SUBSURFACE SOIL CHARACTERISATION USING ELECTRICAL RESISTIVITY TOMOGRAPHY FOR PRE-FOUNDATION STUDIES AT THREE ARMS ZONE, MINNA, NORTHCENTRAL NIGERIA

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AUGUST, 2023

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF GEO-PHYSICS

AUGUST, 2023

DECLARATION

I hereby declare that this thesis titled: **"SUBSURFACE SOIL CHARACTERISATION USING ELECTRICAL RESISTIVITY TOMOGRAPHY FOR PRE-FOUNDATION STUDIES AT THREE ARMS ZONE, MINNA, NORTHCENTRAL NIGERIA"** is a collection of my original research work and it has not been presented for any other qualification anywhere. Information from other sources (published or unpublished) has been duly acknowledged.

IBRAHIM, Abdulkareem ………………………
MTech/ SPS/ 2018/ 8490 Signature/Date

CERTIFICATION

This thesis titled: **"SUBSURFACE SOIL CHARACTERISATION USING ELECTRICAL RESISTIVITY TOMOGRAPHY FOR PRE-FOUNDATION STUDIES AT THREE ARMS ZONE, MINNA, NORTHCENTRAL NIGERIA"** by IBRAHIM Abdulkareem (MTech/ SPS/ 2018/ 8490) meets the regulations governing the award of the degree of (MTech) of the Federal University of Technology, Minna and it is approved for its contribution to science knowledge and literary presentation.

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DEDICATION

This thesis is dedicated to my late parent Mr/Mrs Ibrahima Onuhuari Sule and Ibrahim Osheiza Chatta for their earnest prayer toward making my dream a reality.

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ABSTRACT

The growing rate of incessant failure of buildings and other engineering structures in Nigeria which has resulted to loss of lives and properties worth billions of naira owing to poor foundation. The major factor responsible for these trends is caused by poor building materials, salinity and old age of building structures. Resistivity profiling is a type of surveys employed to detect lateral variations in resistivity. Unlike soundings, profiles employ fixed electrode spacing, and the center of the electrode spread is moved for each reading. These experiments thus provide estimates of the spatial variation in resistivity at some fixed electrode spacing. The 2D electrical resistivity tomography (ERT) and induced polarisation (IP) were integrated to characterise the subsurface lithology for pre-foundation studies at three arms zone, Minna, Northcentral Nigeria, in order to determine the competence and suitability of the subsoil as basis for foundation support of any engineering structures. Measurements involving 2D horizontal profiling (Wenner alpha array) configuration were used to qualitatively study and interpret the geoinformation of the subsoil nature of each geoelectric layer across the four profile lines within the study area. The pseudosection resulst revealed three different lithology based on their resistivity values which are top soil, weathered basement rock and fresh basement. The three geoelectric layers with resistivities ranging between 1.09 Ωm to 1769 Ωm. The results revealed the presence of peat/clay and laterite clay materials with resistivity value (1.09 – 104 Ωm) at the depth of 2.5 m to 48.0 m at varying lateral profile distance across all the four profile lines while high resistivity value (138 – 1769 Ωm) is believed to be weathered basement to fresh basement rock with varying depth across the profile lines. The negative chargeability expressed across all the profiles may be attributed to wet clay materials that are predominant within the subsurface or bad data obtained due to noise and other factors during the field measurement. It is concluded that the subsurface region with high resistivity value (138 – 1769 Ωm) and moderate chargeability value (17 – 38.9 msec.) is considered best for construction of any types of any types of civil engineering structures.

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LIST OF SYMBOLS AND ABBREVIATIONS

(ERT)	Electrical resistivity tomography
(IP)	Induced polarization
(ERI)	Electrical resistivity imaging
(EIT)	Electrical impedance tomography
(DC)	Direct current
(AC)	Alternating current
(HZ)	Hertz
(SAS4000)	Signal averaging system 4000
(ABEM)	America board of emergency medicine
(N)	North
(E)	East
(Km)	Kilometer
(FUPRE)	Federal university of petroleum resources Effurum
(RES2DINV)	Resistivity of two dimensional inversions
(Ω)	Ohm's
(Ωm)	Ohm's meter
>	Greater than
<	Less than
≥	Greater or equal to
≤	Less or equal to
=	Equal to
Ft	Feet
VES	Vertical Electrical Sounding
2D	Two - dimensional

mS	Millimeter seconds
m^3	meter cube
%	percentage
SPT	Standard penetration test
ERP	Electrical resistivity profiling
PDP	Pole – dipole
T	Transverse
MC	Moisture content
CPT	Cone penetration test
WL	Liquid limit
WP	Plastic limit
PI	Plastic index
HRP	Horizontal resistivity profiling
1D	One – dimensional
Ma	Apparent chargeability
DCPT	Dutch cone penetration test
σ	Conductivity
NE	North east
NS	North south
EHP	Electrical horizontal profiling
GPS	Global positioning system
CPUs	Central processing units
RAM	Random access memory
C1, C2	Current electrodes one and two
P1, P2	Potential electrodes one and two

SP	Self potential
RMS	Root means square
V	Voltage
I	Current
A	Area
L	Length
J	Current density
∇	Gradient
Vs	Secondary Voltage
Vp	Primary Voltage
V0	Initial Voltage
V(t)	Voltage at time t
M	chargeability

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

The growing rate of incessant failure of buildings and other engineering structures in Nigeria which has resulted to loss of lives and properties worth billions of naira owing to poor foundation. The major factor responsible for these trends is caused by poor building materials, salinity and old age of building structures (Oyedele *et al*., 2011). It is a common habit that much consideration is not given to the subsurface conditions of the soil or rock which support the foundation of any building. In as much as every building structure have their base on the surface of the earth with different soil or rocks composition, then it is required to have the details knowledge of the types of soil or rocks supporting the substructures in order to guarantee structural integrity, reliability and competence of the proposed structures on the site before any construction work is carry out. In order to achieve these as part of necessary requirement for construction work, Subsurface soil characterisation is required to provide comprehensive and sufficient information about the subsurface region that will enable civil engineers, town planners and builders in the design and sitting of foundations of civil engineering structures (Omoyoloye *etal.,* 2008).According to Ayininuola *et al.* (2004) the possible causes of structural failure include the following stages that took place in building and design process: conception-design stage, construction-supervision stage, and post construction-service stage. In order to achieve quality jobs in above stages of building processes, a high level of trained professionalism is required

Electrical resistivity tomography (ERT) is usually employed as geophysical methods for imaging subsurface features. The technique can be made to estimates the distribution in resistivity of the ground, which can vary with water content and lithology. In the ERT surveys, the measured quantity is called apparent resistivity ("ρa"), which is the equivalent resistivity for a homogeneous soil volume which yields the same potential value as the true model. In order to estimate the true resistivity distribution, an inverse numerical modeling (inversion) is used to create a model based on the apparent resistivity data (Dahlin, 2001). The inversion adjusts a finite difference or finite element model in an iterative process by comparing the measured apparent resistivity versus the calculated resistivity from the inverted model (Dahlin, 2001). The use of ERT profiles and additional data from the subsurface, such as drilling reports and borehole loggings, makes it possible to estimate the thickness, depth, and morphology of different units of the subsurface (Martínez *et al.,* 2009).The commonly used methods of subsoil evaluation usually adopted by civil engineers such as cone penetrometer test, and other geotechnical methods in determining the strength of materials for the support of engineering structure are costly expensive, time consuming and at the same time not giving reliable and effective information about the subsurface of the given site and quality depth of investigation. Thus, it become necessary to combined the conventional method with cost effective geophysical method that are commonly used by engineers for site investigation purposes (Akintorinwa and Adeusi, 2009). Geophysical method of survey reveals the details information on the degree of competence of the subsoil in engineering foundation (Ofomola *et al.,* 2009).

Electrical current passes through the subsurface soil shows the possible relationship between the soil strength and electrical resistivity based on the parameters which control soil strength as well as electrical resistivity such as grain size distribution, degree of saturation, porosity and cementation (Sudha *et al.,* 2009). The geoelectric method is one of the geophysical methods that works based on physical parameters in the form of rock resistivity. In principal, the electric current is injected into the soil and then the potential difference is measured (Sudha*et al.*,2009). In this research, electrical resistivity and induced polarisation (IP) methods were used in determining the competence of the subsoil at the proposed site of three arms Zone, Minna, Northcentral Nigeria.

1.1.1 Electrical resistivity tomography (ERT)

Electrical Resistivity Tomography (ERT) or electrical resistivity imaging (ERI) is a geophysical technique for imaging subsurface structures from electrical resistivity measurements made at the surface, or by electrodes in one or more boreholes. If the electrodes are suspended in the boreholes, deeper sections can be investigated. It is closely related to the medical imaging technique electrical impedance tomography (EIT), and mathematically is the same inverse problem. A related geophysical method, induced polarisation (or spectral induced polarisation), measures the transient response and aims to determine the subsurface chargeability properties. Electrical resistivity measurements can be used for identification and quantification of depth to groundwater, detection of clays, and measurement of groundwater conductivity (Budhu, 2011).

1.1.2 Resistivity profiling

Resistivity profiling is a type of surveys employed to detect lateral variations in resistivity. Unlike soundings, profiles employ fixed electrode spacing, and the center of the electrode spread is moved for each reading. These experiments thus provide estimates of the spatial variation in resistivity at some fixed electrode spacing. Surveys that are designed to locate lateral variations in resistivity are referred to as resistivity profiles. An example of a problem for which one might employs resistivity profiles is the location of a vertical fault (Telford *et al.*, 1990).

1.1.3 Induced polarisation method

Polarisation is a geophysical imaging technique used to identify the electrical chargeability of subsurface materials, such as ore (Zonge *et al.*, 2005). This survey method is similar to electrical resistivity tomography (ERT), in that an electrical current is transmitted into the subsurface through two electrodes, and voltage is monitored through two other electrodes.

Induced polarisation is geophysical method used extensively in mineral exploration and mine operations. Resistivity and IP methods are often applied on the ground surface using multiple four-electrode sites. In an IP survey, in addition to resistivity measurement, capacitive properties of the subsurface materials are determined as well. As a result, IP surveys provide additional information about the spatial variation in lithology and grain-surface chemistry.

The IP survey can be made in time-domain and frequency-domain mode. In the time-domain induced polarisation method, the voltage response is observed as a function of time after the injected current is switched off or on (Olsson *et al.,* 2015). While in the frequency-domain induced polarisation mode, an alternating current is injected into the ground with variable frequencies. Voltage phase-shifts are measured to evaluate the impedance spectrum at different injection frequencies, which is commonly referred to as spectral IP. It has been observed that when a current is applied to the ground, the ground behaves much like a capacitor, storing some of the applied current as a charge that is dissipated upon removal of the current. In this process, both capacitive and electrochemical effects are responsible. IP is commonly used to detect concentrations of clay and electrically conductive metallic mineral grains (Telford *et al.*, 1990).

1.1.4 Resistivity methods

Surface electrical resistivity surveying is based on the principles that distribution of electrical potential in the ground around a current carrying electrode depends on the electrical resistivity and distribution of the surrounding soils and rocks. The conventional practice in the field is to apply an electrical direct current (DC) between two electrodes injected in the ground and to measure the difference of potential between two additional electrodes that do not carry current. Normally, the potentials electrodes are in line between the current electrodes, but in principle, they can be located anywhere. The current used is either direct current, commutated direct current (current) i.e. a square-wave alternating or AC frequency (typical about 20 HZ). The distribution of potential can be related theoretically to ground resistivity and their distribution for some simple cases, notably, the case of horizontally stratified ground and the case of homogeneous masses separated by vertical planes e.g., a vertical fault with a large throw or vertical dike. For this kind of resistivity distributions, interpretation is usually done by qualitative comparison of observed response with that of idealized hypothetical models or on the basis of empirical methods (Wightman *et al.,* 2003)

1.1.5 Apparent resistivity

Whenever measurements are made over a real heterogeneous earth, as distinguished from the fictious homogenous half-space, the symbol ρ is replaced by ρ_a for apparent resistivity. The resistivity surveying problem is reduced to its essence, the use of apparent resistivity values from the field observations at various location and with various electrode configurations to estimate the true resistivity of the several earth materials present at a site and to locate their boundaries spatially below the surface of the site. By definition, apparent resistivity is defined as the resistivity of an electrically homogeneous and isotropic half-space that would yield the measured relationship between the applied current and potential difference for a particular arrangement and spacing of electrodes (Wightman *et al.,* 2003).

1.2 Statement of Research Problem

The incidence of building failures and collapses has become major issues of concern in the development of the Nigeria nation as the frequencies of their occurrence and the magnitude of the losses in terms of lives and properties are now becoming very alarming, to the extent that it has become familiar occurrence, even to layman on the street in Nigeria (Fagbenle and Oluwunmi, 2010).The geotechnical engineering methods are expensive, time consuming and at the same time not giving reliable and effective information about the subsurface of the given site and quality depth of investigation (Olorunfemi *et al.,* 2002).

1.3 Justification for the Study

The need to provide solution to environmental disaster such as building collapse and structural failures in Nigeria through scientific approach has become a serious issue of concern as many lives and valuable properties have lost through structural failure. The study area is a proposed location for the construction of the state government three (3) arms zone which is a government residential area. The area is anticipated to witness an extensive expansion in term of new residential buildings, offices, schools, clinic and market facilities which by implication require to study the subsurface structure in the area.

The contribution of buildings to Nigeria's development has not yielded the desired potentials because of building failure/collapse and more recently their poor functional performance (Windapo and Rotimi, 2012). Although, geotechnical site investigation is one of the most effective method of subsurface study usually employed by civil engineers to explore the subsoil lithology before sitting any civil engineering structures. However, problem of quality depth investigation and high cost have been the major limiting factors particularly to its wide application in poor nation like Nigeria. Hence, the need to provide alternative approach in solving this ugly trend usually attributed to poor knowledge of subsurface structure has become imperative. The above problem has necessitated this research to adopt geophysical approach which is cheaper, reliable and high-quality depth of investigation over the conventional method of geotechnical survey. Therefore, Geophysical site investigation is necessary to explore the subsurface condition which will aid the engineering section in decision making with respect to the foundation type to be adopted for future engineering projects in order to guarantee structural integrity.

1.4 Aim and Objectives of the Study

The aim of this study was to investigate the subsurface region of the study area by using Electrical Resistivity Tomography method.

The specific objectives of this study are to:

i. Characterise the subsoil lithologies at three arms zone using electrical resistivity imaging;
ii. Determine the resistivity, depth and thickness of the subsurface layers;
iii. Delineate the subsurface area that may likely cause damage to the foundation; and
iv. Determine Subsurface region suitable for building and other civil engineering structures.

1.5 Scope of the Study

The study employed the use of electrical resistivity 2D Wenner alpha and induced polarization techniques for the investigation of subsurface structures of a 300 m x 300 m area of land using ABEM SAS4000 Terrameter. A total of 31 electrodes at 10 m minimum and 90 m maximum inter-electrodes spacing was use to probe across the four profile lines at 100 m inter-profile intervals to properly map out the subsurface region with most competence for civil engineering work.

1.6 Location of the Study Area

The research study is located at the three-arm zone Eastern bypass Minna, Niger State. The proposed site is fall within latitude $09^{o}37'32''$N to$09^{o}\,37'31''$N and longitude $06^{o}34'52''$E to $06^{o}35'2''$E and directly opposite Niger State fire service located within the study area.

