2-D ELECTRICAL RESISTIVITY INVESTIGATION OF SOLID WASTE DUMPSITE AT GONIN-GORA, KADUNA STATE, NIGERIA.

BY

ASUERIMEN MIKE B.Sc. (ABU 2008)

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MAY, 2014.

DECLARATION

I hereby declare that:

The research work presented in this thesis entitled "**2-D ELECTRICAL RESISTIVITY INVESTIGATION OF SOLID WASTE DUMPSITE AT GONIN-GORA, KADUNA STATE, NIGERIA**",hasbeen performed by me in the Department of Physics under the supervision of**Dr. A.L. AHMED and Dr. K.M. LAWAL.**

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

ASUERIMEN, Mike

| --- | --- | --- |
| Name of student | Signature | Date |

CERTIFICATION

This research thesis entitled "**2-D ELECTRICAL RESISTIVITY INVESTIGATION OF SOLID WASTE DUMPSITE AT GONIN-GORA, KADUNA STATE, NIGERIA"**,by **ASUERIMEN Mike** meets the regulations governing the award of degree ofMasters of Science (M.Sc.) of Ahmadu Bello University, Zaria, and is approved for itscontributions to knowledge and literary presentation.

---------- …… ----------

Chairman, Supervisory Committee Signature Date

Dr. A.L. AHMED

---------- …… ……

Member, Supervisory Committee Signature Date

Dr. K.M. LAWAL

---------- ---------- ……

Head of Department Signature Date

Dr. U. SADIQ

---------- ---------- ……...

Dean, Postgraduate School Signature Date

Prof. A. A. JOSHUA

DEDICATION

This research thesis is dedicated to the **Almighty God** for His guidance, provision and all His goodness throughout the programme. This research thesis is also dedicated to my parents **MR. and MRS. ASUERIMEN.**

ACKNOWLEDGEMENT

First and foremost, I express my sincere thanks and appreciation to God Almighty for His countless blessings upon me and for enabling me to achieve this important milestone in my life.

Thanks to my supervisors,Dr. A.L. AHMED and Dr. K.M. LAWAL, I appreciate your efforts for finding time to go through this work despite your busy schedule.

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Special thanks go to my Air Traffic Controller's (AC-56) course mates, who encouraged me during the course of my studies and during this research. I appreciate you all. God bless you all.

Finally, my sincere appreciation goes to Hon Tajudeen Abbas and Family, Mrs.Okechukwu, Mr. and Mrs. Linus Nwosu,Onwube Joy, Ajele Dele Moses, MotunrayoEkunseitan, Atebe Pius, Wonah Peters, Abraham Attama, Femi korogo, Mr. and Mrs. Ike Nwosu, YakubuAttai Gowon, Mr.seunAdegbite, Yusuf Bah Abubakar and most importantly, my Love LilianNwosu. You are all wonderful. God bless you.

That a name is not mentioned here is not meant to disregard many others that contributed in whatever form, but the omission is as a result of space constraint, please pardon me and thank you all.

ABSTRACT

Leachate effluence from refuse dumpsite is an important source of soil and groundwater pollution. Consequently, assessing the impact of Leachate is an active area of soil and groundwater research. 2-D Electrical Resistivity imaging survey was carried out at a dumpsite in Gonin-Gora area of Kaduna State, with the aim of determining how accurately electrical measurements could delineate the influx of leachate into soil and groundwater. A modern and state-of-the-art field instrument, the ABEM Automatic LUND Imaging System (Terrameter SAS 1000 and ES 464), produced by ABEM instrument AB, wasused to accomplish this task. This uses multi-core cables with takeouts at 2m intervals, having a total of 42 electrodes covering a spread of 200m. Six profiles were covered and the data were processed to display the variations of electrical resistivities using the RES2DINV software. Four of the profiles were inside the dumpsite while two profiles were outside the dumpsite.Also, one Vertical Electrical Sounding (VES) was conducted inside the dumpsite with thesame ABEM TerrameterSAS 1000,and was interpreted using computer software (IPI2win) which gives an automatic interpretation of the apparent resistivity data.The results of this survey in correlation with a Borehole log of the area revealed three layers: The topsoil, which consists ofreddish brown lateritic and sandy clay, has resistivity values between 8Ωm and 850Ωm and its thicknessvaries between 0.01 m to 7.00 m. The second layer is the weathered basement, and has resistivity values between 150Ωm and 940Ωm. Its thickness ranges between 2.00 m to 16.00 m. The resistivity of the fresh crystalline basement which forms the third layer ranges between 820Ωm to 4000Ωm. The 2D Inversion delineated contamination plumes as low resistivity zones with resistivity values ranging between 1Ωm and 27Ωm, from the ground surface to

varying depths of 0-3 m in profile 1 and profile 4, believed to be leachate derived from decomposed waste of higher concentrations, while profile 2,profile 3 and profile 6 delineated contamination plumes withresistivity zones ranging between 100Ωm to 200Ωm, from the ground surface to varying depths, believed to be leachate from decomposed wasteof lower concentrations.There was no evidence of topsoil or groundwater contamination as revealed by the inversion model in profile 5.The VES data revealed that the area has a shallow aquifer of about 4m, indicating that the topsoil as shown in all the profiles except profile 5, and the groundwater in profiles 3 and profile 6 are contaminated.A comparison ofthe measured apparent resistivity pseudosection and the calculated apparent resistivitypseudosection resulted in a reasonably good agreement with the inverse model resistivity section.

The study area has a shallow depth to Basement of 1.30m and a depth to water table of about 4m.The inverse model revealed weak zones which could be interpreted as fractures, which aid in the migration of the leachate as shown in profile 3 and profile 6.

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CHAPTER ONE

INTRODUCTION

1.1 General overview

Wastes, which are described here as materials that result from an activity or process, but have no immediate economic value or demand and must be discarded, have been managed in a way that contaminates water and the environment. In this area, like in most other areas and cities, wastes are generated daily and most of the wastes are discarded in improperly situated dumping sites that are not engineered. The dumping site is located close to residential areas, markets, farms, roadsides, and others. This threatens the groundwater and road facilities, not sparing the aesthetics of such affected areas.

The importance of groundwater as a valuable source of portable water cannot be over emphasized. Groundwater forms the most important natural resources of any region and compliments surface sources in the provision of portable water for domestic and industrial applications. The populace is also dependent on the abundance, fertility and integrity of the soils for agriculture, shelter, and other economic and industrial activities (Jatau and Ajodo, 2006). Unfortunately, the qualities of these natural resources have been impaired by the indiscriminate location of dumpsites without regards to the health of the people and damage to the environment.

During the peak of the rainy season, dumpsites are covered by flood water and this contributes to the formation of leachate (water that has percolated through waste and contains various ions in solution). It is this contaminated liquid (leachate) that forms a "plume" that moves outwards and downwards into the surrounding and underlying aquifers (Carpenter et al., 2012). These plumes may

contain dissolved Carcinogens such as heavy metals (e.g., lead, mercury, chromium, cadmium, arsenic, etc.), volatile organic compounds (VOCs: benzene, ethyl benzene, toluene, etc.) and less harmful ions (sodium, calcium, iron, sulphate, chloride, etc.). A high concentration of chlorine ions in solution (referred to as chloride), in particular, makes leachate electrically conductive. Acids dissolved in water (indicated by pH values less than 7) release hydrogen ions into solution which also enhances electrical conductivity.

Geoelectrical method has been found very suitable for this kind of environmental study. This is due to the fact that generally, ionic concentration of leachate is much higher than that of groundwater and so when the leachate enters the aquifer, it results in a large contrast in electrical properties and the method will identify these zones as an anomaly which enables the leachate plume to be detected.

1.2 Location of the Study Area

The area under study, Gonin-gora, (Fig. 1.1) in Kaduna State, is located at kilometer 4 Kaduna-Abuja express way and covers a total area of about 4km^2. The Area is bounded approximately byLatitude $10^0$24’24.54”N and$10^0$26’30.15”N and Longitude $7^0$24’45.12”E and$7^0$28’51.22”E.The terrain is relatively flat and accessible by road. Solid waste from surrounding industries in the area e.g.Textile, Petrochemicals, Iron and Steel, Breweries, Fertilizer Plants, Flour Mills, Automobile, Glass Industries, Food and Beverage, form the surface compositions of the dumpsite (Fig. 1.2).The study area can be reached through the federal high way of Kaduna – Abuja road.

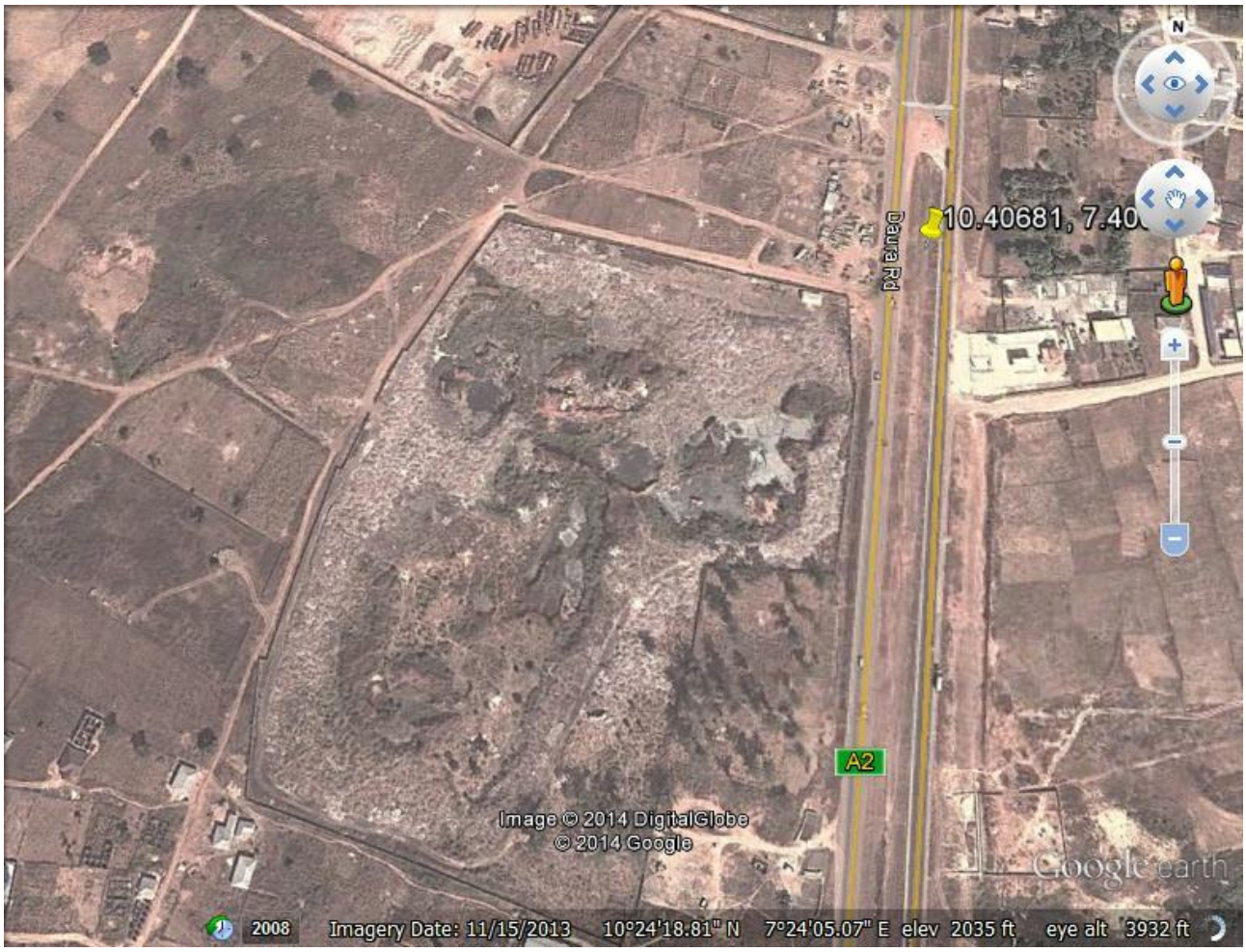


Figure 1.1: Google Image of the Study Area.



Figure 1.2: Dumpsite showing its surface compositions (Photograph)

1.3 Climate and Vegetation

The area is in the Guinea Savannah climatic belt of Nigeria with distinct dry and wet seasons. The land surface is covered by vegetation which is typical to the Savannah grassland characterized by shrub bushes generally less than 3.0m high and interrupted by large trees. The vegetation assumes various shades of green in the wet season and turns brown or pale in the dry season. Normally the thick vegetation cover helps to trap rainwater and prevent severe subsurface run-off which usually gives rise to high erosion and gullying. The presence of large vegetation in the area is of advantage in arresting the depletion of groundwater and reducing the rate of evapotranspiration.Groundwater occurrence in the study area is, not only a consequence of hydrologic and geologic events, but also of the climatic (rainfall) conditions. Invasion of two (2) air masses are witnessed here; the northern air mass that is dry and continental in origin, and the southern air mass which is moist, this is known to come from the Atlantic.

1.4 Hydrogeology of the Study Area

Exploration for groundwater potential of the study area has not been fully undertaken. Hence, information related to the magnitude and mode of formation of the surface water is inadequate. However, in the Basement Complex the permeability and storability of the groundwater system are dependent on structural features such as the extent and volume of fractures together with the thickness of weathering (Clark, 1985;Eduvie, 1998). It has also been discovered that below the veneer of regolith, the Fresh Basement rock is highly fractured at shallow and even at great depth. This, according to Eduvie(1998) makes the basement complex rock, and their derivative to constitute large reservoir of groundwater. Relative high annual rainfall (1270mm) and temperature of 32^0C in Kaduna have resulted in the formation of deep weathered zones.Also, high

density of fractures has contributed tremendously to good aquifers and high yields of boreholes (Eduvie, 1998). Geophysical investigation and borehole drilling report have clearly established two major aquifers. These are the Overburden weathered aquifer and the Fractured Crystalline aquifer. These aquifers are characterized by thick overburden found within basement depressions with maximum value of 65 m and resistivity values between 10Ωm and 756Ωm (Abdullahiet al., 2014). The Overburden weathered aquifer holds a great quantity of groundwater hence, most of the hand dug wells are sunk into it for domestic water supply. At some locations, these aquifers are interconnected and form a hydrological unit of water table surface.

