CHAPTER ONE

INTRODUCTION

1.1 Background to Study

Municipal solid waste (MSW) consists of refuse from households, hazardous solid waste from industrial, commercial and institutional establishments (including hospitals), market waste, yard waste, and street sweepings (Ogwueleka,2009). Solid waste dumps constitute integral parts of the soil hydrological system and pose a serious pollution threat to both groundwater and downstream surface water (Dahlin *et al*., 2010). In a solid waste dump, high concentrations of materials such as heavy metals, nutrients, and organic substances lead to a risk of pollution of the surrounding environment. The pollutant load to the environment depends on the quantity and quality of the water that percolates through the waste dump into the surroundings. According to Christensen *et al*. (1992), the major local environmental problem of solid waste dump is the discharge of leachates into surrounding ground and surface waters. Indeed, the leakage from municipal solid waste deposits is usually associated with high ion concentrations and hence very low resistivities. This makes geoelectrical imaging techniques particularly interesting for mapping the three-dimensional extent of contamination around landfills (Bernstone and Dahlin, 1999).

In Nigeria and other developing countries, waste disposal management has become a problem (Agunwamba, 1998; Ogwueleka, 2009). Large refuse dumpsites that need remediation are seen surrounded by residential quarters in our urban cities. In the majority of these dumpsites the contaminants are heavy metals. However, the levels of contamination are often unknown (Ogwueleka, 2009). Pollution of groundwater under and near waste disposal sites happens when rain falls and water passes through the waste dump, producing a waste fluid called leachate which can infiltrate across the unsaturated zone into the water table. Every conceivable inorganic and organic material may be present in the leachate that can degrade the groundwater quality thereby putting the local community under serious health risk.

Akwa Ibom State faces major environmental challenges associated with poor waste management culminating in unregulated waste dumpsites in parts of the state. The dumpsites pose great risk to ground water quality as a result of leachate accumulation. Although the layer parameters and geology of the area are essential in understanding the impact of leachate accumulation on groundwater, this information are not known, hence the need for this study. Moreover, open waste disposal sites often lack reliable geological or artificial barriers, so that leaching of pollutants into the groundwater is a concern, particularly for waste dumped in erosion gullies and ravines (like in Uyo), many of which extend to below the groundwater table.

Nevertheless, the inhabitants of the study areas, Uyo, Ikot Ekpene and Oron Local Government Areas with a population of about 754,067 (Census, 2006), rely on groundwater for about 90% of their total water consumption. Increased urbanization and growing population have accelerated problems with the collection and disposal of both solid and liquid wastes. Solid waste management in Nigeria is characterized by inefficient coverage of the collection system and improper disposal of solid waste. Every year the importation and use of packaged consumer goods add to the growing amount of non-biodegradable wastes generated. Pollution from industrial waste and sewage and disposal of toxic chemicals are significant contributors to marine pollution and coastal degradation. Man-made chemicals, many of them very toxic, can be difficult to recycle and expensive to destroy. Most wastes, hazardous or not, are simply dumped together at the nearest available government-owned land. Perhaps more dangerous is the widespread use of toxic agricultural chemicals in areas where these can later pollute rivers and groundwater sources. Groundwater contamination is common in fresh-water sources adjoining agricultural areas. Most notably, the water is also contaminated with raw sewage routinely dumped by trucks from around the state capital.

However, there is need to carry out a fast, reliable and non-invasive method of geophysical investigation in studying waste dumpsites across the study area because investigations of contaminated sites are increasingly needed, both because of the pressure to reuse the land and because of increasingly stringent legislation to monitor contamination. According to Carlson *et al*. (2015), the geophysical applications are key environmental and economical tool for studying many old, poorly documented dumpsites that once were at a distance from urban areas and have been engulfed by expanding cities. Indeed, surface geophysical methods allow subsurface features to be located, mapped and characterized by making measurements at the surface that respond to a physical, electrical, or chemical property.

1.2 Statement of the problem

The Uyo dump site viewed as a natural gully erosion is rather an artificial one owing to poor construction work done by the former Cross River State Ministry of works in 1979. In 1989, the late Sole Administrator of Uyo Local Government Area sited the dump site at Old stadium road- end by Udo Street with the shadowy thought of reclaiming the ravine. The already bad situation was made worse by the contiguity of the dump site to human residences. Due to blocked water-ways, large-scale landslides have rendered some people homeless and many are deprived of access to their homes.

Akwa Ibom State, Nigeria, faces major environmental challenges associated with waste generation and inadequate waste collection, transport, treatment and disposal. Significantly, the problem associated with the location of dumpsites in gullies with porous and permeable rock units is that they are unprotected from surface contaminants and are therefore easily contaminated thereby putting the health of the people at risk. Waste disposal sites can seriously affect local wells and drilled holes used for public water supply and therefore, their locations must be planned and monitored carefully (Matias *et al*.,1994). Intake of water contaminated has led to cholera, alimentary canal diseases such as typhoid, paratyphoid and other salmonellosis, enteroviruses, yersinosis. Respiratory diseases are the commonest impact with potentially fatal consequences. Actually, the governmental and non-governmental agencies cannot cope with the volumes of waste generated due to increasing urban populations, and these impact on the environment and public health.

In addition, the study area is experiencing rapid urbanization without proper planning with respect to all the social and environmental amenities. Indeed, population growth and mostly the development of cities is a major contributor to increasing MSW in the study area.

The use of waste dump for obvious reasons is not favourable because, it anticipates blowing garbage, foul odours, rodent infestations, increased truck traffic in the neighbourhood as the trucks that bring the wastes drive in and out, hide-out for criminals and lowered property values. From an environmental and public health standpoint, probably the most legitimate concerns about a waste dump are the potential to pollute the underlying groundwater with leaking liquid, called leachate. Majority of the populace in the study area depends on groundwater as its source of drinking water; therefore, worries about leachate contamination are understandable. Contamination of any kind may be a signal that pollutants that are in fact hazardous to health and the environment are being transported from the solid waste disposal site into groundwater.

In this research, the feasibility of using electrical resistivity to investigate the internal structure of waste disposal sites compared to other areas is assessed in Uyo, Ikot Ekpene and Oron Urban, as well as the hydrochemical analysis in order to assess the level of contamination of the groundwater. Details on the contents of a dumpsite may be difficult to acquire but are essential for evaluating the level of risk associated with leaking pollutants. Observation of poor water quality in adjacent wells/boreholes are indicators that leachate is being produced and is moving (Jegede *et al*., 2011). Contaminated water represents a significant risk to public health, so their detection in situation assessment is critical in order to prevent access to such water.

The adverse effects of pollutants on human health via food chain, groundwater included, impinge on social and economic spheres (sickness and death rates, migration of population, lower working output, impact on people's mental state, etc.). The health risks posed by different kinds of pollutants in groundwater should therefore be the subject of continuous control and evaluation, because they may assume enormous significance for present and future generation.

Significantly, the layer parameters and the geology of the materials above the aquifer are not fully known, as this information can be of help in understanding the level of leachate contamination. It is against this background that this study focuses on the integration of electrical resistivity and hydrochemical methods in determining the impact of solid waste on groundwater quality.

1.3 Aim and Objectives of Study

Aim of Study

The aim of this research is to determine the impact of solid waste dump on groundwater quality in selected dumpsites in Uyo, Ikot Ekpene and Oron, Southeastern Nigeria

Objectives of the Study

The objectives of the study include to:

1. Carry out geophysical surveys in order to obtain vertical electrical sounding data in the study areas.
2. Carry out a detailed interpretation of the vertical electrical sounding curves obtained and delineate the leachate/plume contaminated layers.
3. Delineate the migration paths.
4. Generate geoelectrical attributes of the area.
5. Correlate the geo-electric sections/VES curves with various lithologies using borehole logs.
6. Analyse for physicochemical and microbial parameters in the groundwater within the vicinity of the waste dumps.
7. Produce risk model maps of the leachate level.

1.4 Scope of Study

The scope of this study using both electrical resistivity (Schlumberger array) and hydrogeochemical methods to establish major environmental challenges associated with waste generation and inadequate waste disposal and treatment.

The study area is limited to Uyo, Ikot Ekpene and Oron areas of Akwa Ibom State, Nigeria. The applications of electrical resistivity method involves vertical electrical sounding (VES) and tomography. Hydrogeochemical method involves the evaluation of physicochemical and microbial properties of the groundwater. Interpretation of the layers of rock encountered in the study areas, some layer parameters including the Dar Zarrouk parameters will be evaluated.

1.5 Significance of Study

At the end of this research, a lot of people especially those in the environment, water, health and petroleum sectors will find solutions to major environmental challenges associated with waste generation and inadequate waste collection, transport, and disposal. Those to benefit in the study includes, the government ministries of health, water, environment and petroleum, and future researchers and students.

The knowledge gained from the study will help the government through their agencies in the ministries of environment, water, health and petroleum to appreciate the adverse effects of uncontrolled dumpsites on the immediate environment, as well as the associated diseases caused by the pollutants from the dumpsites. More so, the study will provide facts and figures on the level of groundwater contamination/pollution in areas proximal to the dumpsites for the governmental ministries. Government at various levels, researchers and even the host communities will find this study very useful. It should be categorically stated that no new water boreholes should be cited in areas where physicochemical and microbial parameters exceed the permissible WHO and NSDWQ limits without first finding out the reasons for these high values.

Finally, future researchers and students who intend to undertake related study on the impact of solid waste in dumpsites areas using electrical resistivity and hydrochemical data will hopefully find the study useful. Literature reviewed as well as findings from the study will present them with vital information that will adequately guide their research. More so, the findings of this work will be applicable to any other areas in the region or beyond.

1.6 Locations of Study

Akwa Ibom State is in South-eastern part of Nigeria, located between latitudes 4^0 30^I and $5^0 30^I$ N and longitudes $7^0 30^I$ and $8^0 20^I$ E (Fig. 1.1). The State is bounded on the east by Cross River State; on the north-east and north by Cross River and Abia States; on the west and south-west by Abia and Rivers State; on the south by the Atlantic Ocean, with a 129-km maritime coastline which extends from Ikot Abasi in the west to Oron in the east. The study areas viz.: Uyo, Ikot Ekpene and Oron, are located in the central, north-west and south-east parts of the State respectively (Fig. 1.1). Uyo dumpsite is a ravine adjoining Udo, Eka streets and University of Uyo. The maps of these locations are shown in Figures1.2, 1.3, 1.4 and 1.5 respectively.