Figure 1.1: Satellite image of the study area (GPS Satellite Earth Map)

CHAPTER TWO

LITERATURE REVIEW

2.1 The Geology of Niger State

Niger State fall between latitudes $8^{o}15'$–11°15’N and longitudes 4° $00'$–$7°15'$ E. It is bordered in the north by Kaduna and Kebbi states and in the south by Kogi state. It shares boundary in the west with Kwara state and Benin Republic and in the east with the Federal Capital Territory and Kaduna state. It is divided into twenty-five local governments with a landmass of about 80,000.00 square kilometers and a population of 3,920,000 in 2006 census. The climate is like much of West Africa comprising of a rainy season and a dry season. North- About one half of the land mass of Niger State is underlain by the basement complex rocks while the other is occupied by the Cretaceous sedimentary rocks of the Bida Basin and part of the Sokoto (Iullemeden Basin).

The basement rocks consist of a suite of Precambrian gneisses, migmatites and metasedimentary schists crosscut by granitoids (Oyawoye 1972). The migmatite-gneiss complex includes migmatites, gneisses, mylonites and amphibolites. The mylonites are major shear zones which mark the stratigraphic breaks between the gneissic basement complex and the cover rocks of the Birnin-Gwari Schist formation (Truswell and Cope1963). The schist belts area occur as two elongated bodies separated by the older granite suite. The tips of the two formations are separated by a 40 km expanse of the older granite suite (Ajibade *et al.,* 2008).

The sedimentary formations belong to the Bida Basin of deposition, the Bida Basin otherwise known as the mid-Niger Basin or the Nupe Basin is a NW–SE trending intracratonic sedimentary basin extending from Kontagora in Niger State to areas slightly beyond Lokoja in the south. Its total length is estimated at 400 km with a maximum width of about 160 km which tapers to less than 60 km at Dekina. The largest portion of the basin (the northern part), occurs in the southern half of Niger State.

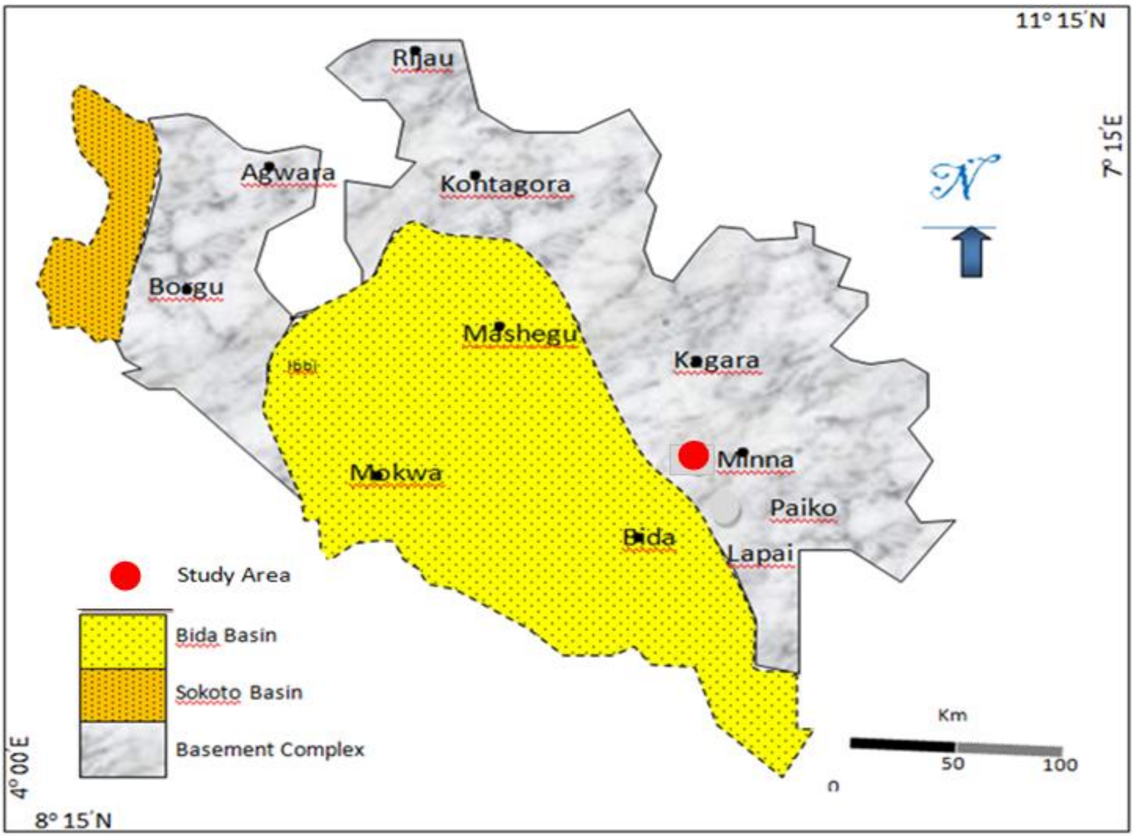

Figure 2.1 Geological Map of Niger State (Amadi *et al.*, 2012).

2.2 Related Geophysical Review

Alaminiokuma and Chaanda (2020) conducted Vertical Electrical Sounding around four buildings in Federal University of Petroleum Resources Effurun (FUPRE), Nigeria. The target is to delineate the soil types and determine the subsurface conditions responsible for perceptible cracks on these buildings. Data acquisition was acquired with the Schlumberger array method. The variation in soil resistivity and types were revealed through the optimization of measured field and calculated apparent resistivity data and interpretation of electrical resistivity imaging (ERI) generated using RES2DINV software. Clayey-sand and sand are the two major sub-soil types that underlie the study area from top to bottom. The clayey-sand is found to represent the area of low resistivity values ranging between 250 and 953 Ωm while the sand has resistivity values ranging between 1324 and 2957 Ωm. The results show that there is prevalent insertion of clay within the sands at depths ranging from 0.1 to 2.0 m where the foundations of these buildings are located. The intrusion of clays in the sands is pointing out the possible seasonal moisture and volumetric expansion and shrinkage and irregular ground settlement underneath these buildings. Therefore, foundations of these type need to be bolstered up by excavating to depths ≥2 m (6ft) below the ground surface in order to avoid the area of this weak zone, especially underneath the foundations of multi-storey buildings.

Alagbe and Faleye *(*2020) conducted 2D electrical resistivity imaging (ERI) and vertical electrical sounding (VES) to map the subsurface lithology at a pre-engineering construction site in Akure, southwestern Nigeria, in order to admeasure the competence and suitableness of this site for engineering structures. The study involved four 2D horizontal profiling (Wenner array) to qualitatively interpret the geoinformation of the lithological nature of each geoelectric layer within the study site. Four vertical electrical sounding were also conducted using Schlunberger configuration. The VES data were processed and inverted using computer software such as master curves and WinResist, while the 2D inversion was done using Diprowin. The results of the 2D horizontal profiling depicts that the study area is composed of four subsurface geo-electric layers with resistivities ranging between 6.91 Ωm to 93.6 Ωm. These results also revealed an expansive clay formation to the depth probed. While the VES results showed three subsurface geo-electric layers with resistivities ranging between 8.4 Ωm to 640 Ωm with the second layers where the foundation is supposed to be laid confirmed the presence of clay with resistivities ranging between 8.4 Ωm to 13.0 Ωm with depth ranging between 4.9 m to 7.9 m. The results revealed the site to be an expansive clay formation which indicate that shallow foundation may not be possible for massive engineering structures owingto the presence of clay materials in the area. But the area has the strength capacity for small or light engineering structures.

Ahmad *et al.* (2020) carried out a research study at MARDI Seberang Perai with the aimed of understanding hydrological characteristic of groundwater aquifer through the use of electrical resistivity tomography (ERT) and induced polarisation (IP) method applied for tubewell development in Alluvial deposit. By knowing the difference in electrical resistivity and induced polarisation values in alluvium deposition will facilitate to identify any groundwater occurrence. In agriculture sector, shallow tube well will be option to farmers due to more economic. The resistivity measurements proved to be a good tool for mapping the subsurface in the Alluvium, especially when used in combination with Induced Polarisation parameters. Alluvial deposits or fluvial deposits are composed of particles of gravel, sand, silt or clay size that are not bound or hardened by permeable mineral, by pressure, or thermal alteration of the grains. Consideration of gravelly deposition is the higher hydraulic conductivity. Furthermore, coarse to fine sand are the second higher followed by silt and clay are the lowest values. From the case study, the electrical resistivity tomography of these deposits ranged from 40 to 1000 Ωm, while the values of chargeability were 0 to 20 mS/m. The bottom of the aquifer consisted of a layer with gravelly sandy silt, and the resistivity was 260 Ωm, while the chargeability was 6.5 mS/m. The shallow tube well in quaternary aquifer was constructed at 51 m depth with thickness of aquifer was 24 m to 51 m depth into the ground will consider for groundwater resources. The groundwater discharge from tubewell is 6.53 m^3/hr in mixed gravel, sandy and silt.

Rafiu *et al.* (2020) carried out a research study which aimed to reveal the horizontal and vertical geological discontinuities on Minna – Bida road that has suffered repairs in the past. Probable zones of untimely failure along the road are then investigated by variation in resistivity. The resistivity values for profiles A, B, C, D and F range between 0.10 and 30.4 Ωm; were indicating failed segments which are typical of fractured or fissured zone, as a result of clayey nature of the topsoil/sub-grade soil on which the road pavement is founded. The stable segment which is characterized by high ranging resistivity (16.4 – 4628 Ωm) shows no evidence of any major geologic feature such as fault and fractured zone that could have precipitated failure. The range of values characteristically places the regions in a basement complex area with the presence of clay-sandstone intercalation. The causes of road pavement failure on the studied road was found to be majorly as a result of a combination of clayey topsoil/sub grade soils, water-logged sands with characteristically low resistivity values and thin pavement unable to withstand pressure exerted on the road.

Ndanusa *et al.* (2020) conducted a research study along London road Mnna, Niger State. The aim of the study was to investigate the causes of road failure. Two profiles parallel to the road of the study area of 300 m in length were investigated using Wenner array electrical configuration method. The electrode spacing was at equal interval of 7.5 m and current was sent into the ground using both current electrodes while potential electrodes received the signal which is display by the terrameters in resistivity. A total of 42 electrodes were probed. The calculated apparent resistivity pseudo section of profile A shows low resistivity. At the distance between 205 - 250 m the material is of low resistivity which can also lead to failure of the road. Profile B shows some anomalies between the distances of 45-60 m which is likely to be clay.

Aigbedion *et al.*(2019) carried out a research within the Sedimentary terrain of RCCG, Calvary Love Parish 2, Ukpenu, Ekpoma, Edo State, Nigeria. The geophysical investigation involved the Vertical Electrical Sounding (VES) technique using the Schlumberger configuration and Dipole-Dipole Horizontal Profiling. The profiles were set up along E – W direction cutting across geologic strike. A total of two profiles were set up with total length of 90 m and of varying inter-profile spacing. A total of four (4) VES stations were positioned to cover the entire study area. The acquired data were processed and interpreted entirely to explicate the shallow subsurface geology of the study area. The results were qualitatively and quantitatively interpreted and are presented as sounding curves and geoelectric sections. The geoelectric sections of the study area show a total of three subsurface layers namely: the topsoil, clayey sand and sandstone. The topsoil comprising of clay, clayey sand, sandy clay and sand with the resistivity values ranges from 142 to 552 Ω-m with its thickness varies from 0.7 to 1.2 m, the clayey coarse sand comprises of clay, clayey sand and sand with resistivity values range from 115 to 291 Ω-m and thickness ranges from 2.2 to 11 m while the sandstone layer resistivity varies from 1187 to1797 Ω-m. The resistivity values of the topsoil are indicative of clay, sandy clay, and clayey sand. This layer may not be of any particular interest since topsoil is usually excavated. Hence, foundation of the proposed structures cannot be found on this layer. The 2 D imaging (Dipole-Dipole) covered a distance of about 90 m along East to West Orientation. It delineated three to four major subsurface material/layer components, identified with various colour for easy characterisation; The layer lithological materials varies from Topsoil comprises of clay, clayey sand and sandy clay material as indicated in green/blue colour with layer resistivity variation of 93 to 306 Ωm. Following this layer is another characterized by low resistivity variation from 600 to 4707 Ωm with the dominant resistivity being between 5000 Ωm and 246122 Ωm. These are as characterized by lithologic units that can be classified sandy shales, and shaly sands, with layer thickness varying from 1 to 10 m they are indicated with green, light green, and green/blue colour. These zones are characteristically weak and made up of attributes of low foundation integrity.

The few zones with materials of high/moderate integrity can be found around the pegging of the traverse within 40 to 95 m to a depth of 5 m along traverse one and two. The geoelectric section at a distance 25 to 35 m demonstrated weak zone which also coincides with Dipole – Dipole Pseudo-section. This also agrees with the low resistivity zone observed on the dipole-dipole pseudo-section at a distance 25 to 35 m and geoelectric section which indicate low integrity and high susceptibility to failure, if the structure is lay within this zone. Correlating the electrical resistivity methods employed along traverses one and two highly show a weak zone. These weak zones will contribute a great deal to any structure within this zone.

The result shows that clay/shale and clayey sand is more predominant within the study location which is the major factor and a challenge responsible for 90% problem of construction. Notwithstanding, various weak zones were delineated by the two techniques and from the broad interpretation, it can be concluded that the building is liable to fail, if it is constructed within incompetent clay materials and lateral inhomogeneity. The choice of foundation materials, clay content and topography elevation are factors to be considered.

Olayinka *et al.,* (2019a) carried out a research work at Ahmadu Bello Universty Phase II Zaria lies between longitudes $7^o37'98''E$ and $7^o39'07''E$ and latitudes $11^o7'86''N$ and$11^o8'50''N$. 2D electrical resistivity tomography were used to characterised the soil in Ahmadu Bello university Phase II Zaria. A multi-electrode resistivity meter (ABEM Terrameter SAS 4000) was used for data acquisition on the field using a dipole-dipole array and the data were processed and interpreted using RES2DINV.

The 2D electrical resistivity model was used to depict the distribution image of subsurface resistivity. The results of the three profiles from these images were characterised by low and high resistivity values ranging from <26.4 to >2500 Ωm. Generally, for foundation studies, the highly resistive material is usually considered and mostly fresh basement rock is the most suitable materials for the foundation. The topsoil of the profiles is the overburden that consists of laterite, reddish-brown sandy clay and is about 8m thick. It is characterised by low resistivity values which are less than 200 Ωm, except at the horizontal distance of 95-105 m where it is intruded by high resistive material. It dominates the northern part of profile 2.

This low resistive material is not competent enough for the foundation structure to be laid on it. The second lithological layer which is the weathered basement also has a low resistivity value, though higher than the first layer, it ranges from (200-1953 Ωm). The layer beneath the weathered basement is a fractured basement. It is more pronounced at the lateral distance of 8095 m and at the depths of 17.5 m in profile 1 and the resistivity values (1275 -3969 Ωm). This layer is an important factor in terms of groundwater prospect. Similarly, to the first and second layer, it also poses a threat to the foundation and building structures. The last lithological layer is the fresh basement, whose resistivity values is 4000 Ωm and above. The depth also ranges from 15.9m to infinity. From this investigation, it can be deduced that the most suitable and competent layer for the foundation of the last building structure is the fresh basement layer and this is due to its high resistivity value which is a characteristic of a competent layer. Hence, for a high rising building, it is suggested that the foundation should be laid on the fourth layer.

