GEOPHYSICAL INVESTIGATION OF A SEWAGE TREATMENT SITE AT AHMADU BELLO UNIVERSITY, ZARIA (MAIN CAMPUS) USING 2-D ELECTRICAL RESISTIVITY TOMOGRAPHY

BY

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M. Sc/Scien/01639/2006-07

A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL OF
AHMADU BELLO UNIVERSITY, ZARIA
NIGERIA

IN PARTIAL FULFILLMENT FOR THE AWARD OF MASTER OF SCIENCE IN APPLIED GEOPHYSICS

DEPARTMENT OF PHYSICS
AHMADU BELLO UNIVERSITY, ZARIA
NIGERIA

JUNE, 2011

DECLARATION

I declare that the work in the thesis entitled "Geophysical Investigation of a Sewage Treatment Site at Ahmadu Bello University, Zaria (Main Campus) using 2-D Electrical Resistivity Tomography" has been performed by me in the Department of Physics under the supervision of Professor I. B. Osazuwa and Dr. K. M. Lawal.

The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any university.

Name of student	Signature	Date

DEDICATION

I dedicate this research work firstly, to God Almighty for His infinite mercies and also to Eng. Bayo Soetun of blessed memory for his unforgettable roles in my life. May his gentle soul rest in peace. Amen

CERTIFICATION

This thesis entitled "Geophysical Investigation of a Sewage Treatment Site at Ahmadu Bello University, Zaria (Main Campus) using 2-D Electrical Resistivity Tomography" by JIMOH, Lateef Agbaiyero meets the regulations governing the award of the degree of Master of Science of Ahmadu Bello University, Zaria and is approved for its contributions to knowledge and literary presentation.

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ACKNOWLEDGEMENT

I exalt God Almighty for making this program possible. His mercies and grace were more than sufficient to sustain me during the difficult moments, when I was down and out, which have translated into this breakthrough at this junction of my academic pursuit. May His name forever be glorified.

I am greatly indebted to my Major Supervisor, Prof. I. B. Osazuwa, who suggested this topic and showed concern and absolute devotion through out the pursuit of this thesis and for his untiring efforts in seeing the research work concluded. I have benefited abundantly from his store of knowledge and wealth of experience. Sir, thank you and may God bless you. I will forever be grateful to my supervisor, Dr. M. K. Lawal, for his indispensable contributions, and his timely push when I was not forthcoming is highly appreciated. I must express my appreciation and gratitude to the Course Coordinator, Dr. P. O. Sule, my wonderful Lecturers, Dr. A. L. Ahmed, Prof. L. A. Dim, and Mr. C. C. Chiemeke for their academic and moral support. I also acknowledge the support and assistance of the technical staff of the Department of Physics for their immeasurable availability and flexibility during this academic pursuit, particularly at field school.

I'd like to appreciate the Head of Department, Dr. R. Nasiru, the PG coordinator, Dr. U. Sadiq and the entire staff of Physics Department for their help, care and services rendered during this course.

I should not forget to express my gratitude to all my course mates, for their relevant intellectual contributions and friendship.

And to my family and loved ones, you are wonderful and still remain a part of the most treasured people in my life.

JIMOH, Lateef A.

ABSTRACT

A systematic and dedicated effort has been made to collect two-dimensional resistivity data of the subsurface formation of a sewage treatment site on Ahmadu Bello University main campus, Samaru, Zaria, Kaduna State of Nigeria, for research study. The Research site is located within the South-West region of the main campus, between latitude 7.657^0 N to 7.659^0 N and longitude 11.135^0 E to 11.139^0 E, and part of the Kubanni Basin underlain by Precambrian rocks of the Nigerian basement complex.

The main aim of the study is to use the two-dimensional Wenner based configuration electrical resistivity tomography (ERT) technique to characterize the subsurface lithology of the site. Electrical resistivity tomography method is based on the measurements of electrical resistivity along a profile, where a series of electrodes (smart electrodes) are regularly placed.

In all, geo-electrical surveys were carried out on a total of six profiles, two of equal length of 300m each and the remaining four, 200m each long. The measured resistivity data were used to deduce the true resistivity variation of the subsurface formation and related to geological features or materials. The interpretation of the two dimensional pseudo sections showed averagely top deposits or overburden thickness varying between 4m and 15m. The depth to weathered basement rocks varies from about 4m to over 20m underneath some parts of the sections. The fractured basement rock occurred averagely from depth above 15m, while fresh basement rock was encountered averagely from depth of 25m. Structural

features suspected to be fault, that may serve as conduit for passage of waste were also identified, particularly on model sections of profiles LundDam01 and LundDam02.

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CHAPTER ONE
INTRODUCTION

1.1 General

Sewage is human and domestic waste matter from buildings, especially houses that are carried away by water through sewers. Sewage is a major carrier of diseases and toxin, thus its treatment and disposal is very crucial to any community. A typical sewage treatment method is in three major stages which include: primary, secondary and tertiary stages. The primary stage particularly deals with removal of inorganic materials like debris, grits and a small extent of organic matter in the sewage through processes such as filtration, sedimentation, flotation, digestion and drying. The secondary treatment stage usually involves harnessing and activating nature's process of waste disposal through biological conversion of organic matter to stable forms, such as carbon dioxide, water, nitrates, and phosphates, as well as other organic matter, by bacteria in the presence of oxygen (aerobic condition). The tertiary stage includes additional steps to improve effluent quality by removing refractory pollutants and phosphorus, especially if wastewater is to be reused. The secondary stage and tertiary stage processes of sewage treatment can be adequately implemented through a popular system referred to as 'Waste Stabilization Pond' (WSP) and currently being practiced within the study area.

Although, the significance of waste stabilization ponds (WSP) cannot be over-emphasized, (especially since it offers one of the simplest, lowest costs, and most efficient wastewater treatment technologies available, and particularly suited to warm climates), not withstanding, there are numerous problems, that may be associated with this cleverly

designed system, which mostly occur within the shallow earth subsurface depth and may hinder its efficiency, thereby, undermining its full potential. These problems are geotechnical and environmental and may depend on the permeability at the ponds' liners. Such problems include flow-induced deficiencies or failure such as overtopping, piping, leaks, scour, and erosion; Pond instability that may prevail from presence of geological fault, slides or liquefaction; and pond deformation due to settlement, heave or cracking.

However, the physical properties of many rocks are significantly altered by the presence of groundwater (which directly or indirectly relates to environmental problems by its location and its protection from contamination sources of various kinds) in pores, and fissures, the degree of alteration varying with the nature and content of contaminants present makes it possible to locate water-bearing structure, identify and probably solve problems associated with design and construction of sewage ponds on such structure, through investigation using appropriate geophysical techniques. The aim of this research work is to characterize or map the shallow subsurface lithology of a sewage pond on Ahmadu Bello University campus by applying electrical resistivity tomography geophysical technique.

Electrical resistivity tomography (ERT) is now a well established tool for environmental and engineering site investigation, and is routinely applied to the detection of pollution (Daily et al, 1998; Goes and Meekes, 2004), the characterization of geologic (Meads et al, 2003) and engineering structures (Daily and Ramirez, 2000), and to hydrogeologic studies (Binley et al., 2002; Sandberg et al., 2002).

ERT provides a relatively low cost, non invasive and rapid means of generating spatial models of physical properties of the subsurface. It is especially beneficial for contaminated land investigations where it is generally desirable to minimize ground disturbance. A category of environmental and engineering problems for which ERT has proved to be particularly useful are investigation of structural failure in buildings (Osazuwa, et al, 2006), mapping of chemical pollution flumes or agricultural polluted site, delineation of water-saturated zones in landslide bodies (Cangkat Jering, Malaysia), detection of zones of fractures, fissures, deep weathering, and find depth to soil or bedrock interface, the investigation of landfill sites, where it has been used to map landfill geometry (Reynolds and Taylor, 1996; Bernstone and Dahlin, 1997) and compositional variations (Yuval and Oldenburg, 1996; Bernstone et al., Guerin et al., 2004), and to detect bedrock contamination (Aristodemou and Thomas-Belts, 2000; Yoon et al., 2003; Abu-Zeid et al., 2004; Naudet et al., 2004) and many more.

1.2 Site Investigation

Ahmadu Bello University wastewater treatment site (WSP) is located within the west region of the main campus, between latitude 7.657^0 N to 7.659^0 N and longitude 11.135^0 E to 11.139^0 E. The site is underlain by Precambrian older granite that has been weathered to laterite. The lateritic outcrop exposed in a section by erosion is about a two meters thick and becomes less compacted with depth. The site consists of numerous pits or ponds which are divided by functions mainly into 'Facultative lagoons' and 'Maturation lagoons' forming a waste stabilization pond system (WSP). These ponds are connected to each other by a structure of concrete pipes. Other structures on site include filtration chamber and

manholes which grant access to solve blockage in pipes. These ponds are expected to store the sewage for a period of time when natural biological processes of treatment might have occurred followed by final application of chlorine to destroy pathogenic organisms before stabilized water is discharged as effluent down the slope, some few metres, into the downstream, which is connecting the spillway of the Ahmadu Bello University dam. Fig. 1.1 shows a satellite image of the site.

The aim of this research work is to use Geophysical methods to characterize the sewage treatment site subsurface lithology so as to determine the constituents and condition of the subsurface materials. This might serve as guide to solve geotechnical problems that may lead to project failure and also to detect fracture zones, fissures or loose ground that may serve as pathways for groundwater contamination and transfer of pollutant.

1.3 Problem Definition

The fact that the study area is a wastewater treatment site, poses a potential environmental hazard if proper preventive measures are not put in place: the construction of wastewater stabilization ponds or 'Lagoons' in the site can cause escape of accumulated organic waste water and diffusion of contaminants into surface water and ground water, especially if the subsurface rocks are fractured or if the overburden sediments are loose. Also, if the subsurface layer is clayey, the construction work may be at risk of collapse: - the clayey layer may expand and contract, the soil resistance to flow may weaken, due to porosity and impermeability thereby entrapping the wastewater and causing flood or landslide if the weight of trapped water becomes unmanageable by the overburden soil resistance thereby

destroying the existing structure of concrete pipes, manholes, filtration chamber, etc, and rendering the project invaluable.



Fig. 1.1 A Google Earth satellite image of the Research Area

For the sewage stabilization pond or 'Lagoon' to achieve its full potential, and to understand how it might constitute environmental problems, we need to know the type and condition of the subsurface rocks or geological formation within and along the sewage treatment site. Electrical resistivity tomography (ERT) technique which establishes correlation between resistivity and geological formation can conveniently achieve this goal.

1.4 Research Motivation

Geophysical exploration has rapidly expanded over the past 50 years, and most recently is its successful application in environmental and engineering issues. The study area is been researched now because it is utilized as a waste stabilization pond system and expected to store accumulated organic wastewater for a period of time. And despite this high potential environmentally hazardous project, no geophysical analysis seems to have been carried out to assess the degree of fracturing, looseness of the ground and clay formation within the area. Geophysical methods unlike other methods are quick, inexpensive and non-invasive means to provide vital information about the earth's subsurface properties such as depth to bedrock, location and distribution of conductive fluids, location and orientation of fractures and faults (Reynolds, 1997). Vogelsang(1995) reports on cost analysis, for an actual environmental investigation of a landfill project conducted in 1993 in North Germany, indicated that geophysical methods are the cheapest and fastest over large area in comparison to others . Proper application of geophysical methods can optimize exploration by maximizing the rate of ground coverage and minimize drilling requirements.

1.5 Aims and Objectives

The aim of this research work is to use two-dimensional resistivity imaging technique to characterize the subsurface geological formation of the sewage treatment site at Ahmadu Bello University, Zaria (Main Campus).

The specific research objectives set out include:-

- Lithology delineation of the subsurface rocks.
- Determination of depth to the fresh basement rock, thickness of weathered basement and overburden.
- Mapping of structural features such like faults, fissures and hydraulically active fracture zones.

In summary, it is envisioned that this research work might establish the magnitude of seepage from the wastewater treatment site and might be used to proffer adequate measures that can be put in place to avert, control or remedy possible adverse effects that may prevent waste stabilization ponds system from achieving its full potential.

1.6 Previous Work in the Study Area

1.6.1 Geophysical Study

Due to unavailability of geophysical survey record of the research area, one may suggest that none has been carried out. The area is under study now because it is expedient to know the nature of its subsurface, especially, since it is designed to store or accumulate wastewater for a period of time before final discharge as effluent down the slope into the Kubanni stream.

Although, numerous geophysical studies have been carried out in the Kubanni Basin, on which, in the North-Western part, the study area is situated. Notably amongst, which is the closest to the Study area is that of Ososami (1968), who carried out a groundwater assessment of part of the North-western part of the Basin, mainly around the main campus of A.B.U. Zaria, using vertical electrical sounding and found that aquifer in the area has variable thickness and depth to the bedrock varies from less than a meter to a maximum depth of about 30m. Shemang (1990) also conducted vertical electrical soundings and estimated that the range of the depth to the basement to be about 3m just to the west of A.B.U. Zaria dam, to about 44m around Unguwan Kubanni.

1.6.2 Geological Study

Generally, geological study of the Kubanni Basin dates back to 1967 when Olowu carried out a study of the surface water and its effect on the groundwater in Zaria area (Hassan, 1987). Other works include that of McCurry (1970), Wright and McCurry (1970) who studied the basement geology of the Zaria sheet 102 S.W. and found that the basement rock is mostly made up of biotitic granite-gneiss and older granites. Akpoborie (1972) studied the hydro-geological structures which control the underground water in the Samaru Creek and found that the flow of groundwater into the Creek is controlled by structures like joints and fractures developed in the rocks. Tokarski (1972) worked on Heterogeneous Terrace Arrangement West of A.B.U. Zaria, which covered the study area and classified the main elements as Aeolian cover, Upper Savannah Loam, Younger laterite and Lower Savannah Loam. He divided the Quaternary sequences into three types of terraces

according to their ages of deposition, relationship between their mineral content and the mineralogy of the underlying basement complex rocks.

