APPLICATION OF 2D ERT FOR GROUND WATER POLLUTION STUDIES AT HEALTH CENTER UNIVERSITY OF BENIN, NIGERIA

BY

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B.SC APPLIED GEOPHYSICS

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A PROJECT WRITTEN IN THE DEPARTMENT OF PHYSICS AND SUBMITTED TO THE DEPARTMENT OF PHYSICS IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF SCIENCE DEGREE IN PHYSICS, UNIVERSITY OF BENIN, BENIN CITY, NIGERIA.

OCTOBER, 2025.

CERTIFICATION

I hereby certify that this project was carried out under my supervision by **AREWAH WENDY OKHIAOFEH,** a final year student of Department of Physics, Faculty of Physical Sciences, University of Benin, Benin City, Edo State, Nigeria.

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Dr. ELVIS IGHODALO Date

Supervisor

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PROF.C. O. AIGBOGUN Date

Head of Physics Department

....

EXTERNAL EXAMINER Date

DEDICATION

This research work is dedicated to God almighty, for his sufficient grace upon my life, protection, guidance, unending love, and above all his presence during my period of study in University of Benin.

ACKNOWLEDGEMENTS

My utmost appreciation goes to my Supervisor, Dr Elvis Ighodalo, for his fatherly guidance, during the course of this research work.

I appreciate my parents Mr. Williams and Mrs. Augustina Arewah who went the extra mile to make sure all my needs are met, especially my financial needs, I also thank them for their encouragement, prayers, support, love and advice all through my academic session

Lastly, to all the staff and workers who contributed one way or another to make sure all necessary needs were met in the department of Geophysics, I appreciate you all, may God almighty continue to bless every one of you in Jesus name, Amen.

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ABSTRACT

The threat that groundwater is being polluted is a major environmental and health threat to society, especially around urban centres where waste disposal is not well controlled. The present research used the two-dimensional Electrical Resistivity Tomography (2D ERT) to determine potential pollution of the ground water at the Health Centre, University of Benin, Nigeria. The study was also meant to map the changes in resistivity of the subsurface and locate possible contamination areas that could be related to infiltration of the leachate. On-site measurements were obtained in two traverses in the WennerSchlumberger array format and put into the RES2DINV software to provide resistivity sections. The resultant resistivity models presented values of between 217 Ωm and above 15,000 Ωm in the area of study. Such values outweigh the 100 Om mark normally considered as the contamination level of the leachates in the contaminated area, a fact that suggests that the groundwater was not polluted in the depth to which the test was carried out. Empirical resistivity of upper layers (07 m) were high (700 – 2700 Ωm), which was viewed as lateritic or compact sandy soils whereas generic layers (718 m) were moderate (700 – 1700 Ωm) and were regarded as sandy-clayey formations that held natural moisture. The resistivity of deeper zones (>18 m) was extremely high (>4000 Ωm) and was characterised by weathered or solidified lateritic materials and bedrock. According to the resistivity distribution, the subsurface is well-drained, dry and contains no leachate or chemical deposits. It can therefore be concluded that there is no contamination of ground water in the area under the Health Centre. The findings demonstrate the usability of 2D ERT as a simple and efficient instrument of early detection of ground water contamination and as a tool of implementing sustainable ground water protection control measures in the environmentally sensitive locations like learning and healthcare facilities.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Groundwater can be considered to be one of the most essential natural resources in support of human population all over the world. It gives a reliable source of drinking water to both home and agricultural, and industrial use, particularly where there is no or untrustworthy surface water. Its growing need has rendered ground water essential but it has on the other hand made it a major environmental issue as well as being exposed to pollution. Contrary to water in the surface, ground water pollution is usually unnoticeable, chronic, and hard to cure when it has moved into it. This necessitates prevention, monitoring and early detection of contamination as a sustainable water management tool (Binley et al., 2015).

Open dumpsites, and poorly engineered landfills are some of the major sources of groundwater contamination in urban and peri-urban settings. In most of the developing nations, wastes are thrown in an indiscriminate manner and in most cases the wastes are not lined, they lack leachate collection facilities, and lack proper capping. The rain or surface runoff that penetrates through such wastes forms leachate; a complex and highly contaminated liquid. The leachate is usually dissolved with salts, ammonium, chloride, sulfates, heavy metals, organic acids, and other toxic materials (Alao et al., 2024). When this fluid is transporting towards the ground, it changes the chemical composition of the groundwater and this causes harm to human lives, farming and the environments (Okpoli, 2013).

The transport of leachate to the groundwater systems is dependent on a number of physical and chemical processes. Precipitation patterns, soil or waste material permeability, and heterogeneity of the sub-surface affect the rate of infiltration. With soils that are very permeable like the sands and the gravels, the migration of leachates may be fast where the contaminants may travel long distances within a very short time. The contaminants can be held by adsorption and ion exchange in less permeable soils (clays) but they usually slow down but do not eliminate the migration (Binley et al., 2015; Ugbor et al., 2021). When leachate enters the saturated zone, it spreads laterally, in accordance with hydraulic gradients and, in certain cases, it pollutes drinking/irrigating wells (Dahlin and Zhou, 2004).

It is especially problematic because of the chemical composition of leachate. It has a high ionic content that enhances the electrical conductivity of the pore fluids hence reducing the resistivity of the affected soil and groundwater. This physical characteristic is an indirect yet a sure method of identifying contamination by geophysical means (Alao et al., 2024). Electrical Resistivity Tomography (ERT) has emerged particularly useful in aiding the mapping of the extent and movement of leachate plumes among the existing tools (Okpoli, 2013).

ERT is a non-invasive geophysical technique that is used to detect electrical resistivity distribution of the subsurface (Airen and Ighodalo, 2024). The methodology is characterized by the use of electrical current injected into the ground using electrodes and recording potential differences between different points in the surface. Numerical models are then used to invert the resulting data to produce two-dimensional images of variations in subsurface resistivities (Dahlin and Zhou, 2004). Since the contaminated areas are often characterized by lower values of resistivity than the uncontaminated soils and rocks, ERT gives a potent method of detecting and marking leachate plumes (Ugbor et al., 2021).

The benefits of ERT in environmental studies are well known. It is able to be deployed quickly on a site, has the ability to cover extensive areas with the least amount of disturbance, and delivers both vertical and horizontal data about the conditions of the subsurface (Binley et al., 2015). In the case of dumpsite case studies, it is essential as leachate plumes tend to be irregularly shaped whereby vertical penetration is through under the waste body and horizontal dispersal to the nearby soils and aquatic horizons (Okpoli, 2013). The fact that ERT can detect these patterns simultaneously in two dimensions is what provides the possibility of a more comprehensive definition of the risks that contamination may present (Alao et al., 2024).

In addition, the anomaly of the resistivity is also interpreted to give important insights about the processes in the subsurface. Any of the zones of choosely low resistivity around the vicinity of a dumpsite can be an indication of active leachate infiltration, whereas long conductive zones that extend beyond the waste body indicate the migration routes (Ugbor et al., 2021). Where groundwater movement is shallow, the anomalies may show the probable routes of transportation of the contaminants. This kind of information is critical in determining the vulnerable receptors, including hand-dug wells or boreholes, as well as prioritizing remediation activities or monitoring (Dahlin and Zhou, 2004).