1.5 Geomorphology of the Area

The main factors that affect the availability of surface water in Kaduna area are rainfall, temperature, evapo-transpiration, runoff and seepage (Jatau,1998). The relief of the area range between 370m and 650m (Mamman, 1992; Aboh, 2001). The drainage system of Kaduna and environs are dominated by the numerous tributaries to River Kaduna. The major ones include Rafin- Guza, Rigasa, Romi and Rido. The duration of flow in these streams depends on a number of factors which include; size of the drainage basin, the permeability of the regolith, the size of the flood plain and the gradient of land surface. These drain off into the Kaduna- Niger drainage system (Aboh, 2001).

1.6 Aim and Objectives of the Survey

The primary aim of this research is to use 2-dimensional electrical resistivity imaging techniques to investigate leachate generation and migration paths and the potential impact on human health and the environment.

The specific research objectives set out include:

- To determine the subsurface geoelectric formations.
- To determine the depth to water table.
- Lithology delineation of the subsurface.
- To detect and map contaminated zones.

1.7 Justification of the Study

The study area is surrounded by many Industries which include; Textiles, Petrochemicals, Iron and Steel, Breweries, Fertilizer Plants, Flour Mills, Automobile, Glass Industries, Food and Beverage Industries, etc. Thus, solid, liquid and gaseous wastes are dumped or discharged into the dumpsite (Fig. 1.2), which could affect soil and groundwater. The citing of boreholes as the source of potable water in this area has become a serious challenge. The challenge is worsened by the fact that there are inadequately trained waste disposal personnel and equipment, poor waste collection, sorting and disposal methods, and location of this disposal site without regards to the local geology and hydrogeology of the area (Jatauand Ajodo, 2006).

As a result of the imminent impact of solid waste on the environment, it has become necessary to investigate the potential for the contamination of soil and groundwater around the dumpsite.

CHAPTER TWO

LITERATURE REVIEW

2.1 Previous Geophysical and Geological Investigations in the Study Area

Amadiet al. (2011) carried out macro and micro-structural strain measurements on rocks of the areas covering Rijana, SabonKasarami and Wuya situated 43 km South of Kaduna along Kaduna–Abuja Road. This was done to determine bulk strain and to interpret correctly the degree and variability of metamorphism as well as the extent of deformational effects on the rock types resulting from the different tectono-metamorphic cycles. Observations of the ellipsoidal shapes of different rock types across the area show progressive grain deformation from the migmatite and biotite gneiss and fine grained biotite gneiss corresponding to the west-east strain variation.

Abdullahi (2009) carried out an integrated geophysical technique in the investigation of groundwater contamination at two waste disposal sites in Kaduna Metropolis. The result of the research indicated three to four layers in the area and the resistivity imaging had delineated the leachate plume in the area as low resistivity zones (6- 33Ωm). Also, the physio-chemical analysis of water samples from existing hand dug wells indicated contamination of the groundwater as a result of solid waste leachate accumulation.

Alheriand Jatau (2009) carried out a geophysical survey to determine the weathered regolith using Seismic Refraction method in some part of Kaduna South Industrial Area. They concluded from the research that the area had three to four layers, and that the borehole log of the study area revealed the same geologic unit with their research.

Jatauet al. (2008) carried out a chemical analysis on trace metals in surface and subsurface water in Kaduna South Industrial area. They concluded from the research that due to the high percentage of trace metals concentration level that exceeded the maximum contaminant level accounting for about 73.68% of the total contaminants and the water within the area was polluted and unfit for drinking.

Jatau and Ajodo(2006) in their preliminary geo-environmental studies of Kaduna North Metropolis stated that some wells were slightly acidic. They stated that the microbial analyses obtained from both ground and surface water samples contained coli-form bacteria. They further stated that leaches from waste came into contact with the groundwater through dilution and weathering processes.

Rahaman (1988) carried out a geological survey of some areas within the Southern part of Kaduna, and he found out that the rocks of the area consisted mainly of vertically dipping hornblende and biotite gneisses of variable grain sizes and migmatites. He concluded that unlike the biotite and migmatic gneisses, the hornblende gneisses formed generally NW – SE dissecting ridges which werelitho-stratigraphically conformal and parallel to quartzitic ridges. The biotite displayed alteration rims and elongated spene which occurred in accessory quantity.

2.2 General Geology of the Study Area

The study area lies within the Basement Complex of Nigeria (Figure 2.1). The Basement Complex includes all rocks older than the late Proterozoic (McCurry, 1976), and is composed mainly of Gneisses, Migmatite, Granites and some extensive areas of Schist, Phyllites and Quartzites (Preeze and Barber, 1965;Baimba, 1978). According to McCurry (1976), the whole Basement has undergone at least two Tectono-metamorphic cycles and consequent metamorphism, migmatization and granitisationhave extensively modified the rocks so that they generally occur as relict rafts and xenoliths in Migmatiteand Granites.

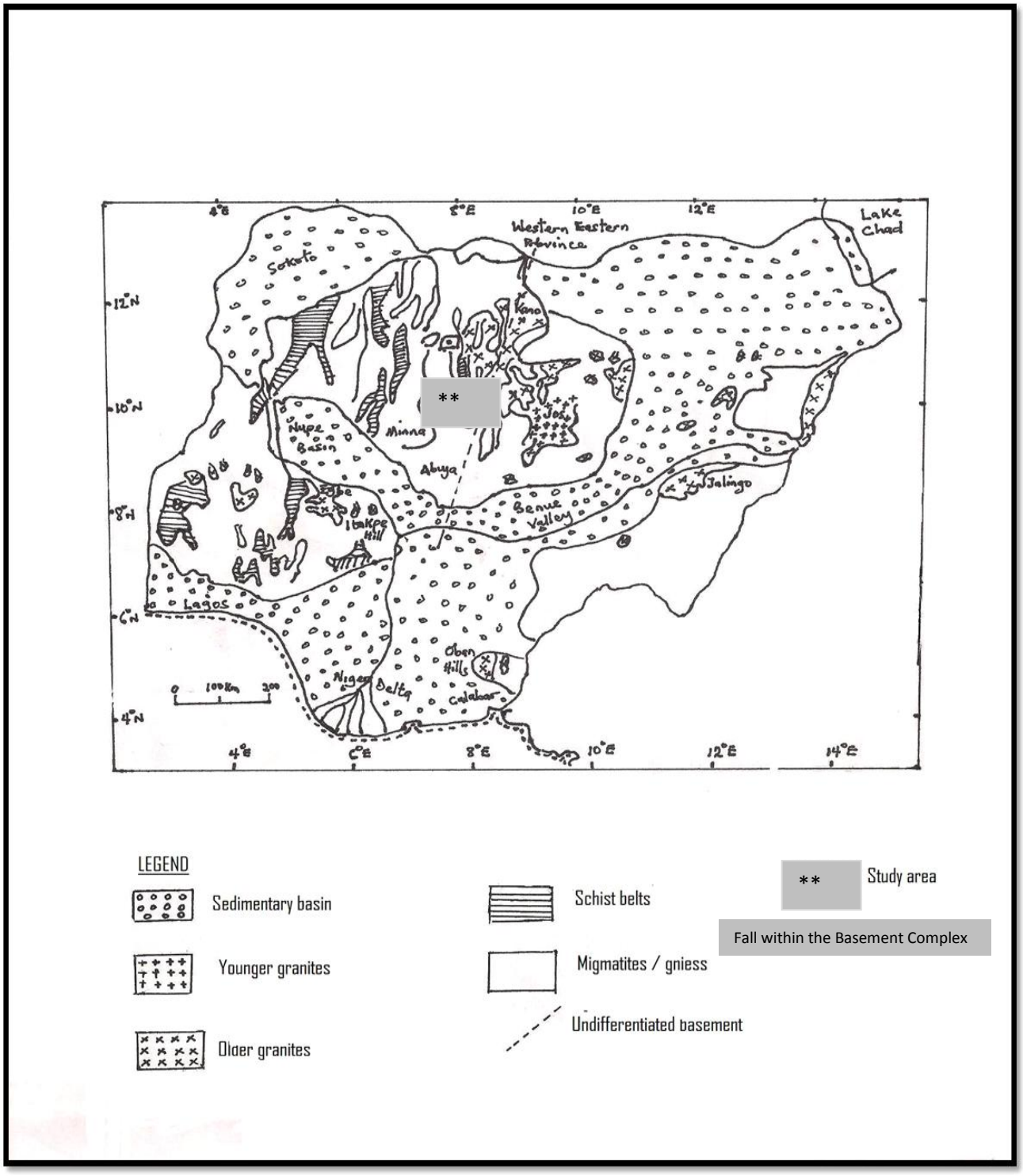


Figure 2.1: OUTLINE GEOLOGICAL MAP OF NIGERIA (modified after Ajibadeet al., 1989)

Two groups of granites are present and these are the Older Granites and the Younger Granites. The Older Granites are widespread and often give rise to smoothly domed hills which typically rise to about 170m above the surrounding plains (Russ, 1957). The Younger Granites which include Granites, Syenites and Rhyolites cover extensive areas in the Plateau province but there are also smaller masses in Southern Kaduna, Kano and Bauchi provinces. These rocks are hard, with low permeability and generally not water bearing. The rocks are aquifer only when they are either weathered or fractured, otherwise they are dry or at best contain just little amount of water (Olabodeet al., 1999). Over most of the area underlain by the Basement Complex there is a thin discontinuous mantle of weathered rocks, mostly pronounced where the topography is subdued. The average thickness of the mantle is probably of the order of 15m, but in some areas it may extend to depth of up to 60m (Russ, 1957). The actual depth of the weathered zone depends on the length of time in which the rocks have been exposed to surface or near surface conditions and its original minerals. The interface between weathered and unweathered rocks is usually sharp. Weathering tends to be particularly well developed along fissure systems, which allow deep percolation of the weathering agents principally oxygenated water. River systems can sometimes be a guide to fault lines and associated fissure systems because they represent lines of weakness for erosion and weathering (Olabodeet al., 1999).

2.3 Factors controlling the risk of groundwater contamination by any Leachate:

Depth to water table, Concentration of contaminants and Permeability of Geologic strata:

If the water table depth is high (far away below the ground surface), water will become partially filtered as it percolate downwards through the soil. If the water table depth is low (close to the ground surface),contaminants can enter groundwater directly without filtration by soil.A high concentration of contaminants in leachate will make groundwater pollution more likely. Also, highly permeable geologic strata allow leachate to quickly percolate through receiving little filtration along the way. Strata consisting of relatively impermeable material such as slit and clay act as natural barrier to leachate and thus, impede the downward percolation of leachate.

2.4 Importance of Electrical Imaging

Electrical prospecting involves the detection of the surface effects produced by electrical current flow in the ground. A good number of electrical techniques are available because of the large variation in the conductivity of earth materials (rocks and minerals) describing the single property of earth material that varies over a wide range of the area. Thus, theoretically at least the resistivity methods are the most superior of all the electrical methods because quantitative results are obtained using a controlled source of specific dimensions (Telford et al., 1990). The applicability of the different resistivity methods supported by the ABEM Terrameter SAS 1000/4000 is summarized in Table 2.1.

Table 2.1 Applicability of Different Resistivity and Induced Polarization Methods.

SP= Self Potential, VES= Vertical Electrical Sounding, Imaging= Profiling (withdifferent electrode separations) and IP= Induced Polarization, (ABEM Terrameter SAS 1000 / SAS 4000 instruction manual, 2010).

Object of search or investigation	SP	VES	Imaging	IP
Archeological sites			*	
Dam safety and leakage	*		*	
Groundwater in sedimentary areas		*		
Fracture zones in rock			*	
Groundwater in crystalline rock			*	
Groundwater/clay distinction				*
Groundwater flow	*			
Ores in hard rock areas	*		*	*
Overburden thickness		*		
Pollution of soil and groundwater			*	
Salt water invasion				*
Fissures in rock			*	

CHAPTER THREE

METHODOLOGY

3.1 Introduction

In geoelectrical resistivity tomography (near-surface), a large number of electrodesare inserted into the ground and a computer-based system scans the whole array, thusrealizing a combined sounding and profiling. If the target in a proposed survey area isnarrow and extends over a long distance (the 2D case), the technique effectively investigates a series of depth ranges on a profile line, resulting in a pseudosection of apparent resistivities.

Tomographic surveys normally employ arrays of electrodes on the surface of the ground for data collection. The survey technique involves measuring a series of constant separation traverses with the electrode separation being increased with each successive traverse. Since increasing separation leads to information from greater depth, the measured apparent resistivities may be plotted as a contoured section, which reflects qualitatively the spatial variation in resistivity in the vertical cross-section. Length of profile, depth of penetration and resolution required determine the unit electrode spacing.

3.2 Field-Work Planning

The field work was accomplished between 3rd of March and 10th of March, 2013, before the start of the rainy season. This period was chosen for the field work, to avoid disturbance by rain which would slow down the work.

Electrical resistivity imaging using Schlumberger array was used along the six (6) profiles.A direction of S-N azimuth was employed in profiles 3and 5, and a W-E azimuth in profiles 1, 2, 4 and 6, in the orientation of the profiles (Fig 3.1).