1.7 Geology of the Study Area

The Study Area is situated on the Ahmadu Bello University main campus, Samaru, (Zaria, Kaduna State of Nigeria) which is occupying 9% area of the Kubanni Basin (Fig. 1.4) and positioned on the North-Western part of the Basin.

The Kubanni Basin lies in the North-Western part of Nigeria and falls into the Nigeria Basement complex rocks (Fig. 1.3). According to Oyawole (1964), the Nigeria basement complex is the end result of at least two major Orogenic cycles. The last of the cycles probably extended from late Precambrian to lower Paleozoic. The cycles were believed to be initiated by the deposition of thick sands, mud and graywacke on igneous material cover and eroded metamorphic basement during the preceding cycle. Subsequent extensive re-metamorphism and partial mobilization of the underlying basement, let to transformation of accumulated materials into high-grade gneiss, migmatites and older granite (Truswell and Cope, 1963; Wright and McCurry, 1970).

The basin is underlain by rocks of the Precambrian age. Biotitic gneiss predominates in the area and outcrops, mainly in stream valleys where they are deeply weathered (Wright, 1970). The biotitic gneiss complex consists of medium to coarse grained and moderate to weakly foliated rocks which constitute about 30-40% of the basement complex exposed in the basin (Wright and McCurry, 1970).

The superficial deposits that cover most of the basement rocks in the Kubanni Basin act as recharge areas where they are underlain by weathered basement (Eigbejo, 1978).

Eigbejo (1978) stated that, two phases of deformation took place in the basin: one along an E-W axis while the second was roughly along N-W axis. The later was so strong that it obliterated evidence of the former and left a dominant N-W structural trend.

Wright and McCurry (1970) also observed the basement structure in the basin to be relatively simple because of the uniform regional foliation trends and numerous joints and fractures were found to have occurred in the basin after the Pan-African Orogeny.

The A.B.U. main campus, Samaru, Zaria being part of the Kubanni Basin, is therefore underlain by Precambrian rocks of the Nigerian basement complex. The survey site is situated within the South-Western part of the campus and underlain by muscovite biotitic-gneiss (Eigbefo, 1978). The alluvial deposit in Zaria area consists of gravels, sands, silts and clay which are mostly found along stream channels. Their thicknesses range from 5-15m (Olowu, 1967).

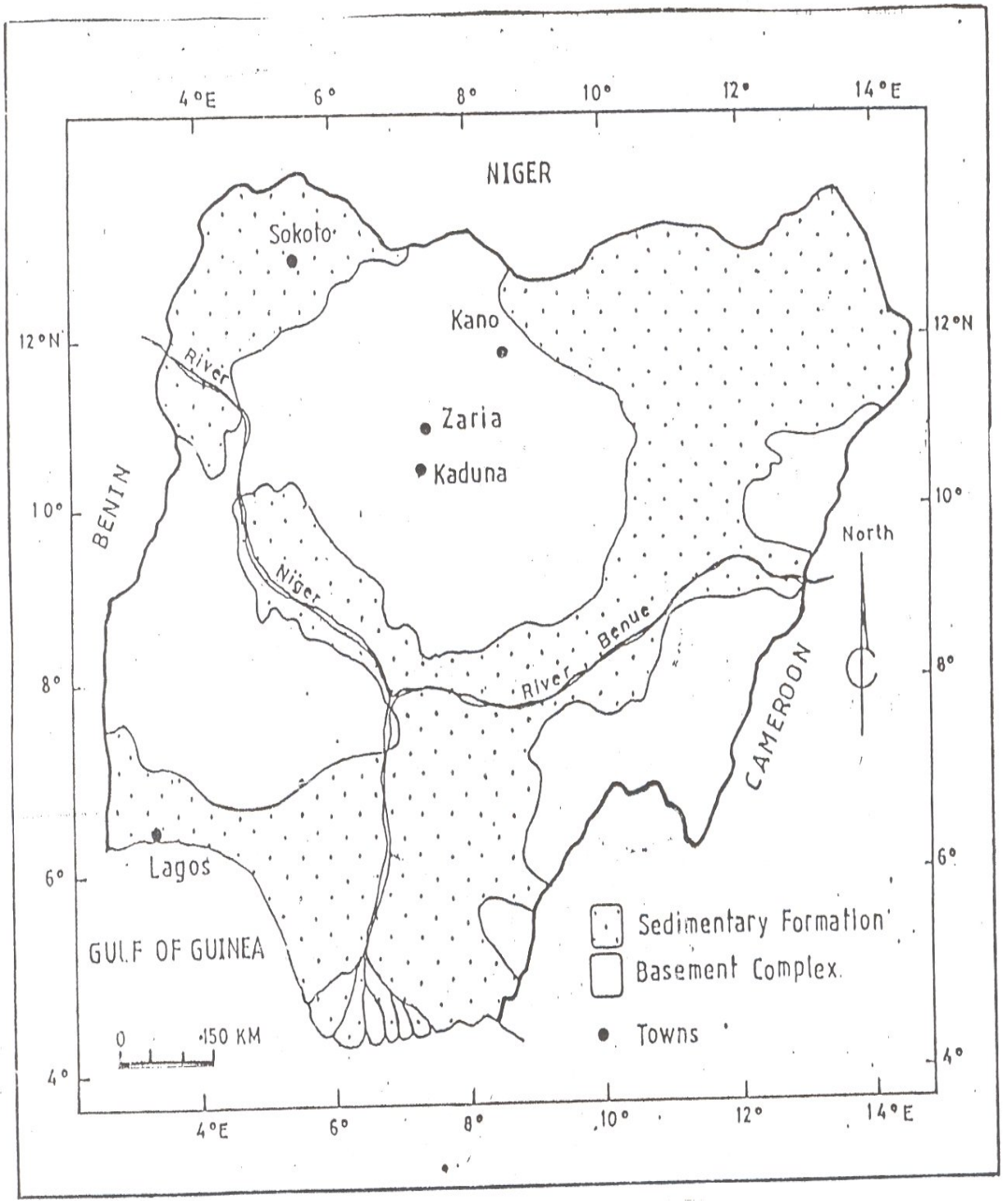


Fig. 1.2 Simplified geological map of Nigeria showing location of Zaria area (Courtesy of G.S.N., 1970)

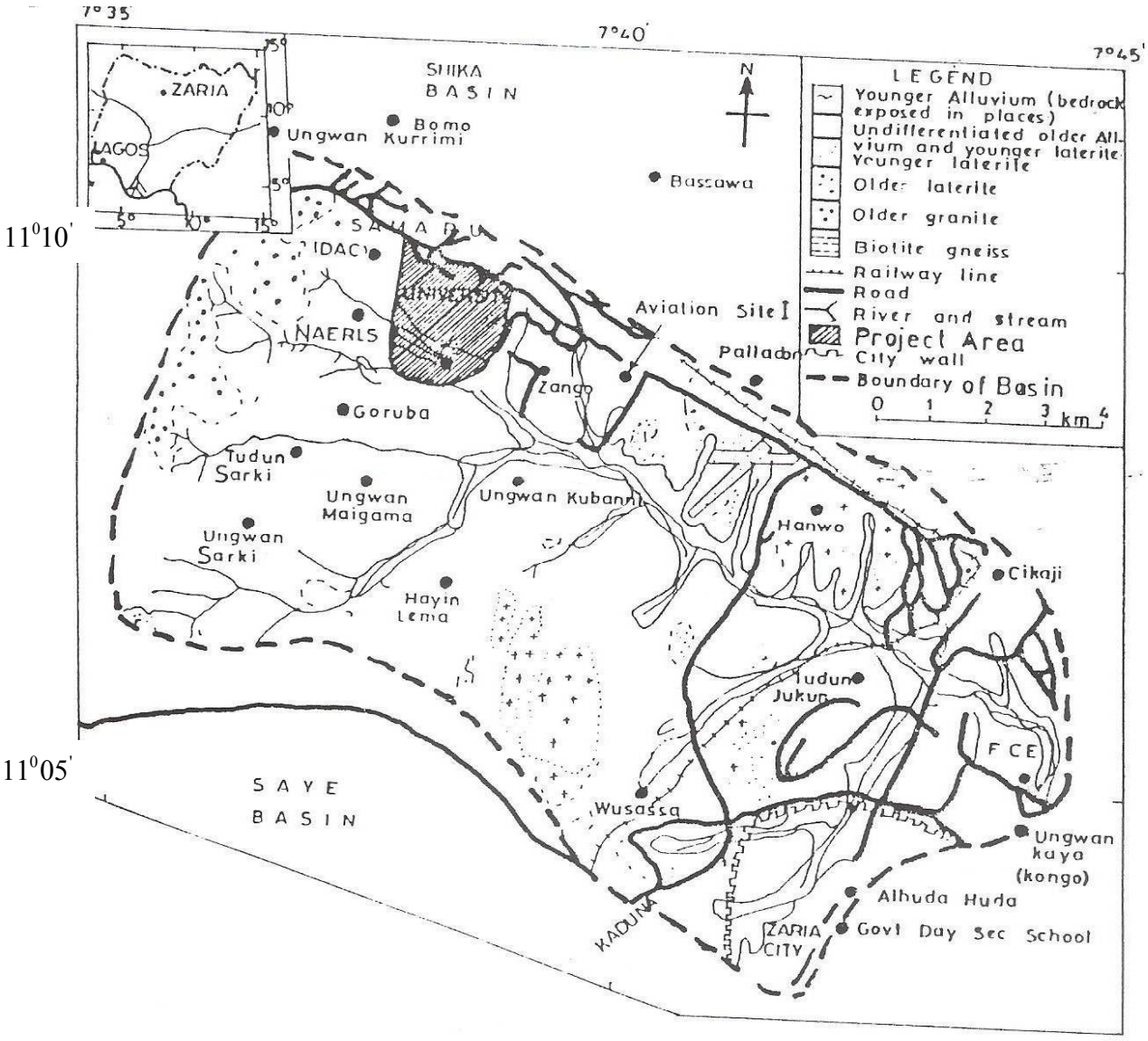


Fig. 1.3 Location of A.B.U. Samaru Campus within the Geological Map of the Kubanni Basin (Modified From Shemang, 1990)

CHAPTER TWO
METHODOLOGY AND THEORY

2.1 Introduction

Until recently, the electrical method of prospecting was more commonly in use than other geophysical methods of prospecting because of its large variety of techniques and its ability and suitability to measure numerous properties (potential, current, conductivity, etc.) in a variety of ways. It is user friendly, low cost and its interpretational aids are readily available (Fitterman and Stewart, 1986). The other prospecting methods make use of a single force or anomalous property such as gravitation, magnetism, elasticity, and radioactivity.

Generally, hard rocks are bad conductors of electricity, but many geological processes can alter a rock and significantly lower its resistivity. For instance, dissolution, faulting, shearing, columnar jointing, weathering, and hydrothermal alteration usually increase porosity and fluid permeability, and hence lower resistivity. If clay minerals are present in a water-bearing rock, a relatively large number of ions may be released from such minerals by ion exchange processes thus increasing the conductivity. All rocks containing clay minerals (in wet state) exhibit abnormally high conductivity on this account.

Because resistivity is an extremely variable parameter, not only from formation to formation but even within a particular formation, it is considered suitable for this particular research where a complex subsurface geology might be expected or envisaged.

In the past, the conventional DC Resistivity method was often successful; it entails using arrays of grounded electrodes (Wenner, Schlumberger, dipole-dipole, etc.) to inject current into the ground and measuring the resulting potential difference. But because it is always laborious, time consuming and ambiguous in its data interpretation, a recent 2D-electrical imaging or electrical tomography technique (ERT) was developed which allows for the collection of more data in the same time as in the traditional profiling and sounding techniques and quite useful in areas of both simple and complex geology. The electrical resistivity imaging method differs from the DC resistivity survey in using of a multi-electrodes array system (Griffiths and Baker, 1993) and in recording the maximum number of independent measurements on the array (Michel et al., 1999).

The two-dimensional model is more accurate model of the subsurface than one-dimensional, where the resistivity changes in the vertical direction, as well as in the horizontal direction along the survey line. Though in theory, the three-dimensional resistivity survey and interpretation model should be even more accurate, but however, at the present time, 2-D surveys are the most practical economic component between obtaining very accurate results and keeping the survey cost down. In many geological situations, 2-D electrical imaging surveys can give useful results that are complementary to the information obtained by other geophysical methods. For instance, seismic methods can map undulating interfaces well, but will have difficulty (without using advanced data processing techniques) in mapping discrete bodies such as boulders, cavities, and pollution plumes. Other methods like ground radar surveys can provide more detailed pictures but have limited depth penetration in areas with conductive unconsolidated sediments such as

clayey soils. Therefore, for a very intensive study of research area subsurface, the 2-D electrical survey was used for this thesis. The Wenner array (2D), a robust array popularized by the pioneering work carried by the university of Birmingham research group (Griffiths and Turnbull, 1985; Griffiths, Turnbull and Olayinka, 1990) was considered appropriate for this work due to its sensitivity to both horizontal and vertical structures and among the common arrays, it has the strongest strength (signal strength is inversely proportional to geometric factor; Wenner has lowest geometric factor)..

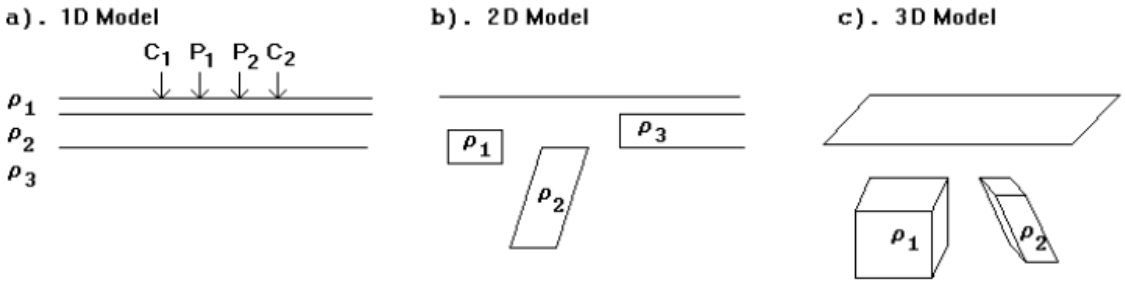


Fig. 2.1 the three different models usually used in the interpretation of resistivity measurement

2.2 Basis of the Resistivity Survey

Basically, resistivity survey involves introducing current of artificial source, into the ground through point electrodes or long line contacts and the resulting potential differences measured at the surface thereby determining an effective or apparent resistivity of the subsurface. Anomalous conditions or inhomogeneities within the ground, such as electrically better or poorer conducting layers, are inferred from the fact that they deflect the current and distort the normal potentials. This technique of resistivity survey was

developed by Conrad Schlumberger, who conducted the first experiments (1912) in the fields of Normandy.