Olayinka *et al.* (2019b) conducted a research study at Ahmadu Bello University phase 11, Zaria, Nigeria. Two – dimensional resistivity and induced polarisation has been successfully used to characterize the subsurface earth materials for groundwater exploration at Ahmadu Bello University Phase II, Zaria, Nigeria. Two imaging profile lines were established, with each profile length of 200 m. The electrical resistivity and induced polarisation measurement on each profile lines were achieved using Wenner electrode array configuration. The data obtained from the survey were processed and interpreted using Res2Dinv software. The results of the 2D imaging profiles of resistivity and chargeability were calibrated using borehole data of the study area. The profiles revealed two to three layers, which comprises of brownish lateritic sandy clay, light brown clayey sand and greyish hard weathered rock. The possible location of fractured zones for groundwater exploration was mapped out from the imaging profiles. The zones have the resistivity and chargeability value of range between 0 – 62.8 Ωm and 0.0001-0.167 ms respectively with a thickness of 9 m. Based on the results obtained from this study, it shows that groundwater exploration is feasible in the study area and drilling for the exploration of water should be targeted towards the fracture zone because it is hydro-geologically good in basement complex rock. In general, resistivity and chargeability values alongside borehole data have been used to provide better interpretation for groundwater exploration in the basement complex.

Suryadi *et al.* (2019) conducted a research study at Alor Gajah, Melaka, Malaysia. The aim of the research was to locate and delineate groundwater potentials by distribution of subsurface resistivity. The survey of ERI was carried out using ABEM Terrameter SAS 400 and ABEM Selector ES10-64 with pole-dipole configuration of electrode. At the same time, Induced Polarization (IP) survey also carried out to support the result of ERI. There are three-line profiles with 400 m length and 5 m electrode spacing named PS1, KRBG2 and BB3. From three-line profiles, two of them show that the distribution of low resistivity value (20 – 500 Ωm) are located at depth ranging from 20 to 70 m. The low resistivity values are associated with water saturated zone. This result was supported by IP's results that show at that particular depth the value of chargeability ranging 0 to 4 ms. Meanwhile, line profile BB3 indicate low resistivity value (0.5 – 500 Ωm) but the chargeability value is high (10 – 75 ms) interpreted as clay layer.

Peter *et al.* (2018) carried out a research study on the causes of road failure along Kutigi street, Minna, Northcentral, Nigeria. The study investigates the causes of road failure along Kutigi Street and to determine the geo-electric properties of the subsurface of the study area by employing 2D Electrical Resistivity Wenner Array Method. Two profiles covering a distance of 300 meters each were established parallel to the road pavement along the stable and unstable sections of the road. Data were collected along the two profiles using ABEM Terrameter SAS 4000. The observed field data were processed and inverted using 2-D modelling inversion algorithm (RES2DINV Software).The results reveal the presence of low resistivity values at several portion of both profile A and Profile B. Resistivity values ranging from 9.25 Ωm – 115.30 Ωm to a depth of 11.25 m from the topsoil was observed along profile A and resistivity values ranging from 5.20 Ωm – 25.6 Ωm to a depth of 11.25 m from the topsoil was observed along profile B. from the results obtained, it can be deduced that the low resistivity values observed in both profiles comprises of expansive clay and sandy clay materials which has the tendency of absorbing water. These makes them swell and eventually collapse under imposed wheel load stress which leads to failure. Regions of the road with sandy and clayey materials should be excavated from the subsurface to a depth of 4 m – 6 m from the topsoil of the road and replaced with competent fill materials.

Adewuyi *et al.* (2018) carried out an integrated geophysical and geotechnical investigation for a proposed building foundation of an industrial plant layout to determine the competency of the subsoil as foundation materials. Electrical Resistivity Imaging (ERI) and soil analyses techniques were adopted. Two traverses of four Vertical Electrical Sounding (VES) points were carried out and 8 Boreholes for Standard Penetration Test (SPT) were drilled. In addition, soil samples were taken at 1.5 m and 10 m depths and subjected to various laboratory analyses. Three geoelectric layers were delineated from VES including topsoil, saturated sandy clay soil and limestone. The SPT N value indicates that the relative density of the soils is medium dense to very dense while the result of the geotechnical analyses shows that maximum dry density of the soils ranges from 1680-1900 kg/m^3 and 1600-1850 kg/m^3 respectively at 1.5 m and 10 m while the optimum moisture content ranges from 14-19% and 13-19% respectively at 1.5 m and 10 m. The soils are silty sand with low plasticity depicting low to medium swelling potential. Conclusively, the subsurface on which the foundation of the industrial structures will be located within the study area is safe and fairly competent for any engineering work. Owning to the water lodge nature of the area it is advice that the building should rest on pill between 5 m and 10 m depth.

Mannir *et al.* (2018) carried out a research work at Airport Housing Estate, Northcentral Nigeria, Minna. The study area is bounded by latitude $09^o39'$ N to $09^o40'$N and longitude $06^o26'$ E to $06^o27'$Eandlies within the basement complex region of Northern

Nigeria. Vertical Electrical Sounding and Electrical Resistivity Profiling techniques were carried out for the survey. The aim of the survey was to determine the subsurface layer parameters (resistivity, depth and thickness) which shall be employed in delineating sites for building construction. A total of ten profiles with twenty stations along each profile at intervals of 50 m were investigated. The ERP results were used to produce an apparent resistivity contour map from which the high resistivity points were obtained and subjected to Vertical Electrical Soundings. The VES has a maximum current electrode separation (AB/2) of 100 m. The results obtained from VES plots reveal three distinct geoelectric layers; the top soil, the weathered/fractured layer, the fractured/fresh basement layer. Three distinct curve types were observed for the entire VES plotted curves; H-type, A-type and K-type. The areas suitable for building construction and Civil Engineering works are; The South, East and extremes of North-Western and North-Eastern parts of the study area. The points identified as great threat for high rising buildings and Civil Engineering works are E18, A18, G14, D13, G17 and F9 due to presence of clay content and weathered basement at shallow depth ranging between 0.8m to 5.01m.

Alagbe (2018) employed electrical resistivity methods with focuses on the assessment of corrosivity probability of the subsurface layers. A shallow geophysical investigation for the corrosivity of subsurface soil at a proposed filling station site in Akure using 2D electrical resistivity imaging profiling was conducted to produce an approximate model of the subsurface resistivity. A total of three horizontal profiling involving the Wenner array 2D imaging was established in the East-West directions of the site investigated and was used to generate 2D pseudosections for the study area. The pseudosection results revealed the corrosivity status of the subsurface soil in the area based on their resistivity values. To further study the corrosive nature of the subsurface soil in the area, a total of thirteen vertical electrical soundings (VES) ussing modified Wenner array method called specialized engineering spread was used. This method also revealed a three to four earth layer model which the resistivity of the first layers ranging between 23 and 263Ωm, second layers between 52 and 376 Ωm, the third layers between 37 and 1874 Ωm, while the fourth layers ranges between 470 and 217 Ωm. The depth ranges for the layers showed that the first layers have a depth range between 0.6 and 1.73m, the second layers with range between 1.7 and 8.9 m, while the third layers was between 3.9 and 5 m. Columnar sections were also generated to further look into the variations in the resistivity within the depth penetrated. Traverse 1 (T1): The 2D electrical resistivity results across the profiles showed that the zones are viable for burial of the tank between stations 4 to 9 at depth of 2.0 m and 3.5 m (51.9 – 84.9 Ωm) and between station 5 and 10 at depth between 3.5 m and 5.0 m (63.1 – 162 Ωm).

This region falls within the region that is classified as moderately corrosive and mildly corrosive zones which appears to be suitable because of its closeness to a very hard rock or basement. Also, the resistivity results from traverse 3 showed that there are two viable zones for the burial of the tank between stations 4 to 5 at depth between 2.0 m to 3.5 m (63.2 – 555 Ωm) and between stations 5 and 8 at depth between 3.5 m and 5.0 m (66.6 – 99.8 Ωm). These zones also fall within moderately corrosive zones which appear to be suitable, but the tank should be coated with some protective coating materials such as bitumen. Results obtained from various techniques adopted revealed the suitability of the second and third layers for the burial of the storage metallic tank. But with layer three most suitable.

Adeeko and Muztaza (2018) carried out a research study at Sungai Batu, Lembah Bujang, Kedah, Malaysia, 2-D electrical resistivity imaging were adopted to investigate groundwater potential using four survey lines with Pole-dipole (PDP) array at 0.75 m minimum electrode spacing of 9 m by 30 m. The 2-D resistivity data was process using Res2Dinv and Surfer 8 software, the output set apart layers indicated relatively lower and higher resistivity which was used to locate groundwater potential area and depth and the result was correlated with a borehole in the study area, to validate the result, one survey line was correlated with the existing on-site borehole (BH10) to identify groundwater potential and depth. The validated values were applied to the remaining survey lines without borehole records to map subsurface of the study area. The ERI results unveiled that the area was delineated by two main zones, saturated zone consists of clay, sandy clay; clay with resistivity values 0.1 Ωm to 10Ωm with N-value 20, sandy clay with resistivity values 7 Ωm to 100 Ωm with N-value 32 at depth 7 m, and shale zone with resistivity values 20 Ωm to 500 Ωm with N-value 70 which are hard material at depth 10.5 m. In conclusion the aquifer unit in the study area have a significant groundwater potential to the depth 10.5 m to allow reservoir within the aquifer.

Oyeyemi *et al.*(2017) carried out geophysical survey at the construction site located within the unity estate ($\text{Lat.}06^{o}30'\text{N and Long.}03^{o}37'\text{E}$), Ajah Lagos-Island, South-western Nigeria with the primary aim of investigating foundation design at building construction site. Two ERT lines were conducted using Wenner array configuration in combination with four cone penetrating data for 2D geoelectrical resistivity measurements. From the inversion of ERT data, the results of the two geoelectric layers were revealed to be loose silty sand and compacted clayey sand lithological units with the resistivity values ranging 50 – 280 m Ω and 10 – 74 m Ω respectively. A portion filled with saturated water with resistivity values ≤ 3 m Ω due to infiltration of lagoon-water wasequally observed at the base of the second clayey sand layer in ERT line T2. The average cone penetrometer (CPT) value of about 110 kg/cm2 (11 MPa) with an average SPT ‘N’ value of 25 was measured between 6.75 – 30.0 m, which show that the geomaterials within this depths range are of good geotechnical properties. Laboratory tests conducted on the respective soil samples at 3.75 m depth gives moisture content (MC) of 66%. This is owing to the clay contents within the soil samples. The Liquid Limit (WL), Plastic Limit (WP) and Plasticity Index (PI) tests of the soil samples gives 84%, 30% and 54% respectively. The results of the proposed approach which involvedthe combination of both geophysical and geotechnical methods have helped to channelise the choice of the foundation for the investigated building towards a pile-type foundation rather than ashallow one. The pile foundation will cause the higher loadings to transmit the loads to a stable soil layer within the subsurface.

Oladunjoye *et al.* (2017) conducted a research study within Olabisi Onabanjo University, Main Campus, Ago Iwoye using electrical resistivity methods to unravel the competent depth for foundation structures. The study was aimed in delineating the lithological arrangement of the soil. Horizontal Resistivity Profiling (HRP) and Vertical Electrical Sounding (VES) were combined to qualitatively investigate the study area. Three (3) HRP data were obtained within the study area using Wenner configuration to give the Electrical Resistivity Tomography (ERT) of the area in form of 2-D resistivity structure. Eight (8) VES were acquired at random within this study area using Schlumberger Electrode Configuration. From the interpretation of the profiling data, it was observed that Profile 1& 2 are more stable for engineering purposes compare to profile 2 located E-W of the study area. The VES data revealed the same lithology for some of the sounding points, which shows that the same depth for both shallow and deep foundation can be used. The study reveals that the study area comprises of four (4) distinct geoelectric layers viz; lateritic topsoil with resistivity ranges from 529 -1720 Ωm, Gravelly layer with resistivity value ranges between 57.0 – 148 Ωm, weathered basement with resistivity value of 678 – 1310 Ωm and fresh basement 2320 - ∞ Ωm.

High rise structure might require detailed geotechnical information to unmask the details of the transition zones in the area.

Abdullahi and Baba (2017) employed 2D electrical resistivity and induced polarization methods at Kurmin Mashi, in Kaduna metropolis, north western Nigeria with coordinates 10^o32’27.500N and 7^o25’8^o520E. The aim of the study was to generate 2D subsurface resistivity and chargeability models to delineate signatures of buried waste which includes domestic waste, oil sludge and metal scraps at Kurmin Mashi Kaduna metropolis, North Western, Nigeria. Four profiles (A, B, C & D) each of length 100 m with a separation of 10 m were investigated with the help of ABEM SAS1000 Terrameter using the Wenneralpha electrode array configuration with minimum electrode spacing of 3.00 m.

Results from the resistivity model reveals high resistivity values (> 998 Ωm) which corresponds to the position of the buried sludge and a low resistivity values ranging from 33.5 - 88 ohm-m indicating the geo-electric signatures of the buried metal scraps. Both the resistivity and IP models could not resolve the position of the buried domestic waste but the IP models revealed chargeability values of 84 msec and 54 msec corresponding to the positions of the buried oil sludge and metal scraps respectively.

The chargeability model of profile C reveals almost a zone of low chargeability value of - 39.5msec running though out the profile with some pockets of intermittently distributed chargeability of 54.5msec at profile positions 12 m, 24 m, 48 m 72 m and 85m. It is difficult to differentiate categorically the signatures of the metal scraps buried on the profile because IP effect will manifest when there is integration of the buried waste (metal scarp) and the host rock. The results of this research show that integrated technique applied at the same location allows a more precise description of the subsurface and thus reduced the degree of ambiguity and improvement in the interpretation of anomaly greatly.

Ogungbe *et al.* (2017) employed 2D resistivity imaging and vertical electrical sounding (VES) to map the subsurface lithology within Iba Nursery/Primary School, Ojo, Southwest, Nigeria, with a view to ascertaining the thickness and stratigraphy of the beds and their implications on engineering structures. Ten vertical electrical soundings, covering the entire area were conducted using Schlumberger configuration. Three 2D horizontal profiling (Wenner array) was used to qualitatively interpret the geoinformation of the lithological nature of each geoelectric layer within the study area.

The VES data were processed and inverted using master curves and computer software called WinResist, while the 2D inversion was done using Diprowin. Four to five subsurface layers comprising of topsoil, clayey sand, sandy clay, sand and clay were delineated. Qualitative interpretation of VES data revealed five QHA, one QH, one KQH, one KHK, one KHA and one HA curves. The investigation of the study area has revealed that shallow foundation may not be feasible for a massive engineering structure because of the presence of clay materials that are close to the surface. But for small and medium engineering structures, the second layer is found competent due to the presence of sand with relative thickness and high resistivity value that vary from 1.2 m - 13.9 m and 88.5 Ωm – 399.4 Ωm respectively. However, good prospects exist for heavy engineering structures in the study area where the sand formation is relatively thick (19.8 m – 50 m) and has favorable resistivity values ranging between 466.2 Ωm – 560 Ωm. Thus, the application of 2D resistivity imaging and VES has revealed both the lateral and vertical variations in depth to competent sand layers within the study area, hence providing a useful guide for the site engineers in designing appropriate foundation structures.