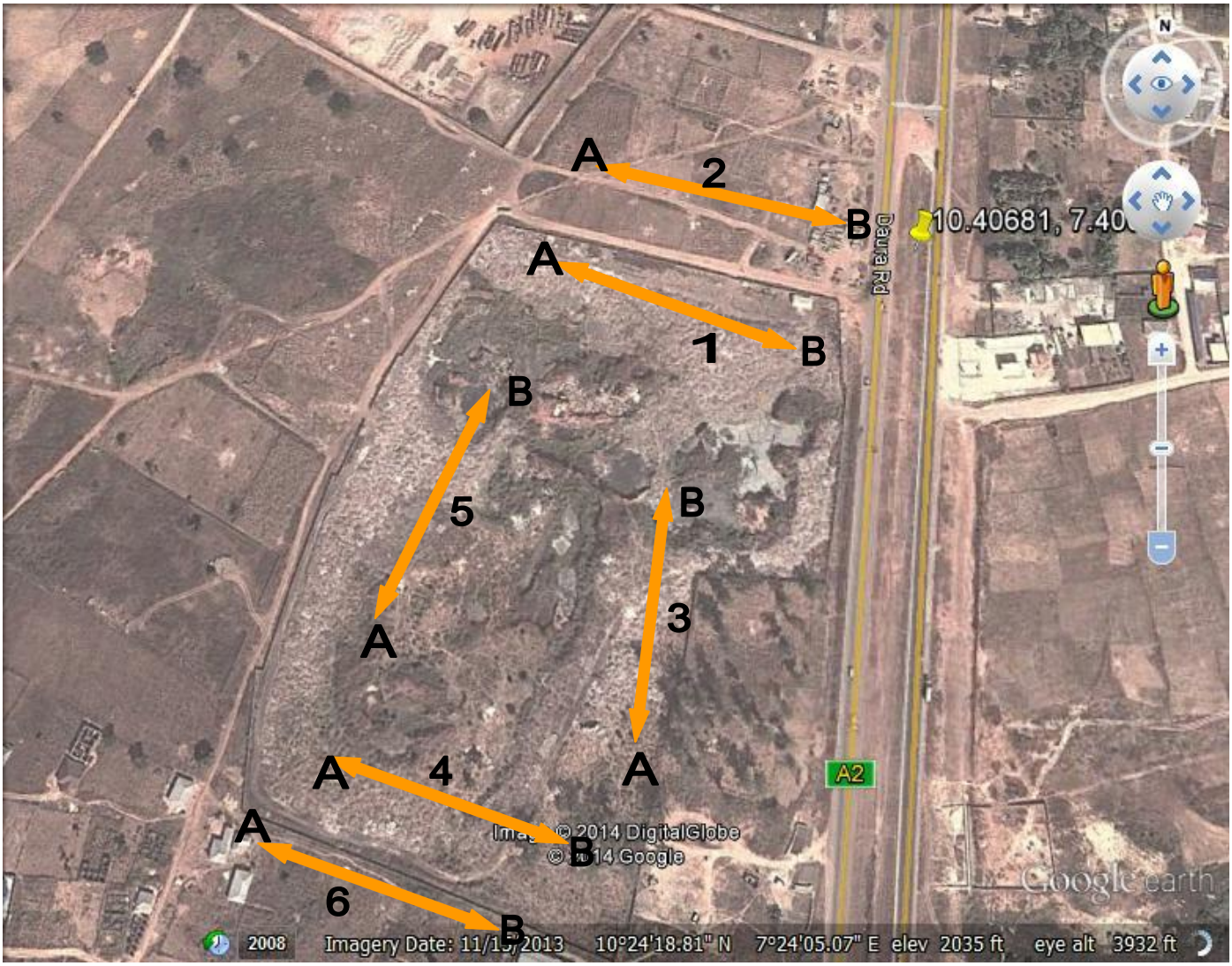


Figure 3.1: Google Image of Study Area Showing Profile Lines

3.3 Choice of the method

Schlumberger electrode layout was used, for the following reasons:

The smaller separation of the potential electrodes (Fig 3.2) reduces noise due to ground current (from industrial and telluric sources) which may limit the useful depth of penetration.It alsoprovides a better horizontal coverage (Fig 3.3),and the maximum depth of penetration of this array is about 15% larger than the Wenner array.

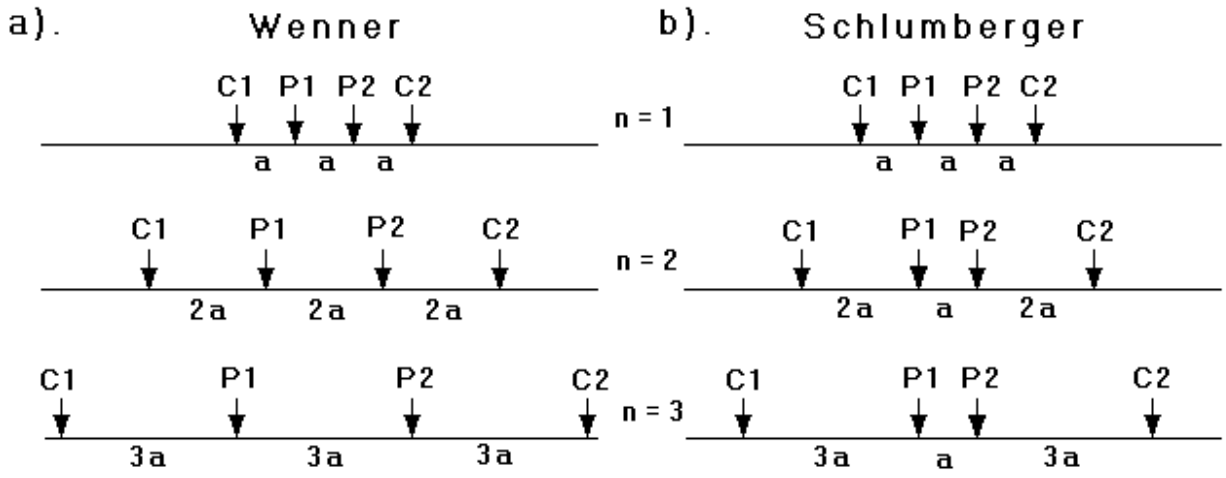


Figure 3.2: The steps used to increase the depth of investigation by (a) Wenner array and (b) Schlumberger array.

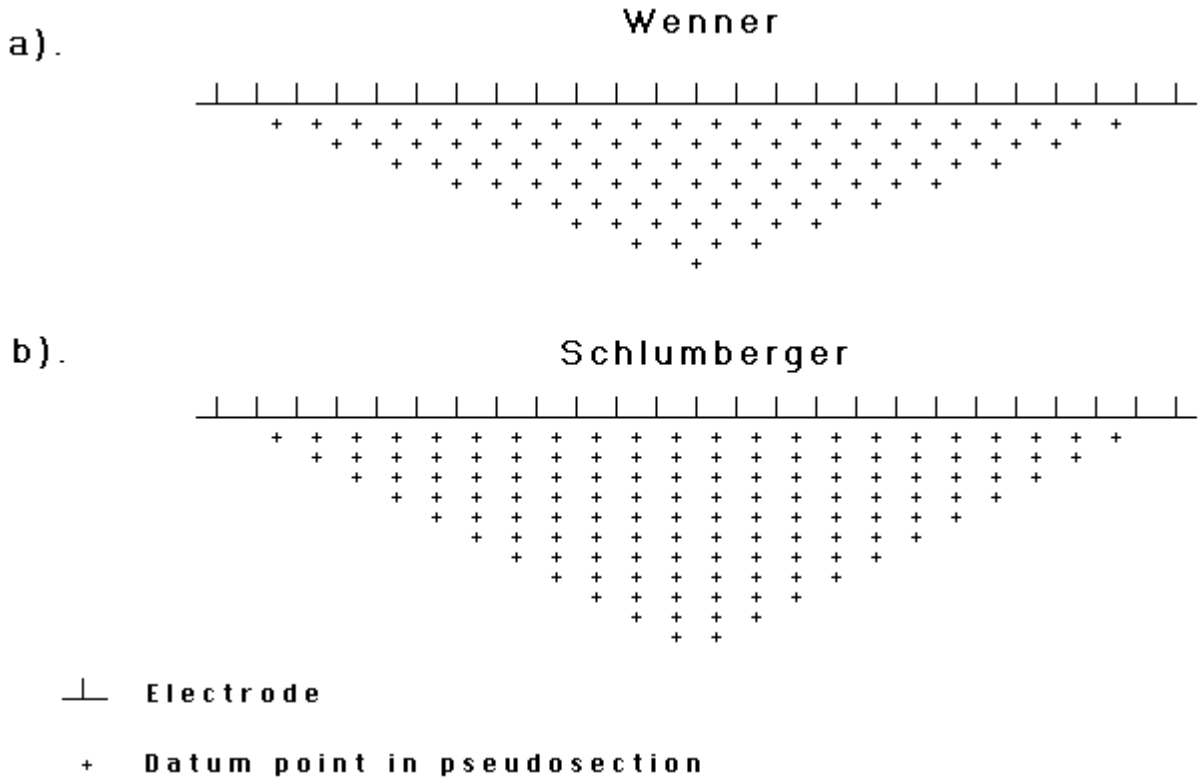


Figure 3.3: Arrangement of data points in the pseudosections for (a) Wenner array (b) Schlumberger array.

3.4 Field Procedure

Electrical Resistivity Tomography (ERT) is a method by which 2D images of subsurface resistivity distribution are generated. Using this method, features with electrical properties differing from those of the surrounding material may be located and characterized in terms of electrical resistivity, geometry and depth of burial. The electrical resistivity tomography data are collected using computer-controlled measurement systems connected to multi-electrode arrays. The data acquisition process is completely controlled by the computer software which checks that all the electrodes are connected and properly grounded before measurement starts. After adequate grounding is achieved the software scans through the measurement protocol selected. The Schlumberger array was chosen for this survey. The batteries of the Terrameter SAS 1000, Electrode Selector ES 464 were charged to full capacity before going to the field. Spare batteries were also taken along. Stainless steel electrodes, cable jumpers or electrode connectors, cable and reels, hammer, external 12 volts battery, a field umbrella, a measuring tape, 3 ranging poles, external battery adapter e.t.c; were conveyed together with the members of the field team to the site of this research project, for commencement of the geophysical investigation. The two electrode cables 1 and 2 depending on the current position along the line of survey were rolled out in the direction of the profile, with the cable reel end facing the highest coordinates. Each cable has 21 take-outs. The Terrameter SAS 1000 and the ES 464 were placed in the centre of the layout. The two cables were connected to the ES 464 at the centre of the cable spread. Take-out 1 and take-out 21 were made to overlap at the cable ends and in the layout centre. The serial port of the Terrameter was connected to the Electrode Selector. The electrodes were connected to all the take-outs at intervals of 2m on the electrode cables using

cable jumpers. For a moist or soft ground, electrodes werejust pushed into the ground by hand and then connected. However, hammering andwetting were done on dry and hard ground. The Terrameter was then connected to an external 12 volts battery and switched on, which automatically switches on the Electrode Selector and the system set-up which was echoed to the screen. The instrument was set to resistivity mode and LUND Imaging System was selected. Electrode test commenced immediately, and grounding improved for theelectrodes with bad ground contact. The connectors were also checked for unsatisfactoryelectrode positions. Electrodes were tested pair-wise against each other starting from the outermost electrodes going towards the centre. The electrode test checks if it is possible to transmit current through all electrodes. This test takes a couple of minutes but saves time afterwards; because programme may stop depending on poor electrode contact. Measurement may also stop if the batteries for either the Terrameter or the Electrode Selector are low. The programme automatically continues to measure using the two electrode cables when the contact is satisfactory.It was ensured that measurements did not stop during the measurement period. As measurement continued apparent resistivity values were echoed on the screen. When measurement on each layout was finished, the programme was stopped and the Terrameter switched off. The cables were disconnected, wound up, and the electrodes and cable jumpers were all collected together. The instrument was then transferred to a new profile and the entire process repeated until all the profiles were completed. While measuring the profiles, the positions of reference points along the lines were noted. The used midpoints along the profiles were noted to facilitate identification of points for further investigation. Six profiles were used.

