING NUMBER: GHV4

Table 4: Results for GHV4

AB/2[m]	MN/2[m]	Adj. Resistivity [Ωm]
1.00	0.4	62.81
1.47	0.4	54.31
2.15	0.4	47.57
3.16	0.4	59.98
4.64	0.4	76.95
6.81	0.4	109.12
10.00	4.00	135.74
14.70	4.00	182.03
21.50	4.00	221.80
31.60	4.00	331.59
46.40	20.00	435.36
68.10	20.00	540.45
100.00	20.00	606.45
147.00	80.00	631.87
215.00	80.00	619.58
316.00	80.00	561.33

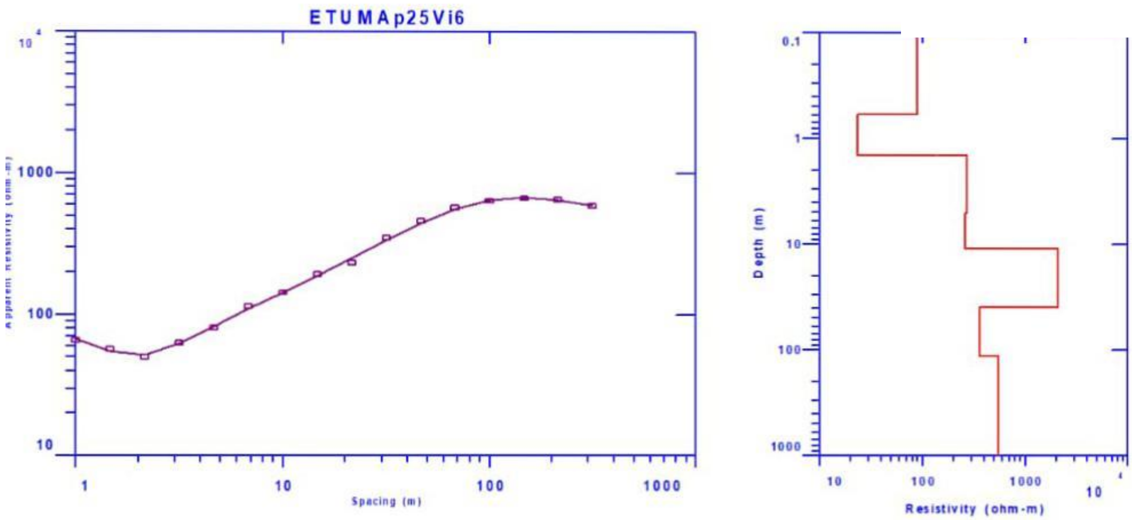

Figure 10: GHV1 Interpreted results: Left; Resistivity curve, Right: Interpreted Geomode.