Adeoti *et al.,* (2016) conducted a research study which is located between (Lat $06^{o}27'40''$N and $06^{o}27'58''$N and Log. $03^{o}23'45''$E and $03^{o}24'10''$E) lies within Lagos State in the Southwestern part of Nigeria. The study applied the use of electrical resistivity methods as a roadbook for a proper geotechnical investigation due to the inhomogeneity of the soil materials cum inability of the drilling beyond 38 m from the three initially drilled geotechnical boreholes which did not allow for proper foundation decisions and thus necessitated the research. Two-dimensional (2D) electrical resistivity data were acquired using the Wenner array along ten (10) traverses of about 500 m long, and forty-four (44) vertical electrical sounding (VES) data were acquired along the various traverses using the Schlumberger array with a maximum spread of 620 m. The VES data were interpreted using partial curve matching technique and one-dimensional (1D) computer iteration using WinRESIST software. The 2D dataset were processed using DIPROWin software. The inversion of the 2D resistivity data was constraint by the VES results and available borehole data.

The result so of the interpretation of the electrical resistivity data reveal that the lithological units underlying the study area compose of clay/peat, clayey sand, sandy clay, and sand. The results of the interpretation of the electrical resistivity data guided by the range of resistivity(ρ) values and knowledge of the geology of the area reveal that the lithological units underlying the study area are composed of peat ($\rho < 10$ Ωm), clay ($10 > \rho < 100$ Ωm), clayey sand ($100 > \rho < 200$ Ωm), sandy clay ($200>\rho<300$ Ωm), and sand($\rho>300$ Ωm). The various layers are intercalated with each other, and thickness values vary from one location to another up to a maximum depth of 70 m. The VES results show that the clayey material underlies the sand-filled topsoil and there are indications of competent sand layers at depth beneath these clayey layers in the study area. The 2D pseudosections reflect that the different lithological units are intercalated with varying thicknesses across the study area. Thus, the study reveals that the subsoil within the study area is quite inhomogeneous and great care and expertise is required for developing the site.

Andres *et al.* (2016) conducted a research study at Punata (Bolivia), the research attempts to use geoelectrical methods, Electrical Resistivity Tomography and Induced Polarisation parameters, for mapping the subsurface in alluvial fans and to demonstrate its applicability. The resistivity measurements proved to be a good tool for mapping the subsurface in the fan, especially when used in combination with Induced Polarisation parameters (i.e., Normalized Chargeability). The Punata alluvial fan characterisation indicated that the top part of the subsurface is composed of boulders in a matrix of finer particles and that the grain size decreases with depth; the electrical resistivity of these deposits ranged from 200 to 1000 Ωm, while the values of normalized chargeability were lower than 0.05 mS/m. The bottom of the aquifer system consisted of a layer with high clay content, and the resistivity ranged from 10 to 100 Ωm, while the normalized chargeability is higher than 0.07 mS/m. With the integration of these results and lithological information, a refined conceptual model is proposed; this model gives a more detailed description of the local aquifer system. It can be concluded that geoelectrical methods are useful for mapping aquifer systems in alluvial fans.

Dahlin and Loke (2015) carried out a research study on negative apparent chargeability in time-domain induced polarisation data and it has observed that negative IP data can however occur as a consequence of the distribution of chargeable zones in the ground, which is well documented in the literature. The resistivity and chargeability pseudsection from the field showed low resistivity of (3 – 8.6 Ωm) at a depth of 6 – 8 m with corresponding chargeability of (- 10 to – 2 mv/v) which can be interpreted as clay with water content. The higher resistivity value (12 – 100 Ωm) with chargeability value of (0 – 10 mv/v) can be interpreted as sandy sediments with organic content. A general mechanism behind negative IP data is proposed as follows: If the chargeable zones are mainly located in the zones of negative sensitivity and there is low or no chargeability in the positive sensitivity volumes in the investigated volume, it will result in negative apparent chargeability.

Numerical modeling confirm that the phenomenon will typically occur for longer electrode separation if the chargeability is concentrated in thin layer at the surface only, but that other distribution of the chargeable bodies can also cause negative of the IP data. Different electrode differs in tendency to produce negative IP data where dipole – dipole and pole – dipole arrays are more prone to generate negative data than nested arrays in the modelled examples. In addition to the relative location of the chargeable zone, the resistivity is important for its impact on the apparent chargeability.

Kowalczyk *et al.* (2015) carried out a research study at Radzymin terrace near Zwierzyniec, ca. 4km to the north-east of Radzymin and 30km to the north-east of Warszawa, central Poland, using electrical resistivity tomography (ERT) surveys in assessing complex soil conditions: the values of apparent resistivity for particular soil horizons were accepted from RCPT sounding conducted in the vicinity of the drilling. The determined range of horizons with similar electrical properties is concordant with the lithological units drilled in the nearby bore hole, as well as horizons evaluated through the Rf friction ratio. Resistivity valuesaccepted after RCPT are as follows: 10 Ωm for clays; 40 Ωm for the first peat horizon, 45 Ωm for the second peat horizon; 50 Ωm for gyttja; 85 Ωm for sat u rated fine sands; and 120 Ωm for sat u rated medium sands. The following values of resistivity were accepted for the remaining soils on the geo logical cross-section: 60 Ωm for tills; 70 Ωm for clayey sands and silts; 300 Ωm for sands in the aeration zone; and 500 Ωm for embankments.the soil horizons are discontinuous, genetically diverse and include organic deposits. From the ground sur face, beneath a thin bed of sands and embankments, there is a continuous clay horizon with a variable thickness between 1.6–2.7 m and with lenses of fine and clayey sand. Deeper occur saturated sands with two peat horizons. The first peat horizon is discontinuous and variably thick between 0.3–4.4 m. The second peat horizon, 1.6–3.0 m thick, is separated from the first horizon by sat u rated sand, 0.6–4.0 m thick. Below the second peat layer, gyttja occurs locally on saturated sands. The lowest strata drilled were silts (with the top at 9.3–10.9 m below ground level) and tills (with the top at 17.5–18.0 m below ground level). The ground water table in the study area was stabilized at ca. 1.3 m below the ground surface.

Oyedele *et al.* (2015) conducted a study on the assessment of subsurface conditions in a coastal area of Lagos, an integrated geophysical and geotechnical survey was carried out at Magodo Estate, Lagos, Nigeria. The survey was aimed at characterising the shallow subsurface in order to delineate fractures that may have caused structural instability that led to cracking and sinking of residential building in the area. To image the subsurface, resistivity profiling (2-D) using a Wenner array and Cone Penetration Test (CPT) was carried out on five profiles of length 180 m each. The acquired data were processed and interpreted integrally to image the shallow geotechnical setting of the site. The results of the 2-D resistivity image of traverse 1 ranges from 20-300 Ωm. The section is characterised by a homogenous conductive zone (< 40 Ωm) highlighted at the center of the section, surrounded by relatively high resistive zone. The highlighted body is located between 65 m120 m from origin and has an approximate depth of 15 m. This material was interpreted as clay while the resistive material was interpreted as sand. The resistivity structure of traverse 2 also highlights the presence of the conductive body (clay) at around the depth of 15 m, but shifted toward the origin of the traverse between

50 m -105 m from origin. The clay material is also surrounded by silty sand (< 165 Ωm). The similarity in geometry and depth of this material with clay occurrence in traverse 1 suggests the lateral continuity of the clay material. The inverted model resistivity of traverse 3 shows more heterogeneity in its electrical response. It indicates the relatively conductive homogenous zone (< 40 Ωm) located between 40 to 115 m at depth of about 15 m. An approximately synclinal shaped medium sand (> 200 Ωm) occurred between 110 and 175 m from origin having thickness which varies to a maximum of 22 m at the center. This is underlain by silty sand (< 165 Ωm) at depth greater than 22 m. The resistivity section of traverse 4 is similar in all respect to traverse 3. This suggests that the geology remain the same beneath the two traverses. The major difference is in the size and configuration of the silty sand body, which occurs essentially as small resistive nuclei in resistivity section of traverse 4. The resistivity structure of traverse 5 reveals the presence of the recurrent homogeneous conductive zone at almost the same depth but which now extends beyond the origin of the traverse to 60 m mark from the beginning of the transect. From the 60 m mark, there occurs a large body of relatively resistive medium sand with incision of less resistive silty sand within which a pocket of sandy clay occurs at the surface. Integrated interpretation led to the delineation of low resistivity, low bearing capacity clay which is identified as the main cause of instability that resulted in potentially dangerous cracking and sinking of residential buildings in the area.

Aderoju and Adebayo (2015) conducted a research study at the Ogudu River Valley Estate in Lagos, Southwestern Nigeria in order to evaluate the competence of subsurface layers, determine optimum depth to competent layers for foundation design. The 2D resistivity structure beneath the different traverses revealed that the lithological units underlying the study area up to a maximum depth of 66 m are composed mainly of decomposed organic matter (peat) with resistivity values ranging from 1 – 10 Ωm and clay layers with resistivity values less than 100 Ωm intercalated with varying degree of sand units (sandy clay/clayey sand/sand) with resistivity values greater than 150 Ωm. The sand unit distribution is inhomogeneous, having different thicknesses and lateral extent at varying depth. The results obtained from previous geotechnical investigations (borehole logging and Dutch Cone Penetrometer Test (DCPT)) carried out in the study area corroborate the results obtained from this study. It can be therefore concluded that, the subsoil on or within which engineering structures will be founded within the study area are generally incompetent and future engineering development may have to consider alternative foundation designs such as pilling and chemical injection.

Oduduru and Mamah (2014) carried out a research work atIhe pond, Nsukka Town, in Nsukka Local Government Area of Enugu State, Anambra Basin, Nigeria. The research focused on theintegration of 2D geophysical methods, Electrical Resistivity Imaging (ERI) and Induced Polarisation (IP) were used to study the subsurface geology and structures around Ihepond, Nsukka in Anambra basin. The research work has delineated the geologic structures and strata responsible for the water in the pond, and determined the origin of the Pond. Three 2D resisitivity profiles of maximum spread lengths of 500, 400 and 500 m were run around the pond. Horizontal profiling, using Wenner array configuration was employed in the data acquisition for both methods. Four faults designated Apo 1, 2, 3 and 4 with colour codes, blue, red, green and black and their fault zones were mapped. The faults were located at points 224, 265 and 325 m on ER model line one, and at points 170, 205, 275 and 296 m on ER model line two. Three lithologic units of consolidated coarse, medium grained, fine-grained sandstones and saturated zones were identified on the ER and IP Psuedosections. The ER and IP values from the three profiles range from 136 – 21559 Ωm and -81.0 to 240 ms respectively.

The faults zone acts as water pathway to the pond. Inverse chargeability models established the faults zones, as large gradients of chargeability. Correlation of strata to known formation depicts the presence of consolidated coarse to medium grained sandstones, while known exposed fault was correlated to Apo 3 fault using coordinates readings. Analysed sample of water from the pond shows low Salinity and sulfides. Soil sample oxide content was also analysed to compliment the geology, and the result shows that Aluminum oxide (Al_2O_3), Silicon oxide (SiO_2), Ferrous oxide (Fe_2O_3), Zinc oxide (ZnO) and Sodium oxide (Na_2O_3) are relatively low and are in conformity with characteristics of laterite.

Ozegin *etal.* (2013) employed 2D electrical resistivity method for the investigation of a building site in south- south Nigeria using the double-dipole technique. The aim was to establish the existence of a subsurface geologic structure in the study area. Two profiles were occupied and the resulting pseudosections delineated four distinct geologic layers. Profile 1 shows four distinct geologic layers. The first layer is a very low resistivity layer of less than 38.7 ohm-m as can be observed at depths between 0 – 3 m on the south and depths of between 0 – 17 m (between 27 – 80 m) across the traverse. This layer indicates the presence of high-water retaining material (e.g. clay) due to its very low resistivity value range. The second layer which is a relatively more resistive having resistivity values in the range of 38.7 – 318 Ωm, can be observed across the section. The depth of this layer ranges between 5 – 10 m to the south, 10 – 20 m at the centre and 5 – 17 m to the north. This area indicates the presence of clayey sand/ highly weathered rock materials. The third layer with resistivity values in the range of 318 – 757 Ωm, stretches across the section. It ranges in depth of between 5 – 10 m in the south and 12 m – infinity (between 47.5 – 75 m) and 20 m – infinity (between 37.5 – 47.5 m). This layer indicates the presence of a weathered/ fractured basement material. However, a medium of very high resistivity values in the range of 962 – 9076 Ωm can be observed on the southern part of the traverse (between 10 – 35 m) at depths of 7 m – infinity, indicating the presence of a fresh basement rock. Profile 2 also shows four distinct geologic layers. A low resistivity (of less than 32.6 Ωm) material with depth of 0 – 5 m can be observed between 15 – 65 m along the traverse, indicating the presence of clay/ alluvium. The second layer has resistivity values in the range of 32.6 – 232 Ωm and can be observed reaching the surface at between 0 – 30 m to the south, and 68 – 90 m to the north of the traverse with depth values in the range of 0 – 7 m in the southern flank and 0 – 10 m on the northern flank. The material can also be seen to be lying between two highly resistive media (between 47.5 – 75 m) with depths in the range of 10 m – infinity. This material indicates the presence of clayey sand/ highly weathered rock materials.

The third medium which is the weathered/ fractured medium has resistivity values in the range of 232 – 421 Ωm. It can be seen between 0 – 60 m from the south and between 72 m – infinity to the north, surrounding the highly resistive media (located south and north). The resistive media have resistivity values in the range of 421 – 15870 Ωm and 435 – 985 Ωm respectively with depths in the range of 7 m – infinity and 11 m – infinity respectively. The high resistivity media indicates the presence of fresh basement in the study location indicates that geological discontinuities and structural dislocations of the underground strata are some of the geological causes of differential settlement in buildings. Such geologic discontinuities can be clearly observed across the study area most especially beneath profile 1 and the hard bedrock can be observed to be lying below the weathered zone. The presence of a geologic structure which is most probably a fracture was established and it was concluded to be a potential source of building failure in the site especially if the building is constructed across the geologic structure.

Ayolabi *et al.* (2012) embark on research study with the primary aim of investigating the causes of foundation defects.2D electrical resistivity tomography (ERT) and geotechnical investigation were carried out at Ogudu Estate in Lagos, Nigeria. The field geometry was made up of eight traverses; each measuring 315 m. 64 electrodes were deployed with inter-electrode spacing of 5 m, to cover the study area. Three cone penetrometer test (CPT) and a standard penetration test (SPT) were conducted to identify the depth to competent layer as a constraint for ERT survey. The CPT and SPT tests show that the subsurface around the area is composed of materials of very low shear strength (< 5 kg/cm^2) interpreted as peat/clay at near surface to a depth of 8.2 m (being the maximum depth probed by the CPT test) and 25 m for the SPT. This agrees with the ERT result as the peat/clay was delineated to a depth of 25 m under the second half of most of the traverses which have high proximity to the SPT test hole. However, the inimical clay/peat layer was mapped to a deeper depth of 50 m under the first half of some of the traverses, alluding to heterogeneity of the subsurface layer in the study area. Generally, the overall depth to competent layer that could support a sizeable engineering structure is confined to the second half of the surveyed area north east (NE) portion as indicated in almost all the profiles at deeper depth mapped by ERT. Thus, the study shows that foundation investigation need be complemented with geophysical survey. By this way, where the engineering soil tests terminates geophysical survey could continue and could be a veritable tool to decipher deeper subsurface structures inimical to engineering construction.