Moreover, the analysis of resistivity anomalies gives useful understanding of underground processes. Areas of abnormally low resistance in the areas surrounding a dump site can indicate ongoing bed leachate infiltration, and long-sweeping conductive areas that move in a direction not associated with the waste body are indicative of migration pathways (Ugbor et al., 2021). These anomalies may be used to predict the probable directions of the contaminant transport in the areas where the groundwater flow is shallow. This kind of information becomes critical in determining the vulnerable receptors, including hand-dug wells or boreholes and in the prioritization of remediation or monitoring (Dahlin and Zhou, 2004).

Along with its benefits, one should note the disadvantages of ERT. Naturally occurring conditions that could cause low values of resistivity include soils with high clay content, ground water with salt or areas with high levels of moisture. This non-uniqueness implies that resistivity anomalies have to be interpreted with caution preferably together with hydrochemical sampling and borehole observations. ERT results are more robust and reliable when they are supported by chemical data based on high levels of chloride, nitrate, or conductivity in groundwater (Binley et al., 2015; Alao et al., 2024).

In the areas such as Nigeria, whereby there is inadequate waste management infrastructure, and most communities rely directly on the shallow aquifers to supply water, then there is an even greater need to employ ERT. Dumpsites are also usually placed near homes with no proper environmental protection measures thus affecting the chances of leachate entering the groundwater. When aquifers are contaminated, treatment is expensive and also technically challenging and thus it is more practicable to detect them early and keep a constant check on them (Okpoli, 2013; Ugbor et al., 2021).

ERT application in dumpsite research thus has many applications. It is a warning system to communities that use groundwater, a diagnostic to environmental regulators and a decision support process to waste management authorities. ERT is used to prioritize contamination hotspots and pathways of migration and, thus, to support the location of monitoring wells, to inform the remediation measures, as well as to facilitate the development of policies to protect groundwater resources (Binley et al., 2015).

1.2 LOCATION OF THE STUDY AREA

The study site is located in the local government of Ovia North-East of the University of Benin, Benin City in Edo State. Its locations are within the latitudes $6^0$19'55"N and $6^0$19'93"N and longitudes $5^0$36'10"E and $5^0$36′16"E. The location of the area of the research is the sedimentary basin of the Niger Delta. As (Short and Stauble, 1967) argue, the dissociation of the South American and African continents was brought about by the accumulation of the aulacogen which initiated the formation of the delta. Weber and Daukoru (1975) report that the delta has three formations which were deposited in environments that were marine to deltaic to fluvial. These are; the maritime Akata Formation that is comprised of dark gray silts and shales and is found at the base of the delta. Itiowe and Lucas, (2020) state that the age of the Formation is the Late Maastrichtian to Late Eocene. The Agbada Formation consists of sandstones and shales with the Akata Formation beneath it (Itiowe and Lucas, 2020). The age of the Agbada Formation, based on foraminefera biostratigraphy is between Oligocene and Early Miocene (Itiowe and Lucas, 2020).

Figure 1.1: Map showing University of Benin and Environs (Mapcarta, 2021).

Benin Formation is above Agbada Formation. The Formation is composed of sand to boulder fraction, the grains are sub-angular and well-rounded and the grains are moderately sorted and well sorted. It is a water bearing Formation which is a source of portable water in the Niger Delta Basin (Esu and Amah, 1999).

1.3 GEOLOGY OF THE STUDY AREA

Nigeria's southwest is where Edo State is located. Nigeria's proximity to the oil reserves of the Niger-Delta region makes it a significant sedimentary basin. The South Sedimentary Basin's sedimentary formation is beneath the Benin region. The top reddish earth, which is made up of literalized or ferruginized clay sand, is typically indicative of the geology. The phrase "Benin sand" was initially used by Parker in 1907 to refer to the reddish earth that was covered in sands, sandy clays, and ferruginized sandstone, which were indicative of the Paleo-Coastal Environment of Pleocene-Pleistocene era. Benin formation, alluvium, drift/top soil, and Azagba-Ogwashi (Azuba-Ogwashi) formation are the geological components of the Benin region.

1. **Benin Formation.**

The Benin formation also has continental sand. It is the shallowest and the youngest of the three stratigraphic units. This formation has only had very minimal oil deposits and is mainly made up of sands and gravels of different thicknesses ranging approximately at 2100 meters. It is also normally water-bearing. It is used as the main source of portable water in the Niger Delta, 90% of the lithologic composition is composed of sandstone. The rest 10% is composed of beds of lignite and clay.

2. **Agada Formation.**

This formation is also referred to as the paralic clastic. It is the second among the three Niger delta complex formation and is the base of the Benin formation. It is an accumulation of sandstones, the sandy part of which forms the major source of hydrocarbons of the Delta oil fields. The paralic series date back to the Pleistocene years to Eocene. The highest level of exploration, up to the maximum depth of three hundred meters.

3. **Akata Formation**

The Akata formation is the lowest moist unit in the delta sequence and is sometimes referred to as marine shales. It is composed of sand, turbiditic clay slits, and shales. The age of marine shale cuts across the Paleocene to the Holocene. They are called imo shale when they are onshore northeast of the delta and offshore along the continental slope in diapers. There is approximately 1223 km of Akata formation. This deposit has probably never been penetrated into its basin by any drilling operation due to its overly compressed and overly pressured character.

1.4 Aim and Objectives

This aim of the study was to apply 2D ERT for Ground Water Pollution Studies at Health Center University of Benin, Nigeria

The objectives of the study are to;

1. acquire 2-D resistivity data of the study area
2. process the acquired data using RES2DINV
3. identify areas of possible contamination from the inverted 2D data

CHAPTER TWO

LITERATURE REVIEW

2.1 GROUNDWATER POLLUTION AND ITS IMPACT

Groundwater is a scarce commodity in the world especially in the developing countries where it is the principal source of drinking, agriculture and industry. It is however very prone to contamination since it is hidden and slow moving and usually leads to prolonged negative consequences. Contrary to surface water pollution, which is more readily noticeable and can be resolved, groundwater contamination may go unnoticed over several years, and that is why it is critical to identify and safeguard it in early years (Yahaya et al., 2021).

Pollution is both anthropogenic and geogenic. Artificial sources encompass poor disposal of waste, industrial effluents, agricultural run-offs and mining wastes. As an illustration, nitrates, heavy metals, and organic pollutants are usually deposited by leachate in the subsurface aquifers (Yahaya et al., 2021). Farming activities tend to increase the levels of nitrates in the ground water through leaching of fertilizers. The geogenic pollution refers to naturally occurring components like arsenic and fluoride which may dissolve in the ground water under certain circumstances.

Contact with contaminated ground water is dangerous to health. The continuous use of nitrates over an extended time is associated with colorectal and gastric cancer due to the emergence of carcinogenic N- nitroso products in the human body (Schullehner et al., 2018). A recent California study established that a 1mg/L increment in exposure to nitrate was linked to a maximum 6.6 per cent increment in the rate of colorectal cancer incidence (Cisneros et al., 2025). Moreover, nitrates are also associated with methemoglobinemia in newborn babies (also referred to as the blue baby syndrome) and may be associated with thyroid issues (Hamlin et al., 2022).