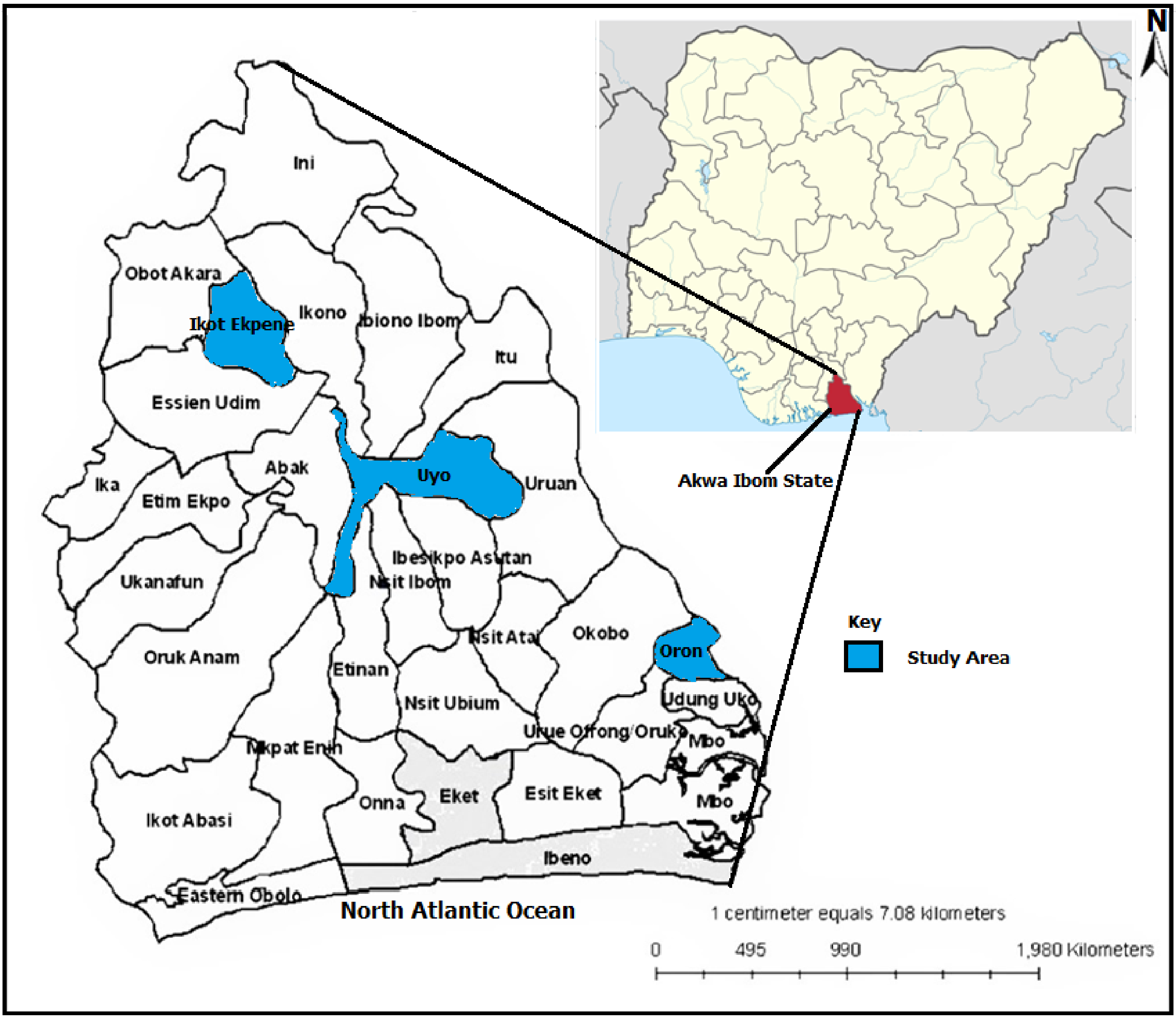


Fig. 1.1: Map of Akwa Ibom State showing Local Government of the Study Area

(Modified after Ite *et al.*, 2016)

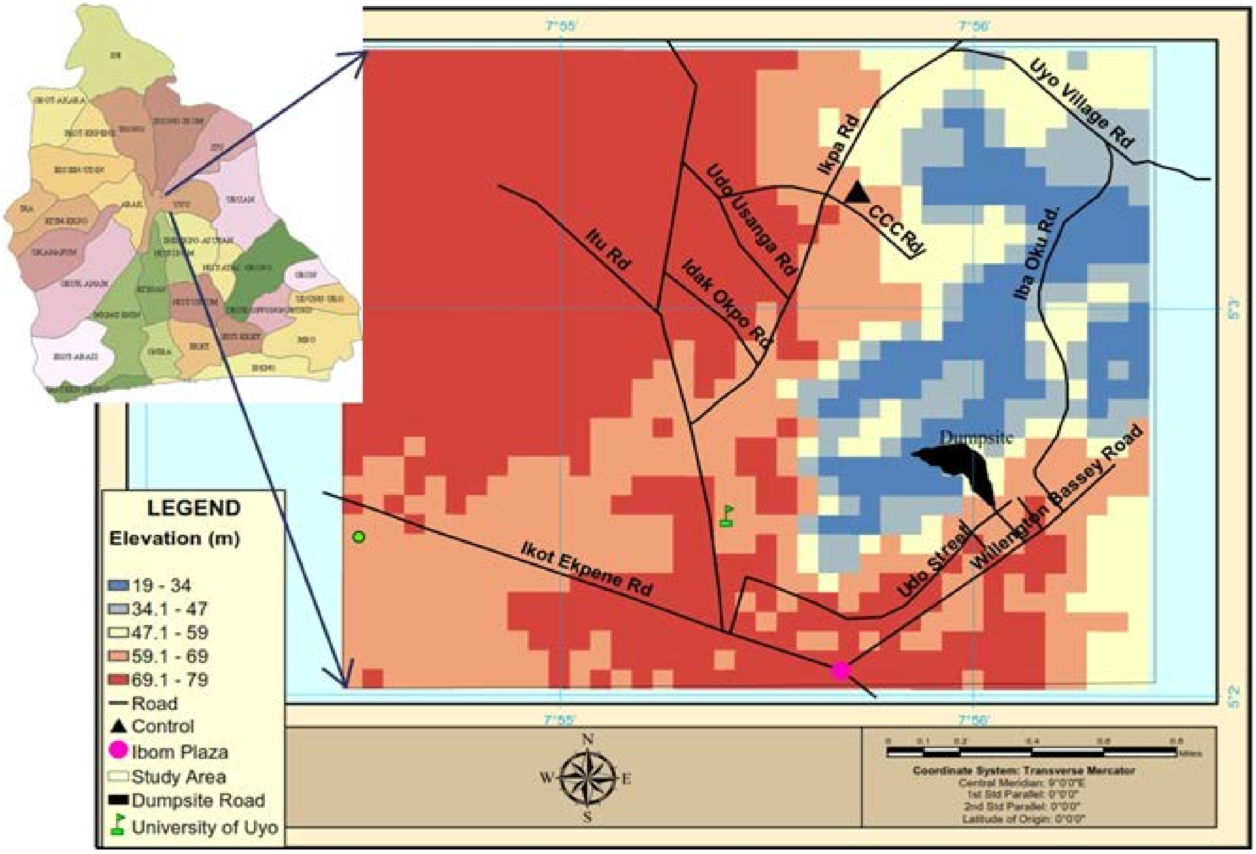


Fig. 1.2: Google Map of Uyo showing the location of the dumpsite and Control Site

Fig. 1.3: A Photograph of Uyo Dumpsite Showing Materials of Various Kinds

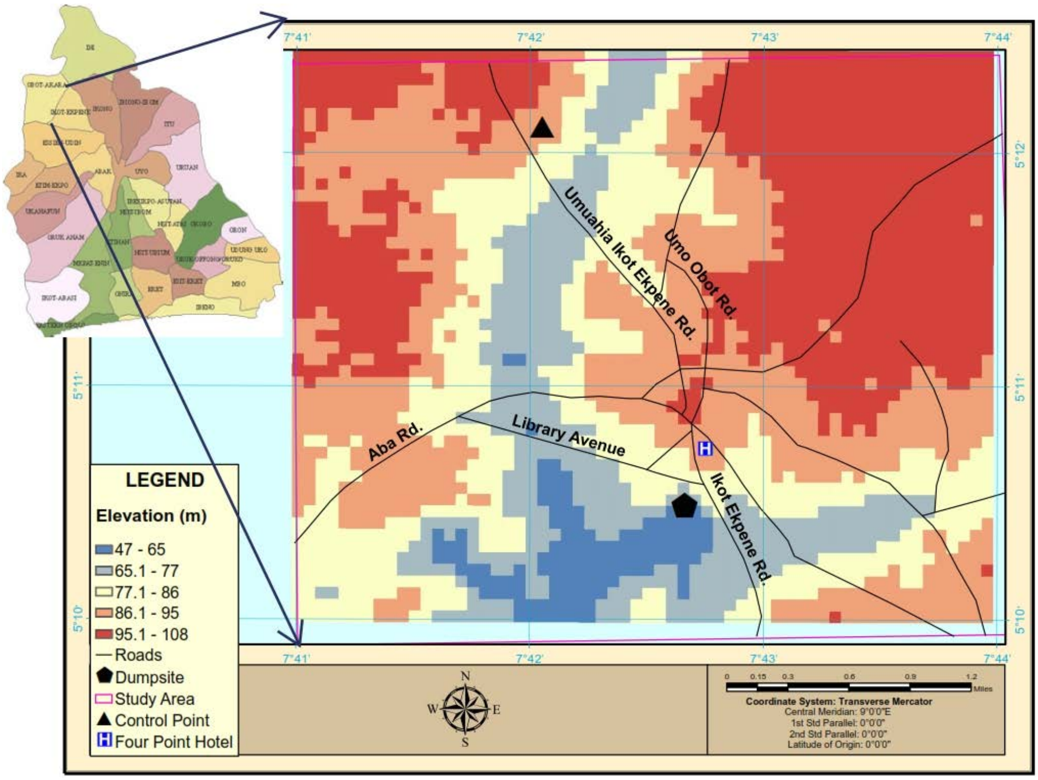


Fig. 1.4: Google Map of Ikot Ekpene showing the Position of the Dumpsite and Control Site