2.3 Theory of the Resistivity Method

Keller and Friscknecht (1966), explained that the simplest approach to the theoretical study of earth resistivity measurements is to consider first the earth as an isotropic homogeneous medium with length L, and resistance, R, through which the current, I, is flowing.

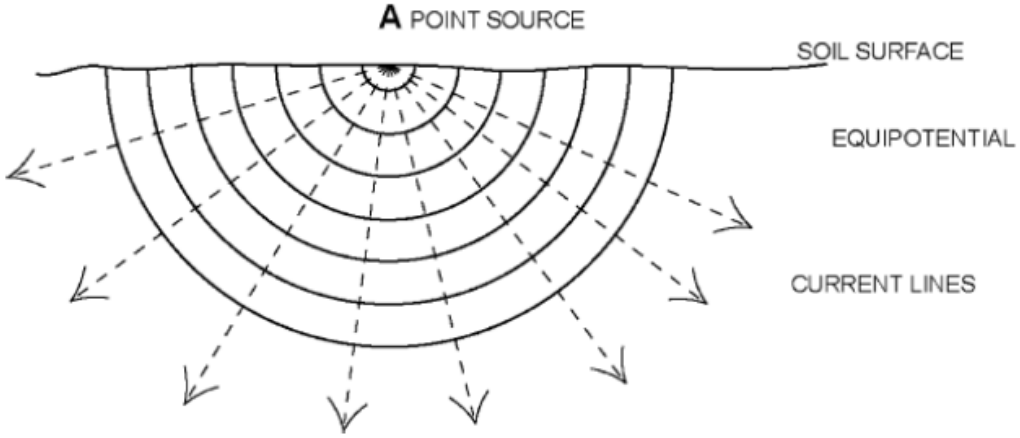


Fig. 2.2 An example of a distribution of current flow in a homogeneous soil

The P.D (Potential difference), ΔV , across the ends of the resistance is given by Ohm's law as:-

$\Delta V = \text{RI}$ …….. (2.1)

Incorporating relationship between R and Resistivity, ρ , equation (2.1) can be rewritten as

$$\Delta V = \mathrm{I}\left(\frac{\rho L}{A}\right) \quad \text{..... (2.2)}$$

$$\frac{\Delta V}{L} = \rho\left(\frac{I}{A}\right) \quad \text{..... (2.3)}$$

If L, length of the conducting medium tends to zero, and considered as an element of uniform resistivity, ρ , then equation (2.30) can be rewritten as

$$\text{-grad V} = \rho \underset{\rightarrow}{J} \text{ or } \mathrm{E} = \rho \underset{\rightarrow}{J}\text{; } \mathrm{E} = -\nabla V \quad \text{..... (2.4)}$$

Where E is the electric field (negative gradient of the scalar potential in the direction of l) in volt/meter, J, is the current density per cross-sectional area in ampere per square meter and ρ , the resistivity in ohm-meter.

From equation (2.4), it can be written that

$$\underset{\rightarrow}{J} = \sigma E = -\sigma \nabla V = -\nabla\left(\frac{V}{\rho}\right) \quad \text{..... (2.5)}$$

Where σ is the conductivity (inverse of resistivity) in mho/meter.

According to the divergence conditions, all the current flowing into a chunk of material must leave on the other side provided there is no current source or sink within the chunk.

This then implies that the divergence of the current density vector must be zero everywhere except at the current source and this is the principle of charge conservation.

Thus divergence of $\underset{\rightarrow}{J} = 0;\ \nabla.\underset{\rightarrow}{J} = 0$ ……..…… (2.6)

Appling the divergence condition {i.e. equation (2.6) into equation (2.5)} gives

$$\nabla.\underset{\rightarrow}{J} = -\nabla.\nabla(\sigma V) = 0$$

Hence,

$$\nabla\sigma.\nabla V + \sigma\nabla^2 V = 0 \quad \text{……..…… (2.7)}$$

Since σ is constant (isotropic and homogeneous medium), the first term of equation (2.7) vanishes and we have Laplace's equation, (2.8) i.e., the potential is harmonic

$$\nabla^2 V = 0 \quad \text{……...…… (2.8)}$$

For spherical polar coordinate, Laplace equation is

$$\nabla^2\ V = \frac{\partial}{\partial r}\left(r^2\frac{\partial V}{\partial r}\right) + \frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial v}{\partial\theta}\right) + \frac{1}{r^2\sin\theta^2}\left(\frac{\partial^2 V}{\partial\psi^2}\right) = 0 \quad \text{…… (2.9)}$$

For a single current source, it is assumed that there is complete symmetry of current flow with respect to θ and ψ directions. The derivative with respect to these directions is zero.

Equation (2.9) becomes,

$$\frac{\partial}{\partial r}\left(r^2 \frac{\partial V}{\partial r}\right) = 0 \quad \text{..... (2.10)}$$

Integrating equation (2.10) twice gives:-

$$r^2 \frac{\partial v}{\partial r} = a; \qquad \frac{\partial v}{\partial r} = \frac{a}{r^2}; \quad \text{..... (2.11)}$$

Therefore,

$$V = \frac{a}{r} + b \quad \text{..... (2.12)}$$

Where “a” and “b” are constants and r is the distance of the single current electrode to from where measurement is taken.

Since V= 0, when $r \rightarrow 0$, then b= 0.

Therefore,

$$V = -\frac{a}{r} \quad \text{..... (2.13)}$$

The current flows radially outward in all directions from the point current electrode, the Equipotential, which are everywhere orthogonal to the current flow lines, will be spherical

surfaces given by r = constant and thus, the total current crossing a spherical surface drawn around the current source can be expressed as:-

$$I= 4\pi r^2 \underset{\rightarrow}{J} = 4\pi r^2 \left(\sigma \frac{\partial v}{\partial r} \right) \quad \text{..... (2.14)}$$

From equation (2.11) and (2.14), it can be deduced that,

$$a = -\frac{I\rho}{4\pi r} \quad \text{..... (2.15)}$$

Hence, substituting equation (2.15) into equation (2.13), then,

$$V = \frac{I\rho}{4\pi r} \quad \text{..... (2.16)}$$

For a point current electrode located at the surface of an isotropic homogeneous medium and if the air above has zero conductivity, i.e., σ = 0, all current is made to flow through a hemispherical surface area of $2\pi r^2$, in the lower medium. The total current crossing the hemispherical surface drawn around the current source can be expressed as:-

$$I= 2\pi r^2 \left(\sigma \frac{\partial v}{\partial r} \right) \quad \text{..... (2.17)}$$

And,

$$A= -\frac{I\rho}{2\pi} \quad \text{..... (2.18)}$$

Substituting equation into equation (2.18) into equation (2.13) then,

$$V=\left(\frac{I\rho}{2\pi}\right)\frac{1}{r}=\frac{I\rho}{2\pi r} \quad \text{.......} \quad (2.19)$$

Where r is the distance of the potential electrode from the current source

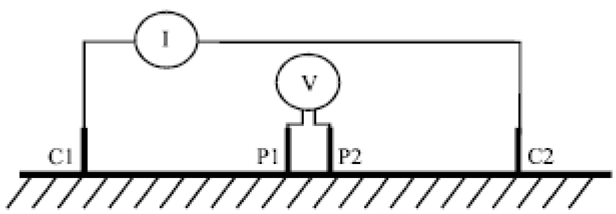


Fig. 2.3 a conventional four electrode array usually used to measure subsurface Resistivity

When two current point electrodes are used and placed linearly with two potential electrodes on the surface of an isotropic homogeneous ground of constant resistivity, as shown in the in Fig. 2.3, a potential difference can be derived through the following expressions:-

Given that,

$r_1 = C1P1$, $r_2 = C2P1$, $r_3 = C1P2$ and $r_4 = C2P2$

As before, the potential due to C1 at P1 is

$V_1 = -\frac{A_1}{r_1}$, where $A_1 = -\frac{I\rho}{2\pi}$

Similarly, the potential due to C2 at P1 is

$V_2 = -\frac{A_2}{r_2}$, where $A_2 = \frac{I\rho}{2\pi} = -A_1$ (since the current at the two electrodes are equal and opposite in direction)

Therefore, the potential at P1 due to both current electrodes is,

$$V = V_1 + V_2 = \frac{-A_1}{r_1} - \frac{A_2}{r_2} \quad \text{..... (2.20)}$$

Substituting the expression of A_1 and A_2 into equation (2.20),

$$V = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \quad \text{..... (2.21)}$$

Similarly, when the second potential electrode is introduced at P2, the potential at P2 due to both current electrodes is,

$$V = \frac{I\rho}{2\pi}\left(\frac{1}{r_3} - \frac{1}{r_4}\right) \quad \text{..... (2.22)}$$

The potential difference between P1 and P2 is,

$$\Delta V = \frac{I\rho}{2\pi}\left[\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)\right] \quad \text{..... (2.23)}$$

And from equation (2.23),

$$\rho = \frac{2\pi}{\left[\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)\right]}\frac{\Delta V}{I} \quad \text{..... (2.24)}$$

$$\text{K}= \frac{2\pi}{\left[\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)\right]} \quad \text{..... (2.25)}$$

Substituting K into equation (2.24),

$$\rho = \text{K}\ \frac{\Delta V}{I} \quad \text{..... (2.26)}$$

2.4 Apparent Resistivity

Equation (2.26) is an expression for apparent resistivity, ρ, in ohm-meter. In field situation, knowing K, the geometric factor, which depends on electrode array or configuration used, and measuring V and I, the resistivity can be calculated.

The calculated resistivity is a true resistivity of the underground, if it is completely homogeneous and will remain constant for different electrode separation and any current. However, if the medium is inhomogeneous, the calculated resistivity varies as electrode spacing is varied or as the whole array is moved about and is called the Apparent Resistivity, ρ_a. The apparent resistivity may be larger or smaller than the real resistivity or in rare cases identical with one of the two resistivity values in a heterogeneous subsurface.

2.5 Electrodes Configuration

The K in equation (2.25) is generally referred to as the Geometric factor and is dependent on the electrodes configuration or arrangement. For field practice, a number of different electrode arrays have been designed. Some of the commonly used linear array-type arrangements are shown in fig. 2.4.

The two dimensional Wenner Array configuration was used for this work. The electrodes are arranged in a manner such that there is a ratio between the distance C1P1 (or C2P2) electrodes and P1P2 potential pair. This ratio is referred to as the n-factor, denoted by 'n' and for this Wenner array n=1. The Wenner array is shown below in Fig. 2.5.

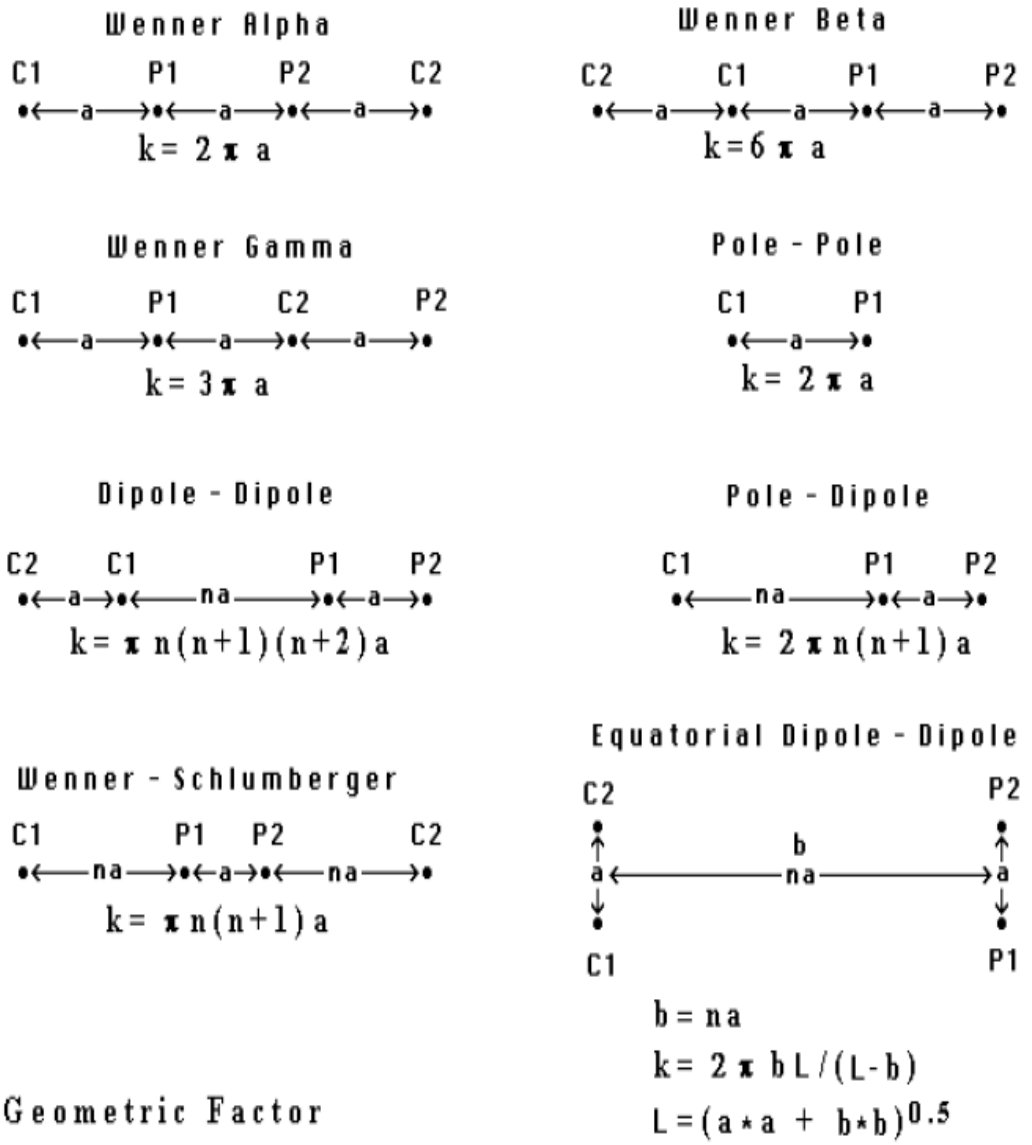


Fig. 2.4 Common arrays usually used in resistivity surveys and their geometric factors