Neurotoxic and cancer causing are heavy metals like lead, cadmium and arsenic, which are usually brought through industrial pollution or naturally. Such pollutants may affect cognitive growth, cause renal damage, and raise the risks of cancer. Also, gastrointestinal illnesses and long-term health effects may occur due to microbial contamination due to insufficient sanitation (Yahaya et al., 2021).

In the scenarios where the contaminated nitrates or heavy metals in the groundwater are used in irrigation, the contaminants may concentrate in the soil and product. This causes bioaccumulation along the food chain which is a significant threat to food safety and human health. Moreover, polluted groundwater flows into the surface waters, destroying aquatic organisms, as well as destroying the fish and microorganisms, which are vital to the balance of the ecosystem.

Polluted groundwater places expensive financial constraints on the concerned communities. Remedies to the treatment, like water filtration or finding alternative sources, may be too costly to afford. Besides, the economic consequences of illnesses in the context of health care, labor productivity, and loss of farm crop have the wider implications to local economies (Yahaya et al., 2021).

Although this is risky, there are no proper ground water monitoring systems in many of the developing regions and in most cases there is weak enforcement of regulations. The fact that contamination is invisible further postpones the detection therefore, permitting further exposure. New methods, including spatial DRASTIC vulnerability modeling and geostatistical software, have been created to evaluate the risk of contamination and prioritize the areas that require intervention (Schullehner et al., 2018; Hamlin et al., 2022). These tools are however under employed because of the unavailability of resources and technical capability.

2.2 PREVIOUS WORK DONE

Ugbebor and Ntesat (2019) examined the impact of leachate migration on the quality of groundwater in two open dumpsites in Rivers State, Nigeria -Rumuosi and Igwuruta. The research comprised a physicochemical and microbiological study of the leachate and ground water samples. It was analyzed using parameters like sulfate, phosphate, total dissolved solids (TDS), biological oxygen demand (BOD), chemical oxygen demand (COD), and heavy metals (Pb, As, Mn, Fe, Zn), and microbial counts in the form of total heterotrophic bacteria (THB) and total coliform bacteria (TCB). Their findings indicated very high levels of TDS

(12,663 mg/L), COD and heavy metals in the ground water around the Rumuosi location, whereas Igwuruta had moderate levels that were still higher than the acceptable levels. The leachate pollution index (LPI) in Rumuosi and Igwuruta was 13.58 and 12.9 respectively, which are very high compared to the safety limit of 7.38. The authors determined that the dumpsites contained leachate that was a great threat to groundwater resources in the area.

The study by Egbelelulu et al. (2019) focused on the geophysical study of the leachate plume migration at a dumpsite located in Minna, Niger State, Nigeria. The authors used Vertical Electrical Sounding (VES) methods, data were gathered on 9 resistivity profiles using 36 sounding points. The iso-resistivity maps were produced as a result of the processed data using WinRes software and the range of depths was covered with the surface up to 10 m. They found that the leachate contamination went down to a depth of about 7m with an estimated contamination rate of roughly 1m per year. The research concluded that those aquifers that were below 7 m were relatively immune to leachate and they had the potential of being safe ground water sources.

Ajani, et al., (2021) studied the leachate migration in the Bowen University campus dumpsite in Iwo, Osun State. This research involved the use of soil sampling and geoelectric resistivity surveys to measure contamination of the soil under the ground. The Schlumberger array configuration was used to set four VES points. The laboratory tests showed the dumpsite soils had a high porosity (54%), and a low bulk density as opposed to the control sites indicating increased infiltration. The analysis of resistivity models inverted indicated areas that had low resistivity beneath the dumpsite indicating the active movement of leachate through surface levels towards the underlying alluvium. The paper highlighted the growing susceptibility of shallow ground water in the research location to pollution.

Adeniji et al., (2021) used the dipole-dipole electrical resistivity and Natural Electric Field (NEF) techniques at the dumpsite of Ojoou-Olayanju, Ada, Southwestern Nigeria, to determine the leachate infiltration pathway. 5 dipole-dipole profiles and 5 NEF measurements were used in the study. The findings indicated non-uniform subsurface conditions that had fractures and conductive areas which were associated with leachate infiltration routes. Such low-resistance anomalies were related to saturated media which was contaminated with leachate. The research found out that the dumpsite soils and shallow aquifers in the site were severely threatened by the constant percolation of the contaminants.

Ugwoha and Emete (2015) conducted research in the Alakahia dumpsite site in Port Harcourt, Rivers State, to establish the impacts of dumpsite leachate on the quality of groundwater. Physicochemical analyses of leachate and groundwater samples in the vicinity were developed including pH, TDS, COD, nitrate, ammonium, hardness, and trace metals (Cu, Cd, Fe). The findings showed that the concentration of these parameters in leachates was well beyond the regulation level. The samples of ground water in the surrounding area had a high level of cadmium (exceeding WHO) and acidic PH (4.19-6.14). The Water Quality Index

(WQI) of ground water surpassed 752 making it inedible. Localized pollution was observed by the authors as the levels of contamination decreased with distance to the dumpsite.

Onyekwelu and Aghamelu (2019) examined how leachate of the dumpsites would affect natural water sources in Enugu Metropolis, Southeastern Nigeria. The experiment involved the examination of organic pollutants and physicochemical values of water samples taken in wells and streams near dumpsites. Findings revealed high contents of organic pollutants and poor indices of water quality which was directly related to the leachate infiltration. This research mentioned the health consequences of using this contaminated water and requested the implementation of immediate waste management measures in Enugu.

Akankpo and Igboekwe (2011) evaluated groundwater contamination in the Uyo, Akwa Ibom State by performing a mixture of combination of electrical resistivity and geochemical analysis techniques. VES stations were spread at 5 dumpsites of choice and the resistivity data were obtained using Schlumberger arrays. The interpreted resistivity curves showed a clear high low high low resistivity sequence, which was explained by the fact that leachate had infiltrated the vadose zone to the aquifer. The geophysical findings were also supported by laboratory results, which indicated that samples of groundwater contained high amounts of ions, which were typical of dumpsite leachate pollution.

Adeoti et al., (2011) considered the Ile-Epo dumpsite at Lagos State by the use of constant-spacing Wenner profiling. Four profiles of resistivity of 160 m -180 m were obtained. The reversed results indicated the presence of aquifer resistivities as low as 4.5 Ωm right below the dumpsite, which was a sign of the leachate-saturated regions. On the contrary, the regions at a distance of 100 m of the dumpsite recorded a higher value of resistivity, which represented rather unexploited aquifers. The authors made a conclusion that electrical resistivity techniques prove to be accurate in determining leachate plumes and marking safe water areas around dumpsites.

Asa-Dam Road reclaimed dumpsite is a site where Raji and Adeoye (2016) examined the location using the two-dimensional geoelectrical imaging technique. The objective of the study was to map the areas of the contaminants leachates which remained even after site reclamation. They found that there were low-resistivity anomalies under the reclaimed area which were explained as residual leachate contamination. The irregularities were in line with the established routes of contaminant flow meaning that ground water under reclaimed dumpsites is still susceptible to long term pollution.