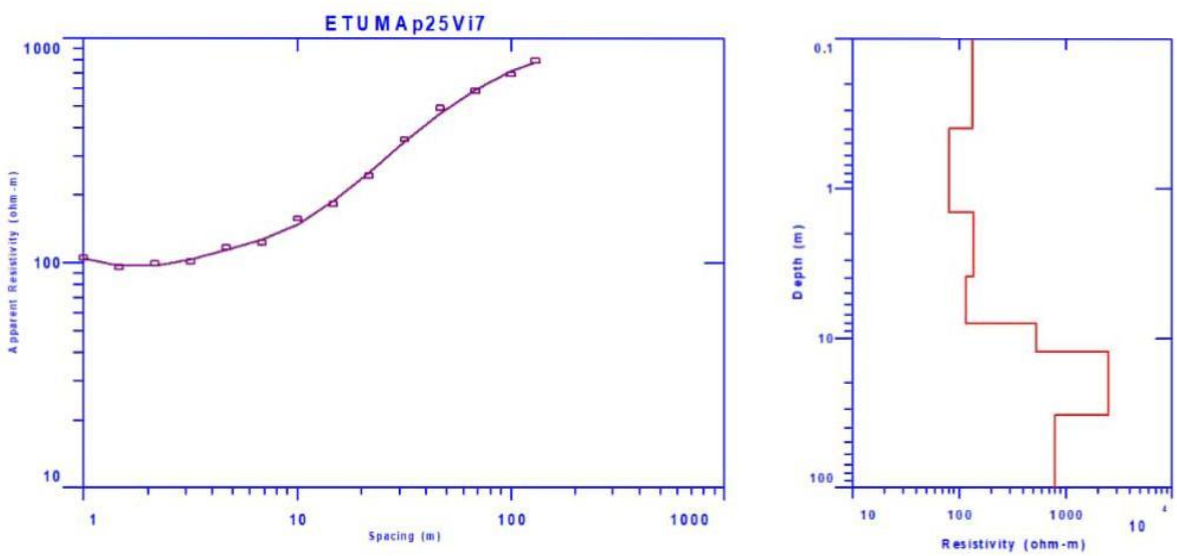

Figure 11: GHV2 Interpreted results, Left: Resistivity curve, Right: Interpreted Geomode.

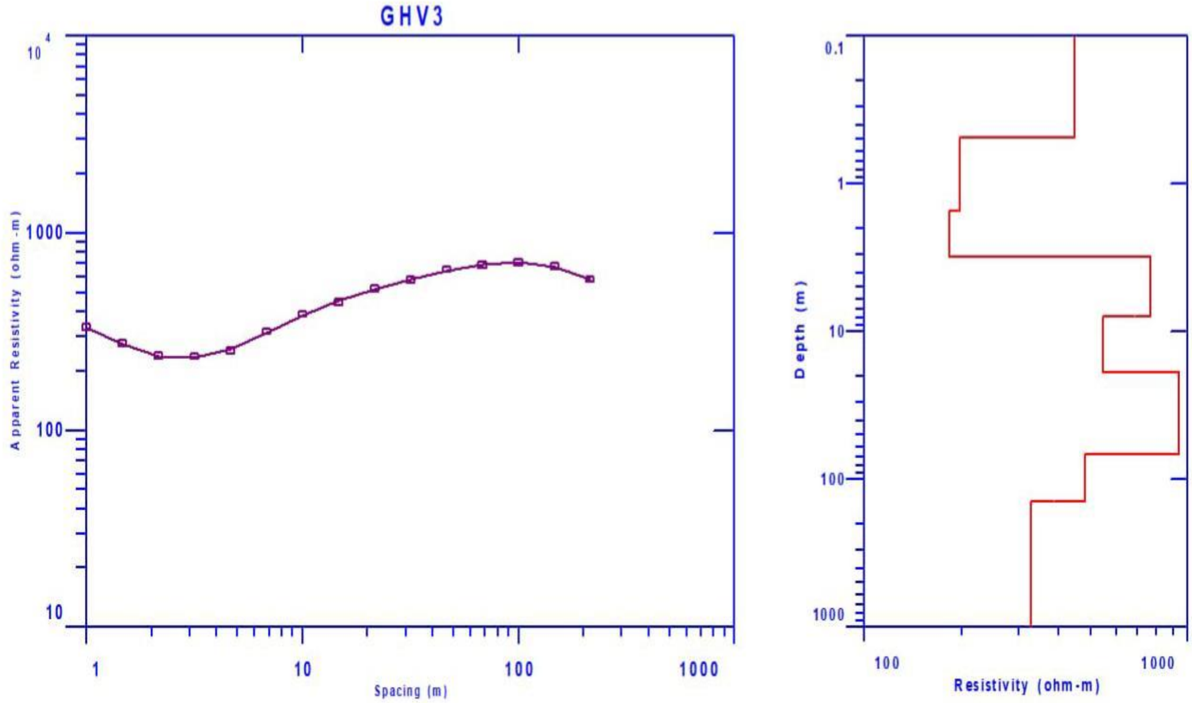

Figure 12: GHV3 Interpreted results, Left: Resistivity curve, Right: Interpreted Geomode