$r_1 = r_4 = na$ And $r_2 = r_3 = 2na$ ……...…… (2.28)

Hence, substituting r_1, r_2, r_3 and r_4 in equation (2.27) into equation (2.25),

K= $2\pi na$ ……. (2.28)

Therefore, substituting equation (2.28) into equation (2.26), the apparent resistivity is,

$$\rho_a = 2\pi na\frac{\Delta V}{I}$$ ……...…….. (2.29)

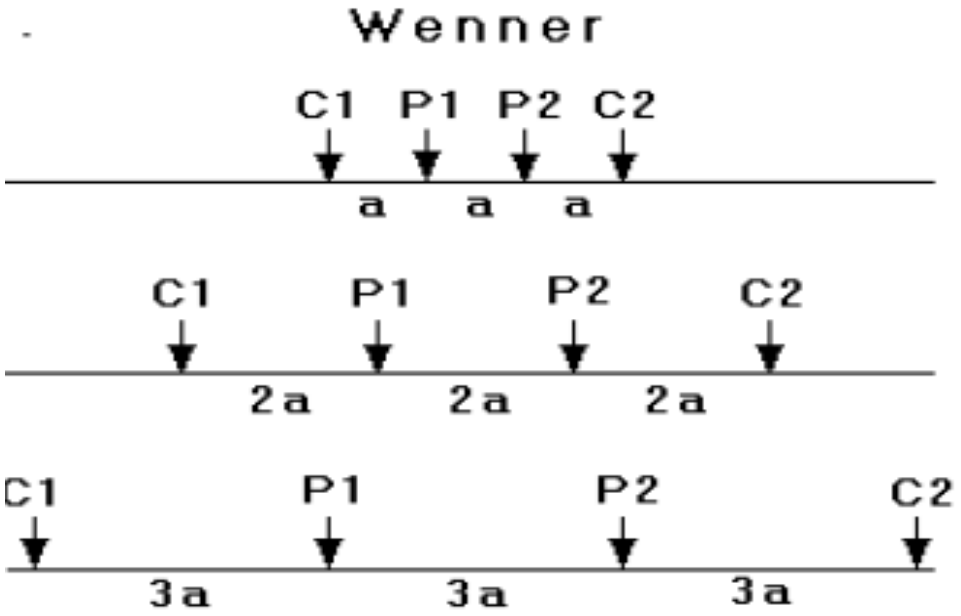


Fig. 2.5 Wenner Array 2D - Configuration

CHAPTER THREE
GEOPHYSICAL FIELD SURVEY

3.1 Resistivity Exploration Procedure

In practice, the resistivity survey is carried out in two distinct procedures, often called, vertical electrical sounding (or drilling), and electric profiling (or trenching). The former reflects resistivity variation with depth (the probing depth of current increases with increase in electrodes separation), while the later detects lateral variations in the resistivity of the ground. But because complex geology of the subsurface, where resistivity can change rapidly over short distances, might be expected at the survey area, both procedures have been simultaneously implemented, making the survey a two-dimensional model.

3.2 Two-Dimensional Resistivity Imaging

2-D resistivity survey starts with arrangement of an array of co-linear, equidistance electrodes on the surface of the ground for data collection. The survey technique involves measuring a series of constant electrode separations with the separation of electrodes being increased with each successive measurement. The resistivity imaging equipment works through a computer program, resident in it, that accepts instructions in a text file. Such instructions determine the sequence of measurement, the array type to use and other survey parameters (such as the current to use), thus, the appropriate electrodes for each measurement is automatically selected (Loke, 2000). The measured apparent resistivity values are then presented in a contoured pseudo section, which reflects in vertical cross-section, the spatial variation in resistivity qualitatively (Griffiths and Turnbull, 1985). The

unit electrode spacing determines the length of the profile, depth of investigation and resolution. The contoured data can be modeled using a two-dimensional finite difference algorithm (Dey and Morrison, 1979) or the data can be inverted automatically with commercially available computer program, RES2DINV to provide an image of true resistivity (Griffiths and Baker, 1993).

3.3 Instrumentation

The 2D-Resistivity data were recorded on the Terrameter. The complete equipment of ABEM Lund Imaging system consists of SAS4000 Terrameter, electrode selector, ES464, 2 Lund cables, 5 meters spacing, 21 take-out with addresses 1-21 (cable no. 1) and 22-42 (cable no. 2), totaling 42 smart electrodes, 2 reels, 42 stainless steel electrodes and 42 jumpers (Fig. 3.1 shows a gathering of these equipment).

Software accessories include;

1. Robust data-acquisition software featuring:
    - Automatic measurement process.
    - Automatic roll-along with coordinate updating.
    - Electrode cable geometry and switching sequence defined in address and protocol files allow user defined surveying strategies and arrays.
    - On-screen echo of measurement progress.



Fig. 3.1 ABEM Lund imaging system used during the acquisition of resistivity data.

2. RES2DINV Software for graphical presentation including:

   - Pseudo section plotting in colour.
   - Automatic 2D inversion and interpretation.

3.4 Data Acquisition

A detailed 2D-Resistivity survey was carried out on each of the six profiles identified from the pre-field work study. The profiles were LundDam01, LundDam02, LundDam03, LundDam04, LundDam05 and LundDam06. Five of the profiles (LundDam01, LundDam02, LundDam03, LundDam04 and LundDam05) lie around the wastewater stabilization ponds, and positioned such that they fall on the foot path as much as possible. The last profile, LundDAM06, falls on the 2 meters laterite outcrop and expected to serve as control during interpretation. Profiles LundDam01 and LundDam02 were 300m each, in length and the remaining profiles were 200m each. Fig. 3.2 shows the profiles and the arrows indicate the end points along the profiles. The longitude and latitude of beginning and end points are shown in Table 3.1.

3.5 Field Measurement Procedure

The field measurement usually started with placing the stainless steel electrode stakes into the ground at an interval of 5 meters along a selected profile. The Lund multi-cable is then laid on the ground and jumpers are used to tie the smart electrode to its electrode stake, making sure that there is an electrical contact between them. The switching off and on of the smart electrodes is controlled automatically by the electrode selector. The cables of electrode 21 and 22 were then connected to the electrode selector. Also, the selector is

connected to the multi-port of Terrameter with a connecting cable, the details of the traverse from which data is to be collected are entered into the Terrameter and made ready for data collection.

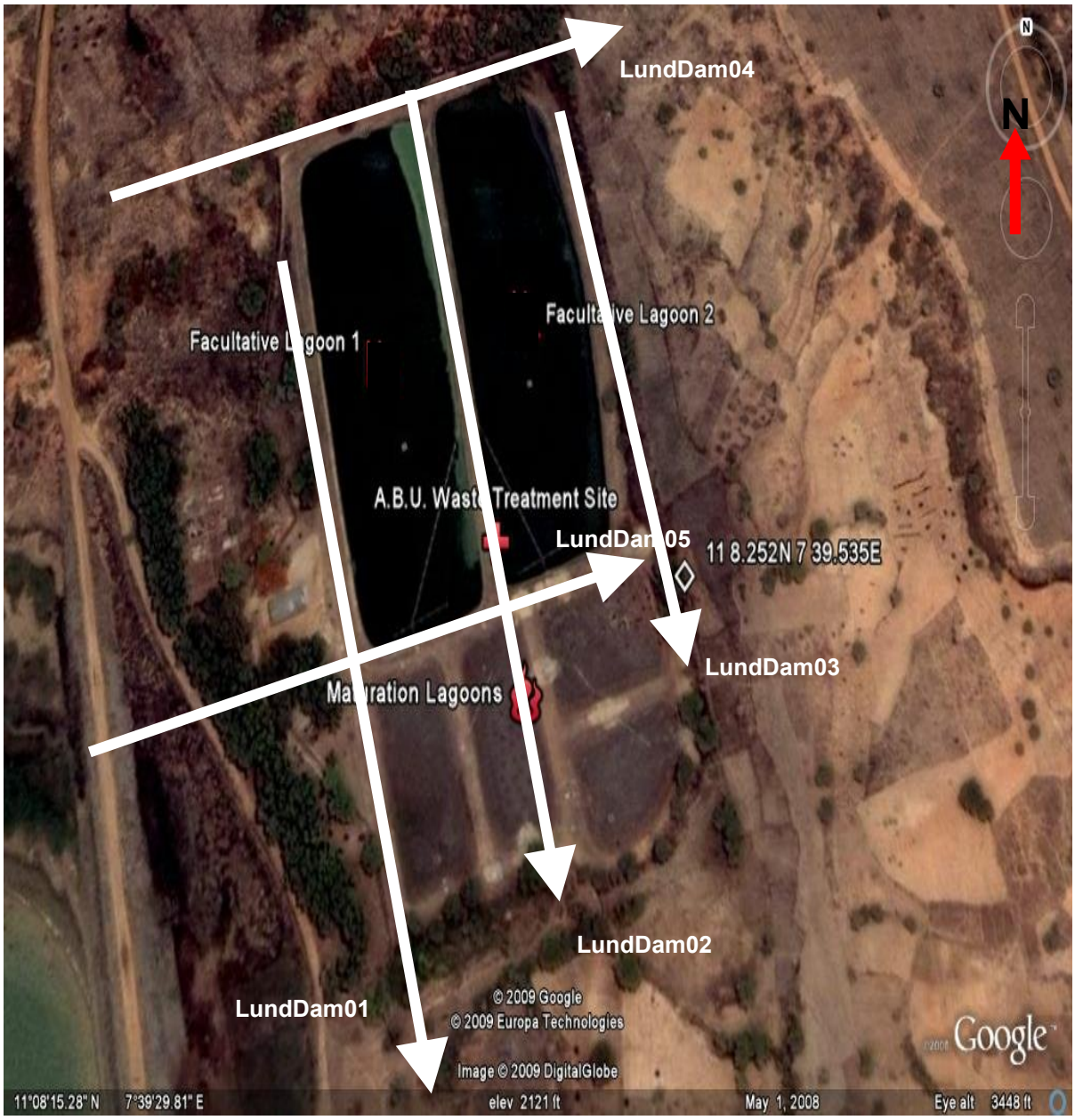


Fig. 3.2 the profiles are indicated in this diagram above. (The arrows on the profiles indicate the end points along the profiles)

Table 3.1 table showing the latitude and longitude of begin and end points of each profile.

Profile	Begin Coordinate		End Coordinate		Length (m)	Azimuth
	Latitude	Longitude	Latitude	Longitude		
LundDam01	11.1387N	7.6571E	11.1360N	7.6584E	300	NW-SE
LundDam02	11.1391N	7.6577E	11.1364N	7.6584E	300	NW-SE
LundDam03	11.1389N	7.6584E	11.1372N	7.6588E	200	NW-SE
LundDam04	11.1392N	7.6582E	11.1379N	7.6579E	200	W-E
LundDam05	11.1371N	7.6570E	11.1377N	7.6587E	200	W-E
LundDam06	11.1407N	7.6567E	11.1389N	7.6570E	200	NW-SE

The actual measurement was carried out after the contact resistance test output gave good results. Otherwise, the causative electrode(s) were checked properly if there may be need for reconnection or watering to enhance good contact. The Terrameter took between 30-45 minutes to complete a spread of 200m.

The first spread began with cable 1 followed by cable 2 with electrodes 1- 21 and 22-42 respectively. Using the Wenner array, with spacing between adjacent electrode differences 'a', all possible measurements with electrode spacing '1a' are made (for this Lund cable 'a' is 5 meters). For the first measurement electrodes 1, 2, 3, and 4 were used. Electrode 1 is the first current electrode, C1, electrode 2, the first potential electrode, P1, electrode 3, second potential electrode, P2 and electrode 4 is the second current electrode, C2. For the second measurement, electrode 2, 3, 4 and 5 were used for C1, P1, P2 and C2 respectively. This trend is followed down the line of electrodes until electrodes 39, 40, 41 and 42 were used for the measurement with '1a' spacing. The next sequence of measurements with '2a' electrode spacing was made. First electrodes 1, 3, 5, and 7 were used for the first measurement. The electrodes were chosen such that the spacing between adjacent electrodes is '2a'. For the second measurement, electrodes 2, 4, 6 and 8 were used. This process was repeated down the line until electrodes 36, 38, 40 and 42 were used for the last measurement with spacing '2a'. The same process is repeated for measurements as shown in Fig. 3.4 with "3a", "4a", "5a" and "6a" spacing (Dahlin and Loke, 1998). After collecting data for the whole spread, for roll-on, the electrodes 1-21 are moved to the front of the line, the cable shifted forward and reconnected. The electrode-order now becomes 22-42 and 1-21 with cables of electrodes 42 and 1 connected to the selector. Measurements

were taken such that overlapping measurements were avoided. The same sequence followed as before until measurements had been taken across a complete profile.