Osinowo and Olayinka (2012) used Both Very Low Frequency Electromagnetic (VLF-EM) and resistivity to determine the vulnerability of groundwater to exploitation in the area of Ijebu-Ode transitional zone, Southwestern Nigeria. Their findings identified subsurface fractures and low-resistivity anomalies which acted as possible conduit of leachate infiltration when it comes to other dumpsites. The research study indicated the effectiveness of geophysical methods in mapping susceptible groundwater areas in sophisticated geological environments.

Agu and Mallam (2023) had a geophysical and hydrochemical investigation of groundwater pollution at Idugosa dumpsite, Abuja, Nigeria. They mapped leachate plumes that existed beneath the ground using Wenner resistivity profiling, Vertical Electrical Sounding (VES) and Very Low-Frequency Electromagnetic (VLF-EM). At the depth of 15 – 30 m, resistivity was observed to range 1.6 – 3.8 Ωm which shows areas of high leachate saturation. These findings were supported by the VLF-EM surveys, which revealed that there was a high density of currents in the prone contamination areas. According to hydrochemical results, there were high electrical conductivity (804.9 µS/cm) in the groundwater around the dumpsite as opposed to 188 µS/cm in the controls sites. These findings established a positive role of leachate on quality of groundwater.

2.3 THEORY OF ELECTRICAL RESISTIVITY METHOD

The resistivity of a mineral is defined as the resistance in ohms between the opposite faces of a unit cube of material (Telford, 1990).

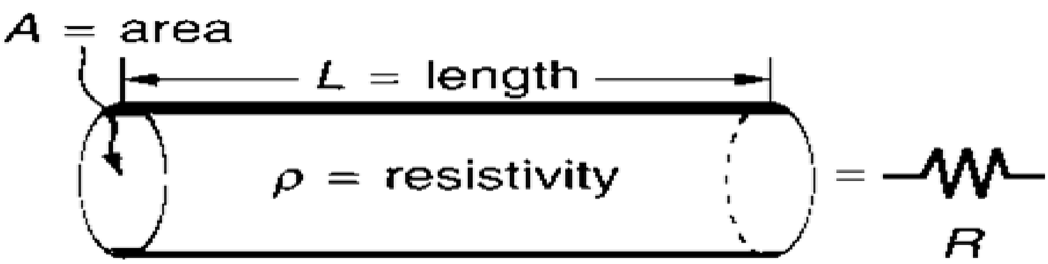

Figure 2.1 Cylindrical wire of length L and area A (*www.wikipedia.com*)

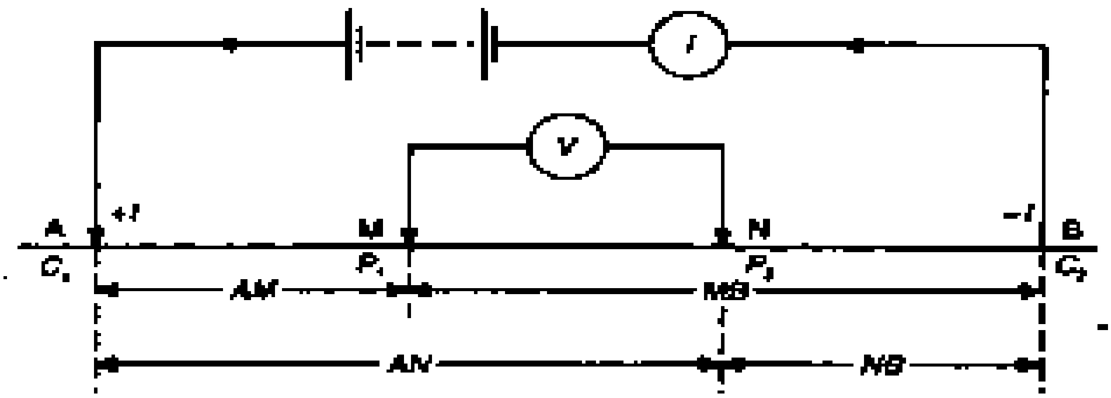

Figure 2.2 Array showing current electrodes AB and potential electrodes MN (*www.google.com*)

The resistance of the wire R is directly proportional to its length L and inversely proportional to the area of cross section.

$$R \,\alpha\, \frac{L}{A} \qquad (2.1)$$

$$R = \ell \frac{L}{A} \qquad (2.2)$$

$$\ell = R \frac{L}{A} \qquad (2.3)$$

Where ℓ is resistivity of wire From Ohms law, the current passing through a conductor with resistance R under an impressed voltage V is given as

$$I = \frac{V}{R} \qquad (2.4)$$

$$V = IR \qquad (2.5)$$

$$V = \frac{I\ell L}{A} \qquad (2.6)$$

The current density J, crossing a hemispherical body at equipotential surface of radius R and thickness ∂r is given as

$$J = \frac{I}{A} \quad (2.7)$$

$A = 2\pi R^2$

$$J = \frac{1}{2\pi R^2} \quad (2.8)$$

But $E = \ell J$

$$E = \frac{\ell I}{2\pi R^2} \quad (2.9)$$

Also, $E = \frac{-\partial V}{\partial r}$

$$\frac{-\partial V}{\partial r} = \frac{\ell I}{2\pi R^2} \quad (2.10)$$

$$\partial V = \frac{-\ell I}{2\pi R^2} \partial r \quad (2.11)$$

On Integrating,

$$V = \frac{\ell I}{2\pi R^2} \quad (2.12)$$

Where V is the potential difference due to current I and E is the electric field. If the current is passed through the ground with C_1 and C_2, then we can say the potential at P_1 due to C_1 is

$$V_m = \frac{\ell I}{2\pi V_1} \quad (2.13)$$

Potential at P_1 due to C_2

$$V_m = \frac{-\ell I}{2\pi V_2} \quad (2.14)$$

Potential at P_1 due to C_1 and C_2

$$V_m = \frac{\ell I}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \quad (2.15)$$

Potential difference (Δv) between P_1 and P_2 due to C_1 and C_2

$$V_m = \frac{\ell I}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} - \frac{1}{r_4}\right) \quad (2.16)$$

But $\frac{\Delta V}{I} = R$,

$$G = 2\pi\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} - \frac{1}{r_4}\right)^{-1} \quad (2.17)$$

G is the geometric factor.

2.4 ELECTRODE ARRAY OR CONFIGURATION

Other electrode configurations have been developed (Loke 1999) although two are the most frequently used when numerous are sometimes used in the special surveys. The simpler type of design is the Wenner design in which current and potential electrodes are placed collinearly and maintained at equal spacing. Every four measurements, when conducting the survey using the Wenner set up, all four electrodes have to be moved. This labour is to some extent overcome by the adoption of the Schlumberger design, where the separation between the outer, current electrodes (2L) is much larger than the separation between the inner, potential electrodes (2l).

The geometric factor of the Wenner configuration is represented by G, and is said to be in meters (m), whereas the depth of study of the Wenner array is approximately 0.111AB. G Geometric factor of a Dipole-Dipole is given as meters (m) and the theoretical depth of a Dipole-Dipole array is approximately 0.195AB.