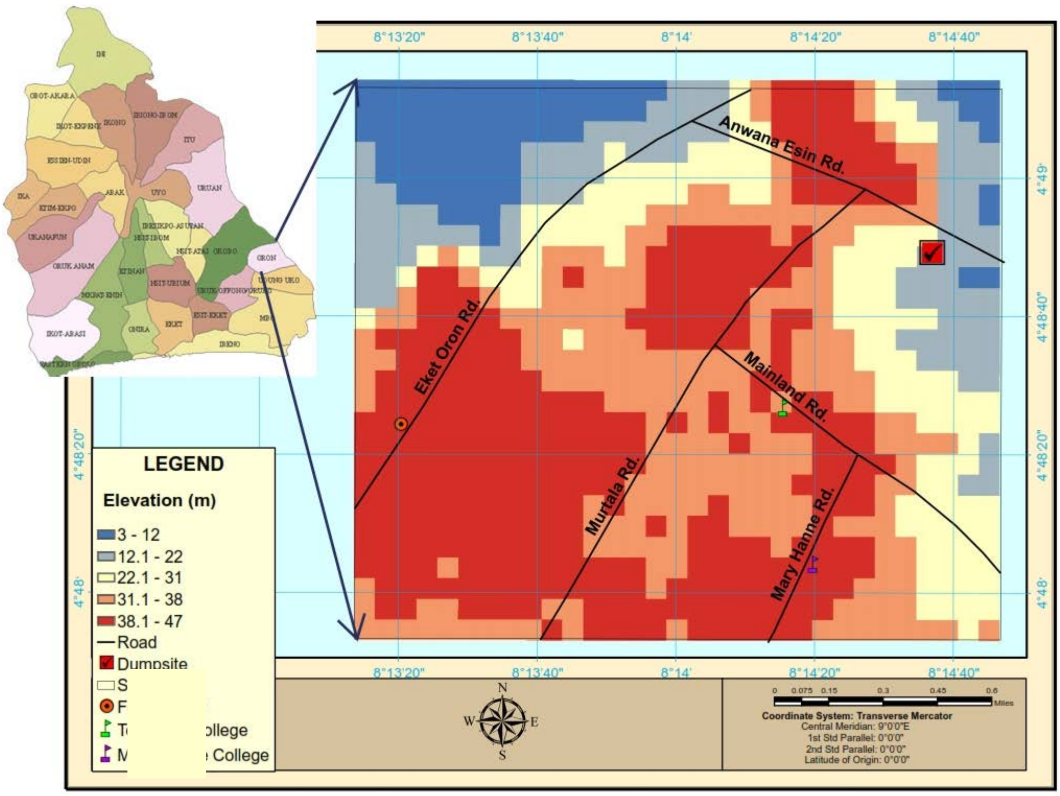


Fig. 1.5: Google Map of Oron Showing the Location of the Dumpsite and Control Site

1.7 Control Site for Study

The Control in this study refers to the areas remote from the dumpsites; that is areas not affected by the solid waste deposits at the dumpsites. Since three dumpsites were studied in this work, there were also three corresponding control points. The Uyo dumpsite control was the Sounding made along Cornelia Cornelly College (CCC) lane, off Ikpa road in Uyo (Fig. 1.2). The Control for Ikot Ekpene was the Sounding made in Community Secondary School, Ikot Abia Idem, along Ikot Ekpene – Umuahia road (Fig.1.4). Similarly, the Control for Oron was the Sounding made in Mary Hanne Girls College, Oron (Fig.1.5).

1.8 Physiography and Climate

The Study area has undulating topography. Creeks and swamps exist due to the influence of the Atlantic Ocean, the Qua Iboe and the Cross River which drain the entire Akwa Ibom State. The study area presents a picture of captivating coastal, mangrove forest and beautiful sandy beach resorts. The study area has basically two distinct seasons. The rainy season lasts from May to October, while the dry season lasts from November to April. However, in the coastal areas, rain falls almost all year round. The harmattan, accompanied by the North-East trade wind occurs in December and early January. On the basis of its geographical location, the climate of Akwa Ibom State can be described as tropical and experiences abundant rainfall with very high temperature. The mean annual temperature of the area ranges between 26^0C and 29^0C and average sunshine cumulates to 1450 hours per year. The mean annual rainfall ranges from 2,000mm to 3,000 mm. Naturally, maximum humidity is recorded in July while the minimum occurs in January. All these have effect on the dispersal of dumpsite elements. Humid conditions hasten the disintegration of waste matter.

CHAPTER TWO

LITERATURE REVIEW

2.1 Studies Related to Waste dumpsites

Karlik and Kaya (2001) combined the electrical and electromagnetic methods to investigate groundwater contamination at an open waste disposal site in Isparta, Turkey, with the objective of mapping the extent of contamination induced by the open waste-disposal site and thus, help to determine where future monitoring wells should be located. From their result, a good correlation between the Very Low Frequency-Electromagnetic (VLF-EM) and direct current (DC) resistivity methods employed for the study was observed, where soil chemical and previous hydrogeological surveys had indicated high levels of chemical concentration. They concluded the existence and spread of groundwater contamination and contributed to the efforts of groundwater protection and the assessment of installation sites for monitoring wells.

Soupios *et al*. (2007) carried out a study on estimation of aquifer hydraulic parameters from surficial geophysical methods around Keritis Basin in Chania, Greece, in order to know the aquifer parameters which are essential for the management of groundwater resources. The researchers applied geophysical methods in combination with pumping tests which provided a cost-effective and efficient alternative to estimate aquifer parameters. They used geophysical method to obtain aquifer characteristics that are previously estimated through pumping tests. They established a correlation among the parameters at other sites where pumping has not been carried out. In this way, the entire investigation area could be covered to characterize an aquifer system. They concluded that their study area is required for the management of groundwater in the region.

According to Dahlin *et al*. (2010), solid waste dumps constitute integral parts of the soil hydrological system and pose a serious pollution threat to both groundwater and downstream surface water. In a solid waste dump, high concentrations of materials such as heavy metals, nutrients, and organic substances lead to a risk of pollution to the surrounding environment. The pollutant load to the environment depends on the quantity and quality of the water that percolates through the waste dump and reaches the surroundings. It is related to this present study because the researchers evaluated the effect of solid waste dumps in relation to groundwater resources.

Awokunmi *et al.* (2010) conducted a study on the effect of leaching on heavy metals concentration at dumpsites by analysing samples of soil collected from different dumpsites located within Ikere and Ado Ekiti metropolis, South Western Nigeria. The samples were analysed for concentrations of Cd, Co, Cr, Cu, Fe, Pb, Mn, Ni, Sn and Zn. Control soil samples were taken at 200 m away from the last sampling point on each dump site down the slope and were also analysed for the presence of these heavy metals. The results of the analyses showed a significant difference in the concentration of these metals from the centre of each dumpsite at interval of 10 – 70 m down the slope ($p < 0.05$). The dumpsites were found to contain significant amount of toxic heavy metals.

Amadi (2011) assessed the effects of Aladimma dumpsite in soil and groundwater using water quality index (WQI) and factor analysis. The results suggested that the groundwater around the dumpsite is poor in quality while factor analysis revealed five sources of groundwater pollution. The poor quality of groundwater around the dumpsite was attributed to leachate percolating into the subsurface thus contaminating the groundwater.

Jegede *et al*. (2012) carried out a geophysical survey (Induced polarization and Electrical resistivity tomography using 2D approach) in a potentially polluted part of Zaria, Kaduna

State, with the aim of imaging the subsurface to delineate leachate plumes and their pathways into the groundwater at shallow depths and to monitor the extent of the vertical and lateral migration over a period of ten months. From their results, the horizontal and vertical extents of leachate plumes were delineated. Also, the induced polarization survey revealed that the waste in the dumpsite was buried to as much depth as over 10.0m. The rate of migration was found to depend on the degree of compaction of the soil, the presence of loose soil, fractures, depressions, undulations and dipping topography.

‘Utom *et al.* (2012) conducted a study on estimation of aquifer transmissivity using Dar Zarrouk Parameters derived from surface resistivity measurements in parts of Enugu town, Nigeria. They employed many investigation techniques with the aim of estimating the spatial distribution of transmissivity. They were able to deduce the Dar Zarrouk parameter and β constant of 0.32 was used to translate resistivity to transmissivity with clay content as the primary factor controlling the hydraulic conductivity. Their result also shows a strong correlation between aquifer transmissivity and longitudinal conductance. They were able to demarcate areas with good groundwater potential in parts of Enugu town, Nigeria.

Ekwe and Opara (2012) carried out a study on the aquifer transmissivity from surface geo-electrical data around Owerri and its environs, Southeastern Nigeria, using the combination of layer resistivity and thickness in the Da-Zarrouk parameters namely; longitudinal conductance and transverse resistance. Their research revealed that the area is underlain by unconsolidated to semi-consolidated sediments of Benin Formation. They used the Schlumberger array for data acquisition with maximum current electrode spacing (AB) of 1000 m. Four of their soundings were carried out near existing boreholes. Their study revealed that the depth to the water level is shallow around Ife and Egbu areas with a mean depth of 30 m. They deduced semi- deep aquifers around Okpalla and AVU areas with a mean depth of 90 m while very deep aquifers were found around Owerri and Obinze areas with a mean depth of 125 m. Their study revealed aquifer thicknesses in the study area range from 8 m at Ife and 117 m at Owerri. Ekwe and Opara (2012) observed that the hydraulic conductivity varies between 6.19m/day (at Ife) and 24.7 m/day (at Obinze) while transmissivity values also varied between 51.39 m^2/day (at Ife) and 1379.56 m^2/day (at Owerri). They concluded that the results would help in long- term planning of groundwater exploitation schemes within the study area.

Ekeocha *et al.*, (2012) using electrical resistivity method (VES and 2-D resistivity imaging) investigated the effect of solid waste dumpsite at Rumuekpolu in Obio Akpor Local Government Area, Rivers State. From their results, zones of low resistivity were delineated as contaminant plumes in both the VES and 2-D resistivity imaging. They concluded that groundwater around the dumpsite was contaminated to depth exceeding 65.0m.

Ukpong *et al.* (2013) worked on the assessment of heavy metals content in soils and plants around waste dumpsites in Uyo metropolis, Akwa Ibom State. The levels of heavy metals were assessed in five randomly chosen dumpsites. Twenty soil samples were drawn at the depth of 0-15cm and 15-30cm on each of the two sampling points of the five randomly chosen locations and six samples from three locations away from the dumpsites. The result of the analysis carried out showed that the level of heavy metals like iron (Fe), lead (Pb), nickel (Ni), and chromium (Cr) were generally higher at waste dumpsites than control sites.