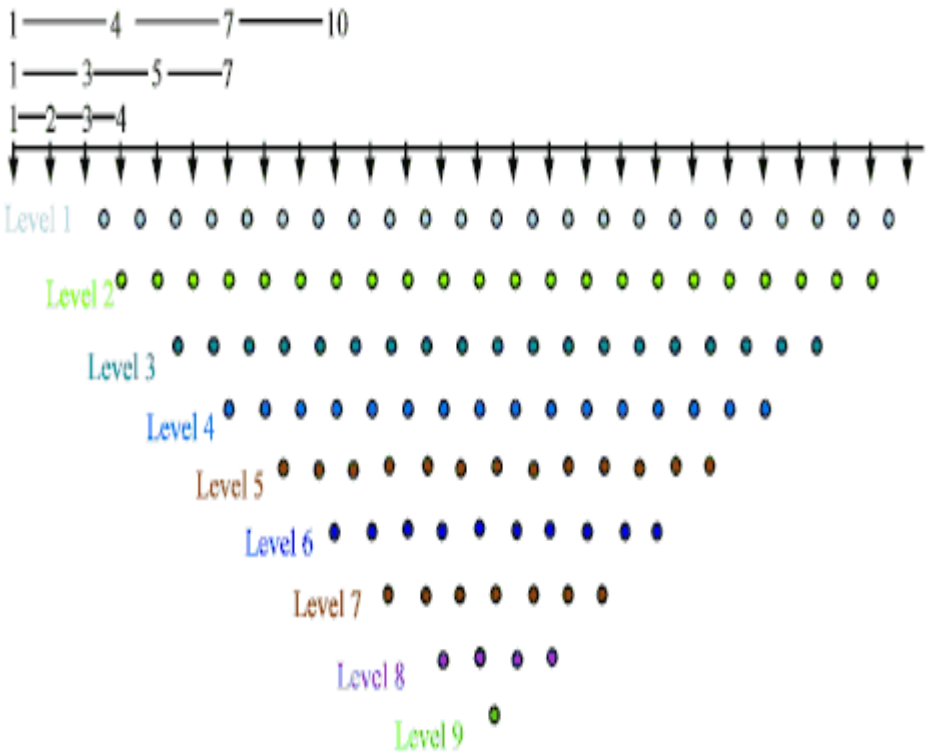


Fig. 3.3 Sequence of measurements as usually recorded by Terrameter

Giving the maximum allowable electrode spacing of 5m by the equipment, and an array of 42 electrodes, some constraints were consequently placed on the length of profiles and the depth of investigation.

CHAPTER FOUR
DATA PROCESSING AND INTERPRETATION

4.1 Introduction

The data processing for this work was done using the RES2DINV program package that accompanied the commercial multi-electrode system used for the Resistivity imaging survey data acquisition. Generally, Res2dinv is a computer program designed by Loke (1992), to invert the apparent resistivity data obtained from electrical imaging surveys into a two-dimensional true resistivity model of the subsurface with less input from the user. The inversion routine used by the RES2DINV program is based on the smoothness-constraint least-square method (deGroot-Hedlin and Constable, 1990), and bases on the following equation:-

$$\left(J^T J + uF\right)d = J^T g \quad \text{.....} \quad (2.31)$$

Where,

$$F = f_x{}^T f_x + f_z{}^T f_z \quad \text{.....} \quad (2.32)$$

f_x = horizontal flatness filter

f_z = vertical flatness filter

J = matrix of partial derivative

u = damping factor

d = model perturbation vector

g = discrepancy vector

The RES2dinv program first divides the subsurface into a number of rectangular blocks (Fig. 4.1) with the main purpose of determining the resistivity of the rectangular blocks that will produce an apparent resistivity pseudo section that agrees with the actual measurements. For wenner, like that adopted for this work, the thickness of the first layer of blocks is set at 0.5 times the electrode spacing and the subsequent deeper layer is normally increased by 10% (or 25%).

The program takes off by not only trying to minimize the difference between the measured and the calculated apparent resistivity values, but the inversion method also attempts to reduce other quantities that will produce certain undesired characteristics in the resulting model (Loke, 2000, Loke and Barker, 1996).

The RES2dinv program uses a forward modeling subroutine (smoothness-constraint method) to calculate apparent resistivity values and a non-linear least squares optimization technique (deGroot-Hedlin and Constable, 1990) for the inversion routine. The optimization method basically tries to reduce the difference between the calculated and measured apparent resistivity values by adjusting the resistivity of the blocks. A measure of this difference is given by the root-mean-squared (RMS) error. However, the model with the lowest possible RMS error can sometimes show large and unrealistic values in the model resistivity values and therefore, might not always be the best model from a geological perspective. In general, the most prudent approach is to choose the model at the

iteration after which the RMS error does not change significantly, and usually occurs between the 3rd and 5th iterations (RES2DINV, 2000).

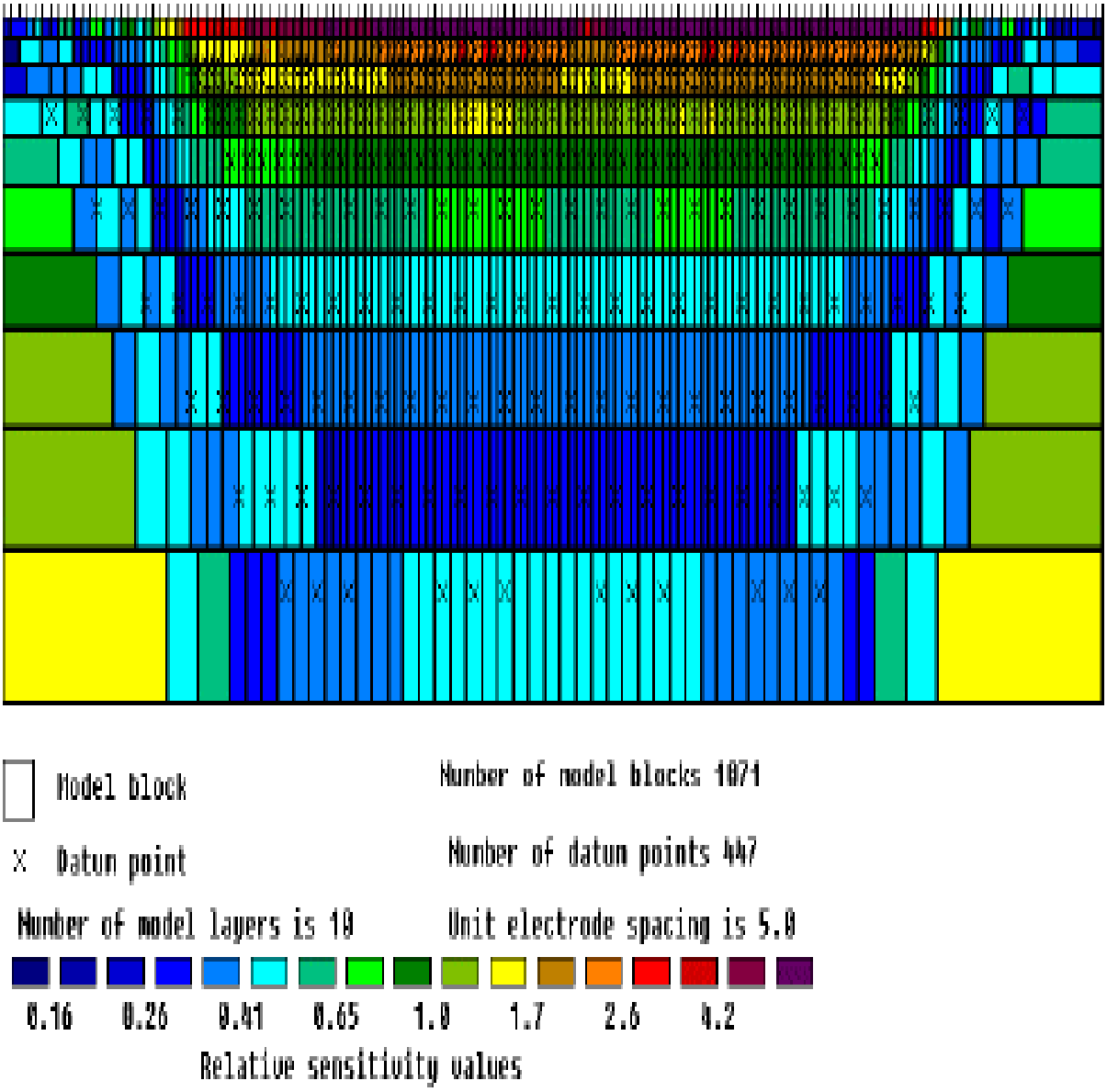


Fig. 4.1 Division of the subsurface into rectangular blocks, a routine during inversion processes

4.2 Data Processing Procedure

The measured apparent resistivity data files for all the resistivity imaging survey lines were downloaded from the ABEM ES464 Terrameter and burnt on rewriteable compact disc to be uploaded on a desktop computer system, in which ABEM file conversion and RES2DINV application software have been installed. The ABEM file conversion program was used to the convert the original data files (in .s4k format) to the appropriate (.DAT format) input files readable by the inversion software RES2DINV. Each converted file, representing a profile was imported into the Res2dinv program. The apparent resistivity data values were edited when viewed as profile, showing each data level, by eliminating or removing inherent data points (example shown in Fig. 4.2). Although, careful procedures were adopted in the field, not withstanding, inherent data points were visible by their unique largeness or smallness when compared to neighboring data points, they might have been generated from sources such as; failure of the relays at one of the electrodes, poor electrode ground contact due to dry soil. Eliminating these data points were inevitable, otherwise, they might influence the final output model.

The inversion of the input data set for each profile was carried out (after satisfactory editing) with least-square inversion routine. A model was accepted at the iteration beyond which the RMS error does not change significantly and this usually occurred between the 8^{th} and 10^{th} iteration. The final output file displayed after inversion was the measured and the calculated apparent resistivity pseudo-section and the true resistivity model section.