Fatoba *et al.* (2010) conducted a research studies within Olabisi Onabanjo University, Ago lwoye Nigeria using electrical resistivity methods. The aim was to delineate the subsurface as a means of determining the causes of the foundation failure. Measurement involving Dipole-Dipole configuration and vertical electrical sounding (VES) were taken along four (4) traverses, using the Pasi Earth (16GL) Resistivity meter. The pseudosection and 2-D resistivity map were qualitatively interpreted and revealed three geoelectric layers, which are top soil, (which contain pocket of clay), weathered bedrock and the fresh basement respectively. The only structure observed along traverse 1 is at distance position 60-75m, which is a highly weathered structure that is outside the building area. The result from the second traverse at distance position from 0-35 m also indicate that the overburden is incompetent which is a weathered basement due to it high resistivity. Toward the end of traverse 2, it has a very low resistivity value of 50 Ωm which is confirmed to be clayey weathered materials that are not good for foundation and this weathered clayey material is up the depth of 4 m. the result obtained from traverse 3 indicate that much failure is not observed in this side of building. It has a low resistivity at distance position 10-35 m with the resistivity value less than 20 Ωm and is incompetent for a foundation structure, but much failure is not observed because foundation design has taken care of the likely damage to building. The loose clayey material is up to the depth of 3 m. the same low resistivity value ranges from 10-15 Ωm in profile 4 is observed to appear less severe mostly because the thick clay layer is uniform along the traverse and causing uniform settlement. It is concluded from these that the building failed due to incompetent clay layer and improper foundation design on some side of the building on which the building was founded.

Olorunfemi *et al.* (2004) carried out an investigation of the causes of foundation failure at the premises of Dental clinic building in the campus of Obafemi Awolowo University (O.A.U), Ile-Ife, Nigeria. The aim of the investigation was to delineate the geoelectric and geologic parameters of the subsurface using electrical resistivity method as a means of determining the causes of the foundation failure. The 2D geoelectric section along the three traverses indicate three distinct subsurface geologic layers which are top soil, the weathered layer, and the basement. The top soil has resistivity values that vary from 84 to 625 Ωm and thickness of 0.5 and 3.7 m respectively. It is composed of clay, sandy clay, clayey sand and laterite. The weathered layer is characterized by resistivity values ranging from 14 to 102 Ωm and thickness varying from 25 to 27.5 m. the low resistivity values (< 105 Ωm) are symptomatic of clay. The resistivity values of the third layer vary between 135 and 11 Ωm. these values suggest partly weathered/ fresh bedrock for a sequence characterized by highly conductive weathered layer. The depth to the geoelectric bedrock varies from 3.1 to 30 m.

The bedrock relief show a major depression beneath VES 3 along $T1_{,}$ beneath VES 3 along T2 and beneath VES 3, 5 and $T3_{.}$ The correlation of the basement depress indicates a N-S trend. The figures show that dental clinic building (Block $B_1\, and\, B_2$) and significantly located within these zones of depression. The dipole-dipole map, the pole-pole maps and pseudosections suggest that clays with pockets of more competent materials underlie the premises. It is concluded that the building failed due to the flow of the incompetent clays on which they were founded. Measurements involving vertical electrical sounding (VES) and horizontal profiling (EHP) techniques were taken along three traverses. These results were presented as geoelectric sections, pseudosection and maps.

CHAPTER THREE

MATERIALS AND METHOD

3.1 Materials

The materials involve this field work include the following: Measuring tapes, Electrodes, Cables, ABEM SAS 4000 Terameter, 24 Volt Battery, Geologic hammer, Handed Global Positioning System (GPS) device and RES2DINV computer software.

3.1.1 Terrameter SAS/4000

SAS stands for Signal Averaging Systems, a method whereby consecutive readings are taken automatically and the results are averaged continuously. The Terrameter SAS/4000 can operate in different modes (resistivity, self-potential and induced polarisation). A useful facility of the SAS/4000 is its ability to measure in four channels simultaneously. This implies that resistivity and induced potential measurements as well as their voltage measurements can be performed up to four times faster. This was employed in this project where resistivity and induced polarisation values were obtained simultaneously. SAS results are very reliable in resistivity and IP surveys; it comprises a battery powered, deep penetration resistivity meter with an output sufficient for a current electrode separation of 200 m under good survey conditions. See Figure 3.1

3.1.2 Electrodes

In DC resistivity surveys, the most widely used electrodes are aluminum, copper, or steel rods about two feet in length. These rods are usually driven into the ground connected with cables to the current source or the battery. Water mix with common salt are usually poured into the ground when the soil is in dry conditions in order toenhanced the conductivity between the ground and the electrode. The electrodes are made up of current and potential electrodes which are usually non-polarizing copper and stainless.

3.1.3 Cables

Cables are needed to connect the electrodes to their various electrical components and these cables are typically insulated wire with stranded copper-cored conductors. Longer cables are required during the field data measurement for a geophysical survey covered a large area. Both the current and potential electrode must be kept at a few distance apart in order to avoid noise due to bridging of the cables. For easy deployment and identification, cables are usually stored on reels, the red and black clips cables indicate positive and negative respectively.

3.1.4 Hammer

Hammer is one of the tools used for driving electrodes into the ground. In a situation where the ground became very hard for electrode penetration, water mixed with common salt is poured around the spot on the ground where the electrode will be penetrated, to enhance easy penetration and conductivity.

3.1.5 Battery

Battery serves as power source of the SAS4000 equipment when performing resistivity measurement. Dc current is usually transmitted from battery which serves as source of power.

3.1.6 Global positioning system

The Global Positioning System is used to measure the coordinates in both Latitude and Longitude direction. The GPS reading was taken at 0.00m, 150.00m and 300.00m in all the four profiles and this coordinate's reading were used to locate the satellites map of the study area

3.1.7 Res2dinvx64

This is a computer program that will automatically determine a two-dimensional (2-D) resistivity model for the subsurface for the data obtained from electrical imaging surveys Loke *et al.,* 2013). It is a Windows based program that also supports multi-core CPUs.

A finite-difference or finite-element modeling subroutine is used to calculate the apparent resistivity values, and a non-linear smoothness constrained least-squares optimization technique is used to calculate the resistivity of the model blocks (Loke *et al.,* 2003). If topography is present, the program uses a distorted finite-element grid so that the surface of the grid matches the topography (Loke, 2000). If I.P data is also present, the program will also generate an I.P. model together with the resistivity model using the complex resistivity method (Kenma *et al.*, 2000). This program can be used for surveys using the Wenner, pole-pole, dipole-dipole, pole-dipole, Wenner-Schlumberger, multiple-gradient and equatorial dipole-dipole (rectangular) arrays. In addition to these common arrays, the program even supports non-conventional arrays with an almost unlimited number of possible electrode configurations. One can process pseudosections with up to 16000 electrode positions and 100000 data points at a single time on a computer with 8 gigabytes (GB) of RAM using the Res2dinvx64 program. Besides normal surveys carried out with the electrodes on the ground surface, the program also supports aquatic and cross-borehole surveys.

3.2 Method

The field measurement of the electrical resistivity data was acquired using ABEM SAS4000 Terrameter along four (4) traverses with Alpha Wenner array configuration using four electrodes comprises of two current electrodes labeled CI and C2 and two potential electrodes labeled P1 and P2. The ABEM SAS4000 equipment has the ability of measuring apparent resistivity, induced polarization (IP) and self-potential (SP) at the same time. This research work measured the apparent resistivity with IP due its ability of identifying various lithologies within the subsurface structures (Ayolabi *et al*., 2010).

The survey area covered 300 m by 300 m square grid pattern and a total of 31 profiling points were established across each of the four traverse lines with minimum electrode location was 0.0 m and a minimum electrode spacing of 10.0 m to 90 m maximum electrode spacing was used as the resistivity readings were collected for 141 (n) acquisition datum points across 9 datum levels. Figure (4.1) shows the arrangement of model blocks and apparent resistivity data points of the field data. High data quality was achieved; therefore, there is no need to exterminate bad data points. The 2-D inversion results indicate that good resistivity data were acquired as the average sensitivity value is 1.75 (Figure 4.2) and the converged RMS misfit was lower than 10 at the maximum fifth iteration of the data. The inter-profile interval was place 100 m away from each profile point, the apparent resistivity and the corresponding IP values were measured using ABEM SAS4000 Terameter and thereafter, both resistivity and IP inverted models were computed with RES2DINV computer software. The resistivities of the blocks were adjusted and iterated until the calculated and field apparent resistivities agreed to barest minimum differences (Loke, 2004). The differences were expressed in percentage as root-mean-square error (RMS error), which ranges from 3.8 to 9.6 for this present work. The inverted sections depict subsurface resistivity values against electrode positions were presented in Figures 4.3, 4.5, 4.7 and 4.9 respectively for the electrical resistivity tomography (ERT and the IP models).

3.3 Data collection

Data acquisition were done by the method of Wenner configuration. This method is to provide a voltage across P1 and P2 electrodes, causing current to C1 and C2, therefore voltage and current is applied and the resistance value were obtained. The ratio of the distance between the electrodes, the schematic position and measurements of voltage and current at the electrode for Wenner configuration can be seen in Figure 3.1

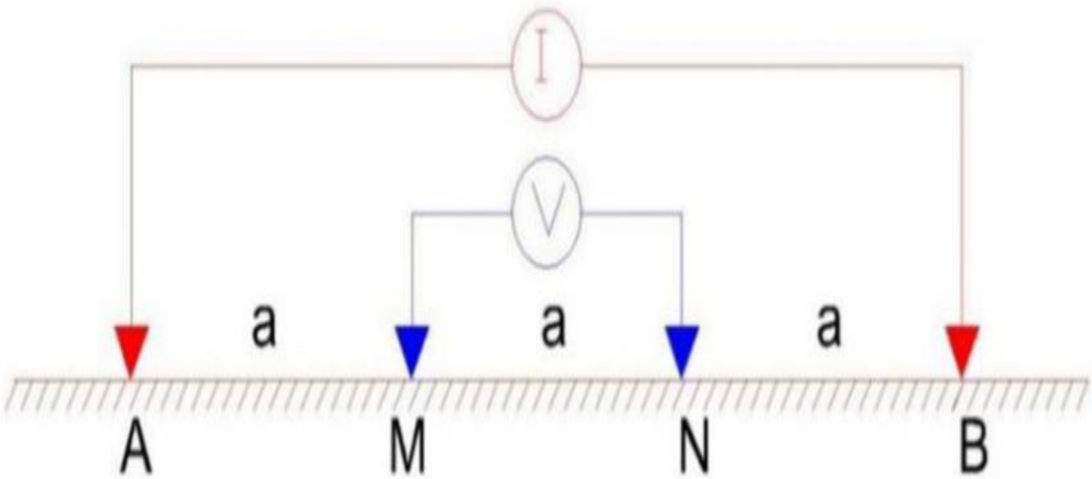

Figure 3.1: Wenner array schematic diagram (Aziz *et al.*, 2019)

3.6 Theory of Methods

Basically there are two theories of method involved in this work and this includes theory of resistivity and theory of induced polaristion.

3.6.1 Theory of resistivity

Electrical resistivity studies in geophysics is the flow of current through a subsurface medium consisting of layers of materials with different individual resistivities. The layers are assumed to be horizontal in nature (Rhett 2001).

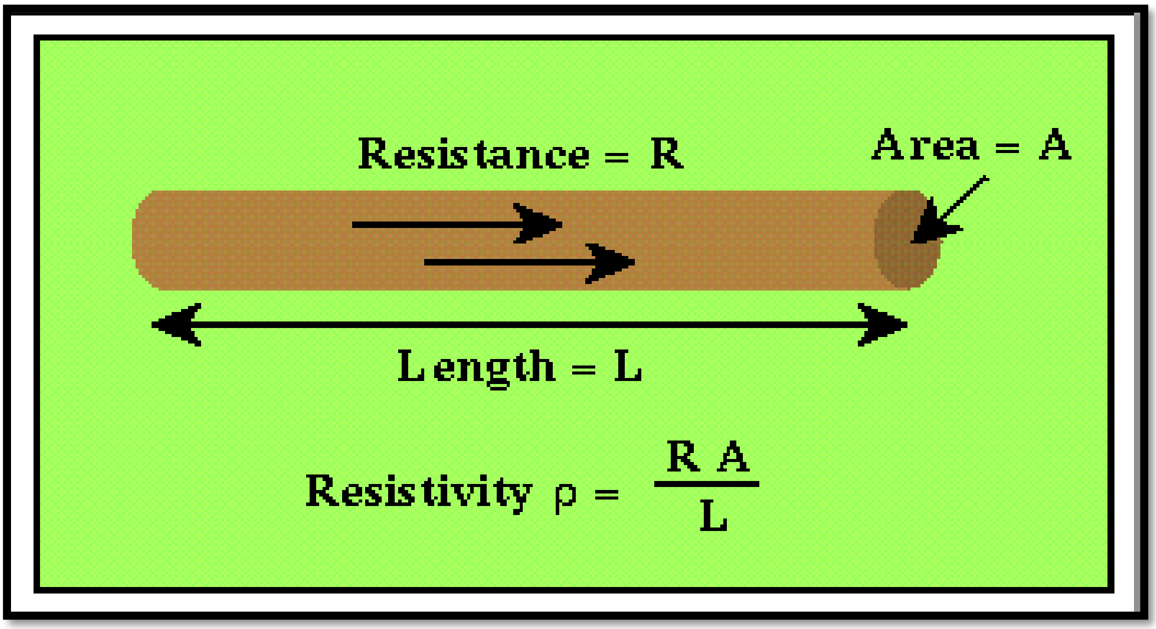

Figure 3.2: Principle of Ohm's law (Rhett 2001)

From Ohm's law, V = IR and R = V/I (3.1)

$$R = \rho\frac{L}{A} \tag{3.2}$$

$$\rho = \left(\frac{V}{I}\right)\left(\frac{A}{L}\right) \tag{3.3}$$

$$\vec{J} = \frac{I}{{}^{1}/{}_{2(4\pi r^2)}} = \sigma E = \frac{1}{\rho}E \tag{3.4}$$

where J = current density, ρ = Resistivity, σ = conductivity, E = Electric field potential, A = Area, R = Resistance and V = Voltage

Also,

$$\vec{J} = \frac{I}{2\pi r^2} = -\frac{1}{\rho}\nabla V \tag{3.5}$$

$$\vec{E} = -\nabla V = -\left(\frac{dV}{dr}\right) \tag{3.6}$$

Integrate equation 3.5 for first-order differential equation

$$-\frac{1}{\rho}\int\frac{dV}{dr} = \frac{I}{2\pi r^2}$$

$$-\frac{1}{\rho}\int dV = \frac{I}{2\pi}\int\frac{1}{r^2}dr \qquad (3.7)$$

$$-\frac{1}{\rho}(V_r) = \frac{I}{2\pi}(r^{-2+1})$$

$$-\frac{1}{\rho}(v_r) = -\frac{I}{2\pi r}$$

$$\frac{1}{\rho}(v_r) = \frac{I}{2\pi r} \qquad (3.8)$$

Make (V_r) the subject formula in equation 3.8

$$(V_r) = \frac{\rho I}{2\pi r} \qquad (3.9)$$

This equation 3.9 represents the potential at a distance r from electrode and I is the total current flowing from one current electrode to the other through the ground.