3.5 Typical Resistivity Values of Earth Materials

Of all the physical properties of earth materials (rocks and minerals), electricalresistivity shows the greatest variation. Resistivity of metallic minerals may be as smallas $10^{-5}\Omega$m, that of dry close-grained rocks like gabbro could be as large as $10^{7}\Omega$m. Themaximum possible range is even greater, from native silver, $1.6x10^{-8}\Omega$m to pure sulphur$10^{16}\Omega$m. A conductor is usually defined as a material of resistivity less than $10^{-5}\Omega$mwhile an insulator is one having a resistivity greater than $10^{7}\Omega$m, between this limit liesthe so-called semi-conductors (Telford et al., 1990).The common minerals forming rocks and soils have very high resistivity in a drycondition and the resistivity of rocks and soils is therefore normally a function of theamount and quantity of water in pores and fractures. The degree of connection between cavities is also important; consequently the resistivity of a rock type or soil type may vary widely. The electrical resistivity varies between different geological materials dependingmainly on variations in water content and dissolved ions in the water. Resistivityinvestigations can thus be used to identify zones with different electrical properties,which can then be referred to different geological strata. However, the variation may belimited within confined geological area and variations in resistivity within certain soil orrock type will reflect variations in physical properties.For example the lowest resistivities encountered for sandstones and limestonemean that the pore spaces in the rock are saturated with water, whereas the highest valuesrepresent strongly consolidated sedimentary rock or dry rock above the groundwatersurface. Sand, gravel and sedimentary rock may also have very low resistivities provided the pores in the rock are saturated with saline water. Fresh crystalline rock is highlyresistive apart from certain ore minerals, but weathering commonly produces highly conductive clay

rich saprolite. The variation in characteristics within one type ofgeological material makes it necessary to calibrate resistivity data against geologicdocumentation for instance, surface mapping, test pits or drilling. A typical range of resistivities of geologic materials is shown in Figure 3.4

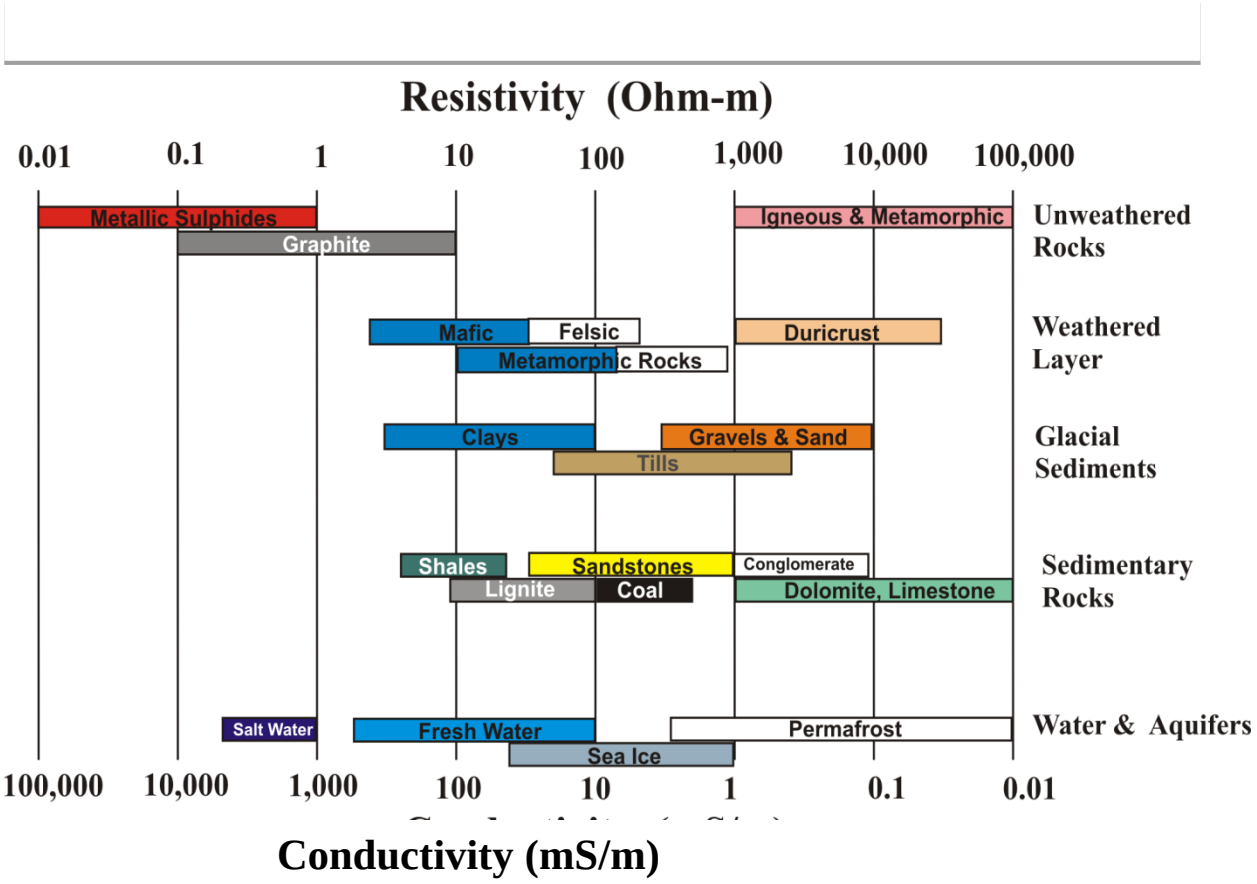


Figure 3.4: A Typical Range of Resistivities of Geological Materials (ABEM Instruction Manual, 2010).

The amount of water in a material depends on the porosity, which may be divided into primary porosity and secondary porosity. Primary porosity consists of pore spaces between the mineral particles and occurs in soils and sedimentary rocks. Secondary porosity consists of fractures and weathered zones, and this is the most important porosity in crystalline rocks such as granites and gneisses. Secondary porosity may also be important in certain sedimentary rocks such as limestone. Even if the porosity is rather low, the electrical conduction taking place through water filled pore spaces may reduce the resistivity of the material drastically. The degree of water saturation will of course affect the resistivity, thus the resistivity above the groundwater level will be higher than below if the material is thesame. Consequently the method can be used to find the depth to groundwater in materials where a distinct groundwater table exists. However, if the content of fine grained material is significant, the water content above the groundwater surface, held by hygroscopic and capillary forces may be large enough to dominate the electrical behaviour of the material. The resistivity of pore water is dominated by the concentration of ions in solution, the type of ions and the temperature. The presence of clay minerals strongly affects the resistivity of sediments and weathered rock. The clay minerals may be regarded as electrically conductive particles which can absorb and release ions and water molecules on its surface through an ion exchange process. Very roughly, igneous rocks have the highest resistivity, sedimentary rocks the lowest and metamorphic rocks intermediate. However, there is a considerable overlapping. Resistivities of particular rock types vary with age and lithology, since the porosity of the rock and the salinity of the contained water is affected by both. For example the resistivity range of Precambrian volcanic is 200Ωm – 5000Ωm while for quaternary rocks of the same kind is 10Ωm – 200Ωm (Telford et al., 1990). As the variation in temperature of the ground is generally small, the temperature

influence is normally negligible. However, in geothermal applications the variation could be significant even in permafrost regions. The mobility of ions increases with increasing temperature as the viscosity of water is lowered. Hence, a decrease in resistivity with increasing temperature can be observed for materials where electrolytic conduction dominates.

3.6 Theory of Direct Current Resistivity Method

The electrical resistivity method is one of the most relevant geophysical methods applied for groundwater studies in basement terrains. In groundwater studies for instance, the relevance of the method is based on the usually significant resistivity contrast between the weathered zone and/or fractured column which contains the water and the resistive fresh bedrock. There is a considerable variety of resistivity methods all of which employ artificial source of current which is introduced into the ground through point electrodes or long line contacts. The resulting potential established in the earth is measured at other electrodes in the vicinity of the current flow. The current is noted; hence it is possible to determine the apparent resistivity of the subsurface. In this regard, the resistivity method is the most superior; at least theoretically, to all other electrical methods since quantitative results can be obtained by using a controlled source of specific dimensions (Telford et al., 1990). Direct current or an alternating current of low frequency is used and the method is often called D.C. resistivity method. In this method, an electric current is introduced into the ground by means of two current electrodes, which set up a stationary current field, and because of the ohmic potential drop, an electrical potential field is also created. This field gets distorted in the neighbourhood of a subsurface zone of anomalous conductivity, and the aim is to search for such anomalous zones in the electrical field with a pair of potential electrodes. The assumption made here is that the current flow in the

potential measuring circuit is negligible compared with the current flow in the ground, so that the potential electrodes themselves will have no disturbing effect upon the electrical field (Grant and West,1965). Schlumberger array (Figure 3.5), was adopted for the survey. A and B are point current electrodes through which current is driven into the ground, while M and N are two potential electrodes to record the potential distribution in the subsurface within the two current electrodes.

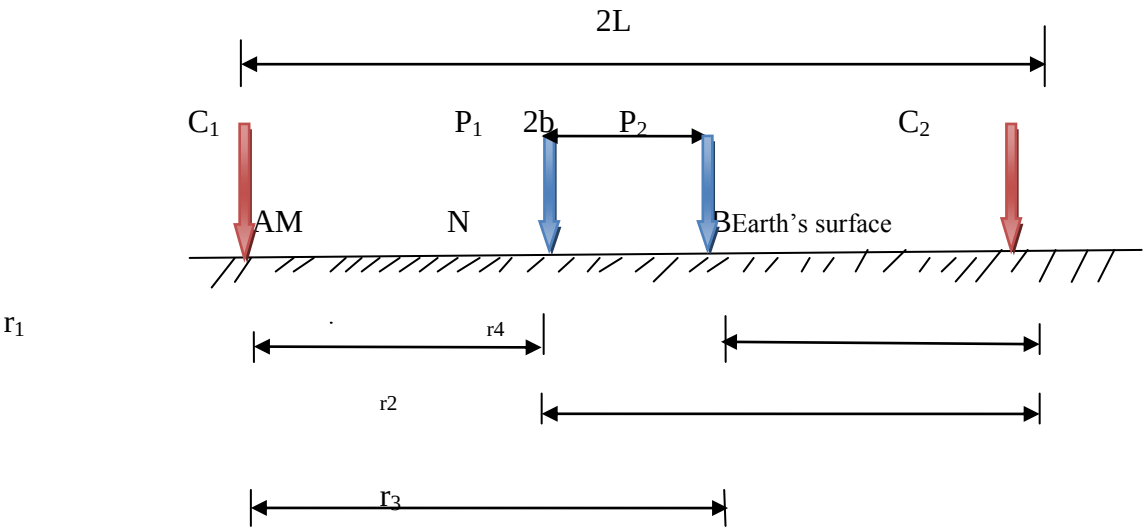


Figure 3.5: Schlumberger Electrode Array

From Ohm's law, the current I and potential U in a metal conductor at constant temperature are related as follows:

$$U=IR \tag{3.1}$$

where R is the constant of proportionality termed resistance and it is measured in ohms. The resistance R, of a conductor is related to its length L and cross sectional area A by;

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

where ρ is the resistivity and it is a property of the material considered. From equations (3.1) and (3.2),

$$U= \frac{I\rho L}{A} \tag{3.3}$$

Schlumberger array involves fixing the potential electrodes at points M and N, and symmetrically increasing the current electrode separation AB about the centre by displacing A and B outwardly in steps. This will increase the depth of penetration within the separation AB. Thus the varying resistivity measured when electrode array position is varied in an inhomogeneous medium is termed apparent resistivity.

For simple treatment, a semi-infinite solid with uniform resistivity, ρ, is considered. A potential gradient is measured between M and N when current electrodes located on the surface of the equipotential surface is semi-spherical downwards into the ground at each electrode. The surface area will then be $2\pi L^2$, where L is the radius of the sphere. Thus,

$$U = \frac{I\rho}{2\pi L} \tag{3.4}$$

By deduction then, the potential at M (U_M), due to the two current electrodes, is

$$U_M=\frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \tag{3.5}$$

Similarly, the potential at electrode N (U_N) is given by

$U_N = \frac{I\rho}{2\pi} \left(\frac{1}{r_3} - \frac{1}{r_4}\right)$ (3.6)

where r_1, r_2, r_3 and r_4 are as shown in Figure 3.5

The potential difference, ΔU, across electrodes M and N is $U_M - U_N$. If the body is inhomogeneous like the study area, apparent resistivity (ρ_a) is considered,

$\rho_a = K\left(\frac{\Delta u}{I}\right)$ (3.7)

Where ρ_a is apparent resistivity in ohm-metre, and

$K = 2\pi\left[\frac{1}{\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)}\right]$ (3.8)

K is called the geometric factor whose value depends on the type of electrode array used. For Schlumberger symmetrical array, if MN =2b and $\frac{AB}{2}$ = L then,

$K = \pi\left(\frac{L^2}{2b} - \frac{b}{2}\right)$ (3.9)

3.7 Principles and Instrumentation

Tomography is defined as an imaging technique, which generates a cross sectional Picture (tomogram) of an object by utilizing the object's response to the non-destructive, Probing energy of an external source. Electrical resistivity tomography is a method by which 2D images of subsurface resistivity distribution are generated (Batayneh, 2006). Electrical Resistivity Imaging (tomography) involves measuring a series of constant separation traverses with the electrode spacing being increased with each successive traverse. Thus, 2D resistivity imaging requires data to be recorded with many different electrode separations along a line. It is important to have a dense enough data to cover laterally and in terms of electrode separations to recover complex structures in the ground. This demands the use of automated multi-electrode data acquisition systems to be practical. The Schlumberger spread was used for this survey.

The basis of the LUND Resistivity Imaging technique follows that of the normal resistivity technique. In both cases, when a current is driven into the earth, any variation of the subsurface resistivity will alter the current flow, which will in turn affect the distribution of the electrical potential. Buried bodies distort the regular pattern of current flow.

A conductive body concentrates electric current flow lines towards itself, while a resistive body causes the current to flow around itself. The potential fields are hence deflected and their deflections can be detected using potential electrodes at the surface of the earth. Thus, from the measurements on the earth's surface of the electrical potential and the current, it is usually possible to obtain information about the variation of the subsurface resistivity. Since sand, fine grained sediments and bedrock are expected to exhibit large contrasts in electrical resistivity, the electrical resistivity method should be well suited to resolving them. When the resistivity values are correlated with differing types of geologic materials, they can provide useful information for interpretation.

For resistivity measurement nowadays, there is a range of instrumentation from very simple to highly sophisticated equipment with the latter including the computer for infield data processing. The basic parts of any resistivity instrumentation are a portable power source which is either a D.C. or a low frequency A.C; Electrodes, preferably stainless steel electrodes and cable and reels, meters for measuring current and voltage both of which may be combined in a single meter reading resistance. With the development of computer-controlled data collection and automatic data inversion, the use of computer-controlled multi-electrode systems with automaticdata measurements and data quality control for the data acquisition, allow a dramatic increase in field productivity. Such is the ABEM LUND Imaging System.

3.8 The ABEM Lund Imaging System

The LUND Imaging System (Fig. 3.6) is a multi-electrode system for cost effective and high resolution 2D and 3D resistivity surveys. It is an automatic electric imaging system suited for automatic resistivity profiling and drilling. The LUND Resistivity Imaging System consists of a basic unit, a standard resistivity meter (ABEM Terrameter SAS1000) and a multi-channel relay matrix switch unit called Electrode Selector ES 464. The system also has four multi-conductor electrode cables wound on reels each with 21 take-outs, stainless steel electrodes and cable jumpers and various connectors. The system is compatible with a portable PC-type computer or note book (laptop). Operating power comes from an internal 12 volts rechargeable NiCd battery pack. Data acquisition software featuring automatic measuring process, in-field quality control of measurements, automatic roll along, electrode cable geometry and switching sequence defined in address and protocol files which allow the user define survey strategies and arrays, onscreen echo of measurement progress, software for graphical and depth interpretation including pseudosection plotting in gray scale or colour.