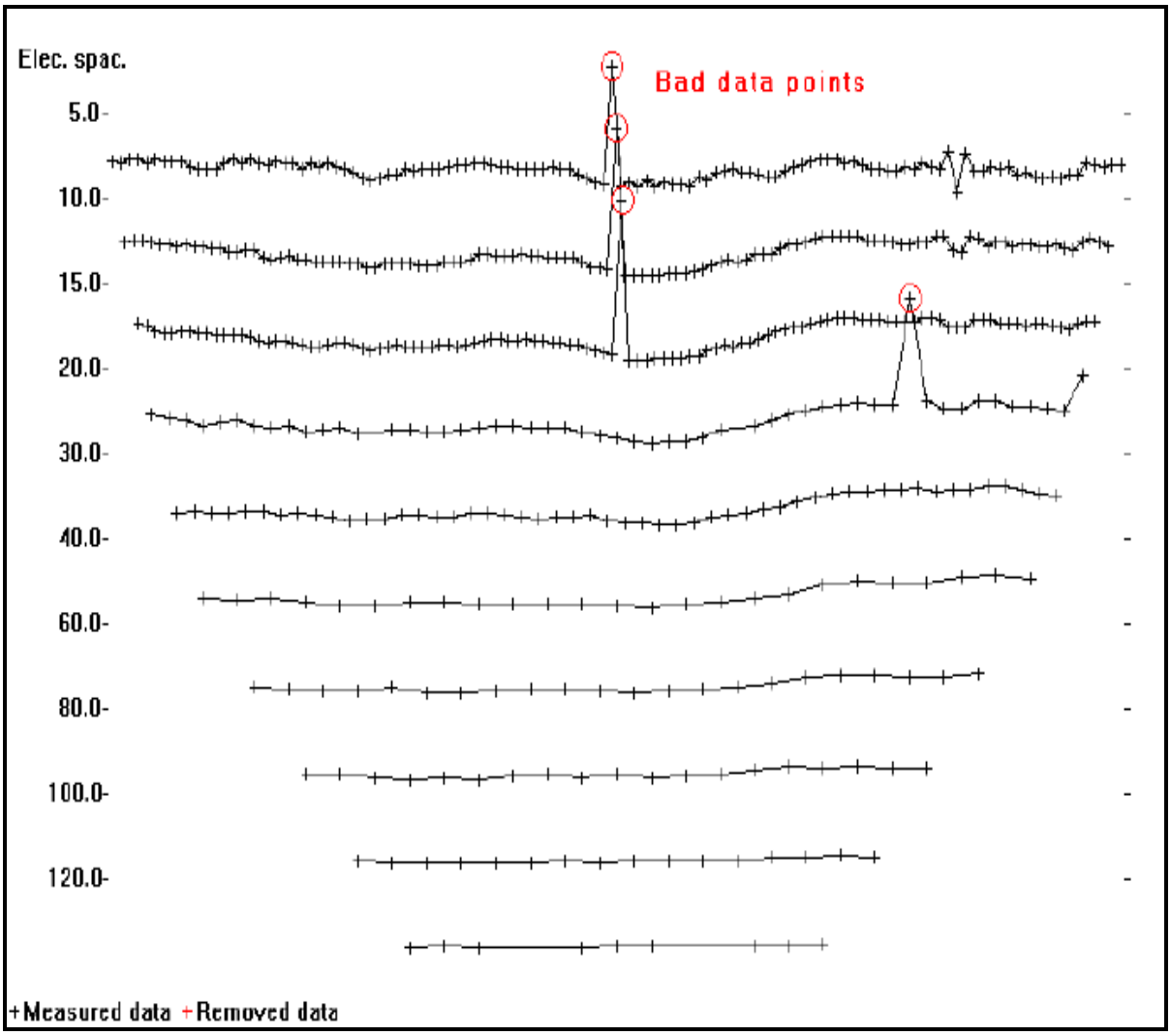


Fig. 4.2 An example of a profile showing data set with a few bad data points

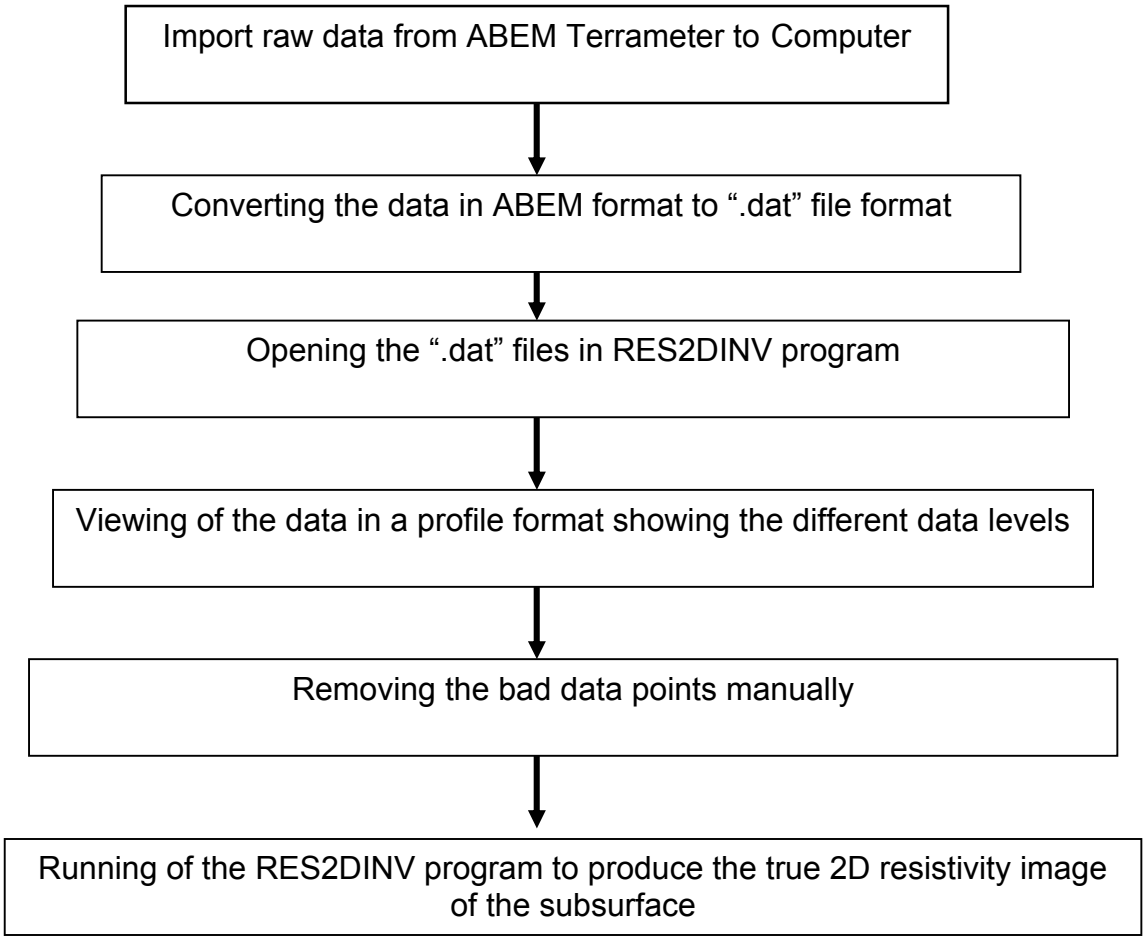


Fig. 4.3 Two-dimensional Imaging data processing flow chart used

4.3 Results and Geological Interpretation

The relevance of any resistivity survey is to establish the subsurface resistivity distribution by taking measurements at the surface and such measurements are utilized to estimate the true resistivity of the subsurface rocks. Resistivity is a fundamental electrical property of rocks that is closely related to rock lithology through various geological parameters such as porosity, fluid content, mineral, degree of water saturation in the rock. Conversion of resistivity picture into geological one requires some knowledge of the typical resistivity values for the different types of subsurface materials and geology of the surveyed area.

Relevantly, five individual sections are discussed here, which represent the five profiles that were surveyed along and across the sewage site. However, the last section which is the sixth profile shall not be discussed. It was carried out to serve as control for the other profiles. The equipment was tested using this profile which shows an outcrop of laterite.

This discussion incorporates information from previous geological work or literature from other geological work some hundred meters away from the survey area and works of other Researchers. The earth materials were interpreted based on the resistivity ranges described after Palacky, 1987 (see Fig. 4.4) and a lithology borehole log of Akenzua (a student hostel on Ahmadu Bello University campus, less than a kilometer away from the study area), shown in Table 4.1

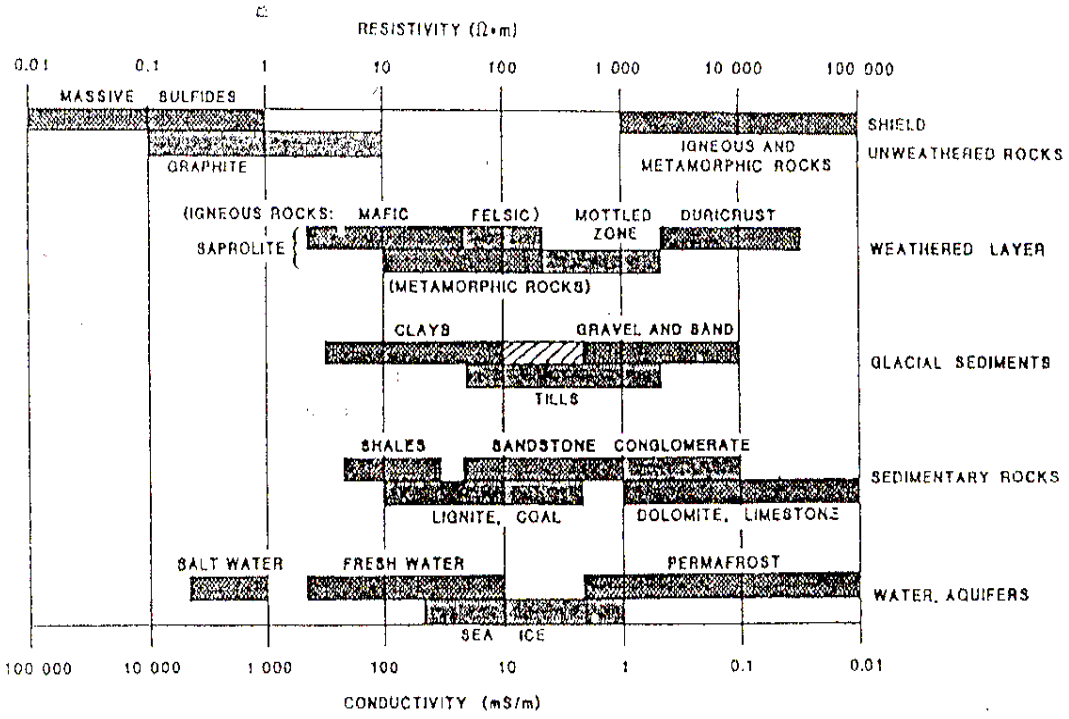


Fig. 4.4 Typical ranges of electrical resistivity of earth materials. (After Palacky, 1987)

Table 4.1 Akenzua Lithology Borehole Log

Depth (m) From	To	Thickness (m)	Interpreted Lithology	Hydrogeologic Characteristics
Overburden 0 - 8m				
0	3	3	Reddish brown Top soils	
3	8	5	Reddish brown sandy clay	
Weathered Basement 8 – 18m				
8	10	2	Grayish brown sandy clay	
10	15	5	Mottled clay	
15	18	3	Coarse/medium grained sand	Aquifer
Fresh Basement 18 – 27m				
18	27	9	Fractured Basement	Aquifer

4.3.1 Geological Interpretation

Profile LundDam01:

Fig. 4.4 shows the results obtained with wenner 2D array and 5.0 meter electrode spacing. The profile runs along the sewage site in an approximately NW-SE direction. The top soil is lateritic consisting of reddish brown soil which may be up to 1.3m in thickness. The electrical image of this profile shows an overburden deposit spanning from subsurface depth of 1.3m to about 29m and having thickness of 7m to about 29m underneath some section. This consists majorly of sandy clay. Underneath this layer is the weathered

basement rock which consists of fine, medium to coarse sand, and occurred from depth of 7m to over 20m, having resistivity between 79 ohm-meter and 137 ohm-meter. The fractured basement rock having resistivity above 137 ohm-meter, occurred from depth of about 17m and the fresh basement rock was encountered at depth of about 27m. The basement rock showed discontinuity at profile distance 160m and may probably be as a result of a fault.

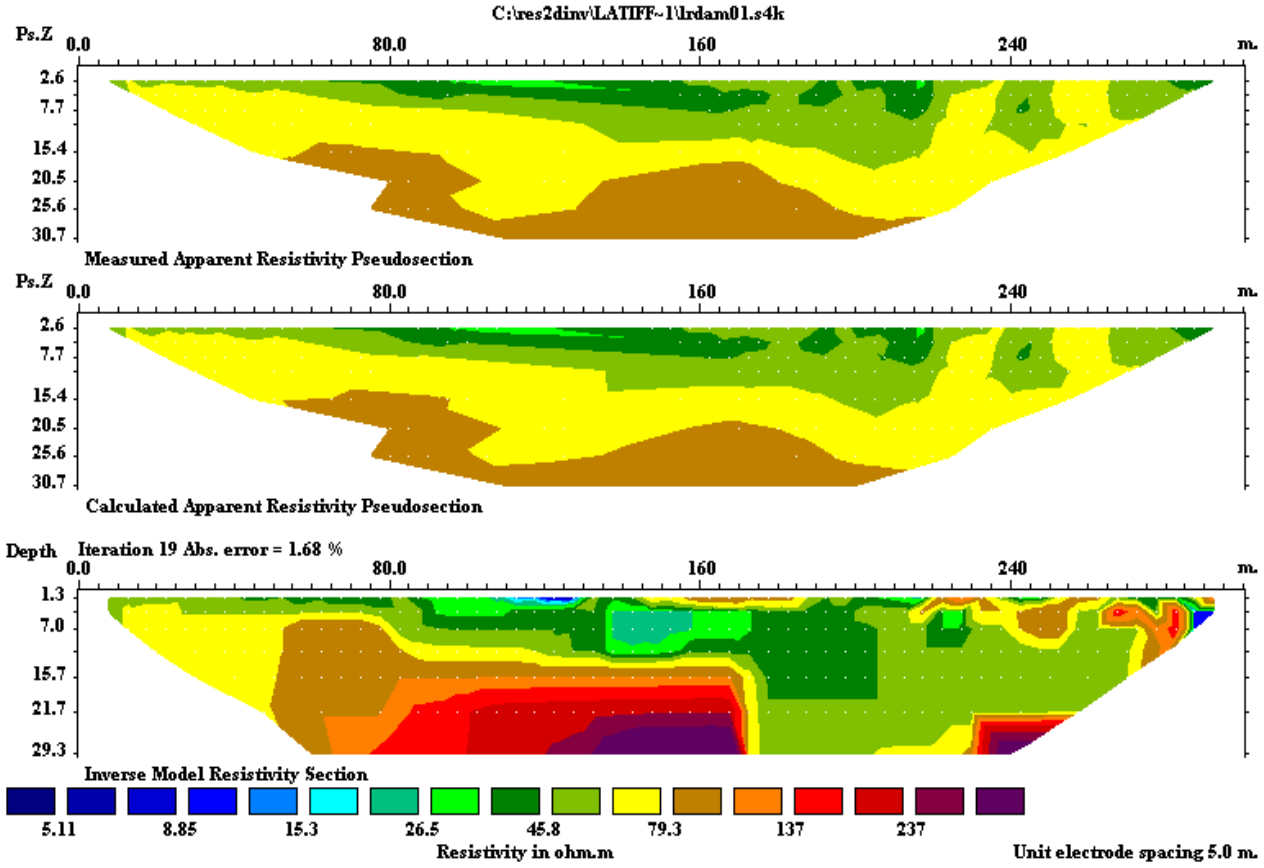


Fig. 4.5 Electrical image section for profile LundDam01

Profile LundDam02:

This profile runs directly along the centre of the sewage site in an approximately NW-SE direction. The electrical image results (shown in Fig. 4.6) indicate significantly about four distinctive layers. The top layer, which due to deposit of sewage, distinguishes it from the subsequent layers and indicates the overburden or sand deposit. It consists probably of clay and clayey sand because of its low resistivity and corresponds to the overburden. The layer is bounded by resistivity between about 14.1 ohm-meter and about 45 ohm-meter, reaching a depth of 7m and extending to about 21.7m underneath some part of the section. The layer underlying this layer is probably the weathered basement rock, and consists of fine, medium to coarse sand. It has resistivity between 48.6 and 111 ohm-meter, and occurred at depth of 7m, extending to about 21.7m underneath some part. The layer underneath this layer is the fractured basement rock extending from depth of about 16m and having resistivity above 111 ohm-meter. The bottom layer is the fresh basement rock and was encountered at a depth of 29m. The result also indicates discontinuity of the basement rock at profile distance 140m and may be as a result of a fault.