The electric potentials measured at M and N in the general array of the four electrodes in linear resistivity surveys are superposition of the potential of equation 3.8 due to each of the two source electrodes located at A and B with the distances between the electrodes given by AM, MB, and V = 0 infinitely far from the current source, therefore, the potential at M and N are given by

$$V_M = \frac{\rho I}{2\pi}\left(\frac{1}{AM} - \frac{1}{MB}\right) \qquad (3.10)$$

and

$$V_N = \frac{\rho I}{2\pi}\left(\frac{1}{AN} - \frac{1}{NB}\right) \qquad (3.11)$$

The total potential difference between the electrode M and N is given as follow;

$$V_{MN}=V_M-V_N=\frac{\rho I}{2\pi}\left[\left(\frac{1}{AM}-\frac{1}{MB}\right)-\left(\frac{1}{AN}-\frac{1}{NB}\right)\right] \quad (3.12)$$

This can be rearranged to yield,

$$\rho = \frac{V_{MN}}{I}K \quad (3.13)$$

By making ρ the subject of the formula in equation (3.10)

Where K can be express as follow;

$$K= 2\pi\left[\left(\frac{1}{AM}-\frac{1}{MB}\right)-\left(\frac{1}{AN}-\frac{1}{NB}\right)\right] \quad (3.14)$$

For wenner array, all the separations are equal to constant value a, and wenner geometric factor assumes the simple form K = 2πa.

Therefore,

$$\rho_{Wenner} = \left(\frac{V_{MN}}{I}\right)K=\left(\frac{V_{MN}}{I}\right)2\pi a. \quad (3.15)$$

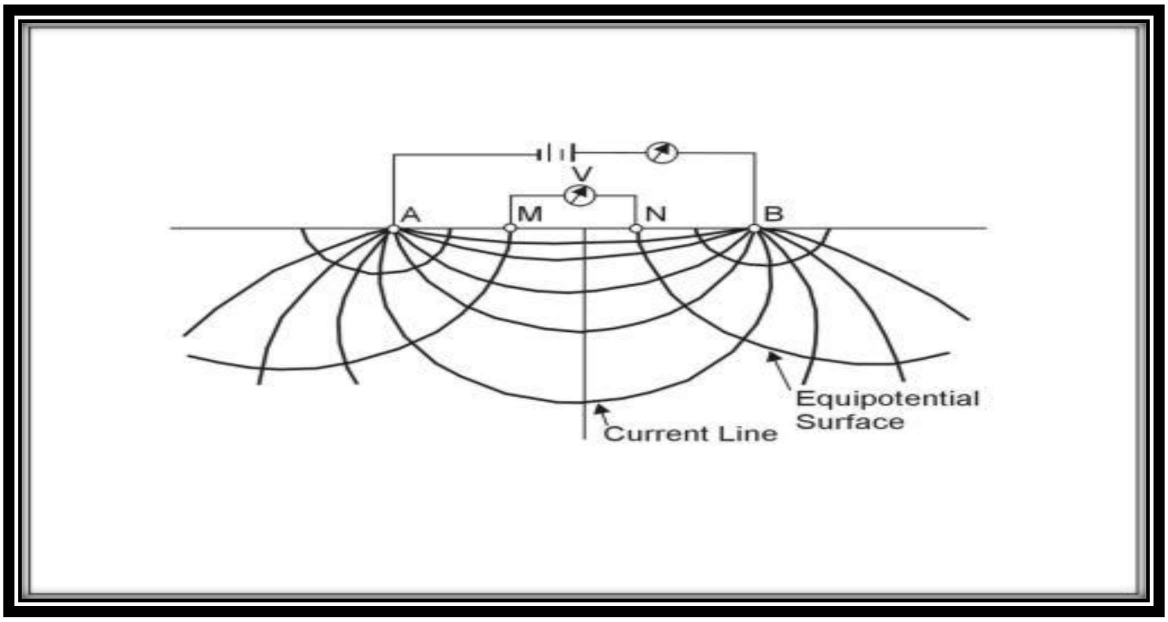

Figure 3.3: Equipotentials and Current Lines for a pair of Current Electrodes A and B on a Homogeneous Half-space (After Telford et al, 1990).

Figure 3.3 illustrates the electric field around the two electrodes in terms of equipotentials and current lines. The equipotentials represent imagery shells, or bowls, surrounding the current electrodes, and on any one of which the electrical potential is everywhere equal. The current lines represent a sampling of the infinitely many paths followed by the current, paths that are defined by the condition that they must be everywhere normal to the equipotential surfaces.

3.6.2 Theory of induced polarisation (IP)

Polarisation is a geophysical phenomenon which measures the slow decay of voltage in the ground after the cessation of an excitation current pulse (time domain method) or low frequency variation of the resistivity of the earth (frequency domain method) (Sumner 1976). In simple terms, the IP effect reflects the degree to which the subsurface is able to store electric charge, analogous to a leaky capacitor.

Chargeability (M), which is a typical measure of the IP effect in time domain, can be defined as the area under the potential decay curve, normalized relative to the initial potential V_0 (Telford *et al.* 1997).

Seigel (1959) defined the apparent chargeability as

$$Ma = \frac{Vs}{Vp} \tag{3.16}$$

Where V_s is the secondary voltage (voltage just after the current is shut off), V_p represent the primary voltage and M_a is the apparent chargeability. The secondary voltage is always difficult to measure accurately from the field and as a result, an integral measure of apparent chargeability is

$$Ma = \frac{1}{(t_{2-t_1})} \frac{1}{V_p} \int_{t_1}^{t_2} V(t)\, dt \tag{3.17}$$

$$Ma = \frac{1}{(t_2 - t_1)} \frac{1}{V_p} [V(t)(t_2 - t_1)] = \frac{V(t)}{V_p} \quad (3.18)$$

Equation (3.18) represent apparent chargeability (Ma)

Where $V_{(t)}$ is the voltage after time t and V_p is the voltage during injecting current

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Pseudosections

Interpretation of the inverse model resistivity section is done using information obtained from the soil resistivity values of the study area combined with colour range segments of resistivity values encountered in the inverse model resistivity sections for all the profiles investigated in this work as shown in Figures 4.3, 4.5, 4.7 to 4.9), the arrangement of model blocks and apparent resistivity data points of the surveyed area was ploted in figure 4.1. A classification model adopted by Bayowa and Olayiwola, (2015) was used for the interpretation of the inverse model resistivity. The different range of colour depicts distinct colours, ranging from blue to purple with blue depicting zones or regions of very low resistivity values (conductive zones) and purple depicting zones of very high resistivity values (high resistive or non-conductive zones).

Table 4.1: Colour Rating

Colour	Resistivity Rating
Blue	Very low
Green	Low
Yellow	Medium low
Red	High
Purple	Very high

(Bayowa and Olayiwola, 2015)

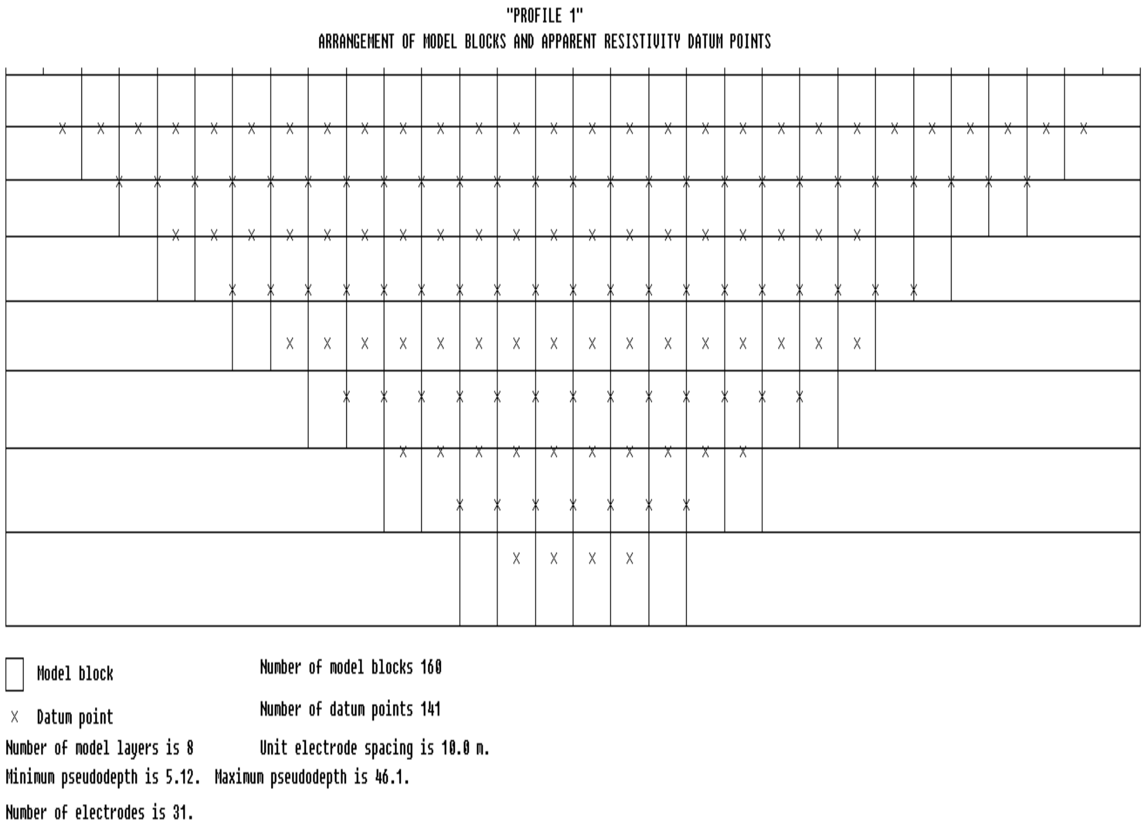

Figure 4.1: Arrangement of model blocks and apparent resistivity data points of the surveyed area

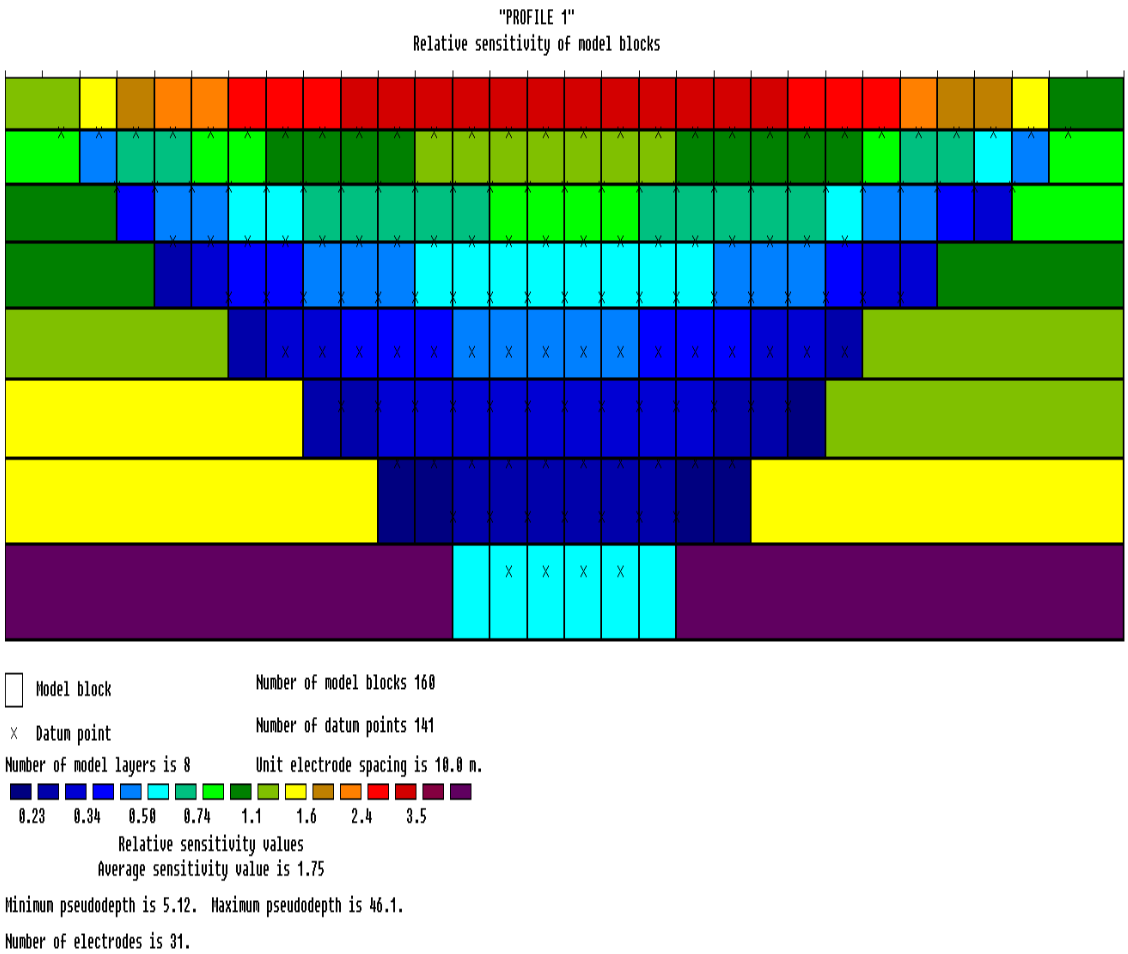

Figure 4.2: Relative sensitivity of the apparent resistivity model block

The results obtained from the inverted resistivity models; Figures 4.3, 4.5, 4.7 and 4.9 showed cross-sections of the true resistivity depth image of the subsurface soil within the area of study. Each of the profile lengths is 300m long and the resistivity distribution of the profiles 1,2 and 3 are almost similar except profile 4 that exhibit very low resistivity which is attributed to the presence of silt, sandy clays soil and Alluvial deposits which composed of clays, sands, and gravel, covers the superficial parts of the profile. The interpretation of ERI results was made together with the normalized chargeability. The inverse resistivity model sections are displayed at the top and the normalized chargeability sections are displayed below it (Figures 4.4, 4.6, 4.8 and to 4.10).

Profile One (RMS 4.5)

The profile one is majorly constituted of moderate to high resistivity value range of 80 Ώm to 1297 Ώm extending to a maximum depth of 40 m. At the profile distance of 60 m to 140 m, 160 m to 180 m and 190 m to 230 m the shallow subsurface is composed of high apparent resistivity value range of 350 Ώm to above 1297 Ώm. These high resistivity areas are attributed to fresh basement to moderately weathered basement rocks. There exists a pocket of low resistivity zones on the profile. At the surface distance of 240 m to 300 m on the profile line, it shows a resistivity range of 10 Ώm to 40 Ώm extending from the ground surface to the depth of 20 m where weathered rock and clay particles with elevated moisture act to increase electrical conductivity. The low resistivity as indicated in the depth range 30 m to 48 m on the profile surface distance of 80 m to 130 m is indicative of groundwater saturated zone (Figure 4.3). The higher resistivity which was dominant across the subsurface in this profile is believed to be a stable region for the erection of engineering structures.