Butu and Mshelia (2014) carried out a research on municipal solid waste disposal and environmental issues in Kano Metropolis, Nigeria in order to examine the municipal solid waste disposal methods and the environmental issues associated with the management of solid waste in Kano Metropolis, Nigeria. The study showed that soil, air and water pollution in the study area are caused by both pathogenic and chemical elements from these heaps of solid waste that dot some of the major streets and open spaces.

Ganiyu *et al*. 2015 investigated the Lapite dumpsite in Ibadan, Southwestern Nigeria to delineate leachate plume migration and possible groundwater pollution using electrical resistivity imaging. Their result revealed the extent of leachate plumes with resistivity values less than 10Ωm. and also delineated location of leachate, clay soil, bedrock and seepage path from the dumpsite. The seepage path from the dumpsite was also established.

Egong *et al*. (2016) carried out a research on the bacteriological health status of adjoining dumpsite soils in Uyo, Akwa Ibom State, Nigeria. Their study revealed that wastes usually increased bacterial proliferation as well as temperature with the release of nutrients, leachates and heavy metals which could pollute the groundwater and adversely affect the soils at close proximity to the dumpsite and the health of the people. Therefore, they suggested that sanitary landfill with leachate cover should be constructed at designated locations so as to prevent surface and ground water pollution.

Obiora *et al.*, (2016) conducted a study on geoelectric survey involving vertical electrical sounding (VES) employing Schlumberger electrode configuration. Their study identified four to six geoelectric layers. The VES curves obtained were QQH, QHK, QHA, QQQ, HAK, KHK, HKH and QQ. From their result, the Dar Zarrouk parameters (longitudinal conductance and transverse resistance) were calculated. The longitudinal conductance ranges between 0.1528 and 4.6 mho. The transverse resistance ranges between 662.4 and 38,808 **Ω**-m^2. Their result also revealed a range of hydraulic conductivity of 1.1645–38.0491 m/day, while the range of transmissivity was 89.66–2100.3 m2/day from the estimated values.

An important problem associated with this MSW is leachate production and the related groundwater contamination. Leachate is a liquid formed from decomposed waste and it can contain groundwater and percolated rain water. Inorganic pollutants increase liquid conductivity due to the presence of dissolved salts. Since the presence of saline fluids in the ground enhances its ability to conduct electrical current, it is possible to locate a leachate plume by measuring the resistivity distribution in the subsurface (Meju,2006). Geophysical methods are particularly valuable because they are largely environmentally benign, that is, there is no disturbance of subsurface materials and they are non-destructive and non-invasive. The contrast between the electrical resistivity of leachate and most groundwater offers significant potential for the deployment of electrical geophysical methods such as D.C. Resistivity, EM Conductivity (Kinnear *et al* 2013).

Gap in Literature:

None of the previous authors generated the risk model map for groundwater within the study area.

2.2 Regional Geology of Southeastern Nigeria

The geology of Nigeria comprises of Basement Complex and Sedimentary basins. The study area is one of the component structural units of the Southern Nigeria sedimentary basins that resulted from the post-Albian tectonic activities believed to be closely associated with the separation of Africa from South America and opening of the South Atlantic Ocean.

Sedimentation in Southeastern Nigeria appears to have been controlled by three major tectonic phases (Short and Stauble, 1967; Murat, 1970) which resulted in a complicated depositional history. The first phase (Albian) was marked by the formation of NorthEast – SouthWest trending Abakaliki-Benue Trough. The second phase (Santonian) resulted in the folding and uplifting of the aforementioned trough into a major depocentre for clastic materials. The third phase (Eocene) resulted in the formation of large deltaic complex in the down dip area of the Anambra Basin (Table 2.1).

The Benue Trough is filled with Albian Shale usually referred to as the Asu River Group resulting from marginal marine transgression. The upper Cretaceous (Cenomanian) sediments resulting from regression succeeded the Albian sediments, starting with the Odukpani Formation found in Odukpani area in Calabar district. Turonian transgression led to the deposition of Eze-Aku Shale. A hiatus occurred between Santonian and mid-Campanian.

The second tectonic phase started from Santonian resulting in folding, faulting and upliftment of the Albian sediments in the Benue Trough. The Anambra platform subsided forming the Anambra Basin and was similarly filled in two sedimentary phases. The transgression, which occurred during the Campanian-Maastrichtian sub-stage, gave rise to deposition of Nkporo Shale (lateral equivalent of Enugu Shale) and which passes laterally to Owelli Sandstone, (Reyment, 1965). Mamu Formation, Ajalli Sandstone, Nsukka Formation and Imo Shale overlie the Nkporo Shale.

Sea regression as a result of the sea becoming shallower lead to the deposition of Mamu (Lower Coal Measures) followed by the deposition of Whitish, friable Ajalli Sandstone. Later, the Nsukka Formation (Upper Coal Measure) was deposited between upper Maastrichian and early Paleocene. During the Paleocene, another sea transgression across the whole Southern Nigeria was recorded and this terminated the advance of the upper Cretaceous Niger Delta. The main rock unit of this age in the Anambra Basin is the Imo Shale, though it is found to outcrop in an actuate belt from

Table 2.1: Correlation Chart for Early Cretaceous Tertiary strata in the Southeastern Nigeria (After Nwajide, 1990).

PICK (m.y)	AGE	ABAKALIKI-ANAMBRA BASIN	AFIKPO BASIN
30	Oligocene	Ogwashi-Asaba Formation	Ogwashi-Asaba Formation
54.9	Eocene	Ameki/Nanka Formation/Nsugbe Sanastone	Ameki Formation
65	Paleocene	Imo Formation Nsukka Formation	Imo Formation Nsukka Formation
73	Maastrichtian	Ajalli Sandstone Mamu Formation	Ajalli Sandstone Mamu Formation
83	Campanian	Nkporo/Owelli Formation/Enugu Shale	Nkporo Shale/Afikpo Shale
87.5	Santonian	Non-deposition	
88.5	Coniacian	Awgu Group (Agbani Sandstone/Awgu Shale)	
93	Turonian	Ezeaku Group	Ezeaku Group (Including Amaseri Sandstone)
100	Cenomanian-Albian	Asu River Group	Asu River Group
119	Aptian Barremian Hauterivian	Unnamed Units	
Precambrian		Basement Complex	

Western to Eastern Nigeria. The end of Paleocene witnessed another sea regression and the deposition of sediments of Tertiary Niger Delta.

The Eocene however showed continued regression (Reyment, 1964) and the deposition of Ameki Formation and its lateral equivalent, Nanka Sands. The regression of this period was as a result of the third tectonic episode in Nigeria. By the end of Eocene, the Anambra Basin was filled with mainly continental sediments and the Niger Delta prograded Southwards towards the Gulf of Guinea marking the beginning of the modern Niger Delta.

However, the study area is located in the southern part of the regionally extensive Northeast -Southwest trending Benue Trough. Nevertheless, the tectonic displacement of the axis of the Benin-Abakaliki Trough created three successive basins (Table 2.1): the Anambra Basin, the Afikpo Syncline and the Niger Delta Basin (Murat, 1972 and Nwajide, 1990).

2.2.1 Geology of the Study Area

Geologically, Akwa Ibom State falls within the sedimentary basins of Nigeria. The area is overlain by Imo, Ameki and Benin Formations. (Fig.2.1) of the Niger Delta sedimentary basin (Mbipom, *et al.,* 1996). The Benin Formation is the uppermost unit of the Niger Delta Complex and consists of alternating sequences of gravels and sands of fine to medium/coarse grain sizes, and Quaternary alluvium (Ugbaja and Edet, 2004). According to Edet and Okereke (2002), Benin Formation comprises of sediments whose age is from Tertiary to Recent. Generally, the sands of the Benin Formation are mature, coarse and poorly to moderately sorted with intercalations of silts and clays.

2.2.1a Nsukka Formation

The Nsukka Formation was formerly known as the Upper Coal Measures. It consists of alternating succession of medium to coarse grained sandy shale, ironstone and

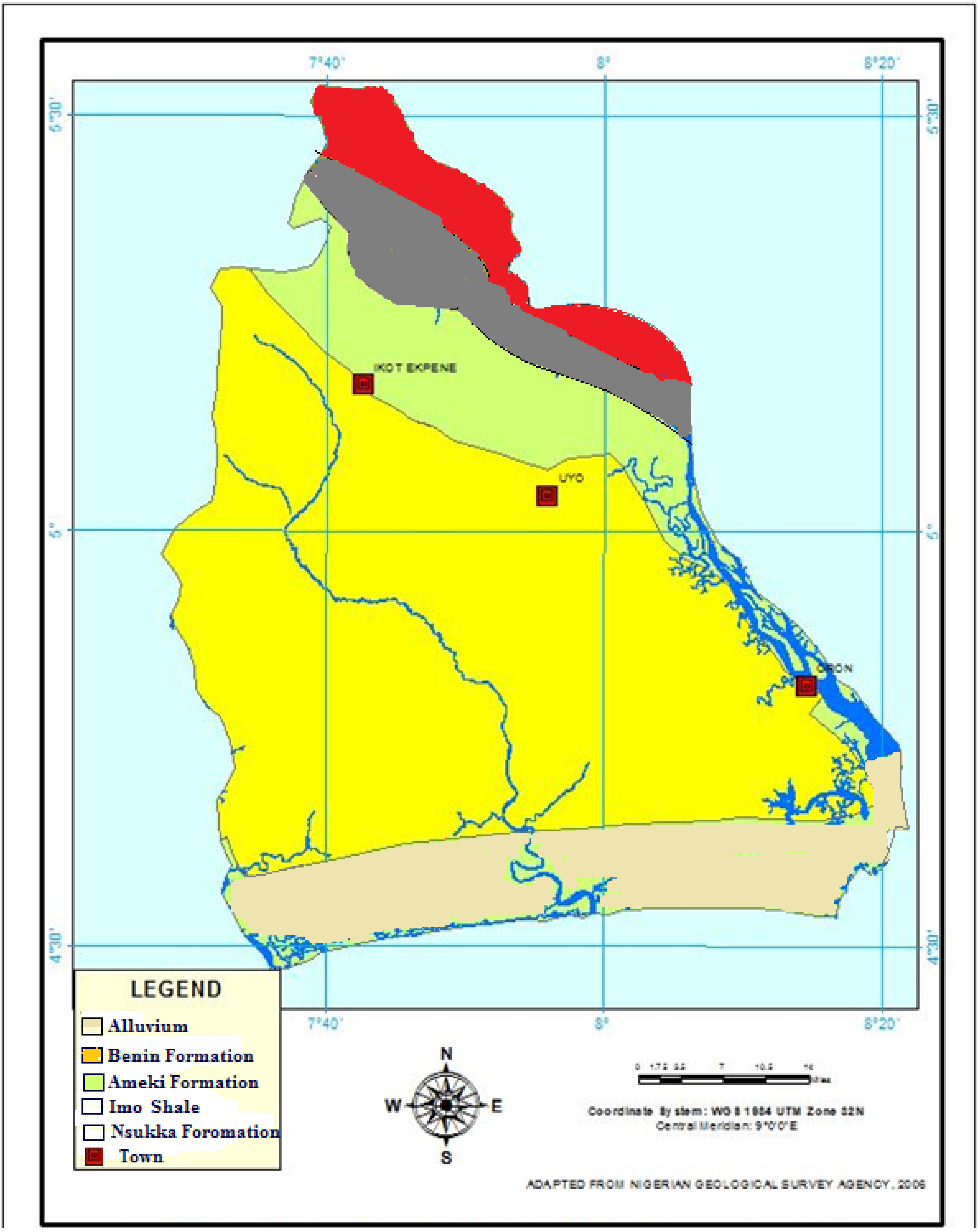


Fig.2.1 Geological Map of Akwa Ibom State, Nigeria (Nigerian Geological Survey Agency,2006).