Model section plotting of 1D and 2D model interpretation sections in colour or gray scale including topography, reference data and reference levels, utility software for extraction of VES, data manipulation and conversion, graphical output in PCX-file format etc, are also available (ABEM LUND instruction manual, 2010).The Lund ES 464 basic system include one ES 464 field unit with clip-on NiCd rechargeable battery pack and one communication cable from electrode selector to Terrameter. It is light weight and has waterproof, rugged cast Aluminium casing. The Terrameter SAS system consist of a basic unit called the Terrameter SAS 1000 and accessories like ES 464. SAS means Signal

Averaging System. It is a method whereby consecutive readings are taken automatically and the results are averaged continuously.



Figure 3.6: (ABEM LUND Imaging System together with Terrameter SAS 1000 and ES 464 used for Electrical Resistivity Tomography)

Signal Averaging System (SAS) results are more reliable than those obtained from single-short systems. The SAS 1000 can operate in different modes, e.g., resistivity, self-potential and induced polarization. In all its modes it is capable of measuring simultaneously in four channels thus making it suitable in all sorts of resistivity surveys. The SAS 1000 is powered by a clip-on NiCd battery pack or by an external 12 volts source, which clips conveniently onto the bottom of the instrument. The SAS-EBA external 12 volts adapter allows the Terrameter to utilize an external 12 volts D.C. source, e.g., a car battery (ABEM LUND Instruction Manual, 2010).Stainless steel electrodes establish electric contact between electronic conductors, which are long cables, to an ionic conductor which is the ground. Electrodes generate noise, which is important only at the potential electrodes. Noise is the fluctuating voltage that appears between a pair of electrodes placed so close that no other natural voltages appear. But stainless steel electrodes create less noise. Current electrodes and potential electrodes make good contact with the ground to ensure low contact resistance and stability respectively (ABEM LUND Instruction Manual, 2010). The cables incorporate heavy guage conductors with excellent insulation to ensure good survey results. The cables are expandable for deeper penetration by connecting them in series with a cable joint. The cables have take-outs at 2m intervals along its length from which the cables are connected to the electrodes using cable jumpers having crocodile clips at both ends. The cables are wound on reels. Figure 3.6 shows the basic instrumentation of the ABEM LUND Imaging System and accessories.

CHAPTER FOUR

FIELD RESULTS AND INTERPRETATION

4.1 Introduction

In electrical resistivity tomography(ERT),prior information about unknown parameters (such asresistivity values and depth of the layers) is of paramount importance for inversionprocessing (Cardarelliand Fischanger, 2006).

As in all other geophysical methods, the interpretation of data from electricalimaging involves expressing in geological terms the information obtained from themeasured apparent resistivity data. Such an interpretation demands, on the one hand,considerable practical experience with the method and, on the other hand, a soundknowledge of the geology of the region under consideration.

An automatic iterative method based on the smoothness-constrained least-squaresmethod; known as RES2DINV was used. This rapid 2D resistivity inversion routineconsiderably sharpens up the image, places the structures at approximately their correctdepths and provides acceptable estimates of their true resistivities. In this work, all theavailable geological information on the project area was taken into consideration toconstrain the interpretations. Also in interpreting the data, each layer of rock type wasassumed to be homogeneous and isotropic.

4.2 Data Processing

The raw field data were processed using RES2DINV (Lokeand Barker, 1996). This is a computer programme that automatically determines a two-dimensional (2D) resistivity model for the subsurface for the data obtained from electrical survey. It is a window based programme. This method is based on the following equation

$(\mathbf{J}^T\mathbf{J} + u\mathbf{F})\mathbf{d} = \mathbf{J}^T\mathbf{g}$ ……4.1

Where $\mathbf{F} = \mathbf{f}_x\mathbf{f}_x^T + \mathbf{f}_z\mathbf{f}_z^T$

$\mathbf{f}_x$ = horizontal flatness filter

$\mathbf{f}_z$ = vertical flatness filter

J = matrix of partial derivatives

u = damping factor

d = model perturbation factor

g = discrepancy vector

The forward problem is solved through a finite difference algorithm, whose main features are a versatile user-defined discretization of the domain and a new approach to the solution of the inverse Fourier transform. The forward modelling subroutine is used to calculate the apparent resistivity values. The inverse procedure is based on an iterative smoothness-constrained least-squares algorithm. This computer programme uses a smoothness constrained non-linear least-squares optimization inversion technique to convert measured apparent

resistivity values to true resistivity values and plot them in cross-sections. The inversion process removes geometrical effects from the pseudosection and produces an image of true depth and true formation resistivity. One advantage of thismethod is that the damping factor and flatness filter can be adjusted to suit different types of data. The programme creates a resistivity cross-section, calculates the apparent resistivities for that cross-section, and compares the calculated apparent resistivities with the measured apparent resistivities. The iteration continues until a combined smoothness constrained objective function is minimized. The depth of investigation cannot be determined by simple calculations and it depends on the acquisition geometry, the conductivity structures and data errors (Oldenburg and Li, 1999). However, they have demonstrated through various modelling exercises that there is a loss of reliability in the inverted resistivity values at the bottom and ends of resistivity images where the resistivity values are least constrained by the data.

A common method for presentation of 2D resistivity data is the drawing of pseudosections. A pseudosection is made by plotting the data points in a diagram, using the length axis for the distance along the surveying line and the depth axis for the electrode separations (ABEM LUND Instruction Manual, 2010). The distance for the electrode configuration midpoint is thus plotted against the electrode separation for each measured data point, letting the latter reflect the measurement depth. The corresponding apparent resistivities for the plotted points are then used to contour the variation in apparent resistivity along the surveying line. The pseudosection thus obtained reflects the variation of resistivity in the ground in a qualitative way, and approximate structures and depths to layer interfaces may be estimated. It should be noted that the pseudosection is simply a 2D equivalent of the plotted field data points in a linear

depth scale. In this context, drawing of pseudosections needscomputer assistance to be practicable due to the large amount of data. The PSEUDO.EXE and ERIGRAPH.EXE software have been developed for automatic drawing of pseudosections in grey scales or colours, using linear interpolation between data points(ABEM LUND Instruction Manual, 2010). Linear interpolation involves no smoothing of data, and hence gives a good indication of the data quality. Twelve different colours or grey levels are used for plotting data. Each data point used for drawing the pseudosection is indicated in the section by a dot. Presenting DC-resistivity data in colour plots may be disputable as the data do not contain any spectral information. However, presenting D.C. resistivity data in colour plots makes it easier to see the variations in resistivity. This is important because,small changes in resistivity in one part of a long profile may be significant even if there isa very large variation along the profile. The selection of resistivity interval limit is ofmajor importance when presenting data, as the perception of the plotted data is strongly controlled by the colours. A suitable selection of limits enhances the geological variation while unsuitable selection of limits may hide important information or enhance irrelevant features. A geological reference was used to optimize the data presentation. The programme (ABEM LUND Instruction Manual, 2010) was developed for plotting DC resistivity data measured with a multi-electrode array, implying electrode spacings are always an integer multiple of the smallest electrode spacing used. Furthermore, profile distance coordinates are assumed to fall into the same positions as data for the smallest electrode spacings or halfway between them. For long profiles the data matrix used for the interpolation routine will not be sufficient for plotting the whole profile at once. In cases where the data do not fit, it is automatically divided into small enough portions for the interpolation routine, and plotted one portion after the other in the same section. In this way

there is no limit to the number of data points in the direction along the profile. There is however, a limit to the number of data points in the depth direction, which depends on the array size specified before compiling the programme, but for DC-resistivity data the number of different electrode spacings is normally very limited.

The 2D model used by the programme divides the subsurface into a number of rectangular blocks, to determine the resistivity of the rectangular blocks that will provide an apparent resistivity pseudosection that agrees with the actual measurements. For the Wenner and Schlumberger arrays, the thickness of the first layer of blocks is set at half times the electrode spacing. The arrangement of the blocks is loosely tied to the distribution of the data points in the pseudosection. The distribution and the size of the blocks are automatically generated by the programme, so that the number of blocks, usually do not exceed the number of data points. The depth of the bottom row is set to be approximately equal to the equivalent depth of investigation of the data points with the largest electrode spacing. This arrangement is shown in Figure 4.1(a), (b).

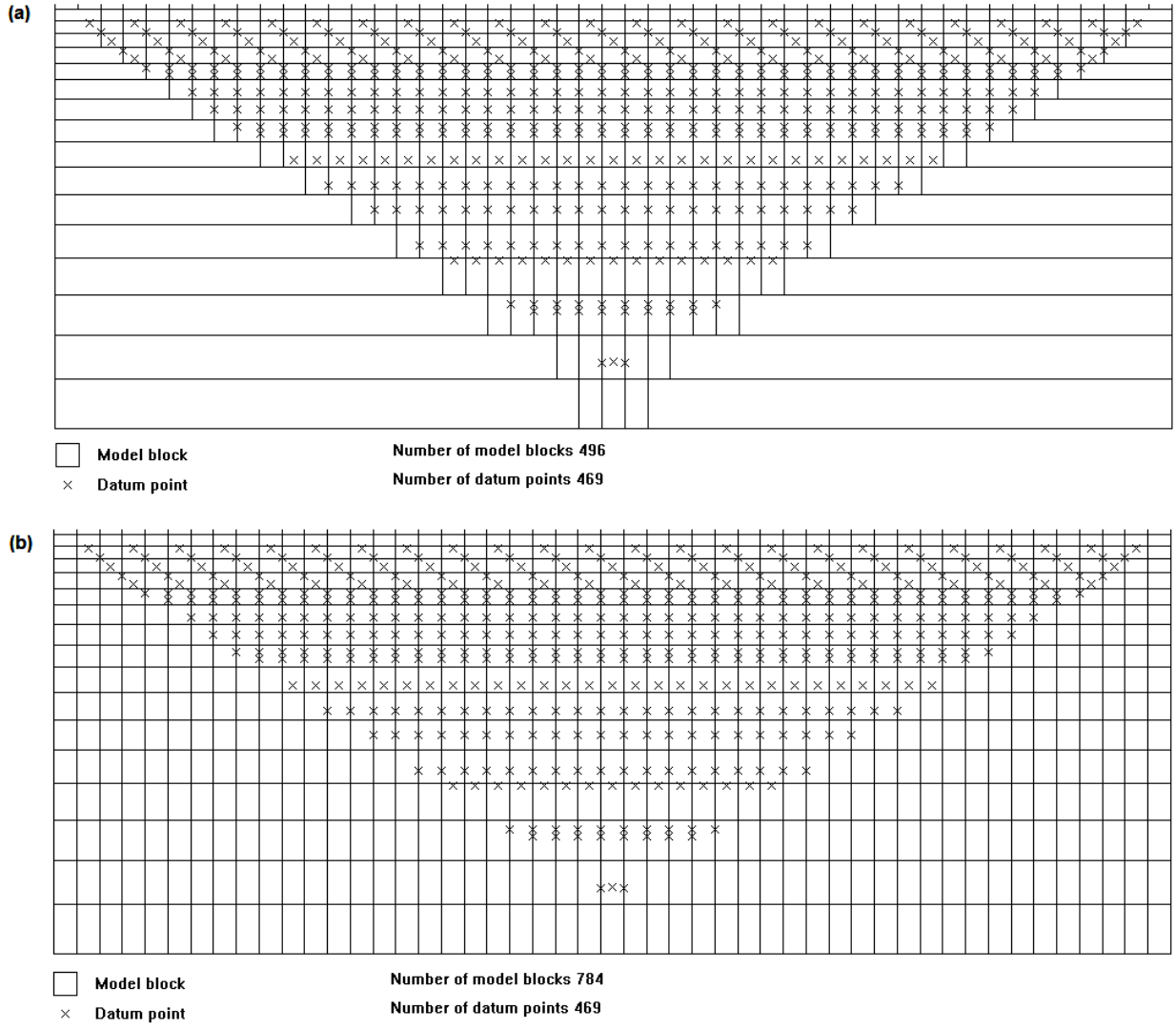


Figure 4.1(a), (b): Arrangement of the blocks used in a model together with the datum points in the pseudosection (RES2DINV).

4.3 Interpretation Technique

For Interpreting the resistivity data consists of two steps: a physical interpretation of the measured data, resulting in a physical model, and a geological interpretation of the resulting physical parameters.

The large-scale data were interpreted with the state-of-the-art interpretation technique, called the 2D smoothed damped least squares inversion algorithm. The results obtained based on 2D inversion of field data and borehole information, were interpreted to determine lithology of the area and the contaminated zone. In interpreting LUND Imaging data, Computer assistance is needed due to the large amount of data collected from the field. The PSEUDO.EXE and ERIGRAPH.EXE software for instance are developed forautomatic drawing of pseudosections in grey scales or colour, using linear interpolating between data points. Third party software packages for resistivity data processing can also be used for advanced interpretation. One example of such a programme is RES2DINV.EXE, which performs smoothness constrained inversion (automatic model interpretation) using finite difference forward modelling and quasi-Newton techniques (Lokeand Barker, 1996).

4.4 Geological Control

A good knowledge and use of the geology of an area is very important for any meaningful interpretation of any geophysical data. Therefore, in this work, information obtained from previous works and borehole log within the area of survey were taken into consideration in the course of interpretation.