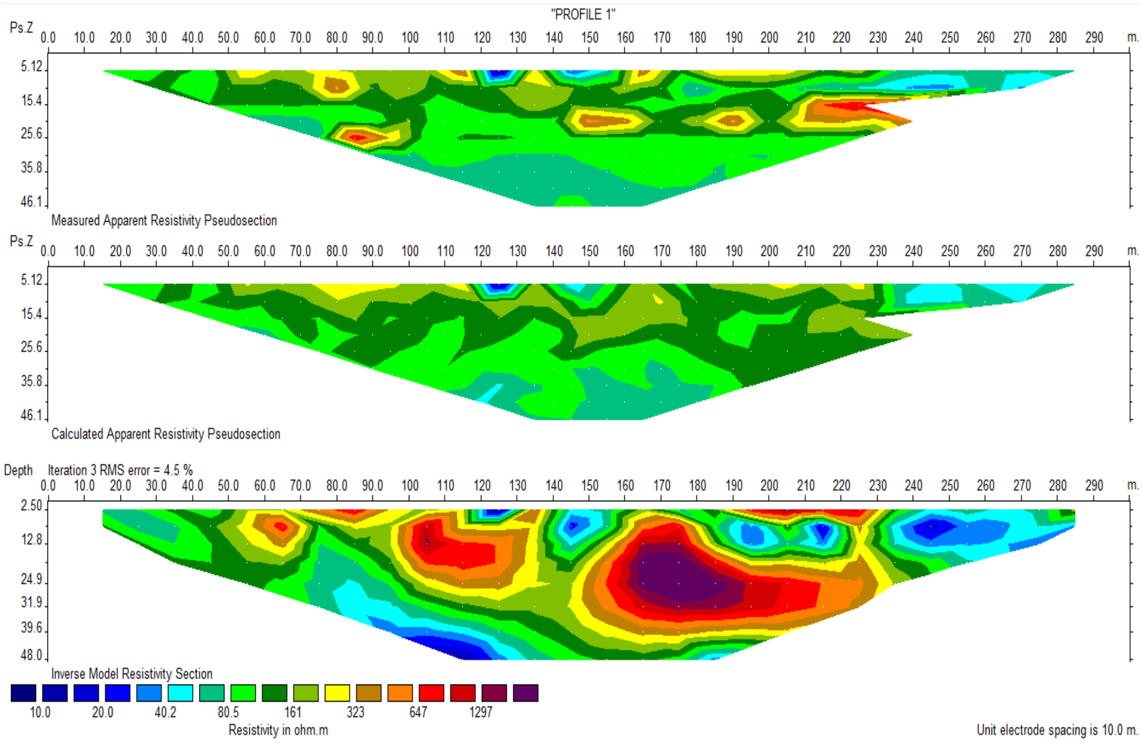

Figure 4.3: Electrical resistivity tomography (ERT) for profile One

The chargeability value of profile 1 ranged from negative chargeability value of -847 msec to a positive value of 363 msec (Figure 4.4). At the profile distance of 10 m to 40 m, 60 m to 170 m and 190 m to 300 m the shallow subsurface is composed of moderate to low chargeability value range between less than 17 msec to 50 msec. These low chargeability zones correspond to moderately weathered basement rocks with elevated moisture content. The minimal portions of the profile that shows relatively high chargeability value range of 190 msec to about 363 msec are attributed to unsaturated clay layers at the shallow depth and moist clay bearing layers at the profile distance of 200 m to 300 m. the low chargeability observed in this profile further suggest that the subsurface of this profile has the competence for sitting of foundation of civil engineering structures.

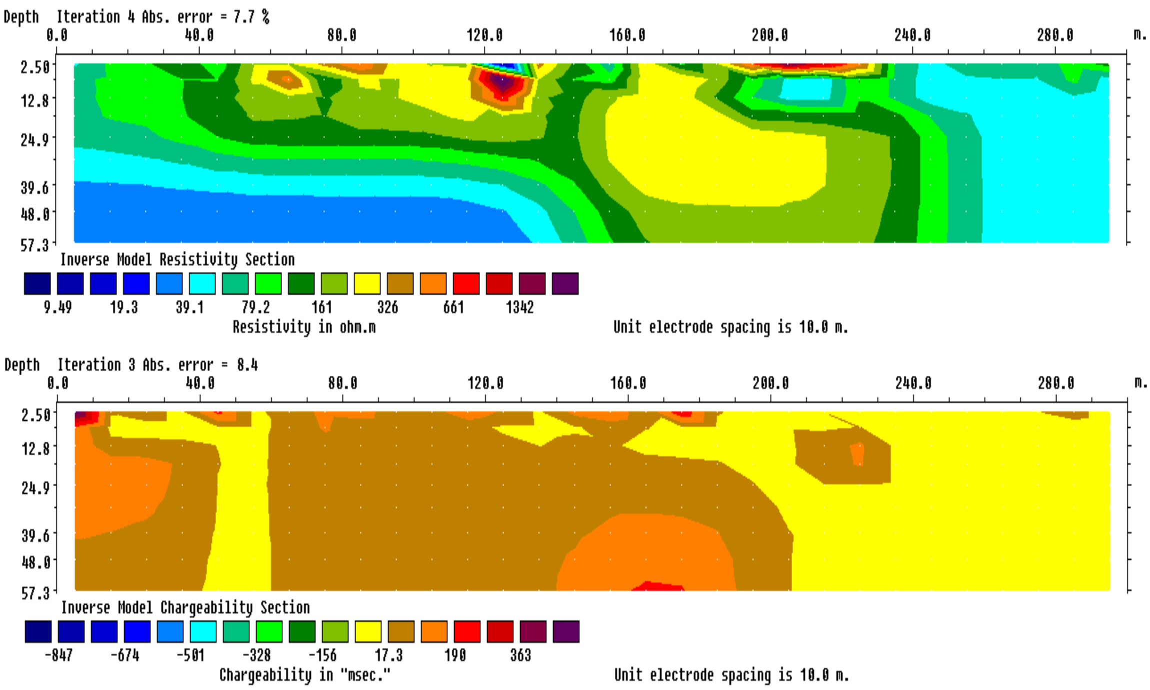

Figure 4.4: Resistivity and Chargeability Plots for Profile One

Profile Two (RMS 6.8 Percentage)

At near surface of less than 2 m below the earth on the surface profile distance of 130 m to 300 m relatively low resistivity value range (24.6 Ωm to 71.6 Ωm) obtained in the profiles reveal that of dry sandy clay/clayey sand usually in water saturated condition during wet season but has dried up and liquefied during dry season. Any engineering structure placed on this section of this profile may result multiple cracks. On the surface profile of 70 m to 120 m from the depth of 12.8 m to 48 m below the surface indicates the presence of saturated soil with resistivity range of less than 0.99 Ωm to 8.43 Ωm. The subsurface of this profile indicates relatively stable subsurface materials capable of sustaining engineering structures as it expresses a resistivity range of 208 Ωm to above 1769 Ωm indicating a weathered to fresh basement rock underlying the subsurface (Figure 4.5).

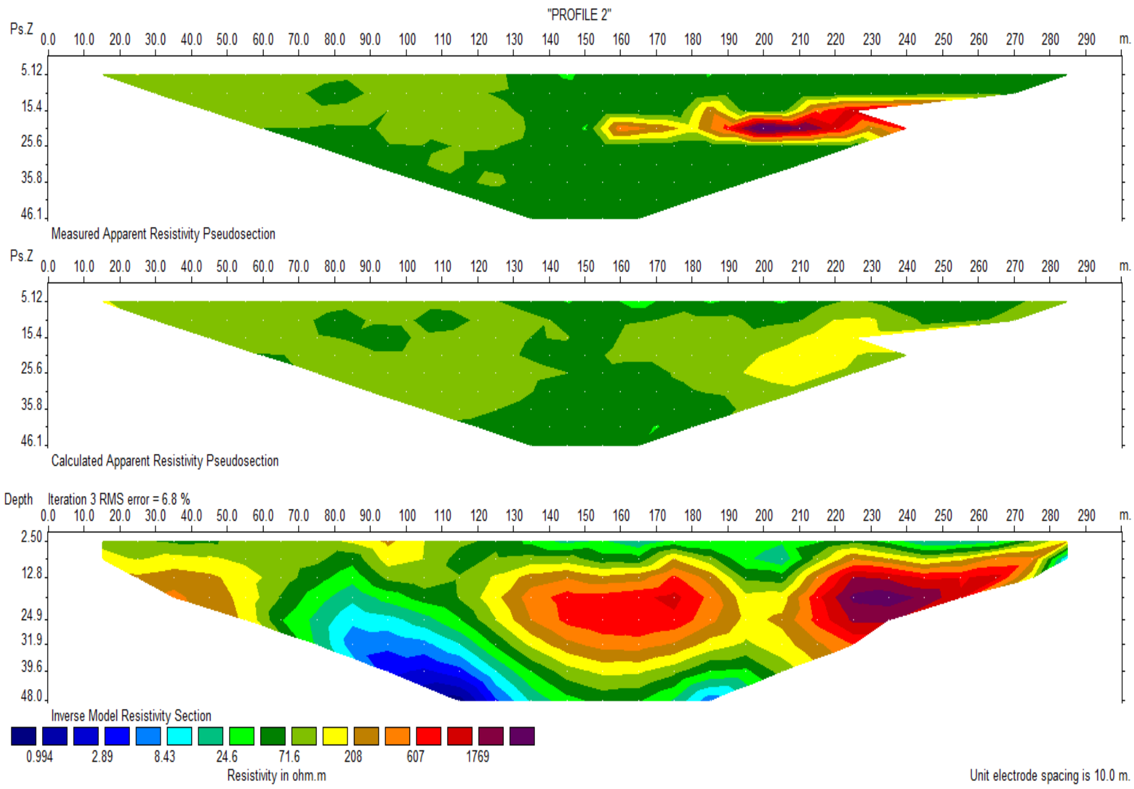

Figure 4.5: Electrical resistivity tomography (ERT) for profile Two

The IP (Chargeability) inverse model section agrees with the resistivity section of profile 02. At near surface depth on the surface profile distance of 20 m to 60 m, 120 m to 150 m, 170 m to 198 m and 230 m to 260 m a relatively moderate chargeability value range of 17 msec to about 132 msec with corresponding low resistivity value

(190 – 164 Ωm) which can be interpreted as clay horizons with variable water content. This portion can be considered incompetent for foundation while the region with high resistivity value (190 – 643 Ωm) with moderate low chargeability value (-98.7 to 16.7 msec.) from the profile distance of 130 m to 180 m and 210 m to 270 m at the depth of 12.8 m to 31.9 m shows strong bearing capacity that can support building foundation.

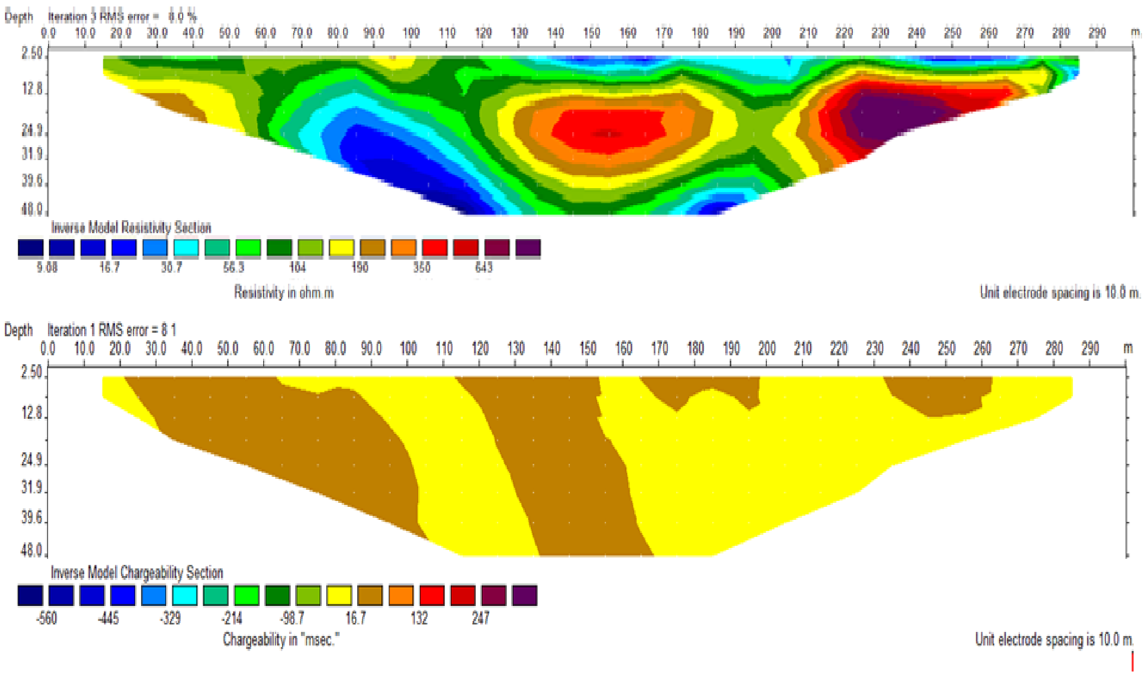

Figure 4.6: Inverted Resistivity and Chargeability Plots for Profile two

Profile 03 (RMS 3.8 Percentage)

The resistivity distributions of the inverted model resistivity section of subsurface soil on this profile shows similar variation of resistivity of the subsurface soil at different depths characterized by moderately high resistivity geomaterials throughout the profile line. The resistivity value ranged from 20 Ωm to above 182 Ωm (Figure 4.5). This is attributed to the distribution of iron rich lateritic soil as the major lithology at shallow subsurface overlying weathered basement rock with various degree of weathering at depths beyond 20 m. At the profile distance of 120 m to 135 m and 180 m to 220 m, there is an occurrence of moderately weathered basement rock which shows resistivity range of 9.78 Ωm to 42.2 Ωm. the subsurface of this profile has good signal strength and moderate features that compromise between the ability to resolve horizontal and vertical resistivity variations which implies its effectiveness to support engineering foundation and designs.