ferruginized sandstone, carbonaceous shale and thin coal seams. The formation is diachronous, spanning upper Maastrichtian into Danian. Depositional environment has been suggested to be similar in many ways to the Mamu Formation (Lower Coal Measures) i.e transitional/shoreline, mud flat and swamps, deposited during a largely regressive phase.

2.2.1b. Imo Formation

This is essentially a mudrock unit consisting mainly of dark grey to bluish grey shale, with occasional admixture of clay, ironstone, thin sandstone bands and limestone intercalations. The formation outcropped in one-third of the landmass of Ananbra State covering both Ayamelum, parts of Awka North and South as well as Orumba North and South Local Government Areas (Fig. 2.1 and Table 2.1). The outcropped formation trends N-S direction in Ayamelum area, where it is overlain by alluvial sediments and veers in NW-SE direction around Igbariam down to Umunze area, yet maintaining a southwesterly dip (average dip of 6^0). A conspicuous Sand Member of the formation known as Ebenebe Sandstone was seen in the area. This is a NW-SE trending ridge that runs from Ebenebe, passing through Ugwuoba and continued its trend in the state through Ufuma, Ajali, Ezira, down to Umunze and Ihite, the boundary with Imo State.

Imo Formation is very rich in clay minerals. These minerals are available at the boundary between the formation and the overlying Nanka Sand. Two main types of clay are available, namely expansive clays and bentonite clays.

2.2.1c. Ameki Formation (Nanka Sand/Nsugbe Sandstone)

Imo Formation is overlain by Nanka Sand, a lateral equivalent of Ameki Formation. The lithology consists of loose flaser bedded, fine to medium sand, with few mudrock breaks. The sands have subrounded to sub angular grains and are often clayey, ferruginised and invariably wave rippled- laminated with ripple crests striking NW-SE. The formation maintains a variable dip (averaging 6^0) in southwestern direction.

Another sandstone facies of Ameki Formation known as Nsugbe Sandstone has been distinguished from Nanka Sand due to its degree of induration. This occurs in areas northeast of Onitsha. The area is strewn with ferruginous sandstone boulders.

Generally, the formation is dominantly covered with thick lateritic sand wherever it outcropped. This accounts for the excavation of huge amounts of laterites in many parts of the state.

2.2.1d Ogwashi – Asaba Formation

This represents the Oligocene – Miocene stratigraphic unit overlying the Ameki Group. The formation outcropped in a NW-SE belt starting from Onitsha through Idemili and Ekwusigo down to Nnewi and Ihiala areas (Fig. 2.1 and Table 2.1). The formation basically consists of white, blue and pink clays, cross-bedded sands, carbonaceous mudstone, shales and seams of lignite. It maintains an average dip of 4^0 in southwestern direction.

2.2.1e Benin Formation

This is the uppermost unit in the Niger Delta and is composed of Late Eocene to Holocene continental deposits. These include the alluvial and Coastal-Plain Sands found at within the study area (Fig. 2.1 and Table 2.1). The sand grains range from fine to coarse and granular; generally, poorly sorted; subangular to well rounded; pebbles are common and consolidation is generally poor.

2.2.2 Hydrostratigraphic Unit of the study area

In Akwa Ibom State, groundwater is ubiquitous due to the availability of the subsurface geomaterials that have the properties which can host water (Obianwu *et al*.,2011). The availability of these formations at shallow depths enhances the exploitation of groundwater reserve in many areas of the state. However, at the north-eastern part of the state, the story is different due to the subsurface geomaterials which are though porous and capable of absorbing water slowly, cannot discharge water in appreciable quantity into a spring or well. These geomaterials in Imo and Ameki Formations include clay and shale which are only porous but not permeable to transmit the fluids **(**Umoren, 1992).

On the basis of stratigraphic relation and lithology (Table 2.2), four main hydrostratigraphic units have been delineated for the entire state (Esu *et al*, 1999). These include three aquiferous units designated as upper, middle and lower sand aquifers. The middle aquifer is the most extensive and is separated from the lower sand aquifer by Imo Shale aquitard.

Table 2.2: Stratigraphic and Hydrostratigraphic Units in Akwa Ibom State (Esu *et al* 1999).

Age	Group(s)/ Formation(s)	Lithology	Aquifer
Recent	Alluvium Ridges	Gravel, lateritic sand, fine to medium-grained and carbonaceous sand	Upper Sand
Pliocene Pleistocene	Benin Formation (Coastal plain sand)	Unconsolidated sand and gravelly sand with clayey intercalations	
Oligocene Miocene	Ogwashi-Asaba	Grit and sand with intercalations of clay and lignite seams	Middle Sand
Middle Eocene	Bende-Ameki Group	Semi-consolidated sandstone and siltstone plus minor shale	
Early Eocene to Paleocene	Imo Shale Formation	Shale with thinner sandstone and band of fossiliferous limestone	Aquitard
Maastrichtian	Nsukka Formation Ajalli Sandstone	Lateritic sandstone and Minor shale	Lower sand

2.3 Solid Wastes

Solid wastes could be defined as non-liquid and non-gaseous products of human activities, regarded as being useless. It could take the forms of refuse, garbage and sludge (Leton and Omotosho, 2004). Since the creation of Akwa Ibom State from the former Cross River State on September 23, 1987, and the resultant influx of people, the State has been faced with the problem of solid waste generation. The implication is serious because the State is growing rapidly and the wastes are not efficiently managed. Of the different categories of wastes being generated, solid wastes had posed a hydra-headed problem beyond the scope of various solid waste management systems in Nigeria, as the streets experience continual presence of solid waste from commercial activities (Geoffrey, 2005). Ogbonna *et al* (2002) have observed that little or no attention is given to some traditional suburban settlements for provision of waste collection and disposal services. The quantity and rate of solid waste generation in the various states of Nigeria depends on the population, level of industrialization, socio-economic status of the citizens and the predominant kinds of commercial activities. Akwa Ibom State generates mainly domestic waste, both organic and inorganic related to agricultural activities. Oluwewimo (2007) reported that Uyo, for instance, generates 20,923 tonnes of solid waste per year.

The study areas namely Uyo, Ikot Ekpene and Oron generate the typical Municipal solid waste (MSW), commonly known as trash or garbage, refuse or rubbish, consisting of everyday items that are discarded by the public. In Uyo, waste collection is performed by the State Government, while those of Ikot Ekpene and Oron are handled by the respective Local Government Authorities.

The term residual waste relates to waste left from household sources containing materials that have not been separated out or sent for reprocessing (https://en.wikipedia.org/wiki/Municipal_solid_waste). The following list represents a typical classification of the waste found at Akwa Ibom dumpsites:

1. Biodegradable waste: food and kitchen waste, green waste, paper.
2. Recyclable material: paper, glass, bottles, cans, metals, certain plastics, fabrics, clothes, batteries etc.
3. Inert waste: construction and demolition waste, dirt, rocks, debris.
4. Electrical and electronic waste (WEEE)- electrical appliances, TVs, computers, screens, etc.
5. Composite wastes: waste clothing, Tetra packs, waste plastics such as toys.
6. Hazardous waste including most paints, chemicals, light bulbs, fluorescent tubes, spray cans, fertilizer and containers.

7. Toxic waste including pesticide, herbicides, fungicides
8. Medical waste. (https://en.wikipedia.org/wiki/Municipal_solid_waste)

2.4 Disposal System

One aspect of waste management in Akwa Ibom State that needs urgent attention is the disposal system. The State Waste Management Authority is yet to adopt the sanitary landfill/controlled tipping method in which the refuse is dumped in accordance with preconceived plan, compacted and covered during and at the end of each day. Unregulated open waste disposal sites consume more space which has become a breeding ground for insects and rodents. It has resulted in spontaneous ignition accompanied by smokes and smells and has resulted in leachate that pollutes underground water. The open dumpsites consist of tipping sites, burrow pits and erosion gullies. For instance, up till now, Uyo, Aba and Onitsha cities have conveniently been using erosion gullies as dumpsites of their solid wastes. The use of erosion gullies is reported to be restricted to areas of structural instability found within the sedimentary rocks of region of Eastern Nigeria. Uyo dumpsite is a ravine adjoining Udo, Eka streets and University of Uyo.

Eja *et al* (2010) reported that the composition, storage and disposal of solid waste in Uyo metropolis potentially have environmental and public health implications. However, the disposal sites are open dumps where aerial pollution may be very high as wastes are discharged from the trucks, especially at distances within a few metres from the dumpsite. Groundwater is also easily polluted due to leachates which percolate through the porous and permeable sedimentary rocks into the water table.

2.5 Contamination

Contamination takes place when an element or substance is present in higher-than-normal levels of concentration. When such concentration leads to severe harmful effects to living organisms, it is called pollution. Infiltration of rainfall into landfill together with the biochemical and chemical breakdown of the wastes produces leachate which is high in suspended solids and of varying organic and inorganic contents (Mosuro *et al*.,2017). Leachate is any liquid that, in the course of passing through matter extracts soluble or suspended solids, or any other component of the material through which it has passed. If the leachate enters surface or groundwater before sufficient dilution occurs, serious contamination incidents would transpire (Desa *et al*.,2009).