4.5 Geologic Section from Borehole Data

Boreholes are a necessary and reliable source of primary data, and electrical resistivity imaging interpretations provide secondary information. Although borehole data provides a good sample for a six-inch diameter vertical cylindrical volume, it can be a poor representation of the several square metres surrounding the borehole. Alternatively, electrical resistivity imaging provides block averages of resistivity. Also, borehole data can be a more expensive data acquisition method when compared to an ERI survey.

The 2D inversion results of the survey were correlated with a borehole log of Gonin-Gora (Table 4.1) obtained from the National Water Resources Institute (NWRI) 2002, Mando, in Kaduna State. The log shows an overburden made up of two layers, 8m thick. The first layer is composed of reddish brown lateritic clay topsoil 0-2m thick. The second layer is made up of a brownish sandy clay material about 6m thick. The weathered basement lies immediately beneath the overburden with thickness of about 17m and extends to a depth of 25m. The fresh crystalline basement rock is encountered at a depth of 25 m and is believed to extend continuously downward from this depth.

Table 4.1: A Borehole Lithology of Gonin-Gora, obtained from NWRI, Mando, Kaduna (2002).

Soil and Rock type	Depth
Topsoil, Reddish brown lateritic clay.	0-2m
Fine partly silt, brownish sandy clay.	2-8m
Weathered basement: Gravel, brownish fine to medium grained sand, clay, quartz and feldspar	8-25m
Fresh crystalline basement rock	25m-∞

4.6 Typical Resistivity values from Previous Works

Resistivity values obtained from previous works(Table 4.2 and 4.3), who worked in different basement areas of Kaduna State, were used to correlate the results of the present survey.

Table 4.2: Typical Resistivity values compiled from previous works (Baimba, 1978and Okwueze, 1978).

Soil and Rock type	Resistivity (Ωm)
Clay –fresh water	30-70
Dry clay	40-100
Weathered basement	50-100
Laterite	200-400
Slightly weathered basement	200-500
Dry sand	500-1000
Fresh basement (crystalline)	>1000

Table 4.3: Typical Resistivity values of rock materials afterEduvie, 1998; Dan-Hassan and Olurunfemi, 1999;Aboh, 2001; Reynolds, 2003.

Soil and Rock typeResistivity range (Ωm)

Unconsolidated Wet Clay	20
Clay (very clay)	50-150
Clayey sand soil	30-60
Sandy soil with clay	60-100
Sand and Gravel	30-225
Lateritic soil	120-750
Laterite	800-1500
Unsaturated landfill	30-100
Saturated landfill	15-30
Fresh groundwater	10-100
Weathered biotite granite	50-100
Weathered granite (low biotite)	50-140
Fractured Basement rock	400-900
Granite	100(wet)-10^6(dry)

Table 4.4:Resistivity values adopted for this work

Soil and Rock type	**Resistivity range (Ωm)**
Dry clay	40 – 80
Laterite	200 – 500
Unsaturated landfill	90–200
Saturated landfill	1 – 30
Weathered Basement	100 – 950
Fresh Basement	800 – 4000

4.7 Field Results

Two-dimensional electrical resistivitysurveying can form a powerful tool forenvironmental and engineering applications includinghydrogeological mapping. In combination with a limited number of drilling referencepoints, with locations based on the resistivity results, reliable models of the subsurfacecan be created (Dahlin, 1996). The field data (pseudosections) are inverted to producemodels representing subsurface electrical resistivities. In cases where resistivity contrastis gradual, smooth inversion is more suitable, while when there is a sharp variation in resistivity contrast, block inversion is preferable (CardarelliandFischanger, 2006).

Mathematical parameters, such as damping factors and the smoothness matrix werechecked and changed appropriately. Furthermore, modifying the inversion results bychanging the starting model appears to be the best way to obtain the valid physical resultsfrom the inversion.

The optimization method basically tries to reduce the difference between thecalculated and measured apparent resistivity values by adjusting the resistivity of themodel blocks. An initial (starting) model, which is generated automatically by the programme, is then modified to reduce the differences between the model response and themeasured data. A measure of this difference is given by the Root-Mean-Square (RMS)error. This process continues iteratively until the RMS

error is reduced to an acceptablelimit. However, the model with the lowest possible RMS error is usually chosen, but cansometimes show large and unrealistic variations in the model resistivity values and mightnot be the best model from a geological perspective. The most prudent approach is tochoose the model at the iteration after which the RMS error does not change significantly(RES2DINV; Batayneh, 2006).

The 2D electrical images along the profiles and their interpretations are discussed inthis section. A total of six profiles were taken for this survey. Profiles 3 and 5 were South-North trending while profiles 1, 2, 4 and 6 were West-East trending. The inversion result for each profile (figures 4.2 to 4.7) shows the images of the pseudosections (geoelectric sections) obtained fromthe processed data.

The results show three distinct images for each profile. The upperimage is a plot of the measured (observed) apparent resistivity pseudosection. Themiddle image is the calculated apparent resistivity pseudosection and thelower image is the true resistivity model obtained after a definite number ofiterations of the inversion programme.

4.7.1 PROFILE 1

Figure 4.2 shows the resistivity inversion results (iteration 3, 5.9% total average RMS error) for profile 1. Thus, indicating that,good fit between the measured and calculated apparent resistivity data were achieved. The Apparent resistivity (in ohm-metre, Ωm) is plotted against pseudo-depth (in metre).The Profile is located at the Northern end inside the dumpsite (Fig. 3.1) and it is 126m long, and runs in the West to East direction. Low resistivity zones (<27Ωm) were isolated near the surface with depth between 0m to 3m which indicates contamination of the topsoil. In this profile the depth to the bedrock is shallow, about 4m and extends from x= 4m to 60m along the profile. Colour variations in the basement rock are indication of contacts between different rocks which can be interpreted as fractures. The red colour indicate the weathered basement with resistivity value (<600Ωm). The purple colour with resistivity value (>1000Ωm) is interpreted as the fresh basement.

4.7.2 PROFILE 2

Figure 4.3 shows the resistivity inversion results (iteration 3, 2.3% total average RMS error) for profile 2. Thus, indicating that, good fit between the measured and calculated apparent resistivity data were achieved. The Apparent resistivity (in ohm-metre, Ωm) is plotted against pseudo-depth (in metre).This Profile is located 50m away from profile 1 outside the dumpsite (Fig. 3.1). This Profile

runs in the West to East direction and it is 84m long.The materials in this profile are very resistive as shown by their resistivity values. The low resistivity (< 200Ωm) zone, indicates the presence of leachates from the surface to a depth of 3m, which could be interpreted as topsoil contamination. The depth to the bedrock is also shallow, which is about 4m. The red and purple colour is the fresh basement as shown with resistivity values (>2000Ωm).

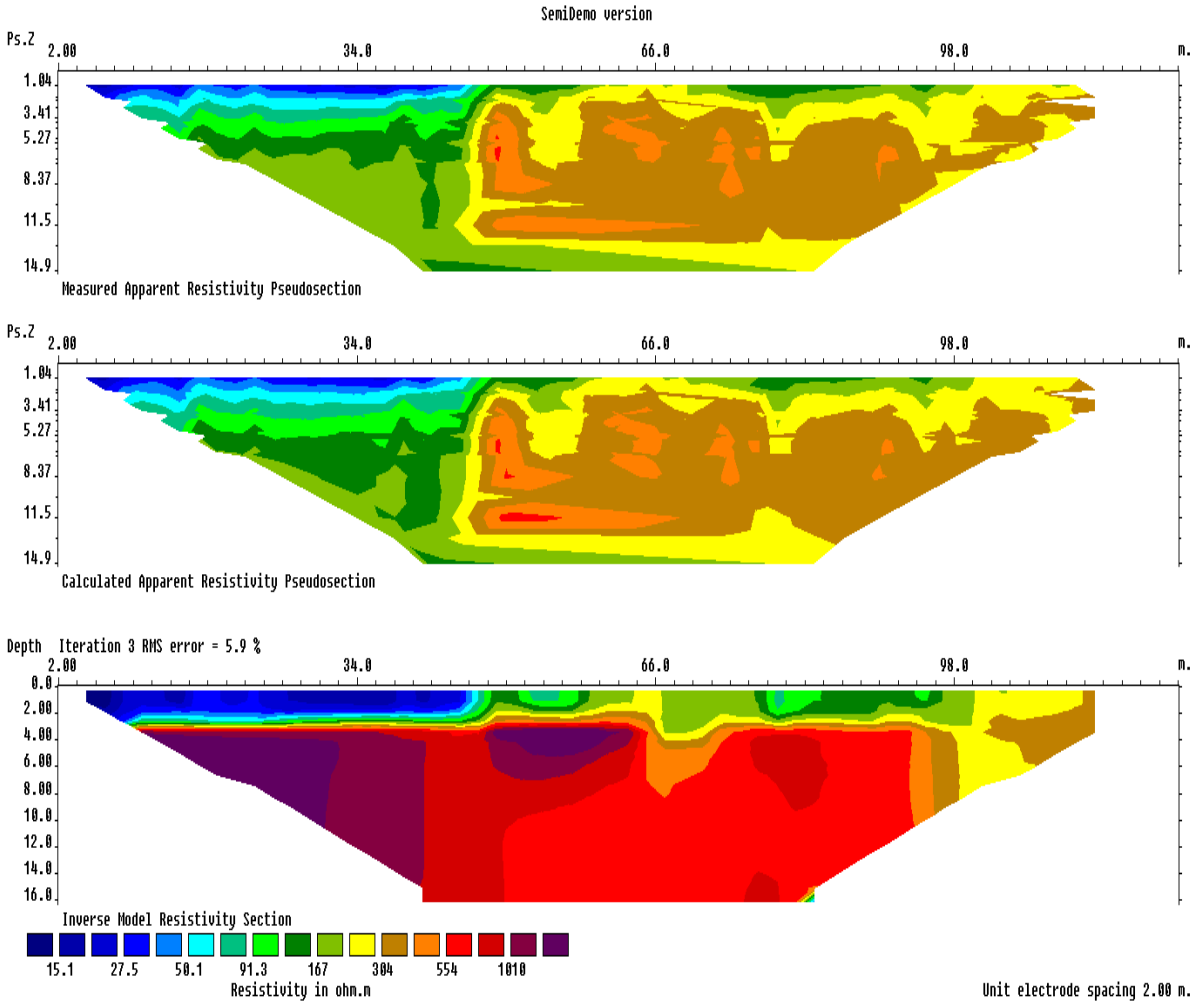


Figure 4.2: Result of 2D inversion of the Schlumberger-array data along profile 1. The upper image is the observed data plotted as a Pseudosection, the middle image

is the calculated Pseudosection and the lower image is the inverse model showing true depth and true formation resistivity.

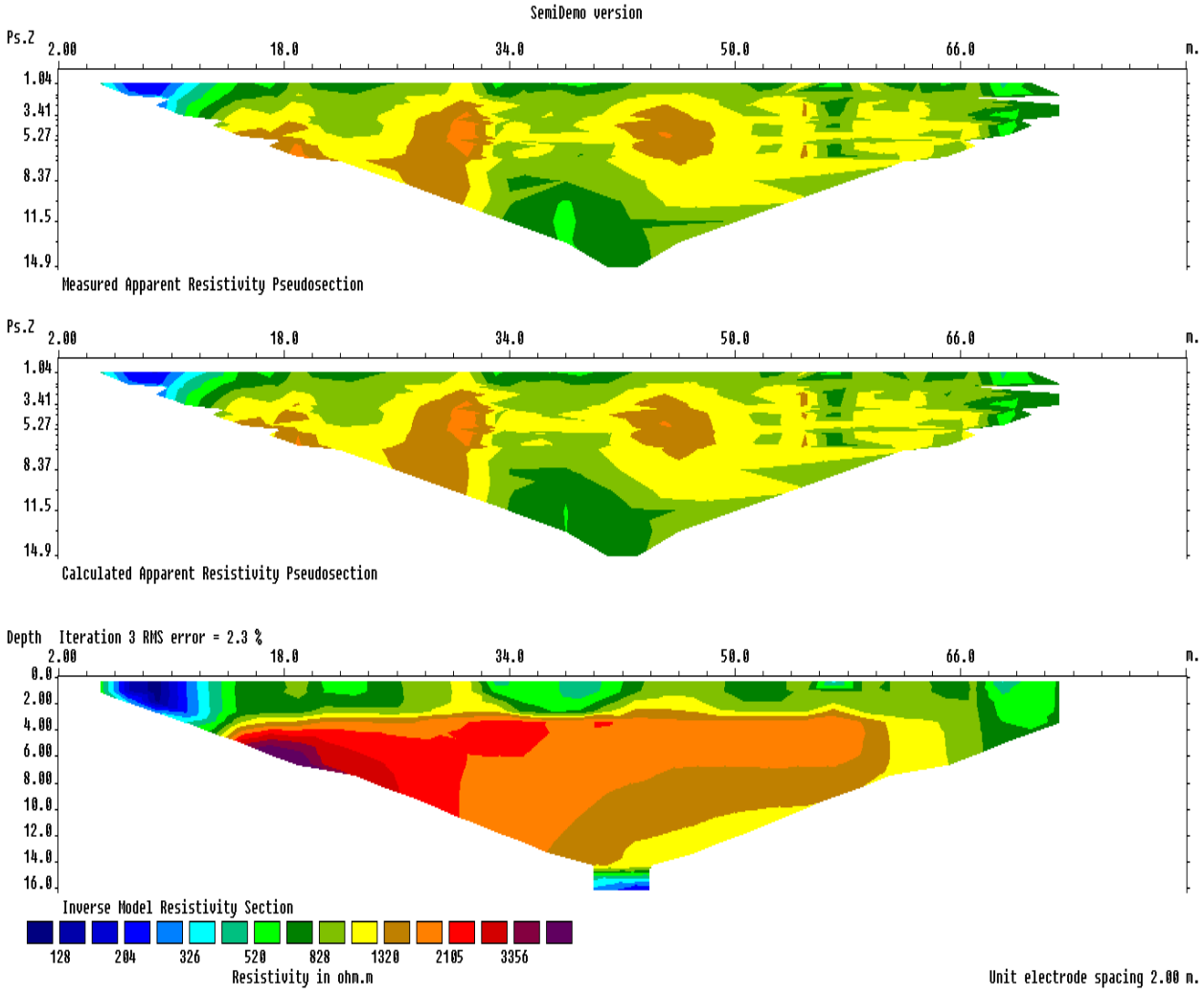


Figure 4.3: Result of 2D inversion of the Schlumberger-array data along profile 2.The upper image is the observed data plotted as a Pseudosection, the middle image

is the calculated Pseudosection and the lower image is the inverse model showing true depth and true formation resistivity.