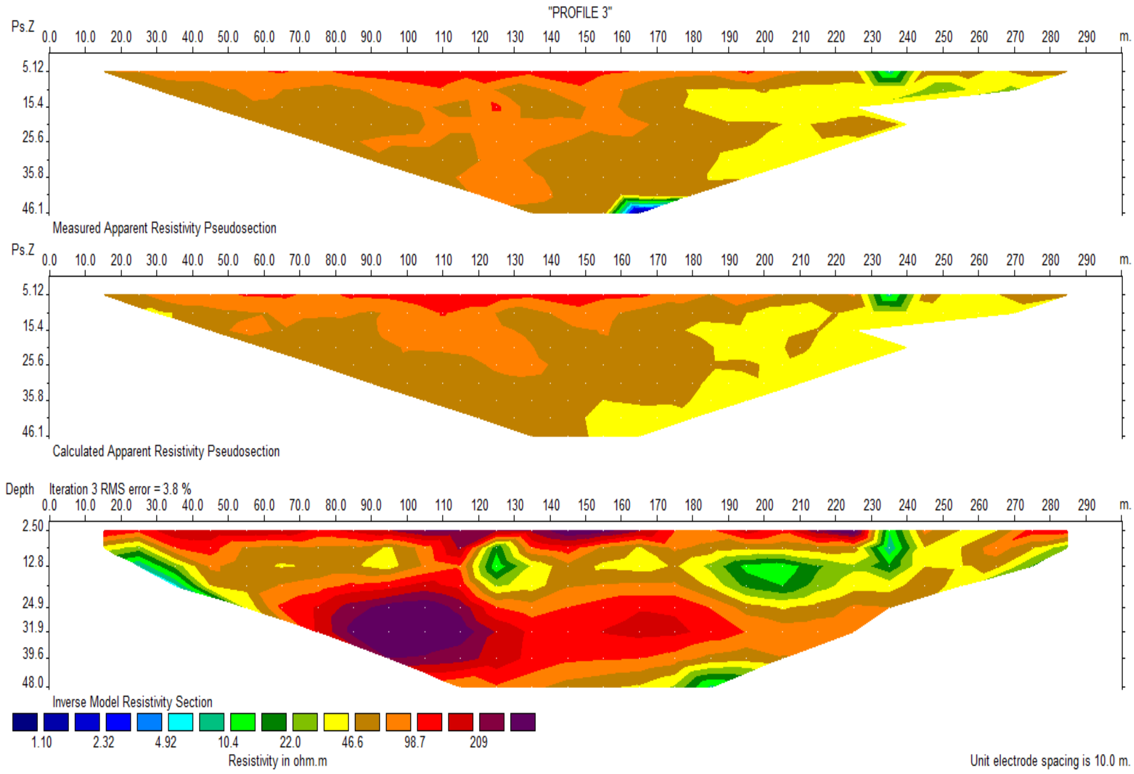

Figure 4.7: Electrical resistivity tomography (ERT) for profile Three

At first sight, there is a clear trend of low to moderate chargeability occurrence within the profile section. Chargeability values at the profile surface distance of 10 m to 60 m, 45 m, 165 m to 215 m and 245 m shows low chargeability values attributed to occurrence of moderately weathered basement rock. Pockets of unsaturated dry clay layers were observed at profile distance 110 m to 130 m and 260 m to 280 m with chargeability values range from 170 msec to 235 msec.

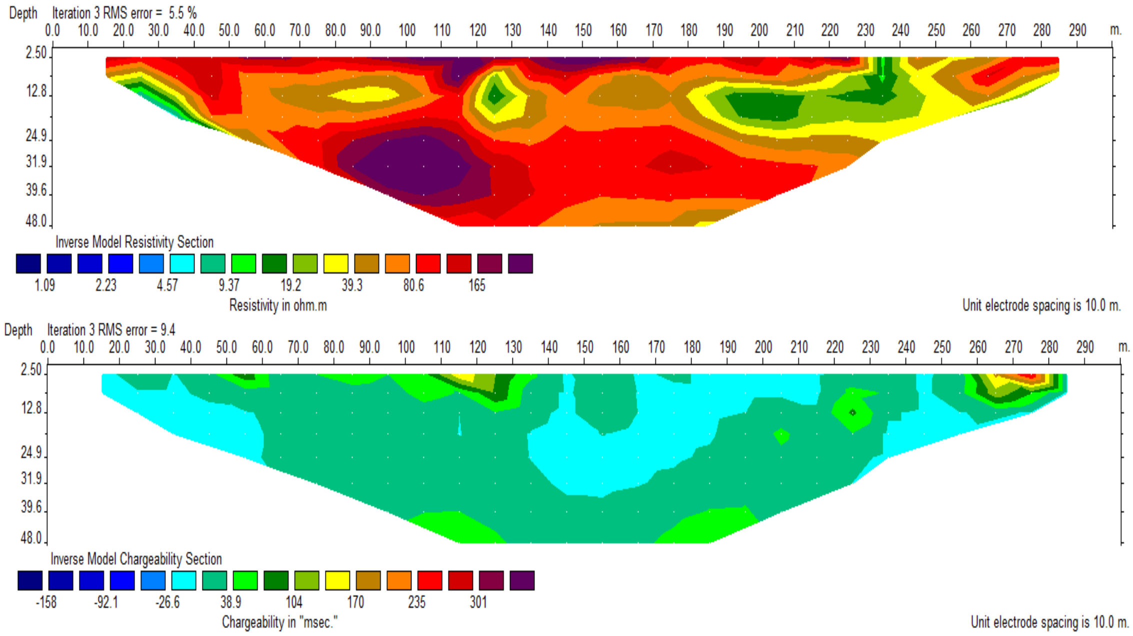

Figure 4.8: Inverted Resistivity and Chargeability Plots for Profile Three

Profile 04 (RMS 9.6 Percentage)

The model for profile 04 presents a heterogeneous picture of the subsurface lithological units. The resistivity of this profile ranged from as low as 10.8 Ωm to above 381 Ωm. The resistivity value ranges from 10.8 Ωm – 29.9 Ωm revealed the presence of silt and sandy clays soil from the distance of 10 m – 70 m which covered an average depth of 2.5 m – 24. 9 m. another anomalous feature is observed within a distance of 80 m – 280 m measured from ERT profile 4 with the resistivity value ranges from 49.7 Ωm – 82.7 Ωm. this feature is likely attributed to an open void filled by moderate resistivity Alluvial deposits which composed of clays, sands, and gravel, covers the superficial parts of the profile and it seems to be irregular with regard to the thickness, this irregularity suggest that the subsurface is underlain by inhomogeneous waste materials dumped on site and covered with peat/clay materials. Peat material is a highly water-saturated material composed of high percentage of decomposed organic matters, silt and humus soil. Also, the resistivity value ranges from 138 Ωm – 381 Ωm which appeared toward the end of the profile point (180 m – 250 m) distance from the depth 2.8 m – 40 m suggest the possible bedrock materials. Thus, it is observed that if structures are to be erected in this profile, there must be need for deep excavation to the depth of 5 m or more and also required engineering reinforcement in the form of raft/pile foundation in order to avoid structural failure. It is visible that the different subsurface lithologies as indicted in the resistivity profile were not resolved reasonably well in this section due to inhomogeneity nature of the subsurface. The geometry and depth variation of the lithologies were not coherently reflected in this section (Figure 4.9).the results from this profile indicate that the subsurface region may not be good for construction of massive engineering structures owing to low resistivity observed across the profile.

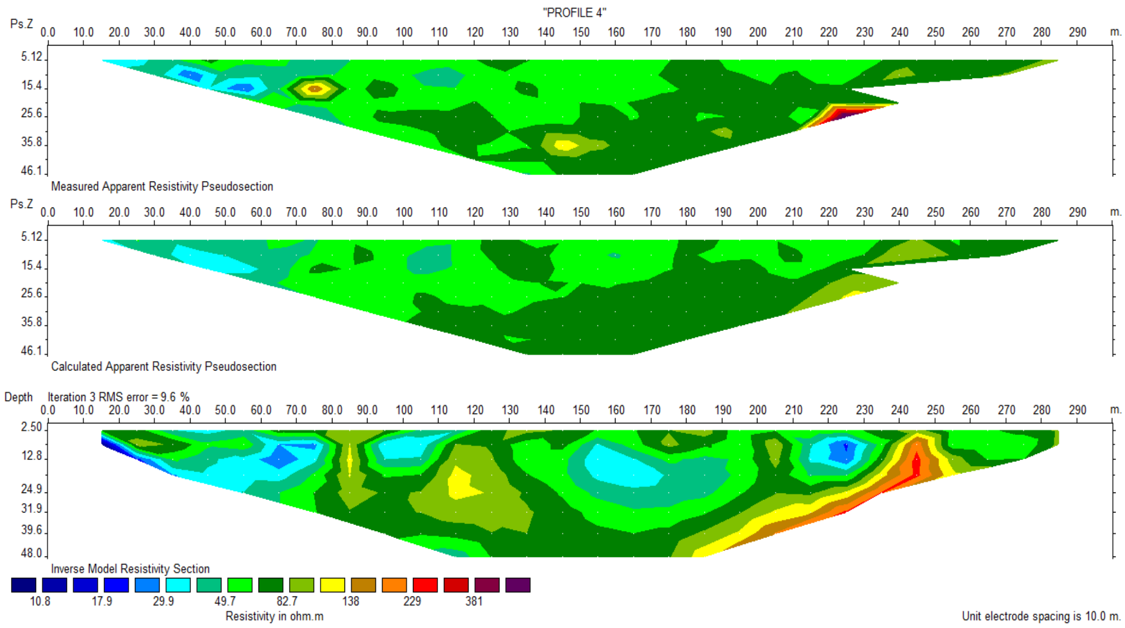

Figure 4.9: Electrical resistivity tomography (ERT) for profile Four

The 2D electrical resistivity section in this profile 4 is in conformity with the inverted IP (chargeability) results as indicated from the Ip profile distance of 10 – 20 m and from 50 – 60 m which suggest a possible clay material present at the near subsurface at the depth of 2.5 – 12.8 m with high chargeability of 80.2 – 179 msec. Also, from the profile distance of 80 – 90 m and 210 – 230 m is an indicative of wet clay material mix with moisture soil that tends to enhance the electrical conductivity.

The negative normalized chargeability which is dominant in this profile may be attributed to saturated peat/clay materials as indicated by the resistivity section of the same profile. This suggests that the foundation inhomogeneous soil may require significant improvement through engineering reinforcement in the form of raft/pile foundation to enhance their bearing capacities.

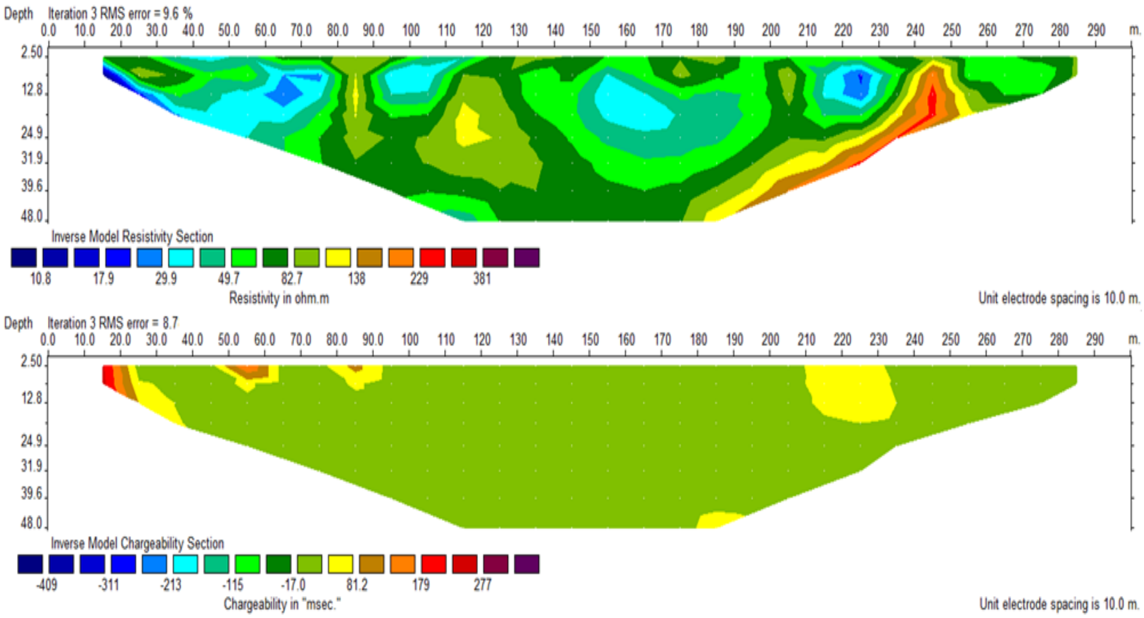

Figure 4.10: Inverted Resistivity and Chargeability Plots for Profile Four

4.2 Summary

The subsurface of these profiles indicate relatively unstable subsurface materials not capable of sustaining engineering structures as it expresses a resistivity range between 1.09 Ωm to above 1342 Ωm and a chargeability range between -847 msec to 363 msec indicating a heterogeneous subsurface lithology involving weathered to fresh basement rock, humus soil and clay materials underlying the subsurface.The IP effects of the near subsurface predict considerable low (negative) chargeability at varying depth for all the surveyed points. It is most likely that paradoxical behaviour of the subsurface showing strong negative chargeability responses in this study may be attributed to the effect of highly conductive zone made up of wet clay concentrations within the study area which is in conformity with Dahlin and Loke (2015), which revealed that negative chargeability can rise as a result of the dissemination of chargeable zones in the subsurface. If the chargeable subsurface zones are predominantly located in zones of negative sensitivity, and there exist low to no chargeability in the positive sensitivity zones, this will result in negative chargeability. The negative chargeability value of the subsurface clay lithology is also supported by the findings of Brandes and Acworth (2003), which states that alternate soft clay possesses pH gradients that are large which form under an applied electrical field. Relaxations of these pH gradients at the samples exterior will create a potential in the opposite sign (negative) to the applied potential, and so produce negative chargeability values.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The subsurface characterisation of soil for pre-foundational studies using geoelectrical survey methods involving resistivity and induced polarisation measurement of the subsurface has been carried out at three Arms Zone, Minna. The assessment includes detailed subsurface studies to evaluate the sustainability and competence of the site for proposed engineering infrastructures. The results of 2D electrical resistivity tomography revealed three subsurface lithologies made up of top soil which includes peat/clay, clay and sandy soil, weathered basement rock and fresh basement rock.

The subsurface resistivity value (323 – 1769 Ωm) and normalised chargeability value (16.7 – 190 msec.) with varying depth of 2.5 m to 39.0 m in profile 1 and profile 2 is believed to be weathered basement to fresh basement rock while low resistivity value (80.6 – 165 Ωm) revealed in profile 3 with negative to low chargeability value (- 153 – 104 msec.) from the depth of 2.5 m to 48.0 m is believed to be fracture weathered rock mixed wet clay content which enhance the conductivity.

The results of the 2D imaging revealed that the shallow subsurface area with resistivity value (1.09 – 104 Ωm) with relative low to high chargeability value (132 – 235 msec.) across the four profile lines may not be feasible for massive engineering structures because of the presence of clay materials which may caused damage to foundation in the near future.

The subsurface region with high resistivity value (138 – 1769 Ωm) with moderate chargeability value (17 – 38.9 msec.) is considered best for construction of any types of any types of civil engineering structures

5.2 Recommendations

1. The foundation soil may require significant improvement through engineering reinforcement in the form of raft/pile foundation to enhance their bearing capacities. The design of proposed buildings should include more column base at the DPC level up to a minimum depth of 5m or more.
2. Based on the findings of this study, it is recommended that other geophysical method such as seismic and geotechnical investigations should be carry out to ascertain the stratigraphic variations in the subsurface lithologies and soil bearing capacities of the near subsurface structures prior to construction of buildings and other engineering structures in the study area. The above measures are necessary to avoid the zone of seasonal moisture and volumetric soil expansions and shrinkages usually attributed to the presence of clayey-sand soil which are predominant at the near subsurface in the study area.

5.3 Contribution to Knowledge

The 2.D electrical resistivity tomography has revealed three geoelectric layers with resistivity values ranging between 1.09 Ωm to 1769 Ωm and normalised chargeability value of - 847 msec. to 363 ms ec. The low resistivity value of 1.09 Ωm to 104 Ωm and normalised chargeability value of – 847 msec. to 235 msec. at varying profiles depth of 2.5 m to 48.0 m has been interpreted as peat/clay and lateritic clay materials which are considered weak for massive engineering structures while the high resistivity value of 13 8 Ω to 1769 Ωm with moderate chargeability value of 17 msec. to 38.9 msec. is believed to be weathered rock to fresh basement rock which are considered best for construction of any types of civil engineering structures.

This research will further advance the field of geophysicist if properly integrated with geotechnical method to enhance the performance of building structures, thereby minimising the rate of building collapses in Nigeria.

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