When conducting an electrical resistivity survey, the following electrode arrays can often be used:

- Wenner array
- Schlumberger array
- pole-pole array
- pole-dipole array
- Dipole-dipole array

- Gradient array
- Lee partition array
- Square array
- Cross Square array

All this electrode configuration or array is determined by the mode of arrangement of current and the potential electrode.

Table 2.1: The median depth of investigation (z_e) for the different arrays. L is the total length of the array (Edwards, 1977).

Array type		z_e/a	z_e/L
Wenner alpha		0.519	0.173
Dipole-dipole	n = 1	0.416	0.139
	n = 2	0.697	0.174
	n = 3	0.962	0.192
	n = 4	1.220	0.203
	n = 5	1.476	0.211
	n = 6	1.730	0.216
Equatorial dipole-dipole			
	n = 1	0.451	0.319
	n = 2	0.809	0.362
	n = 3	1.180	0.373
	n = 4	1.556	0.377
Wenner - Schlumberger			
	n = 1	0.52	0.173
	n = 2	0.93	0.186
	n = 3	1.32	0.189
	n = 4	1.71	0.190
	n = 5	2.09	0.190
	n = 6	2.48	0.190
Pole-dipole	n = 1	0.52	
	n = 2	0.93	
	n = 3	1.32	
	n = 4	1.71	
	n = 5	2.09	
	n = 6	2.48	
Pole-Pole		0.867	

1. Wenner Method

It is a powerful array type that gained popularity through the ground-breaking work done by the University of Birmingham research group (Olayinka, 2000). In the Wenner array the spacing between the electrodes is constant as depicted in Figure 2.5. It is most appropriate to use in profiling since only a single electrode is moved to make measurements. Beard and Morgan (1991) concluded that the growing electrodes of the Wenner array cause false analogy zones which make interpretation difficult The geometric factor of Wenner array is 2a. The geometric factor is not as large as compared to all other arrays. Compared to all other arrays, Wenner array has the best signal strength due to the positioning of the potential electrodes between the two current electrodes. The downside of this array to 2-D imaging surveys is that it possesses relatively low resolution as electrode separation between the electrodes is expanded. This approach does not exploit multi-channel system because only single channel is used in process of testing.

2. **Wenner-Schlumberger Method**

The Schlumberger array is one of the earliest arrays that were used in the 1920s and are still in use today. Schlumberger array is the most widely used array in resistivity sounding survey. The n factor of this array is the ratio of the distance between the electrode between C1- P1 (or between P2- C2) to the distance between the potential pair of P1- P2. Schlumberger array and Wenner array have a slight difference in their sensitivity pattern. The Schlumberger array is moderately responsive to the horizontal and vertical structures having slight vertical curvature beneath the centre of the array, and the values of the sensitivity are slightly lower in the areas between C1 and P1, C2 and P2 electrodes. Therefore, Schlumberger array could be the appropriate trade-off between Wenner and the dipole-dipole array in the regions where both the horizontal and the vertical structure is anticipated. Signal strength of Wenner array is high and the signal strength of Schlumberger array is intermediate between Wenner array and the dipole-dipole array. In comparison to the Wenner array, Schlumberger array has approximately 10% larger median depth of investigation (under identical distance between the exterior (C1 and C2) electrodes).

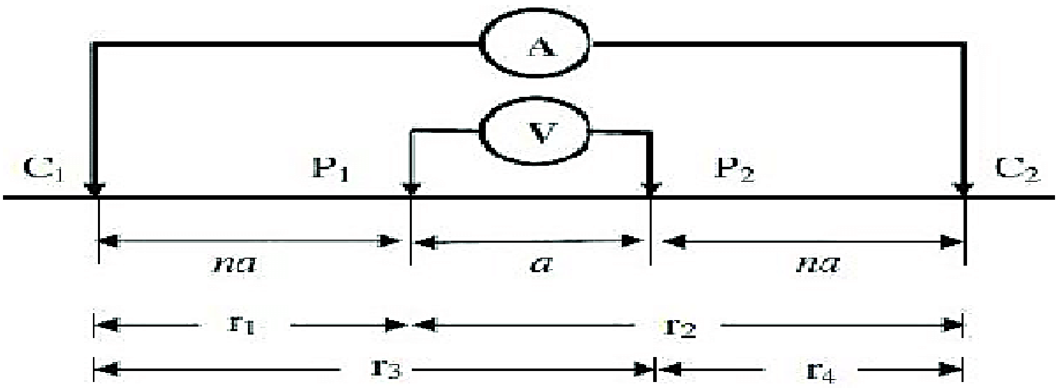

Figure 2.3: Configuration scheme of Wenner-Schlumberger

3. **Dipole-dipole Method**

The most convenient in field logistically is the dipole-dipole array which is particularly in use when large areas need to be covered and the spacing between the electrodes is large. The dipole-dipole is the most sensitive and offers the maximum resolution of vertical resistivity boundaries (Griffiths and

Barker, 1993). The readings made at the dipole-dipole array are however, effortlessly influenced by the variations of resistivity at the near-surface (Griffiths and Barker, 1993). Figure 2.4 indicates the order in which the data were collected in a dipole-dipole array during an ERT study. The letter a stands to represent the spacing of electrodes between the unit and is depending on the needed depth of penetration and needed resolution, as well as the array type. Separations of electrodes and dipoles are fixed with each traverse (n) and increase with the succeeding traverse. Higher electrode spacing gives data of higher depths albeit of low quality.

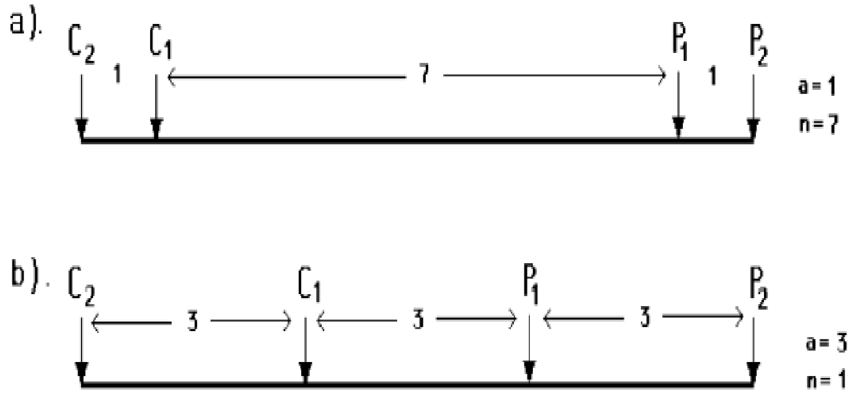

Figure 2.4: Two different arrangements for a dipole-dipole array measurement with the same array length but with different "a" and "n" factors resulting in very different signal strengths (Loke, 1999).

Consequently, the dipole-dipole array is highly sensitive to the horizontal variations in resistivity. In this way, the dipole-dipole array obtains high-resolution of vertical structures, but low mapping of horizontal structures.