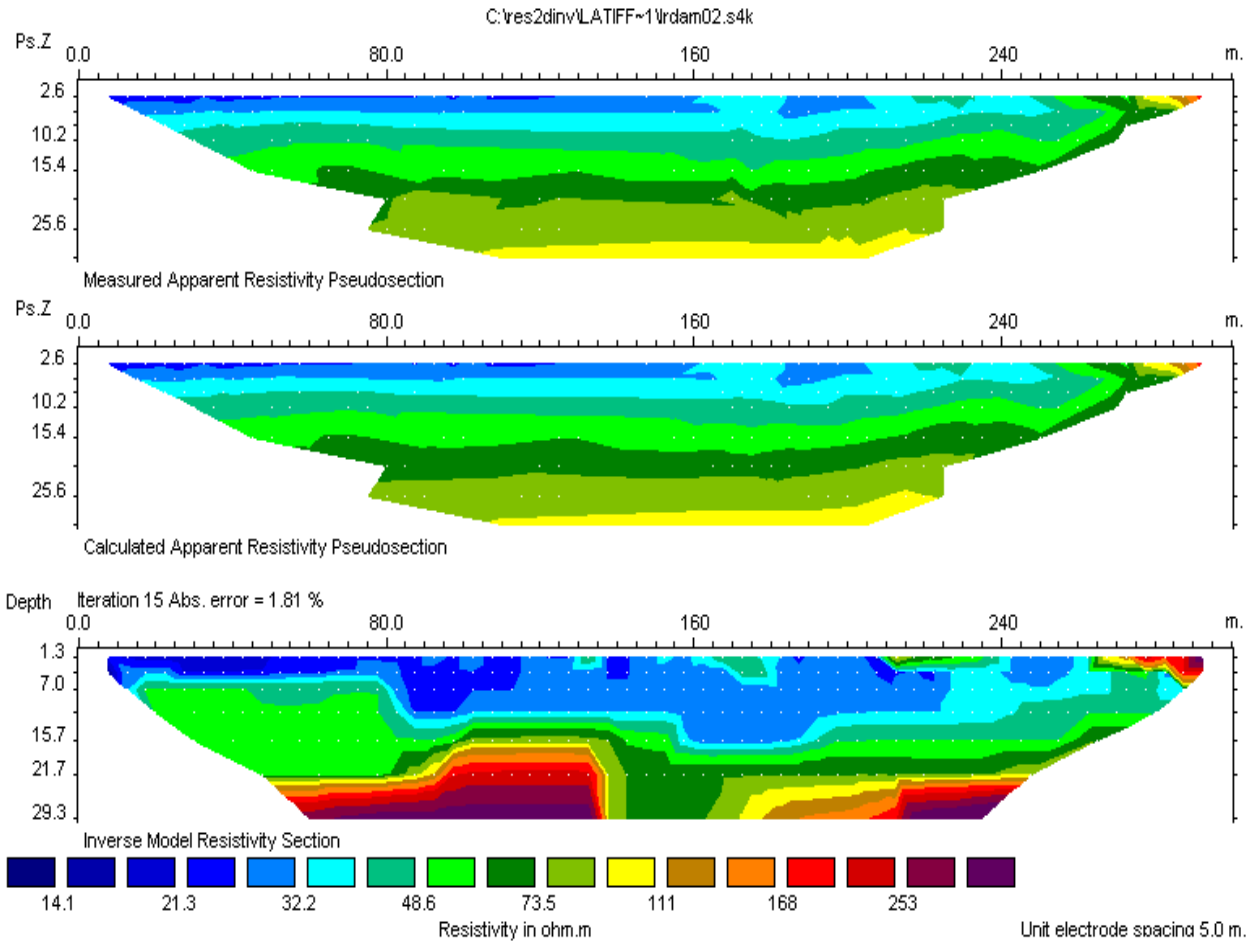


Fig. 4.6 Electrical image section for profile LundDam02

Profile LundDam03:

This profile runs along the sewage site in an approximately NW-SE direction. The electrical image result indicates an overburden of thickness between about 4m and 20m, the weathered basement rock occurred from depth of about 4m to 21.7m with features suspected to be gravels or boulders (due to their unusual high resistivity) occurring within. This layer consists of probably fine, medium to coarse sand particles. Underlying this layer

is the fractured basement rock and was encountered from depth of 25.7m to about 29.3m. The fresh basement rock occurred at depth of 25.7m.

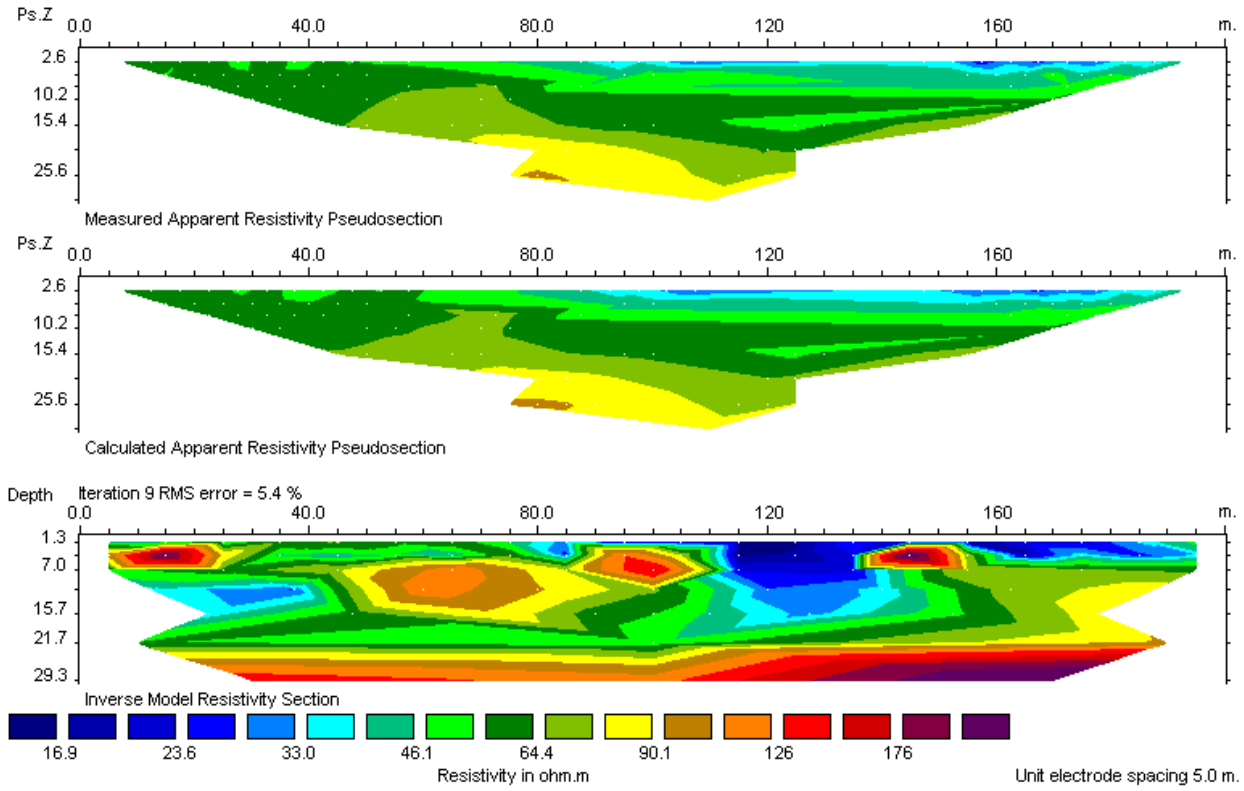


Fig. 4.7 Electrical image section for profile LundDam03

Profile LundDam04:

Fig. 4.7 shows the pseudo section obtained along profile Lunddam04. The profile runs across the sewage site in an approximately W-E direction and situated at the upper end of the site. The electrical image result indicates a partially resistive material at the lower section of the spread, which probably may be as a result of the Laterite outcrop since this part lied directly on the lower part of the outcrop. Down the section, from about 80 meter

to the end of the spread, the overburden sand deposit consists mainly of clayey and sandy clay materials, varying from thickness of about 1.3m to about 22m and bounded by resistivity of 14 ohm-meter to about 70 ohm-meter. Underneath this layer is the weathered basement rock occurring at depth 1.3m to about 29.3m. The fractured basement occurred at approximate depth of 25m with resistivity greater than 137 ohm-meter while the fresh basement rock, which is not too revealed, was encountered at approximate depth of 28m and have resistivity greater than 334 ohm-meter.

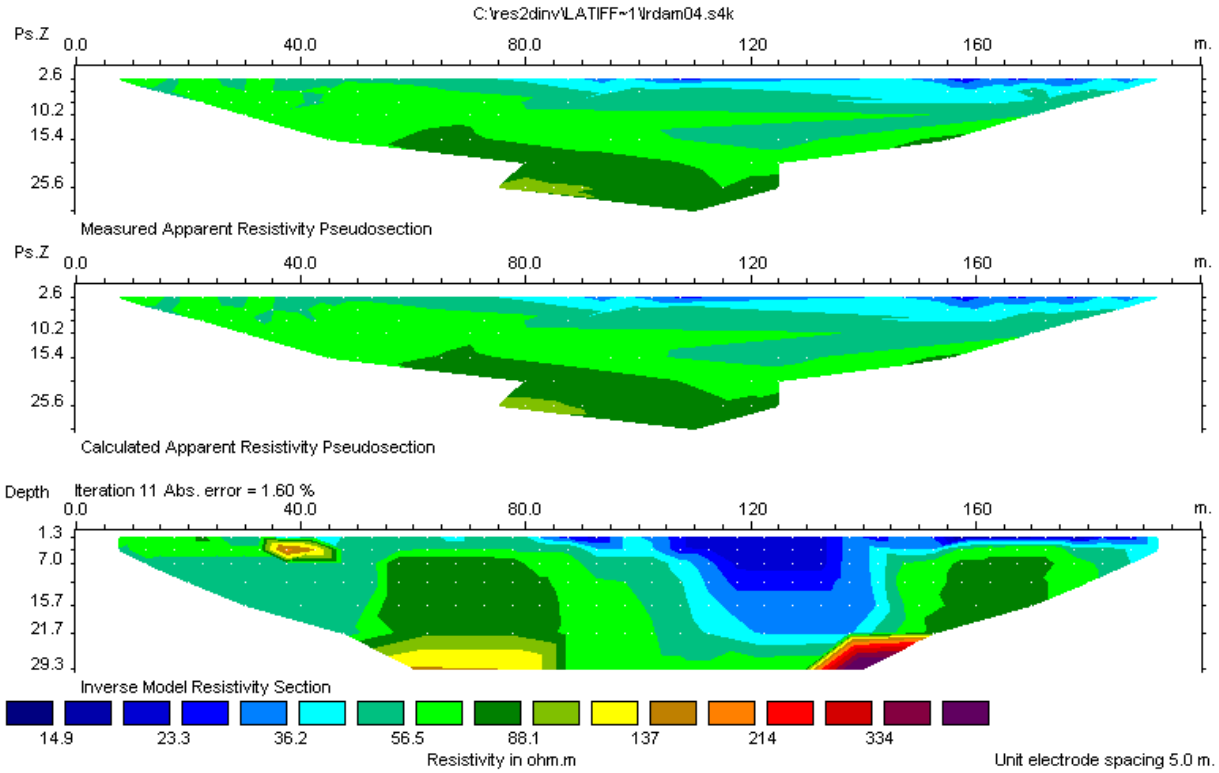


Fig. 4.8 Electrical image section for profile LundDam04

Profile LundDam05:

This profile runs across the middle part of the sewage site in an approximately W-E direction. The model section clearly shows an anomaly of high resistivity value, over 1,000

ohm-meter and might be as a result of an artificially constructed concrete structure underneath the profile. The overburden layer has a thickness of about 7m while the weathered basement rock occurred from a depth of 7m to about a depth of 21.7m. The fractured basement occurred from depth of 21.7m to depth of about 27m from which point the fresh basement rock was encountered.

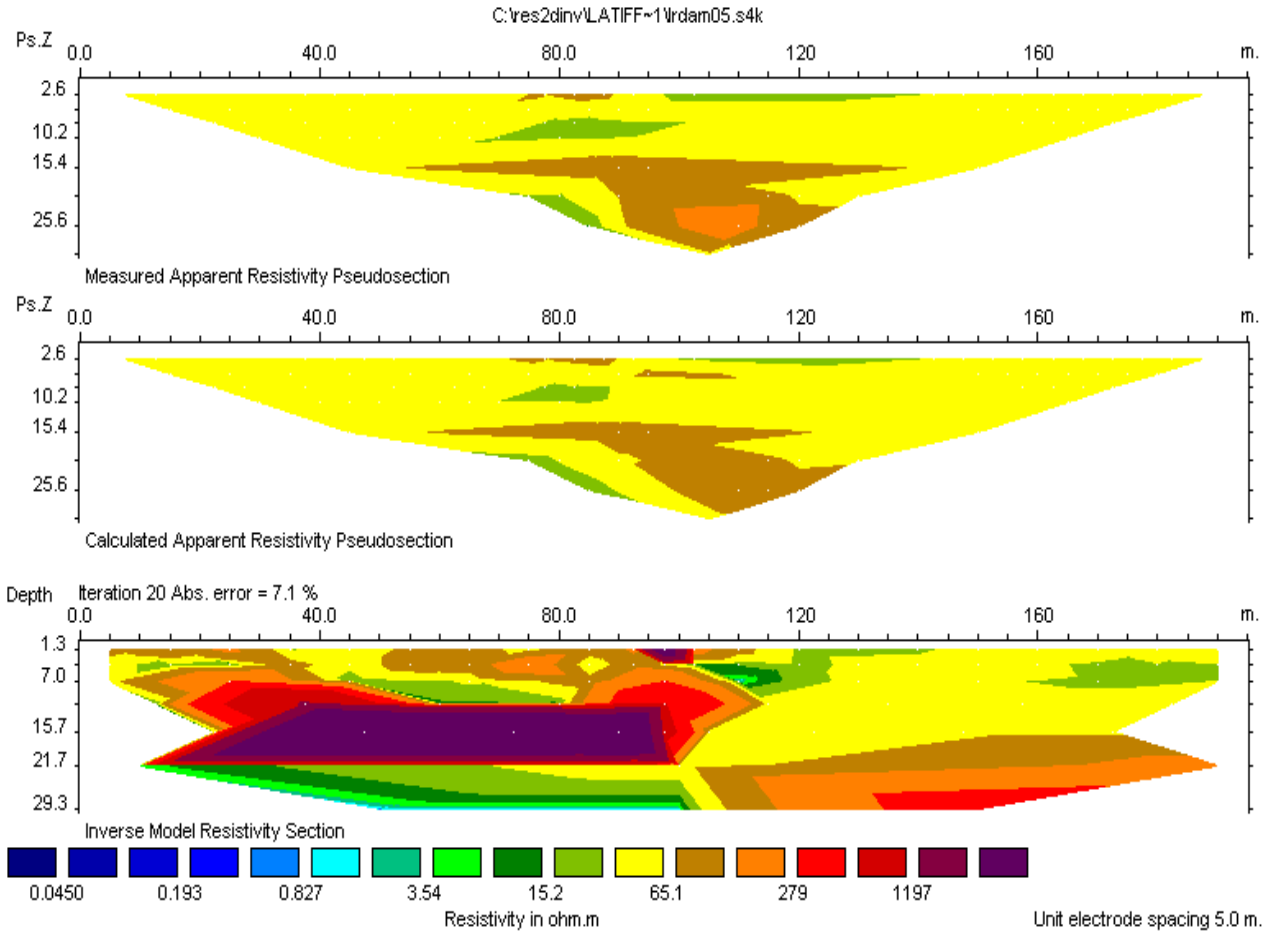
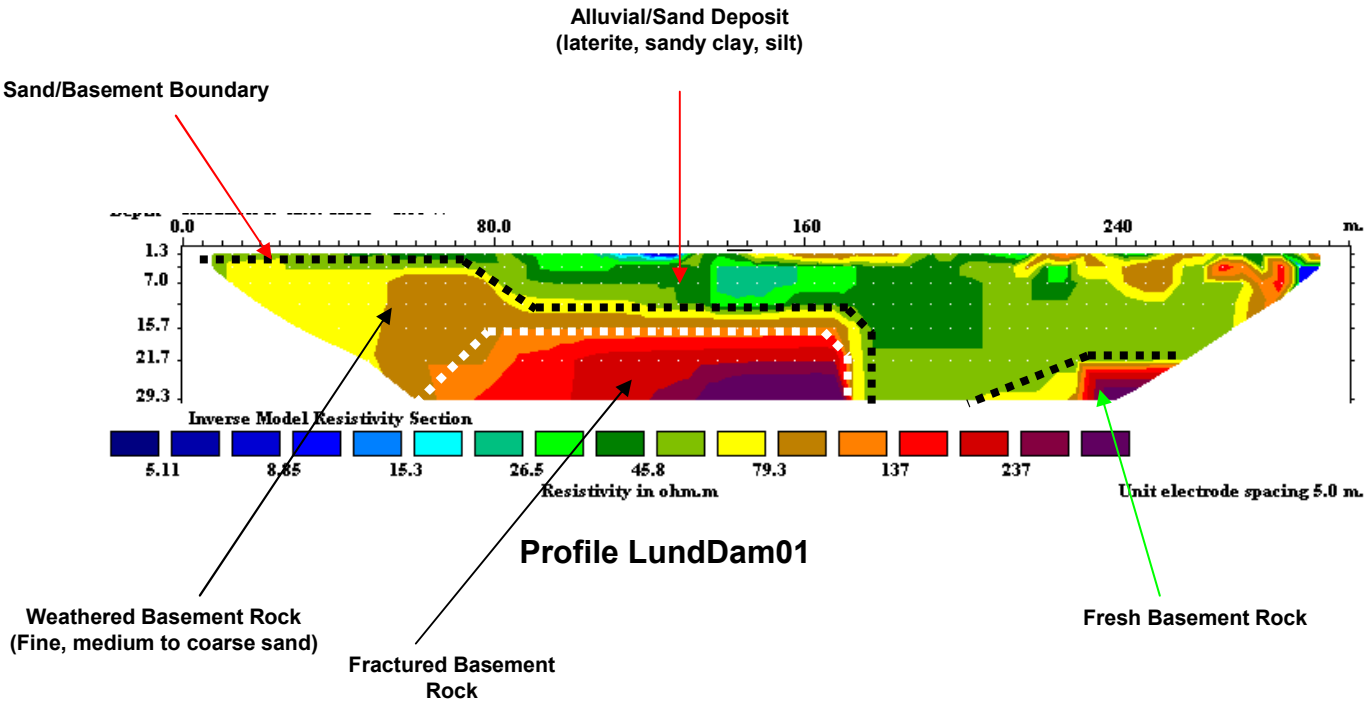