4.7.3 PROFILE 3

Figure 4.4 shows the resistivity inversion results (iteration 3, 3.2% total average RMS error) for profile 3. Thus, indicating that, good fit between the measured and calculated apparent resistivity data were achieved.This Profile is located at the Eastern end of the dumpsite (Fig. 3.1) and runs in the South to North direction of length 84m. Materials here, are very resistive as shown by the resistivity values (>1800Ωm) of red and purple colour. The low resistivity end (< 200Ωm) could be attributed to contamination of the groundwater as a result of invasion of the leachate from x=40m to 44m at 16m depth. The migration of the leachate could be as a result of fractures (contacts between rocks of different materials) or unconsolidated materials (sand or gravel).

4.7.4PROFILE 4

Figure 4.5 shows the resistivity inversion results (iteration 3, 5.1% total average RMS error) for profile 4. Thus, indicating that, good fit between the measured and calculated apparent resistivity data were achieved.This Profile is located at the Southern end of the dumpsite (Fig. 3.1) and runs in the West to East direction. This Profile is also 84m long and is parallel to Profile 1.There is evidence of contamination of the topsoil as shown by low resistivity value

(<25Ωm) which occur between x= 52m to x=62m and from the ground surface to a depth of 3m. There is probably the presence of Clay which is impeding the downward movement of the leachates from West to East of the study area. This profile shows a partially weathered basement as indicated by the low resistivity value(<800Ωm).The colour scaling changing from deep blue to light blue also reflects the changes in the concentration of the leachates as it seeps down due to filtration by the sediments.

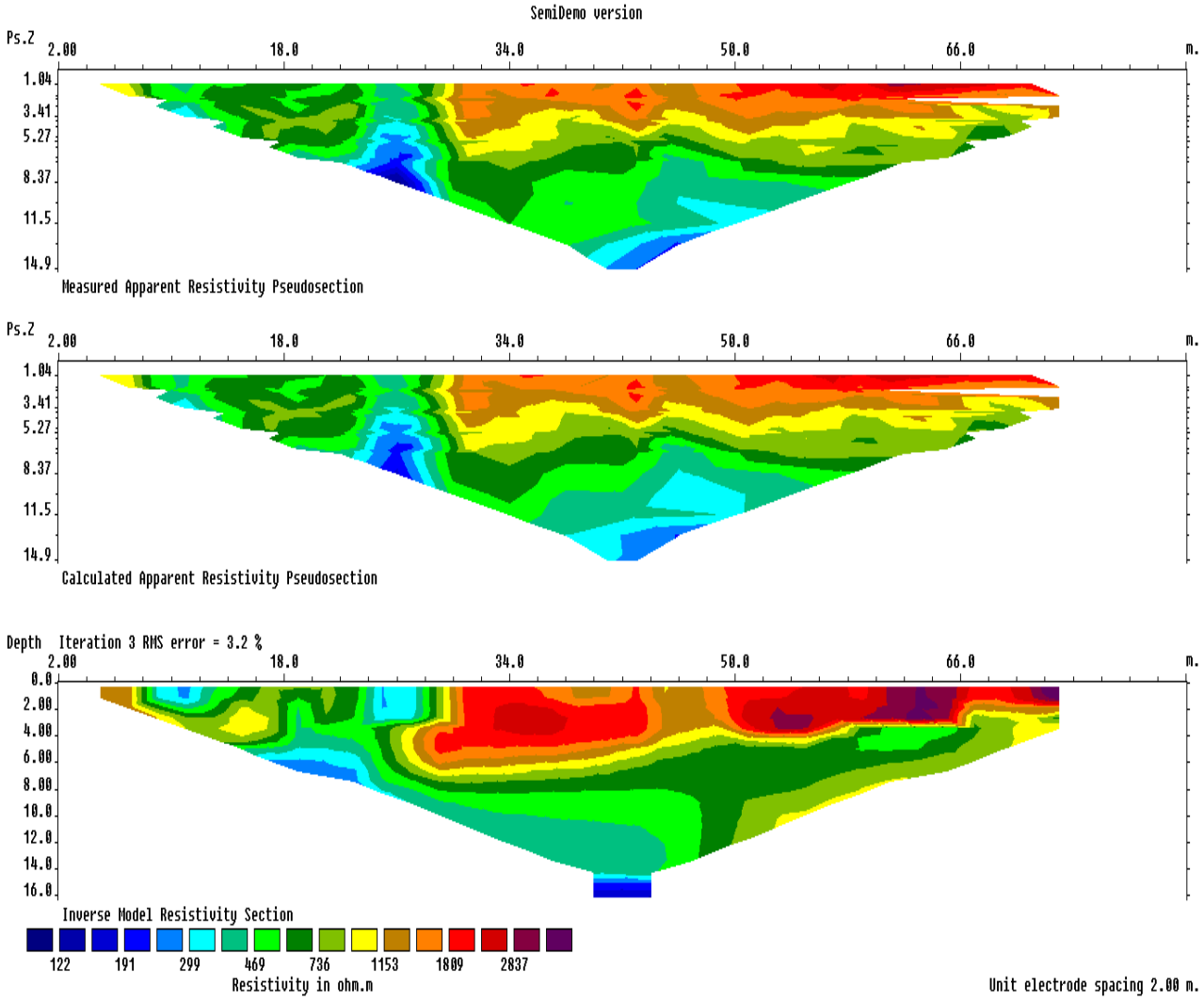


Figure 4.4: Result of 2D inversion of the Schlumberger-array data along profile 3. The upper image is the observed data plotted as a Pseudosection, the middle image is the calculated Pseudosection and the lower image is the inverse model showing true depth and true formation resistivity.

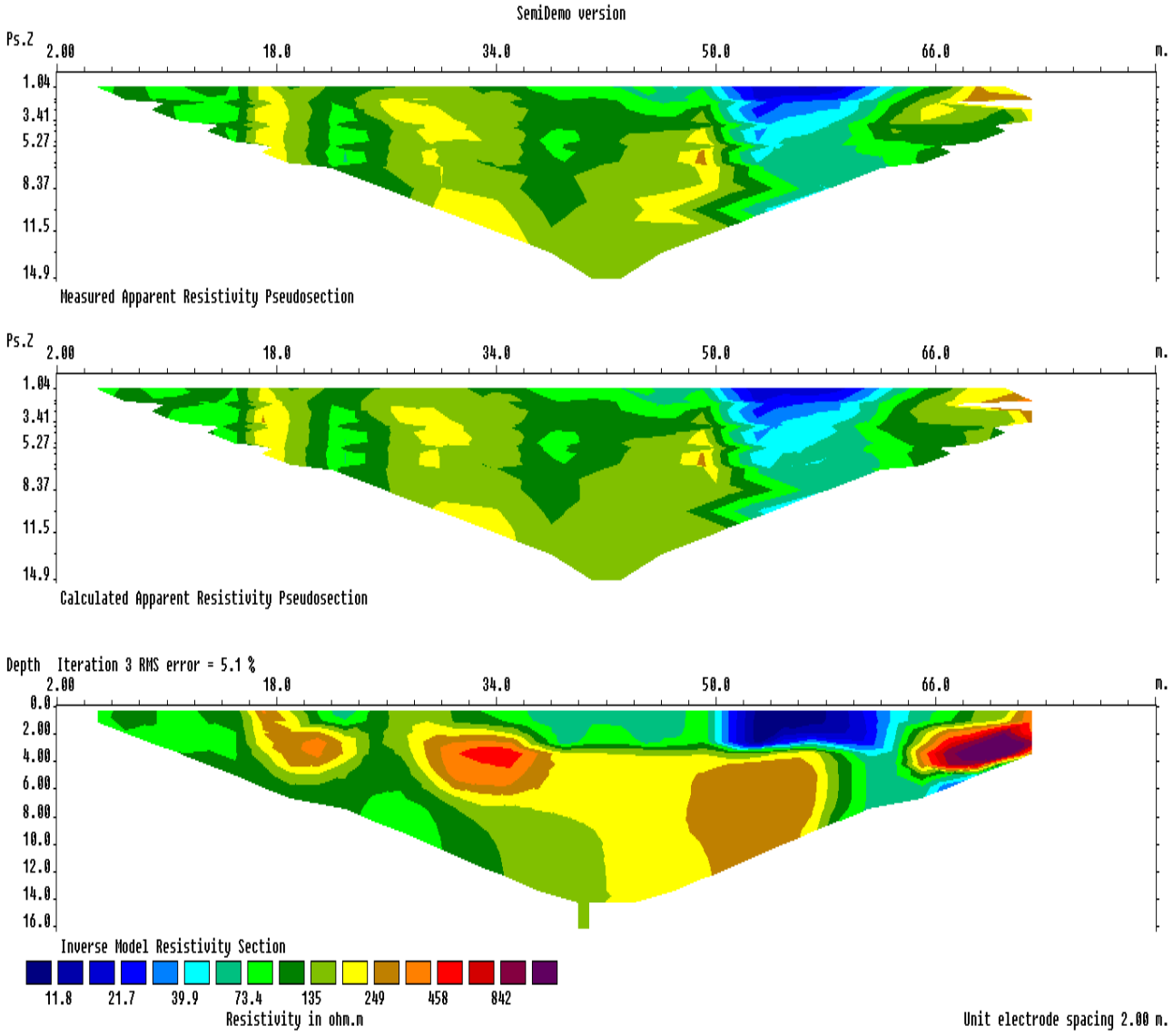


Figure 4.5: Result of 2D inversion of the Schlumberger-array data along profile 4. The upper image is the observed data plotted as a Pseudosection, the middle image is the calculated Pseudosection and the lower image is the inverse model showing true depth and true formation resistivity.

4.7.5 PROFILE 5

Figure 4.6 shows the resistivity inversion results (iteration 3, 8.6% total average RMS error) for profile 5. Thus, indicating that, good fit between the measured and calculated apparent resistivity data were achieved.The Profile is located at the Western end of the dumpsite (Fig. 3.1) and runs in the South to North direction. This Profile is also 84m long and is parallel to Profile 3. There is no evidence of contamination of the topsoil or groundwater as shown by the inversion model.The model shows a shallow depth to bedrock of 3m with resistivity value (>1000Ωm)

4.7.6 PROFILE 6

Figure 4.7 shows the resistivity inversion results (iteration 3, 8.9% total average RMS error) for profile 6. Thus, indicating that, good fit between the measured and calculated apparent resistivity data were achieved.This Profile is located outside the dumpsite (Fig. 3.1) at the Southern end and runs in the West to East direction parallel to profile 4. Low resistivity zones (<200Ωm) are evident throughout the whole profile indicating contamination of the topsoil and

underground water. The light to deep blue colour along the profile indicates varying degree of concentration of the leachate. This profile displays materials that are unconsolidated (sand, gravel and fractured rocks). There is migration of the leachate which is believed to be due to fractures or unconsolidated subsurface material.

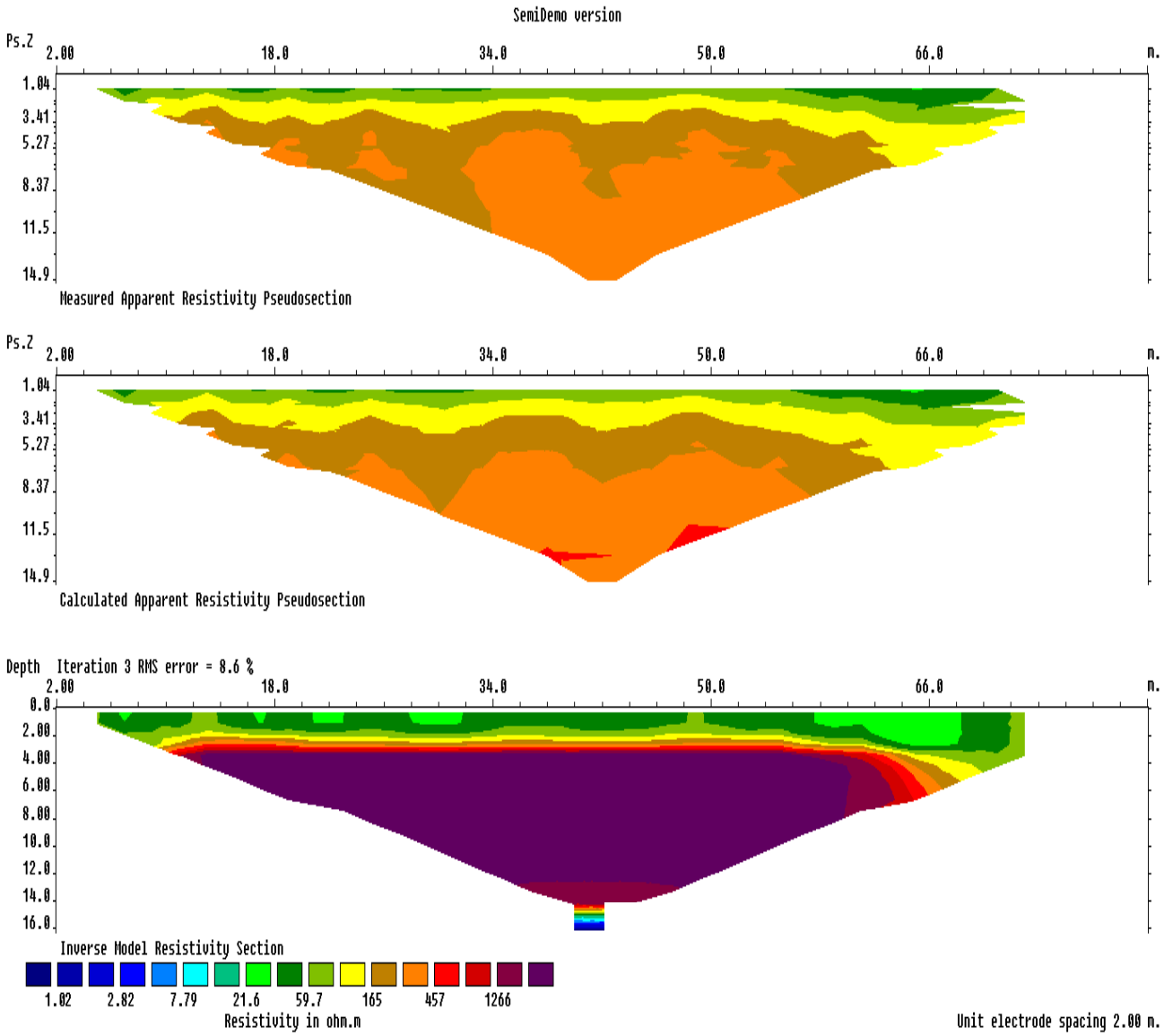


Figure 4.6: Result of 2D inversion of the Schlumberger-array data along profile 5. The upper image is the observed data plotted as a Pseudosection, the middle image is the calculated Pseudosection and the lower image is the inverse model showing true depth and true formation resistivity.