4. Pole-dipole Method

Pole-dipole array Pole-dipole array (Figure 2.7) is an asymmetrical array (in contrast to the other common arrays and over symmetrical structures) with the apparent resistivity anomalies being asymmetrical in the pseudosection. The asymmetry of the recorded apparent resistivity values may in certain instances affect the model obtained post inversion. The result of the asymmetry can be removed by making the measurements again with the reversing arrangement of the electrodes (Figure 2.7). Using forward and reverse pole-dipole arrays together, it is possible to eliminate any bias in the model due to the asymmetry of the array. Signal strength on pole-dipole array is much greater than in dipole-dipole array as well as polepole array and also pole-dipole array is not so sensitive to telluric noise compared to pole-pole array but has rather good horizontal coverage.

Pole-dipole array involves the use of remote electrode, the C2 electrode. This electrode and the survey line should be separated by a large distance. In the case of the pole-dipole array, the C2 electrode performance is similar to the square of the ratio of the distance between C1-P1 and the distance between C2-P1. Therefore the pole-dipole array is not as sensitive to C2 remote electrode as compared to pole-pole array. The error due to ignoring the effect of the C2 electrode is less than 5 percent provided the distance of the C2 electrode is more than 5 times the maximum C1-P1 distance adopted. The precise error is dependent on two aspects, one of them being the position of P2 electrode in a specific measurement, and the second being the subsurface resistivity distribution. It is a desirable array to multi-electrode resistivity meter systems with a relatively small number of nodes since it has good horizontal coverage. The signal strength lines of Wenner and Wenner-Schlumberger arrays with Dipole-dipole arrays where the signal strength of dipole-dipole is the least. In the case of IP surveys, this array is an appealing choice because the signal strength of this array is greater than that of the dipole-dipole array and also EM coupling is reduced in comparison to the Wenner and Wenner-Schlumberger arrays since the circuitry of current and potential electrode is separated.

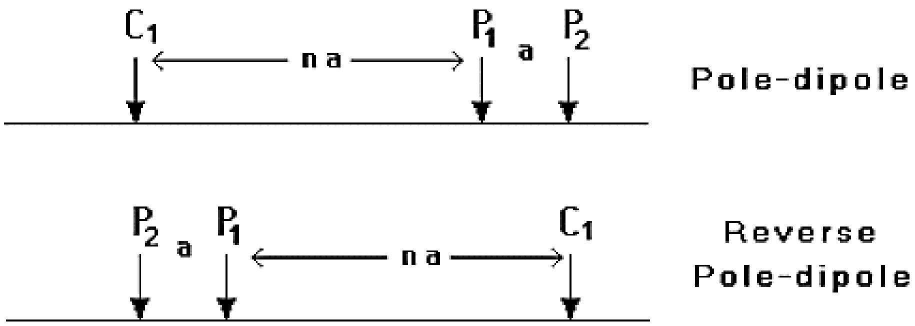

Figure 2.5: Forward and reverse pole-dipole array (Loke, 1999)

The pole-dipole array requires a remote electrode, the C_2 electrode. The distance between this electrode and the survey line should be sufficiently far. For the pole-dipole array, the effect of the C_2 electrode is approximately proportional to the square of ratio of the C_1-P_1 distance to the C_2-P_1 distance. Hence the pole-dipole array is less affected by the C_2 remote electrode when compared to the pole-pole array. If the distance of the C_2 electrode is more than 5 times the largest C_1-P_1

distance used, the error caused by neglecting the effect of the C_2 electrode is less than 5%. The exact error depends on two factors, one being the location of the P_2 electrode for the particular measurement and the other is subsurface resistivity distribution. This is an attractive array for multi-electrode resistivity meter systems with relatively small number of nodes because of its good horizontal coverage. The signal strength lines between the Wenner and Wenner-Schlumberger arrays and Dipole-dipole arrays where dipole-dipole has the less signal strength. For IP surveys, this array is an attractive alternative as the signal strength of this array is higher than dipole-dipole array and also the EM coupling is lower when compared with the Wenner and Wenner-Schlumberger arrays due to the separation of the circuitry of the current and potential electrodes.

5. Pole-Pole Method

This array does not have the usage as the Wenner, dipole-dipole and Schlumberger arrays. In reality, there is no ideal pole-pole array, that is, a single current and single potential electrode. In order to estimate the pole-pole array, the second current electrode (C2) as well as potential electrode (P2) should be located at least 20 times the maximum separation between C1 and P1 electrodes in the survey. The response of C2 (and a similar case of P2) electrode is roughly proportional to the proportion of C1-P1 distance C2-P1 distance. The distance of these electrodes to the survey line should be at least 20 times the maximum C1-P1 distance in consideration of the effects of the C2 and P2 electrodes otherwise the error will be more than 5%. Surveys with greater inter electrode separation along the survey line than several meters may have practical issues in identifying suitable locations of the C2 and P2 electrodes to meet this need. This is also a drawback of the array as due to a great distance between P1 and P2 electrodes, the array may pick up a lot of telluric noise that may significantly impair the quality of the measurements. In such a manner, this array is primarily applied in surveys where relatively small electrode separations (smaller than a few meters) are to be applied. It finds application in certain applications like archaeological survey in which small electrode spacings are applicable. It has also been applied in 3-D surveys (Li and Oldenburg 1992). This array is the most broadly horizontal and the most profoundly investigated. Nevertheless, it is worst in terms of resolution as manifested by the relatively large gap. Dipole-Dipole, wenner-Schlumberger, Pole-Pole arrays have a variety of combinations of electrodes. All forms of combinations have their merits and constraints in respects to lateral resolutions and vertical penetration e.g. as highlighted in table.

2.5 FACTORS INFLUENCING ELECTRICAL RESISTIVITY

Certain factors tend to increase or decrease the value of resistivity. These factors include

Pressure: When the pressure increases this makes a particular kind of rock more resistant. As pressure increases, resistivity decreases and consequently results in the increase of resistivity.

Temperature: The higher the ion mobility and the lower the water viscosity, the greater the electrical conductivity of aqueous electrolytes in higher temperatures. All rocks and minerals are practically semiconductors since their conductivity rises as temperature rises.

$$\sigma = \sigma_0 e\left(\frac{-\varepsilon}{KT}\right) \quad (2.18)$$

Where E represents activation energy, K is the Boltzman Constant (1.38 x 10-23mol-9k -1) and T is the absolute temperature.

Water Saturation: With an increase in water saturation, rocks become less resistant. The conductivity of groundwater is according to an empirical formula which is called as Archie law of rock resistivity.

$$\ell = a\,\emptyset^{-m} a^{-n} \ell_w \quad (2.19)$$

Where ℓ is resistivity of rock, $\emptyset$ is porosity, ℓ_w is water saturation, n, a, m are constants.

Topography: Topography refers to the characterization of the slopes, wavy, and the geomorphology of the surface of the earth. The possible topographical feature also consists of valley, hills, mountains, flat plains et.c.

Rock Types: Resistivity of rock differs with types and geological processes that make them. Reduction in resistivity is caused by an increase in porosity.

2.6 APPLICATION OF ELECTRICAL RESISTIVITY METHOD

a. It is used in searching three dimensional abnormal bodies of electrical conductivity.
b. It is applied in engineering research to investigate the shallow geology of the surface.
c. To detect the potential economic mineral deposits in a particular region.
d. It offers accurate and vivid data of the place of aquifers and quantities that can be stored in these areas.