The fluid phase of interest in many near-surface studies these days is neither water nor air, but a contaminant that has been introduced from surface or subsurface sources (Butler,2005). A contaminant can be defined as any substance occurring due to human activities that degrades water quality with respect to a defined Standard. There is a wide range of contaminants. Fetter (1993) gives an extensive list of synthetic organic chemicals, hydrocarbons, inorganic cations and anions, pathogens, and radionuclides that have been identified as groundwater contaminants.

Waste disposal and pollution are intimately related. Both concern the presence and handling of certain chemicals in our environment. A pollutant sometimes is defined simply as a "chemical out of place," a substance found in sufficient concentration in some setting that it creates a nuisance or a hazard (McKinney and Schoch, 2003). In the past, the purity and sanitary quality of groundwater was assumed, and even when groundwater resources were used for drinking water supplies, little or no treatment was thought to be required. But in recent years, there is growing evidence that this resource is being contaminated locally

(Kovalevsky *et al*.,2004). The main pollution sources are municipal and industrial wastes, sewage treatment and disposal, spills and leaks from storage and transport of liquids, well injection of liquid wastes, agricultural activities, and mining.

The most important causes of groundwater quality deterioration are different kinds of pollution and over-exploitation of aquifers that change the groundwater flow dynamics (Kovalevsky *et al*.,2004). Groundwater pollution is understood to be a process whereby due to human impact, water suddenly or gradually changes its physical, chemical or biological composition and ceases to meet the criteria set for drinking water (Kovalevsky *et al*.,2004). If it contains hazardous or toxic compounds, water becomes dangerous for people and other living organisms and ecosystems. The vulnerability of a groundwater system to changes in its quality depends on hydrogeological conditions, on the above-mentioned chemical, physical and biological processes in soil, rock, and groundwater, and the type and intensity of pollution (Kovalevsky *et al*.,2004).

In this respect, groundwater quality is of particular importance, as it accounts for nearly one hundred percent of drinking water supply for the population of less- developed countries (Kovalevsky *et al*.,2004). Due to its mobility and ability to transport, transform and absorb pollutants, groundwater is becoming one of the most potentially dangerous contaminating media. It has been reported that in less developed countries, polluted water may cause eighty percent of diseases (Kovalevsky *et al*.,2004). By comparison with surface water, groundwater's self-purification potential is markedly lower and lessens with the aquifer's depth, depending on the declining amount of dissolved oxygen (Kovalevsky *et al*.,2004).

2.6 Principles of Electrical Resistivity Methods

Electrical resistivity is a fundamental and diagnostic physical property that can be determined by a wide variety of techniques, including electromagnetic induction. That there are alternative techniques for the determination of the same property is extremely useful, as some methods are more directly applicable or practicable in some circumstances than others (Reynolds, 2011). Furthermore, the approaches used to determine electrical resistivity (Fig. 2.2) may be quite distinct - for example, ground contact methods compared with airborne induction techniques.

There are three ways in which electric current can be conducted through a rock: electrolytic, electronic (ohmic) and dielectric conduction. Electrolytic conduction occurs by the relatively slow movement of ions within an electrolyte and depends upon the type of ion, ionic concentration and mobility. Electronic conduction is the process by which metals, for example, allow electrons to move rapidly, so carrying the charge. Dielectric conduction occurs in very weakly conducting materials (or insulators) when an external alternating current is applied, so causing atomic electrons to be shifted slightly with respect to their nuclei. In most rocks, conduction is by way of pore fluids acting as electrolytes, with the actual mineral grains contributing very little to the overall conductivity of the rock (except where those grains are themselves good electronic conductors). At the frequencies used in electrical resistivity surveying, dielectric conduction can be disregarded. However, it does become important in 'spectral induced polarization' and in 'complex resistivity' measurements (Reynolds, 2011).

The range of resistivities among rocks and rock materials is enormous, extending from 10^{-5} to 10^{15} Ωm (Dobrin, 1976). Rocks and minerals with resistivities from 10^{-5} to 10^{-1} Ωm are considered good conductors; those from 1 to 10^{7} Ωm, intermediate conductors, and those from 10^{8} to 10^{15} Ωm poor conductors. Also, Keller (1966) established table (Table 2.3) showing the ranges within which resistivities have been observed for several types of water-bearing rocks.

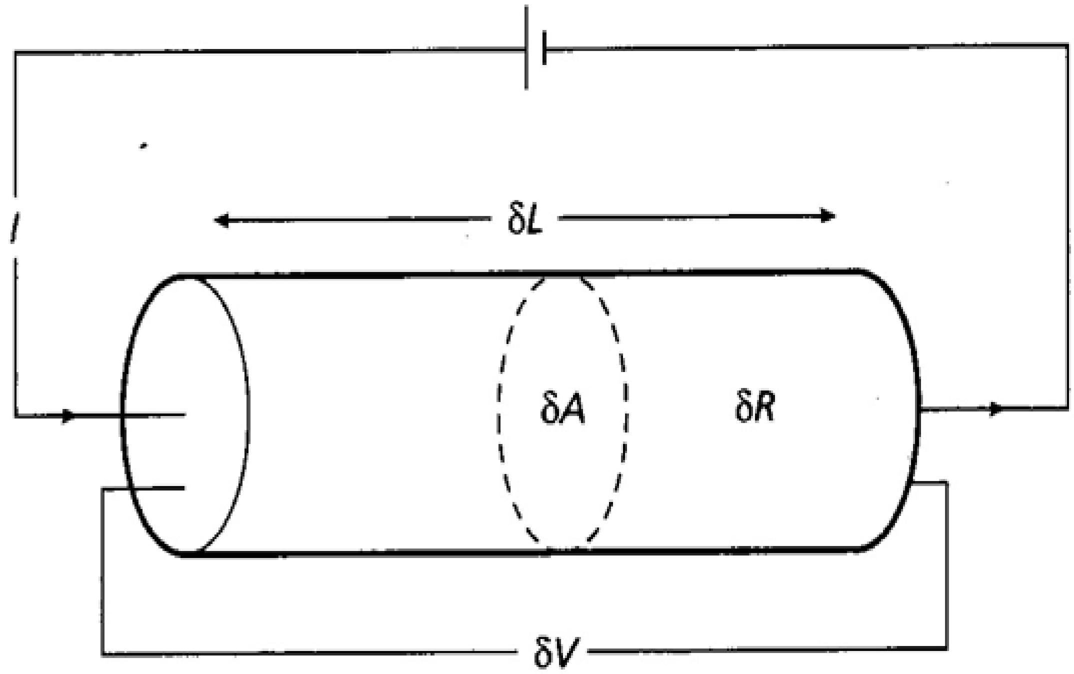


Fig. 2.2: The parameters used in defining electrical resistivity (Kearey *et al*.,2002

Table 2.3 Resistivities for Water-bearing Rocks of Various Types (Keller,1966).

Geologic Age	Marine Sand, Shale, Graywacke	Terrestrial Sands, Claystone, Arkose	Volcanic Rocks, Basalt, Rhyolite, Tuffs)	Granite, Gabbro, etc	Limestone, Dolomite, Anhydrite, Salt
Quaternary, Tertiary	1-10	15-50	10-200	500-2000	50-5000
Mesozoic	5-20	25-100	20-500	500-2000	100-10000
Carboniferous	10-40	50-300	50-1000	1000-5000	200-100000
Pre-Carboniferous Paleozoic	40-200	100-500	100-2000	1000-5000	10000-100000
Precambrian	100-2000	300-5000	200-5000	5000-20000	10000-100000

Fig. 2.3 shows the effect of geologic age upon the resistivity of sedimentary rocks. The horizontal lines show the range of resistivities measured around radio stations for sedimentary rocks with apparently similar lithologic characteristics having ages which cover the entire range of geologic time. Normally one would expect a fairly uniform increase of

resistivity with geological age because of the greater compaction associated with increasing thickness of overburden. But the anomalously high resistivities of the Tertiary rocks reflect the fact that the deposition at this time was mainly in fresh water rather than in saltwater, as was the case during the Mesozoic (Dobrin,1976).

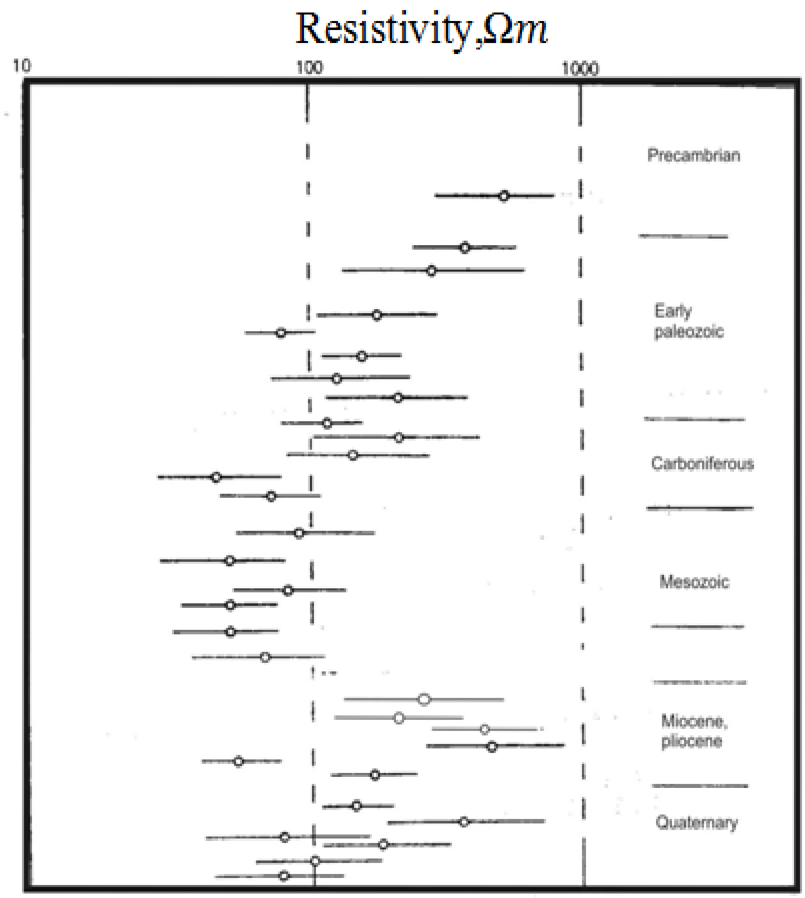


Fig. 2.3**:** Average resistivity for sedimentary rocks of various geologic Ages (Dobrin, 1976) *Each bar indicates the range within which 95 percent of the values fall for the group indicated*.