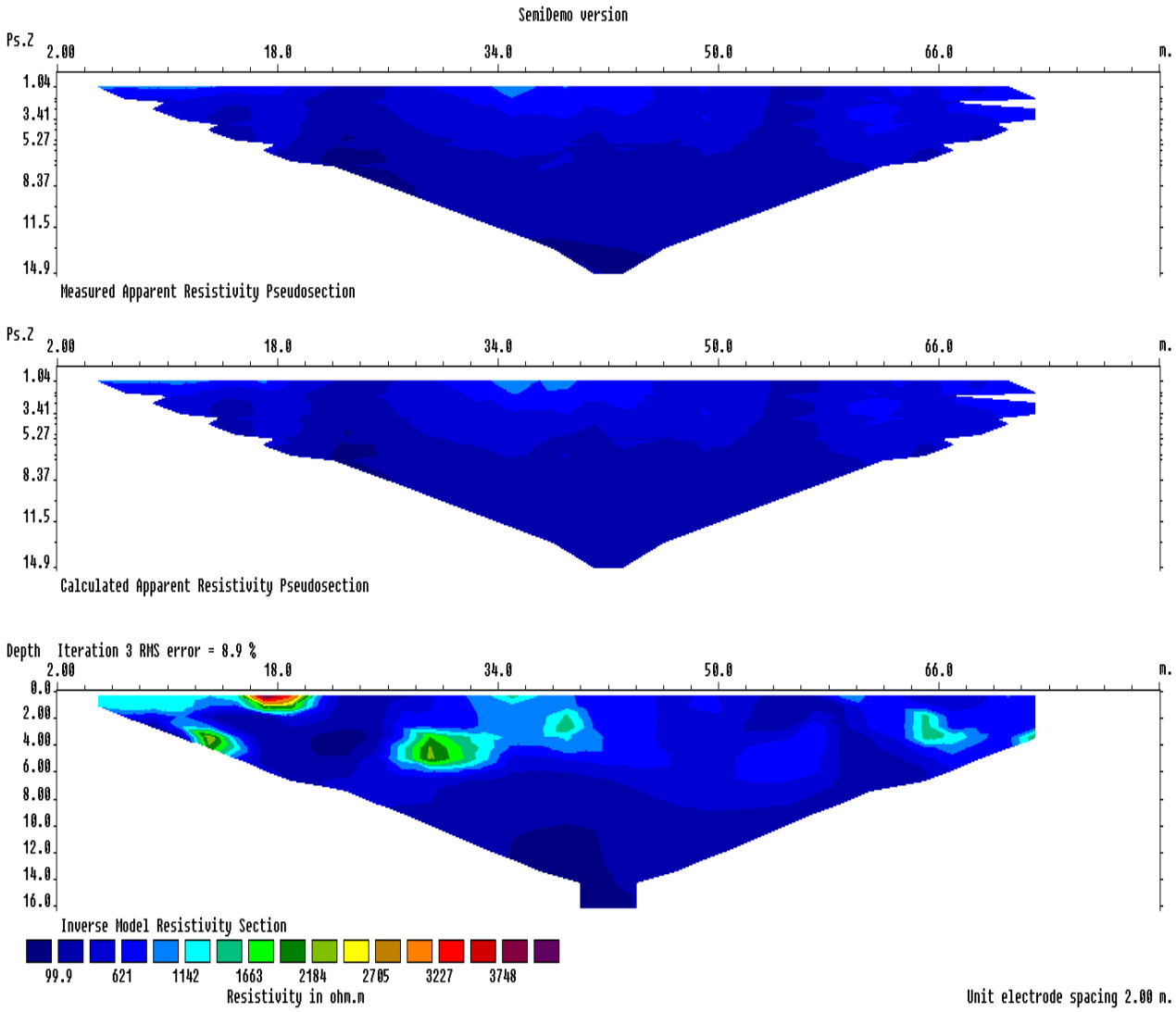
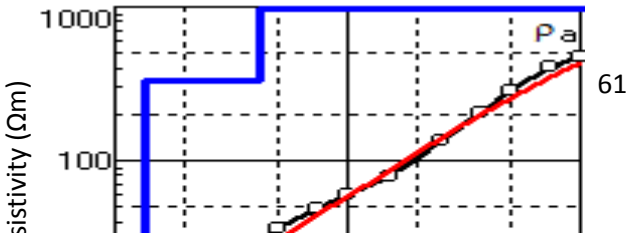


Figure 4.7: Result of 2D inversion of the Schlumberger-array data along profile 6. The upper image is the observed data plotted as a Pseudosection, the middle image is the calculated Pseudosection and the lower image is the inverse model showing true depth and true formation resistivity.

4.8 Vertical Electrical Sounding (VES) Data:

One vertical electrical sounding (VES) employing the Schlumberger electrode array was conducted with maximum electrode spacing of 100 m. ABEM SAS 1000 Terrameter was used to acquire the data and the result was interpreted by IP12 win software. The interpreted VES data measured inside the dumpsite showed a Type A curve of three layers (Fig. 4.8). The first layer of resistivity 8 Ωm with 1.37m thickness and depth is the topsoil. The layer with resistivity of 336Ωm, with thickness and depth of 2.67 m and 4.04m respectively, indicates the weathered basement and the layer with resistivity of 990Ωm whose depth and thickness could not be determined indicates the fresh crystalline basement. The interpreted VES data showed the first layer as contamination plume as low resistivity zones with resistivity value of 8Ωm from the ground surface to a depth of 1.37m, indicating that the topsoil is contaminated. The VES also showed that the depth to water table around the dumpsite is about 4m. The results are presented in terms of layer numbers (N), resistivities (p), thicknesses (h) and depths (d) of the geoelectric section for the VES position (Figure 4.8).



N	ρ	h	d
1	8	1.37	1.37
2	336	2.67	4.04
3	990		

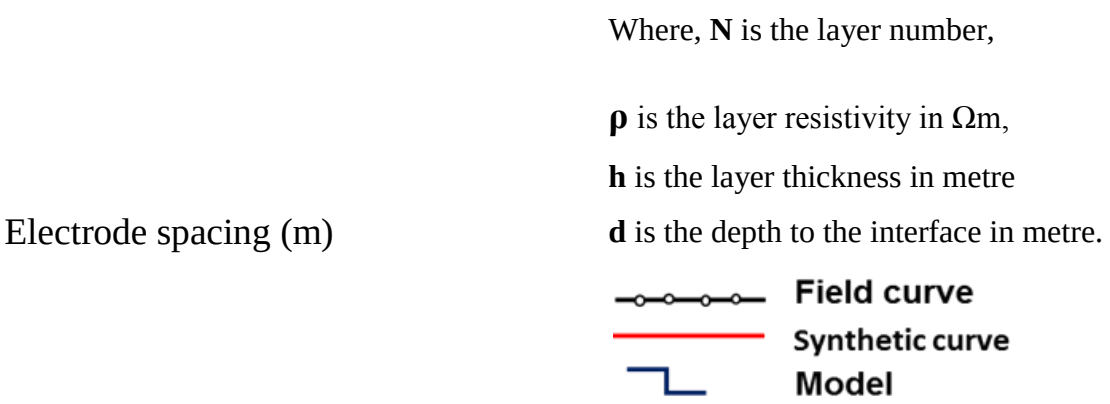


Figure 4.8 VES result for the field data

CHAPTER FIVE

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion

The models obtained from 2D inversion of the field data using different starting models mainly showed that the inversion algorithm was stable. After that, comparison ofthe measured apparent resistivity pseudosection and the calculated apparent resistivity pseudosection resulted in a reasonably good agreement with the inverse model resistivitysection. As a result, this demonstrates the stability of the 2D inversion algorithm that cangive reliable models. The results of this survey revealed three layers: the topsoil, which consists ofreddish brown lateritic and sandy clay, has resistivity values between 8Ωm and 850Ωm and its thicknessvaries between 0.01m to 7.00m. The second layer, is the weathered basement, and has resistivity values between 150Ωm and 940Ωm. Its thickness ranges between 2.0 m to 16.0m. The resistivity of the fresh crystalline basement which forms the third layer ranges between 820Ωm to 4000Ωm. The 2D Inversion delineated contamination plumes as zones with low resistivity values ranging between 1Ωm and 27Ωm, from the ground surface to varying depths of 0-3 m in profile 1 and profile 4, believed to be leachate derived from decomposed waste of higher concentrations, while profile 2, profile 3 and profile 6 delineated contamination plumes with resistivity zones ranging between 100Ωm to 200Ωm, from the ground surface to varying depths, believed to be leachate from decomposed waste of lower concentrations. There was no evidence of topsoil or groundwater contamination in profile 5 as revealed by the inversion model.The interpretation of the VES data revealed the first layer as contamination plume with resistivity value of 8Ωm from the ground surface to a depth of 1.37m,

indicating that the topsoil was contaminated. The interpretation of the VES data also revealed that the depth to water table around the dumpsite is about 4m, indicating that the groundwater as shown in profiles 3 and 6, were contaminated.

5.2Conclusions

Geoelectrical imaging has been useful in mapping resistivity variations at Gonin - Gora refuse dumpsite. Leachate could be inferred from the inverse model sections as well as the VES data: Results suggest leachate migration into the subsurface as well as its ingress into the surrounding soils. This result is supported by a vertical electric sounding made at the dumpsite, previous resistivity data and a Borehole Log of the Area.The study area is mostly characterized by three (3) layered geologic sections which include the Topsoil, Weathered basement and Fresh basement. The 2D Inversion delineated contamination plumes as low resistivity zones with resistivity values ranging between 1Ωm and 27Ωm, from the ground surface to varying depths of 0-3 m in profile 1 and profile 4, believed to be leachate derived from decomposed waste of higher concentrations, while profile 2, profile 3 and profile 6 delineated contamination plumes with resistivity zones ranging between 100Ωm to 200Ωm, from the ground surface to varying depths, believed to be leachate from decomposed waste of lower concentrations. The inversion also revealed weak zones which can be interpreted as fractures, which aid in the migration of the leachate as shown in profile 3 and profile 6. There was no evidence of topsoil or groundwater contamination as revealed by the inversion model in profile 5. The VES data revealed that the area has a shallow aquifer of about 4m, indicating that the groundwater in profiles 3 and profile 6 were contaminated.The conductivity value of the subsurface materials is believed to facilitate the movement of the leachate near and below the surface. The movement of leachate constitutes a threat to the groundwater system and especially surface water in the area since the area has a shallow aquifer and therefore, sinking boreholes around the dumpsite is dangerous.The biological and chemical constituents of these pollutants are unknown. This however, calls for more detailed integrated studies involving geochemistry, drilling of monitory boreholes,

and chemical analysis of water samples. These will actually ascertain the nature of these pollutants around thedumpsite.

The study area has a shallow depth to Basement of 1.30m and a depth to water table of about 4m. The inverse model revealed weak zones which could be interpreted as fractures, which aid in the migration of the leachate as shown in profile 3 and profile 6.

5.3 Recommendations

Based on the result of this research work, the following are recommended:

a) In order to obtain an overall picture of the leachate plume, an integrated approach employing the Seismic method, Vertical Electrical Sounding, induced Polarization and Electromagnetic method should be applied at the dumpsite.

b) Physio-Chemical analysis of water samples should be made inorder to determine the chemical constituent of the contaminated water.

c)Time-lapse resistivity technique, whichis, measurement takenat leasttwice in a year spaced over a long period of time at the same grid point, should be applied in order to determine the rate of migration of the leachate.

d) Detailed geophysical survey should be conducted before the construction of any facility for dumping of domestic and industrial refuse. The result of the detailed geophysical studies will reveal subsurface structures that will be responsible for hydraulic contact between the leachate and the ground.

e) The populace should be sensitized on the danger of drinking leachate contaminated groundwater.

f) Government should as a matter of national priority discourage the practice of citing open dumps most especially in residential areas. This will go a long way in preserving the abundant natural groundwater as well as safeguarding the health of the nation, thereby preventing waste of public funds on health.

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