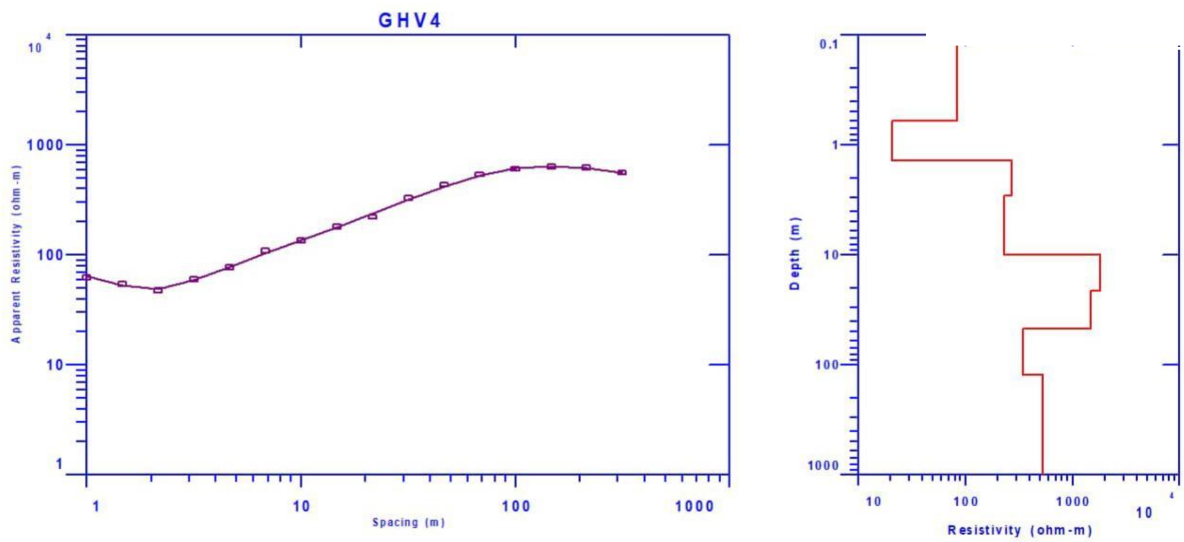

Figure 13: GHV4 Interpreted results, Left: Resistivity data, Right: Interpreted Geomode

Table 5: The interpreted VES result and the corresponding inferred lithologies for GHV1

Geo-electric layers	Layer Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred lithology
1	88.598	0.59124	0.59124	Top soil
2	23.535	0.85186	1.4431	Clay
3	273.83	3.6248	5.0679	Lateritic Sand
4	257.89	5.8352	10.903	Lateritic Sand
5	2079.1	28.248	39.151	Dry Sand
6	362.58	75.486	114.64	Sand (Saturated)
7	555.31			Sand (Saturated)

Table 6: The interpreted VES result and the corresponding inferred lithologies for GHV2

Geo-electric layers	Layer Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred lithology
1	132.92	0.39660	0.39660	Top soil
2	79.890	1.0363	1.4329	Clayey Sand
3	136.46	2.4474	3.8803	Clayey Sand
4	116.95	4.1239	8.0043	Clayey Sand
5	532.58	4.2904	12.295	Lateritic Sand
6	2509.5	20.074	32.369	Dry Sand
7	791.28			Sand (Saturated)

Table 7: The interpreted VES result and the corresponding inferred lithologies for GHV3

Geo-electric layers	Layer Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred lithology
1	448.23	0.4888	0.48884	Topsoil
2	197.31	1.0490	1.5379	Clayey sand
3	183.77	1.5885	3.1264	Clayey sand
4	766.71	4.7840	7.9103	Lateritic Sand
5	546.30	10.894	18.804	Lateritic Sand
6	940.90	49.319	68.123	Dry Sand
7	482.92	72.436	140.56	Sand (Saturated)
8	328.99			Sand (Saturated)

Table 8: The interpreted VES result and the corresponding inferred lithologies for GHV4

Geo-electric layers	Layer Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred lithology
1	84.271	0.60128	0.60128	Topsoil
2	20.722	0.77863	1.3799	Clay layer
3	269.71	1.4969	2.8769	Lateritic Sand
4	232.88	7.1459	10.023	Lateritic Sand
5	1827.8	11.110	21.133	Dry Sand
6	1492.5	25.409	46.542	Dry Sand
7	346.31	76.489	123.03	Sand (Saturated)
8	523.80			Sand (Saturated)