There is no consistent difference between the range of resistivities of igneous and sedimentary rocks, although metamorphics appear to have a higher resistivity, statistically, than either of the other types. Certain rock materials, including some that are sought in mining exploration, tend to have anomalously low resistivities (high conductivities) with respect to surrounding rocks. This makes it possible to locate them by measuring resistivity with instruments on the surface. The resistivity of rocks usually depends upon the amount of groundwater present and on the amount of salts dissolved in it, but it is also decreased by the presence of many ore minerals and by high temperatures.

The main uses of resistivity surveying are therefore for mapping the presence of rocks of differing porosities, particularly in connection with hydrogeology for detecting aquifers and contamination, and for mineral prospecting. Other uses include investigating saline and other types of pollution, archaeological surveying, and detecting "hot" rocks (Musset and Khan, 2000). Resistivity surveying investigates the subsurface by passing electrical current through it by using electrodes pushed into the ground. Traditionally, techniques have either been designed to determine the vertical structure of a layered earth, as vertical electrical sounding, VES, or lateral variation, as electrical profiling; however, more sophisticated electrical imaging methods are increasingly being used when there are both lateral and vertical variations.

The objective of most modern electrical resistivity surveys is to obtain true resistivity models for the subsurface, because it is these that have geological meaning (Reynolds,2011). Data from resistivity surveys are customarily presented and interpreted in the form of values of apparent resistivity (ρ_a). The word 'apparent' is used to denote the fact that the measured values are a function of the volume of earth beneath the sensors and the array geometry and is not the actual resistivity at the plotted point or beneath one of the dipoles (Butler,2005). Apparent resistivity is defined as the resistivity of an electrically homogeneous and isotropic half-space that would yield the measured relationship between the applied current and the potential difference for a particular arrangement and spacing of electrodes.

The apparent resistivity is the value obtained as the product of a measured resistance (*R*) and a geometric factor (*K*) for a given electrode array.

$$P_a \quad = \quad R \times K \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad 2.1$$

The geometric factor considers the geometric spread of electrodes and contributes a term that has the unit of length (metres). Apparent resistivity (ρ_a) has units of Ohm-metres according to equation 2.1.

In reality, the subsurface ground does not conform to a homogeneous medium and thus the resistivity obtained is no longer the 'true' resistivity but the apparent resistivity(ρ_a), which can even be negative (Reynolds, 2011). It is very important to remember that the apparent resistivity is not a physical property of the subsurface media, unlike the true resistivity. Consequently, all field resistivity data are apparent resistivities, while those obtained by interpretation techniques are 'true' resistivities. The term "apparent resistivity" applies to the hypothetical assumption, that the subsurface is electrically homogeneous (which generally it is not). It is also used, since it does not mean the resistivity of any kind of subsurface material, but depends on the electrical resistance, offered by various subsurface layers, furthermore depending on the depth of current penetration. Because the earth is not homogeneous and isotropic, the measured resistivity is generally addressed as *apparent resistivity* ρ_a: the resistivity appears to belong to a homogeneous earth, which is not the case (Kovalevsky, *et al*., 2004). Actual resistivity is determined in the interpretation process with the aid of computer modelling and inversion (Butler,2005).

Wherever these measurements are made over a real heterogeneous earth, as distinguished from the fictitious homogeneous half-space, the symbol ρ is replaced by ρ_a for apparent resistivity. The resistivity surveying problem is, reduced to its essence, the use of apparent resistivity values from field observations at various locations and with various electrode configurations to estimate the true resistivities of the several earth materials present at a site and to locate their boundaries spatially below the surface of the site.

An electrode array with constant spacing is used to investigate lateral changes in apparent resistivity reflecting lateral geologic variability or localized anomalous features. To investigate changes in resistivity with depth, the size of the electrode array is varied. The apparent resistivity is affected by material at increasingly greater depths (hence large volume) as the electrode spacing is increased. Because of this effect, a plot of apparent resistivity against electrode spacing can be used to indicate vertical variations in resistivity. An equation giving the apparent resistivity in terms of applied current, distribution of potential, and arrangement of electrodes can be arrived at through an examination of the potential distribution due to a single current electrode. The effect of an electrode pair (or any other combination) can be found by superposition. Consider a single point electrode, located on the boundary of a semi-infinite, electrically homogeneous medium, which represents a fictitious homogeneous earth. If the electrode carries a current I, measured in amperes (A), the potential at any point in the medium or on the boundary is given by

$$U = \rho \frac{I}{2\pi r} \qquad 2.2$$

Where,

U = potential, in V, ρ = resistivity of the medium, r = distance from the electrode.

For an electrode pair with current I at electrode A, and -I at electrode B (figure2.4), the potential at a point is given by the algebraic sum of the individual contributions:

$$U = \frac{\rho I}{2\pi r_A} - \frac{\rho I}{2\pi r_B} = \frac{\rho I}{2\pi}\left[\frac{1}{r_A} - \frac{1}{r_B}\right] \quad 2.3$$

Where,

r_A and r_B = distances from the point to electrodes A and B.

Fig. 2.4 illustrates the electric field around the two electrodes in terms of equipotential and current lines. The equipotential represent imagery shells, or bowls, surrounding the current electrodes, and on any one of which the electrical potential is everywhere equal. The current lines represent a sampling of the infinitely many paths followed by the current, paths that are defined by the condition that they must be everywhere normal to the equipotential surfaces.

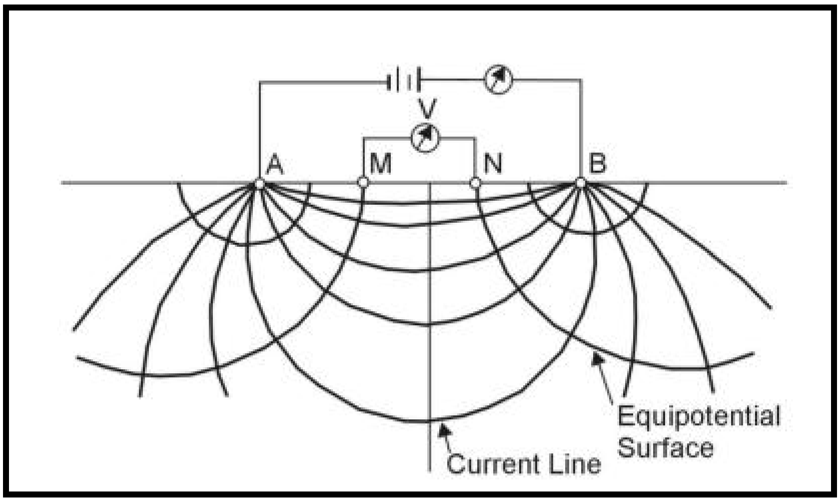


Fig. 2.4: Equipotentials and current lines for a pair of current electrodes A and B on a homogeneous half-space. (Wightman, *et al*., 2003).

In addition to current electrodes A and B, Fig. 2.4 shows a pair of electrodes M and N, which carry no current, but between which the potential difference (V) may be measured. Following the previous equation, the potential difference (V) may be written;

$$V = U_M - U_N = \frac{\rho I}{2\pi}\left[\frac{1}{AM} - \frac{1}{BM} + \frac{1}{BN} - \frac{1}{AN}\right] \qquad 2.4$$

Where

U_M and U_N = potentials at M and N, AM = distance between electrodes A and M.

These distances are always the actual distances between the respective electrodes, whether or not they lie on a line. The quantity inside the brackets is a function only of the various electrode spacings. The quantity is denoted $1/K$, which allows rewriting the equation as:

$$V = \frac{\rho I}{2\pi}\,\frac{1}{K} \qquad 2.5$$

The resistivity of the medium can be found from measured values of ***V, I,*** and ***K,*** the geometric factor. ***K*** is a function only of the geometry of the electrode arrangement.

Equation 2.5 can be resolved for ρ to obtain:

$$\rho = 2\pi K\frac{\Delta v}{I} \qquad \text{(Reynolds,2011)} \qquad 2.6$$

There are two main modes of deployment of electrode arrays: one is for depth sounding (to determine the vertical variation of resistivity) - this is known as vertical electrical sounding, VES. The other is for producing either a horizontal profile (lateral variation of resistivity) using a fixed electrode separation (called constant separation traversing, CST) or both a lateral and vertical variation in resistivity (called subsurface imaging, SSI, or electrical resistivity tomography, ERT).

The choice of array and its dimensions largely depend upon the target: its size, depth, and resistivity contrast with its surroundings (Musset and Khan, 2000). Electrode spacing must be large enough to achieve penetration to the target, but the larger the spacing the poorer the resolution, both laterally and vertically, so it may not be possible to detect a small body at depth. The objective is to deduce the depths and resistivities of layers as precisely as possible. The Schlumberger and Wenner arrays are used, but the former has the advantage that its smaller separation of the potential electrodes reduces noise due to ground currents (from industrial and telluric sources) which may limit the useful depth of penetration.

In a survey with varying electrode spacing, field operations with the Schlumberger array are faster, because all four electrodes of the Wenner array are moved between successive observations, but with the Schlumberger array, only the outer ones (the current electrodes) need to be moved. The Schlumberger array is also said to be superior in distinguishing lateral from vertical variations in resistivity. On the other hand, the Wenner array demands less instrument sensitivity, and reduction of data is marginally easier (Wightman et al.,2003).

The Schlumberger array differs from the Wenner array in having the P electrodes much closer together, though still placed symmetrically about the centre of the array. Readings are taken with only the current, C, electrodes being moved progressively and symmetrically apart. Moving only the C electrodes has two advantages: there are fewer electrodes to move, and with the P electrodes fixed, the readings are less affected by any lateral variations that may exist. However, when expansion causes the value of ΔV to become so small that it cannot be measured precisely, the P electrodes are moved much further apart, while keeping the C electrodes fixed; then further readings are taken by expanding the C electrodes using the new P electrode positions.

For this array (Fig. 2.5a), in the limit as ‘a’ approaches zero, the quantity V/a approaches the value of the potential gradient at the midpoint of the array. In practice, the sensitivity of the instruments limits the ratio of s to a and usually keeps it within the limits of about 3 to 30.