Fig. 4.9 Electrical image section for profile LundDam05



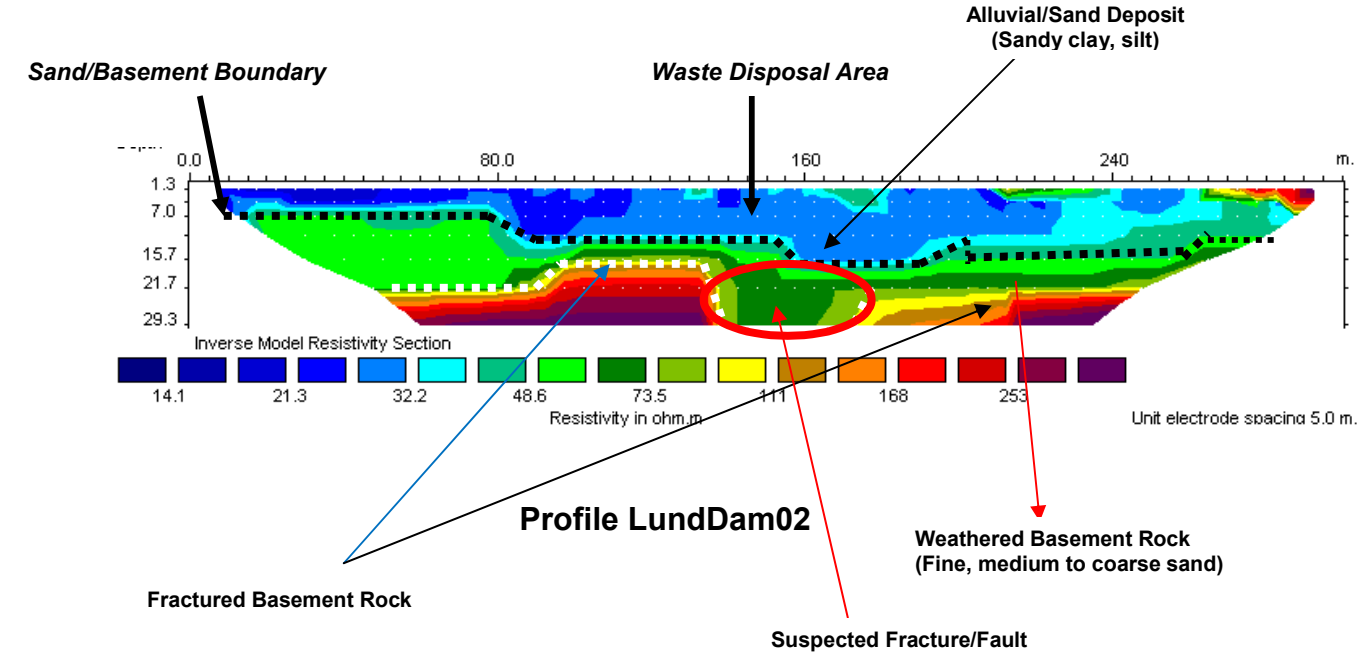


Fig. 4.10 Geophysical Interpretation of resistivity imaging profiles LundDam01 and LundDam02

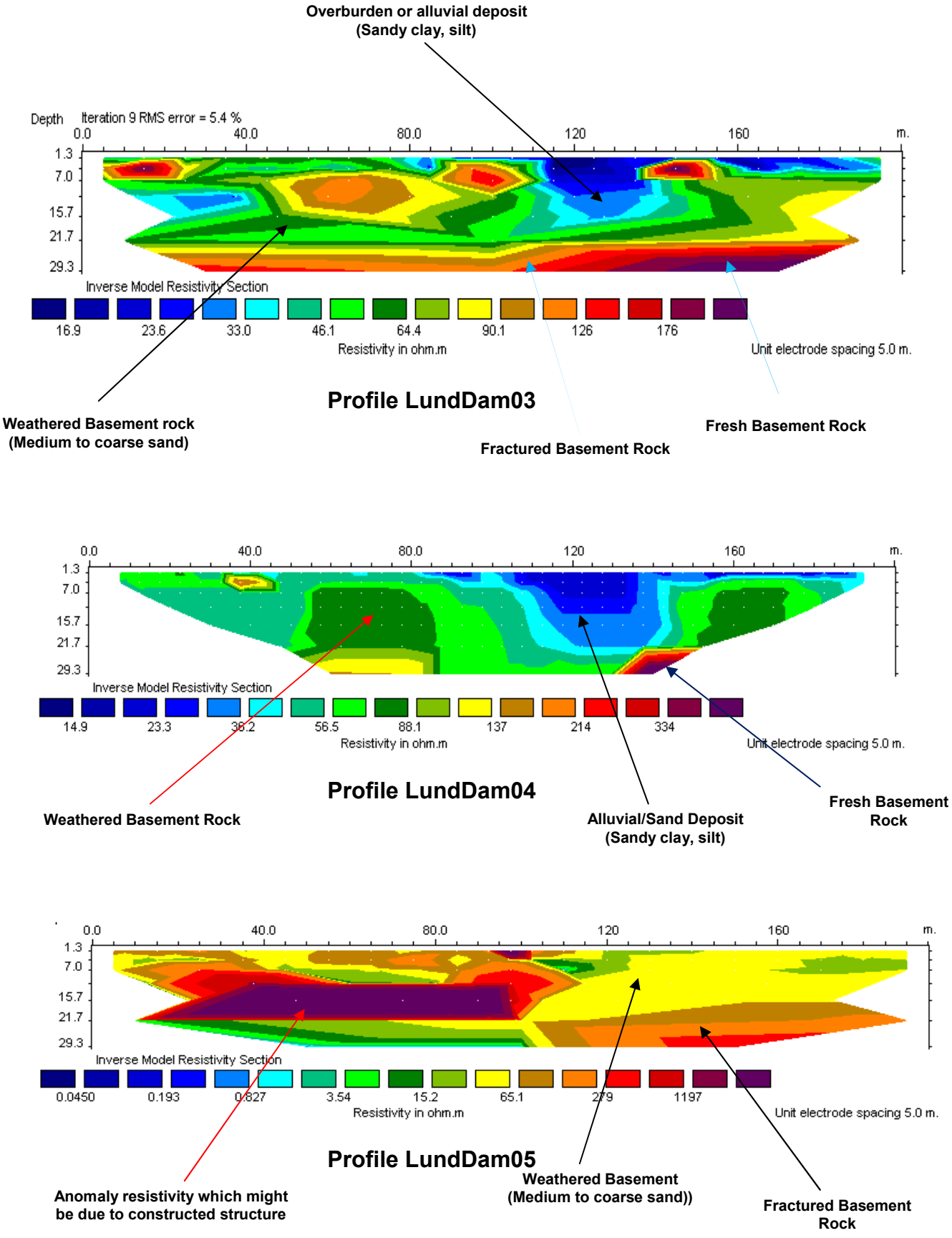


Fig. 4.11 Geophysical Interpretation of resistivity imaging profiles LundDam03, LundDam04 and LundDam05

CHAPTER FIVE
DISCUSSION, CONCLUSION AND RECOMMENDATION

5.1 Discussion and Conclusion

The main target of this research is to characterize the subsurface lithology of Ahmadu Bello University sewage site. Associated with this goal, is the aim to determine such geological processes like weathering, faulting and fracturing.

In all, a total of five profiles were surveyed along and across the site. The profiles showed clearly four distinct layers and in most cases ranging from top alluvial deposit (consisting mainly of sandy clay), weathered basement rock layer (consisting of fine, medium to coarse sand), fractured basement rock and bottom layer of fresh basement rock.

The inversion result of profile LundDam01 reveals an overburden thickness of about 7m to over 29m (resistivity between 26.5 ohm-meter and about 60 ohm-meter). The weathered basement rock occurred from depth of 7m to probably over 29m (having resistivity between 79.3 ohm-meter and 137 ohm-meter). The fractured basement rock was encountered at depth of about 17m (resistivity from 137 ohm-meter), while the fresh basement rock occurred from depth of about 27m. Profile LundDam02 shows overburden thickness ranging between 7m and 21.7m (resistivity between 14.1 and about 45 ohm-meters), weathered basement rock occurring from depth of 7m to over 21.7m (resistivity between 48.6 ohm-meter and about 120 ohm-meter). Fracture basement rock occurred at depth 25m with resistivity from 111 ohm-meter, while the fresh basement rock was encountered from depth 29m. Profile LundDam03 indicates overburden thickness of 4m to

20m, weathered basement rock occurring from depth 4m to 21.7m, fractured basement rock from depth 25.7m t0 29.3m. The fresh basement occurred from depth of 25.7m. Profile LundDam04 shows overburden thickness ranging from about 1.3m to about 22m, weathered basement rock layer occurring from depth 1.3m to over 29m (the lowest depth is the part of the section that fell on the laterite outcrop). The fractured basement rock occurred from depth of about 25m while the fresh basement rock was encountered at depth of 28m. Profile LundDam05 model section shows overburden thickness of about 7m, weathered basement rock occurring from depth 7m to about 21.7m. The fractured basement rock was encountered at depth 21.7m and extending to 27m. The fresh basement rock occurred from depth of 27m.

The contrast in resistivity values between the layers of profiles LundDam01 and LundDam02 suggest that there is passage of waste material through the aquifer zones. The low resistivity of the basement rock indicates high level of fracturing. Some parts, especially indicated in profiles LundDam01, and LundDam02, cutting across approximately NW-SE direction of the study area, due to observed discontinuity or separation of basement rock, suggested the occurrence of a structural feature suspected to be fault and may also serve as conduit for passage of sewage.

Averagely, at the site, depth to weathered basement rocks occurred from about 4m to over 15m underneath some part of the sections. The alluvial deposit (overburden) at the top have thickness varying from about 4m to over 15m and may be related to previous works in Zaria, particularly, Olowu, 1967. The inferred lithological depth sections clearly

outlined the importance of electrical resistivity tomography in waste stabilization pond site studies.

5.2 Recommendations

Considering the results of this research study, it is recommended that a barrier system be designed at the bottom of the ponds to avoid excessive filtration which might cause physical escape of the liquid to either surface water or ground water, and also chemical migration by diffusion, whereby, the contaminants migrate from a point of high concentration to a point of low concentration. Clay liners and geo-membranes are two of the most frequently used barrier systems.

Generally, geophysical survey should be integrated in the investigation, analysis, and design, from the beginning of project planning, through construction and first operation stages. This is important, in order to identify new geological features that may affect project and verify the accuracy of design assumptions.

Seismic geophysical survey should be carried out on the study area so as to have deeper probe or investigation of its subsurface, especially the fresh basement rock. A selective drilling may also be carried out to increase the precision of geological interpretation at the subsurface of profiles surveyed.

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