Table 9: Hydrogeological representation of the VES data

Eastings	Northings	Surface Elevation (m)	Depth to water table (m)	Equipotential (A-B)	Iso-resistivity	VES
5°35’42.48”	6°22’46.33”	103m	39.151	63.849	362.58	GHV1
5°35’35.76”	6°22’42.74	105m	32.369	72.631	791.18	GHV2
5°35’48.81”	6°22’45.1”	104m	68.123	35.877	482.92	GHV3
5°35’44”	6°22’39”	104m	46.542	57.458	523.80	GHV4

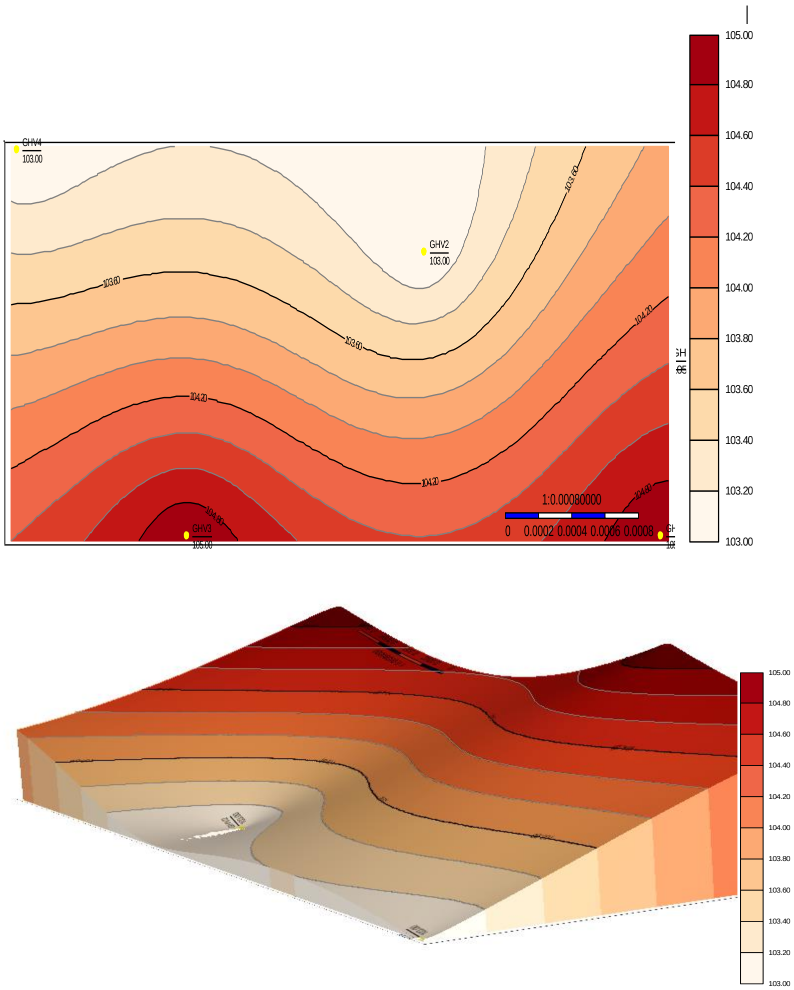

Figure 14: Map of Surface Elevation, Top: 2D Map, Bottom: 3D Map

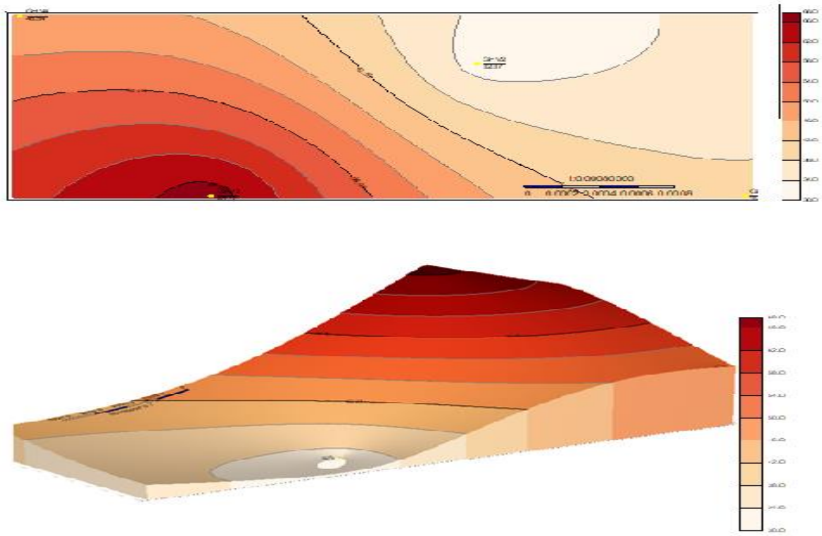

Figure 15: Map of depth to water table, Top: 2D Map, Bottom: 3D Map

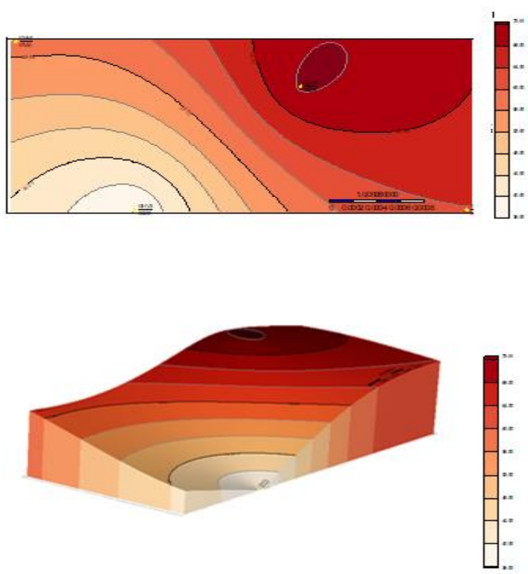

Figure 16: Map of Equipotential Map, Top: 2D Map, Bottom: 3D Map

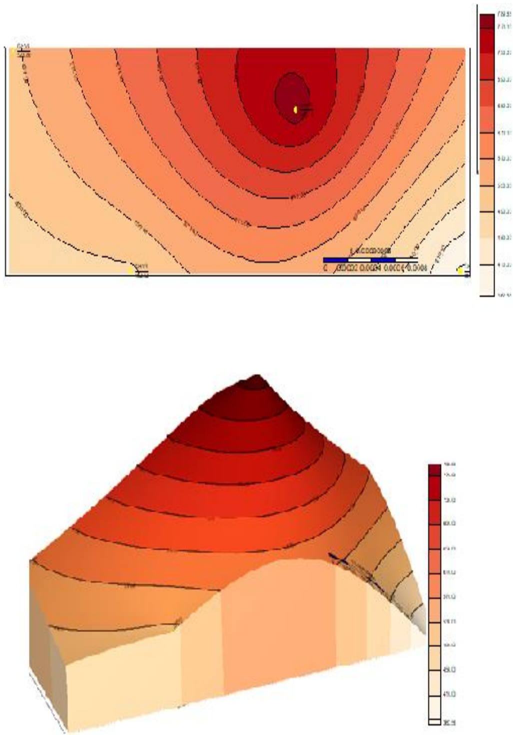

Figure 17: Map of Iso-Resistivity, Top: 2D Map, Bottom: 3D Map

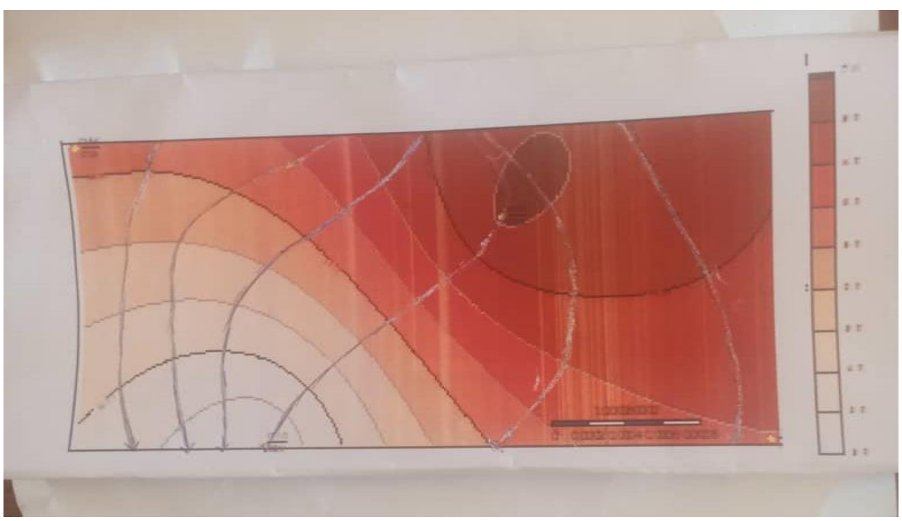

Figure 18: Local Groundwater Flow

4.2 Discussion Of Results

Vertical Electrical Soundings (VES) was analyzed with IX1Dv2 software to map the subsurface geology, revealing the number of geo-electric layers, their resistivity, depth and thickness. An inferred lithology was made. The interpretations indicated that groundwater was found at depths between 32.37m to 68.12m, with aquifer resistivity spanning a wide range of 346.3 Ωm to 791.28Ωm. Five maps were generated from the collected field data. Figure 14, details the map of surface elevation, showing higher terrains in the southern region and a gradual decrease towards the northern region, the surface elevation map highlights potential area of water