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1. MATERIALS

The effectiveness of a resistivity survey depends on the right choice and utilization of items and materials. The materials are necessary in the production of reliable data which gives a true picture of subsurface resistivity distribution. The equipment applied in a resistivity survey consists of different kinds of equipment that is specifically designed to measure the electrical resistivity which ensures correct data collection of electrical resistivity under various field conditions. Some of the factors to consider when choosing materials would be the type of the terrain, the depth of the investigation as well as the objectives of the survey. Calibrated equipment that is properly maintained is essential in reducing measurement errors and ensuring high quality data (Airen and Ighodalo, 2024). Some of the necessary equipment in a resistivity survey has been listed below:

a. Resistivity Meter: A central device to apply current in the ground and to measure the potential difference thereof (Telford et al., 1990).
b. Electrodes: There are four metal electrodes, two getting used as current electrodes and the remaining two as potential electrodes (Keller and Frischknecht, 1966). For 2D electrical resistivity survey, 24 or above electrodes are customary, and it will depend on the survey line length (Griffiths and Barker, 1993).

c. Cables and Reels: These will be required in order to put the resistivity meter to the electrodes (Reynolds, 1997). Multi-core Cable is applied to connect all the electrodes to the imaging system which enables automatic exchange of the electrodes (Loke, 1999).
d. Global Positioning System (GPS): To correctly determine each point of the survey (Sharma, 1997).
e. Field Notebook and Marker: This is necessary to note down the data and label positions on the field.
f. Switch Box: It is an automatic switch between the electrode pairs in the survey, which allows taking fast and effective data (Telford et al., 1990).
g. Hammers: There were four hammers, which weighed up to 6.9kg. These hammers had the effect of driving the electrodes firmly into the ground.

Figure 3.1: Resistivity meter

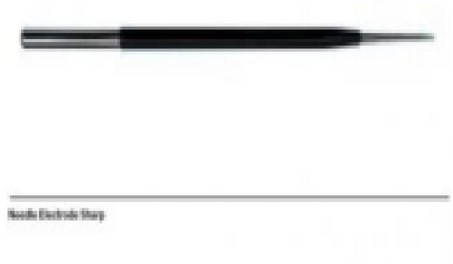

Figure 3.2: Metal electrodes

Figure 3.3: Connecting Cables

Figure 3.4: Measuring Tape

Figure 3.5: Global Positioning System

3.2 METHODOLOGY AND FIELD PROCEDURES

Before beginning an examination, the area's topography, geology, and position were assessed. Wenner array and vertical electrical sounding techniques were employed. To mark the reference point, a fixed central electrode was drilled into the earth. The reference electrode was pushed into the ground by two equal-distance current electrodes and two equal-distance potential electrodes that were on opposing sides of it. First readings are taken with the potential and current electrodes spaced 0.5 and 1 meters, respectively. Turning on the resistivity meter allows one to read the current and voltage on the voltmeter and resistivity meter, respectively. A recording is made for each electrode value after the current electrodes are moved five times on opposite sides and then the potential electrode is shifted. Calculations were then performed following the acquisition of a sizable amount of data.

3.2.1 RESISTIVITY FIELD PROCEDURES

There are three common field methodologies used in the electrical resistivity method, which are based on the objectives of the study. The field methodology concerned with the horizontal change in apparent resistivity of the earth is the one that is referred to as horizontal profiling (HP). The other that is interested in the resistivity contrast with depth is the vertical electrical sounding (VES). Any of the above electrode configurations can be switched to current or potential electrode. The apparent resistivity should be identical in any case by the principle of reciprocity. As an example, using high voltages with large spreads in Schlumberger and possibly Wenner layouts, a switch of current and potential electrodes could come in handy.

3.2.2 VERTICAL ELECTRICAL SOUNDING

Existing electrode separations define the depth under investigation at a certain point at any given time. The more they are separated and the other way the deeper the investigation becomes. The point is fixed although the depth of the study may vary.

Vertical electrical sounding (VES) is the variation in the ground apparent resistivity measured in reference to a fixed center of array. The general concept of the operation is founded on the fact that when there is a change in conductivity at the surface, it will influence how current passes through the earth, which will subsequently alter the distribution of the electric potential (Sheriff, 1991). The basic concept in this method is to monitor the possible drop with help of a second pair of electrodes referred to as potential electrodes by injecting current into the ground through two electrodes referred to as current electrodes. The distance between the current and potential electrodes is kept constant, and the distance between them is slowly increased around an inherent center point. The recessings are so made where the current is slowly downed to lower levels. It has been the most common approach employed in the geothermal survey to map horizontal coverage of porous rock layers and the depth of the overburden.

It is often done by using Schlumbeger arrays. However, the pole-dipole array is not suitable using this method. Thus, the method can be employed to map the thickness, depth, and geologic forms (like faults, joints, and fractures) of each layer.It is preferable to accomplish this procedure in a few points during a trip. Although in other instances, the depth of the bedrock is determined first by vertical electrical sounding followed by the focus on the lateral variation of the region being investigated, in other cases, the focus on vertical variation is initially made under the hope of determining the depth of the bedrock so that electrode spacing can be determined.

The study area was done by using two vertical electrical sounding (VES) locations, with the direct current (D.C.) resistivity technique and a PASI Earth

Resistivity meter. The data was collected by Schlumberger array and electrode spread was made between 1-100 m on the bottom of the field and 1-150 m on the maximum length of the field. Originally the measurements at each of the VES locations were made by symmetric expansion of the current electrodes about the spread center. To investigate the field of a single 2-d line, a run of the field using Wenner arrays was made across the length and the bottom of the field. Two geo-electric section profiles were picked and analyzed using Dipro software.

3.3 FIELD PROBLEM ASSOCIATED WITH ELECTRICAL RESISTIVITY METHOD

1. Introduction of errors by excessive contact resistance due to dry ground; The conduction of the surface is deduced when the electrodes fail to gain the correct contact with the ground.
2. Lateral homogeneity has an impact on the quality of data obtained, thus the wrong interpretation of the curve.
3. Surface and near-surface Geologic effects that may cause spurious voltage, which may degrade resistivity curves, include telephone cables, buried wires, pipes, fences, overhead power lines, and underground tanks.

CHAPTER FOUR

RESULTS AND INTERPRETATION

4.1. GENERAL REVIEW

The geophysical investigation conducted in the study area provided valuable subsurface data, including resistivity variations and layer distributions. The analysis integrates 2D electrical resistivity imaging (Wenner Schlumberger and Dipole-Dipole arrays), offering insights into the underlying geological structures. This section presents and interprets the results.

4.2 2-D ELECTRICAL RESISTIVITY IMAGING

4.2.1 DISCUSSION OF ERT ALONG TRAVERSE 1

The 2D ERT section shows resistivity values ranging from about 217 Ωm to over 4208 Ωm. Since leachate-contaminated zones typically exhibit resistivities below 100 Ωm, no plume or contamination feature is identified in this profile. The generally high resistivity values indicate that the subsurface is dry, resistive, and free from significant leachate infiltration.