accumulation in the northern region, and higher runoff in the southern region. Figure 15, is the map of depth to water table, the map indicates the depth to reach groundwater, with shallower depth in the northeast and deeper depths in the southwest. Figure 16 details the equipotential map, it shows a high elevation of the water table in the northeast, and a general decline in elevation towards the southwest. Figure 17 shows the maps of Iso-resistivity, this reveals a central high resistivity zone. Figure 18, details the Local Groundwater Flow, which shows the flow direction of groundwater from northern direction, particularly the northeast to the southern direction, particularly the southwest with flow radiating from a high potential area in the northeast to the southwest.

CHAPTER FIVE

SUMMARY, CONCLUSION AND SUGGESTIONS FOR FURTHER STUDIES

5.1 Summary

This study employed Vertical Electrical Sounding (VES) to investigate groundwater potential in the Uwasota area of Benin City, Southern Nigeria. Four VES points utilizing the Schlumberger array were conducted, and the resulting data were interpreted to delineate subsurface lithologies and identify potential aquifers. The analysis revealed a typical Benin Formation stratigraphic sequence consisting of topsoil, clay, lateritic sand, dry sand, and saturated sand (aquifer). The resistivity values obtained for each layer are within the expected ranges for these lithologies. The study determined the depth to the water table, which varied across the study area, mapped surface elevation, water table elevation, and iso-resistivity. These findings provide valuable insights into the groundwater potential of the Uwasota region, demonstrating the effectiveness of VES in identifying and characterizing aquifer system within the Uwasota area, Benin city, southern, Nigeria.

5.2 Conclusion

From the results gotten from the investigation at Uwasota area in Benin city southern Nigeria using resistivity method (Schlumberger array), it shows the depth of groundwater varied across the study area, ranging from 32.37m to 68.12m. This variation can be attributed to differences in surface elevation, lithological composition. The elevation of the water table also showed some variation, which could influence groundwater flow patterns.

The iso-resistivity map provided a spatial representation of resistivity distribution, highlighting areas of relatively low resistivity that may suggest zones of higher groundwater potential. However, further investigations, such as borehole drilling and pumping tests, are needed to confirm these findings.

Overall, this study demonstrates the effectiveness of VES as a tool for groundwater exploration in the Benin City. The results provide valuable insights into the subsurface lithology, depth to the water table, and potential groundwater resources in the Uwasota area.

5.3 Suggestions For Further Works

Further exploration can be carried out on the area and environs to get a detailed and more information from the area especially on Groundwater quality.

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