The shallow zone (0–7 m) with resistivities between 1182 Ωm and 2756 Ωm corresponds to dry lateritic or compact sandy soils, reflecting well-drained, unsaturated surface conditions. The intermediate layer (7–18 m), showing 774–1182 Ωm, likely represents sandy or sandy–clayey materials with moderate moisture but no indication of pollution. At greater depths (18–32 m), resistivity values between 217 Ωm and 774 Ωm suggest moist sandy clay or weathered subsoil, possibly associated with natural groundwater rather than contamination.

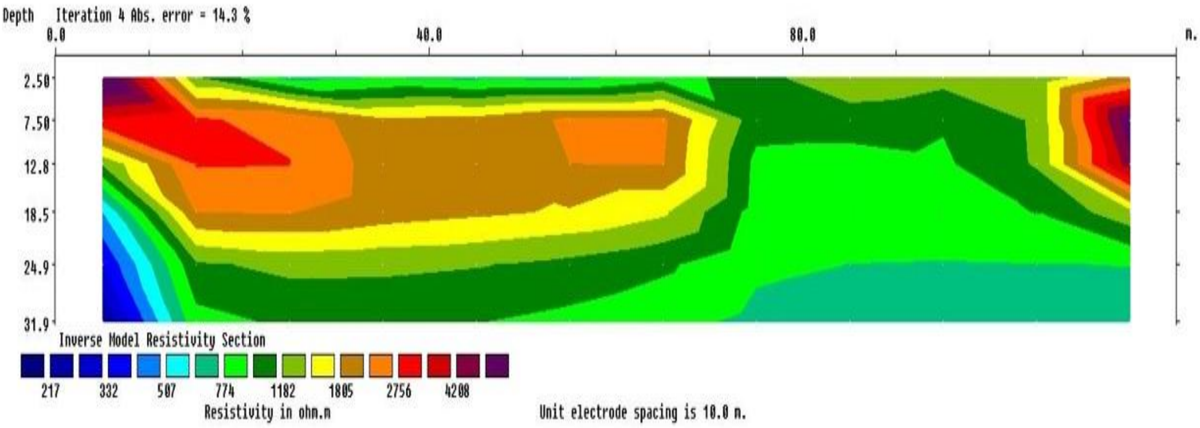

Figure 4.1: 2-D ERT Result along Traverse 1

4.2.2 DISCUSSION OF ERT ALONG TRAVERSE 1

The 2D ERT inverse model shows resistivity values ranging from about 292 Ωm to over 15,131 Ωm. Since leachate-contaminated zones typically exhibit resistivities below 100 Ωm, there is no evidence of leachate plumes or contamination in this section. The high resistivity values throughout the profile indicate a clean and resistive subsurface, free from significant groundwater pollution.

The upper layer (0–6 m depth) displays moderate resistivity values between 712 Ωm and 1740 Ωm, which correspond to lateritic or sandy topsoil with moderate moisture. These materials are generally unsaturated and well-drained. The intermediate zone (6–12 m), with resistivities between 1740 Ωm and 4250 Ωm, likely represents compact lateritic sand or sandy–clayey formations with low conductivity, suggesting natural soil variations rather than contamination.

At greater depths (12–20 m), the resistivity increases significantly, ranging from 4250 Ωm to over 10,000 Ωm, indicating dry, resistive laterite or weathered rock. Such high resistivity suggests well-compacted and low-porosity materials, typical of stable geologic formations.

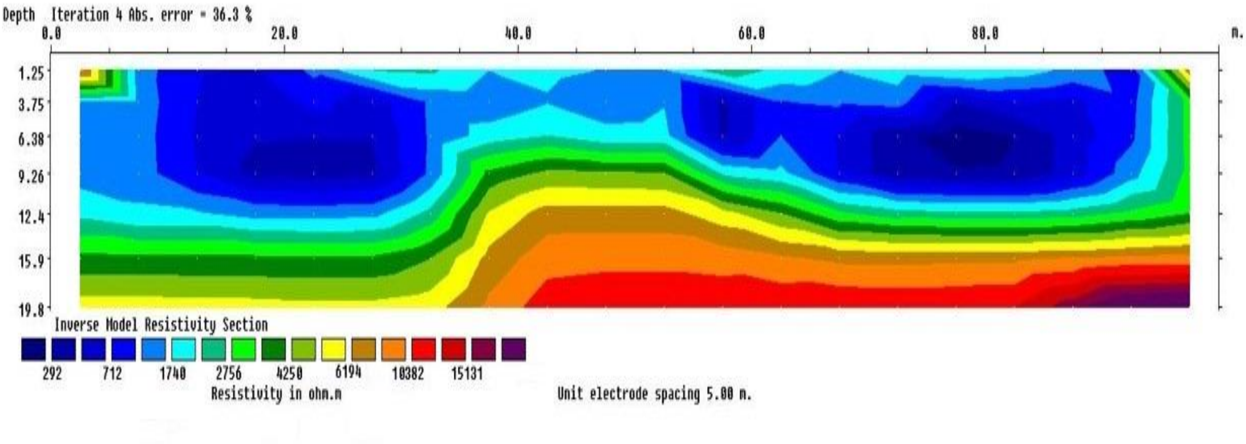

Figure 4.2: 2-D ERT Result along Traverse 2

CHAPTER FIVE

FINDINGS AND CONCLUSION

5.1 FINDINGS

The following are the findings;

1. Resistivity values (292–15131 Ωm and 217–4208 Ωm) reflect lateritic topsoil, sandy–clayey units, and aquifers.
2. No low-resistivity value (<100 Ωm) was detected, indicating absence of leachate plumes.
3. Lateral and vertical resistivity patterns represent natural stratification without plume penetration.

5.2 CONCLUSION

The obtained outcomes of the two profiles of 2D Electrical Resistivity Tomography (ERT) obtained at the Health centre, University of Benin depict an almost exclusively high resistivity beneath the surface with no evidence of leachate pollution. In both parts, the resistivity of 200 + Ωm is always recorded which is very high compared to the standard value of under 100 Ωm that is normally used to define leachate or groundwater contamination. This is a clear indication that there are no leachate plumes and movement of contaminants within the investigated depth in the study area.

The resistivity distributions of the two profiles are more of natural lithological than anthropogenic. The near-surface areas of the two areas are high to very high values of resistivity (around 700 –1700 Ωm) that is characteristic of dry lateritic or compact sandy soils. These are well-draining and resistant materials implying the low level of moisture and no pollution. Moderate resistivity values (approximately 700-1700 ohms) at intermediate depths are associated with either sandy or sandy-clayey formations which can hold a certain amount of moisture but be devoid of contamination. The lower layers that have resistivities of more than 4000 Ωm depict weathered or hardened more lateritic materials and bedrock, which is the bottom of the unsaturated or groundwater-bearing zone.

Taken together, the two ERT profiles represent a stable and clean geology and the observed resistivity differences are due to the natural soil and rock differences than the infiltration of leachate. The high values of the resistivity indicate that the area has good drainage features and is probably composed of dry, compact and resistive features. Consequently, the ground water under the Health Centre at the University of Benin is said to be environmental safe with no record of ground water pollution at the leachate or other pollutants in the depth of the survey.

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