Therefore, it is typical practice to use a finite electrode spacing and equation 2.7 to compute the geometric factor (Keller and Frischknecht, 1966). The apparent resistivity (ρa) is

:$\rho_a = \pi\left[\frac{s^2}{a} - \frac{a}{4}\right]\frac{V}{I} = \pi a\left[\left(\frac{s}{a}\right)^2 - \frac{1}{4}\right]\frac{V}{I}$ (Wightman *et al.* 2003) 2.7

In usual field operations, the linear (potential) electrodes remain fixed, while the outer (current) electrodes are adjusted to vary the distance s. The spacing a is adjusted when it is needed because of decreasing sensitivity of measurement. The spacing a must never be larger than 0.4s or the potential gradient assumption is no longer valid. Also, the ‘a’ spacing may sometimes be adjusted with s held constant in order to detect the presence of local inhomogeneities or lateral changes in the neighbourhood of the potential electrodes. In more recent years the Schlumberger array generally has been the preferred method in groundwater investigations, although the Wenner array also is commonly used.

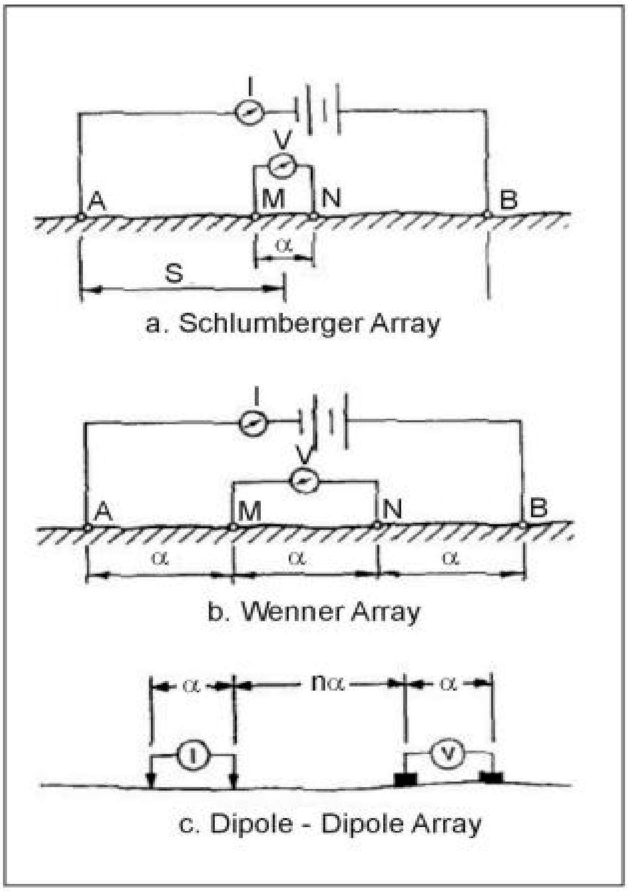


Fig. 2.5a,b,&c: Electrode array configurations for resistivity measurements

(Wightman, *et al*.,2003)

Advantages of the Schlumberger array over the Wenner array include the following (Zohdy et al.,1974) :

- Sounding curves provide slightly greater probing depth and resolving power than Wenner soundings for equal AB electrode spacing.
- Less manpower and time are required for making soundings than for a Wenner array.
- When wide electrode spacings are used, stray currents in industrial areas and telluric currents are more likely to affect measurements with the Wenner array.
- The Schlumberger array is more sensitive in measuring lateral variations in resistivity.
- The Wenner array is more susceptible to drifting or unstable potential differences created by driving electrodes into the ground.
- Schlumberger sounding curves can be more readily smoothed.

The direct current (DC), also called "galvanic" electric resistivity method measures the resistance to flow of electricity in subsurface material. DC methods involve the placement of electrodes, called current electrodes, on the surface for injection of current into the ground. The current stimulates a potential response between two other electrodes, called potential electrodes, that is measured by a voltmeter. Resistivity (measured in ohm-meters) can be calculated from the geometry and spacing of the electrodes, the current injected, and the voltage response.

The resistivity (given the symbol ρ 'rho') characterizes the material independent of its shape; it is measured in Ohm-m (the inverse of resistivity, $1/\rho$ called conductivity and given the symbol σ,sigma, is also used) (Fig. 2.6). Resistivity is the quantity investigated by resistivity surveying (Musset and Khan,2000).

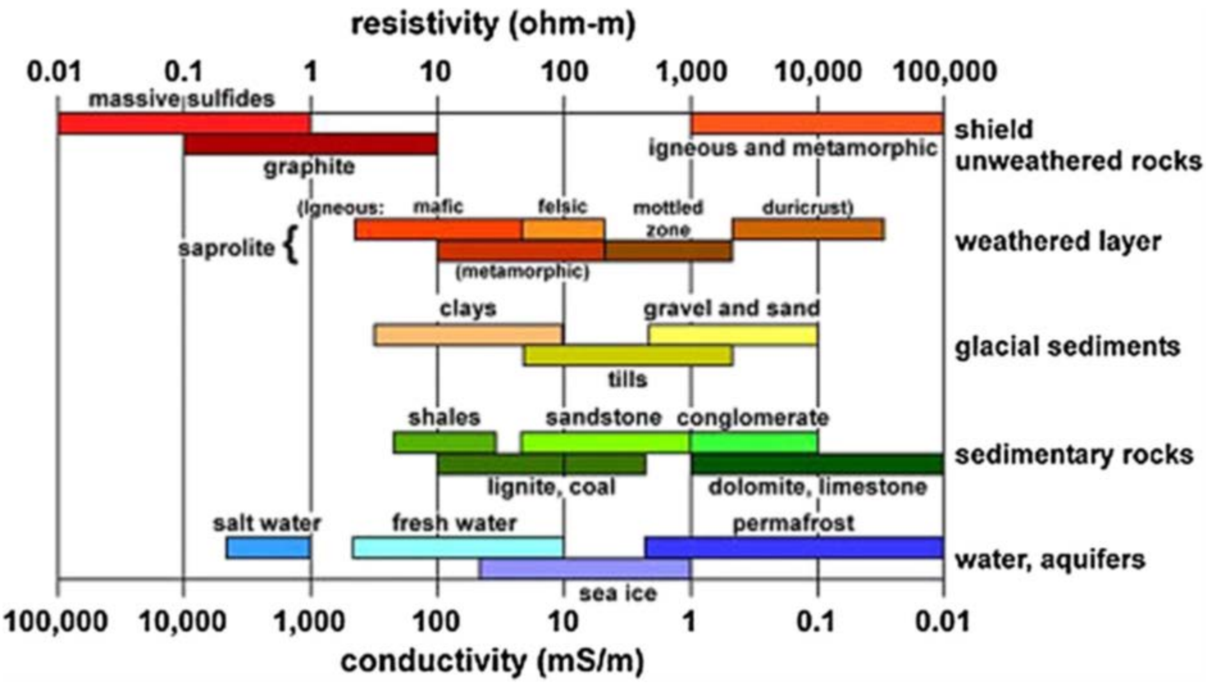


Fig. 2.6: Typical range of conductivities (mS/m) and resistivities (Ωm) of geological materials (Butler,2005).

Direct current (DC) resistivity imaging or electrical resistivity tomography (ERT) is an effective tool to obtain the subsurface resistivity image with high resolution and has been used in various applications (Singh *et al*.,2018). It provides information about subsurface conductors by injecting the electric current into the earth and measuring the injected current and potential differences at various locations using various electrode configurations. The electrodes could be located at the surface and/or in boreholes.

2.7 Review of Hydrogeochemical Method

An analysis of groundwater may range from a value for a single component to a long list of inorganic, organic and biological measurements. The selection of the constituents for analysis is determined both by the overall objective of the investigation and the specific purpose of the chemical and biological analysis (Kovalevsky *et al* 2004). Because of the complexity of many diverse problems for which analyses may be useful, there is no ‘standard’ analysis. For example, the suite of inorganic constituents for geochemical prospecting is appreciably different from the constituents used to monitor a landfill or to determine the effects of mineral diagenesis. However, the conventional point of view has been that a standard inorganic analysis consists of determination of the four major cations (calcium, magnesium, sodium, and potassium) and the three major anions (bicarbonate, sulphate, chloride) together with pH, electrical conductivity and temperature. If there is anthropogenic contamination, nitrate must also be determined. Aluminium becomes increasingly important when the pH is 6 or lower. Dissolved Fe (II) and Mn (II) may occur as major species in anaerobic groundwater. Ammonium, F, PO4, H2S and CH4 are of secondary importance; their analysis is often crucial to resolve the evolution of groundwater quality along flow lines.

2.7.1 Evaluation of groundwater chemical data

Chemical groundwater data are interpreted to find out where the ions come from, how they reach their concentration, what is their form and behaviour, where they are going, and how fast (Kovalevsky *et al* 2004). A first evaluation of the groundwater quality is whether the water is fresh, brackish or salt (Table 2.3).

Nowadays, the amount of dissolved salts is most commonly expressed in one of the following ways:

- The electrical conductivity (EC) of water expressed in S/cm or in µS/cm (10^{-6}S/cm) for fresh water, or in mS/cm (10^{-3} S/cm) for salt water; where S stands for Siemens (formerly called mho), the inverse of the resistance expressed in Ohm (Ω);
- Salinity, where total dissolved solids is expressed as parts per thousand of unit weight of water, for example, normal seawater has a salinity of about 35%;
- Total dissolved solids (TDS) which is the residue on evaporation at 105^0C or 180^0F. A classification of water based on TDS is given in Table 2.3.

The evolution of groundwater in the study area can be explained by the order of encounter as stated by Freeze and Cherry (1979). The theory states that the order in which groundwaters encounter strata of different mineralogical composition can exert an important control on the final water chemistry. As groundwater flows through strata of different mineralogical composition, the water composition undergoes adjustments caused by imposition of new mineralogically controlled thermodynamic constraints.

The concept of hydrogeochemical facies has been used (Seabed 1962, Morgan and Winner, Back 1960) to denote the diagnostic chemical character of water solutions in hydrologic systems (Back,1966). The facies reflect the effect of chemical processes occurring between the minerals of the lithologic framework and the groundwater. The subsequent flow patterns modify the facies and controls their distribution.

According to Edet (1993), the study area belongs to type 2 hydrogeochemical facies namely calcium-sodium-chloride-sulphate-bicarbonate. Groundwater geochemistry indicates the water to be soft, potable, and good for domestic and other purposes. The waters are of low alkalinity, slightly acidic, and aggressive (pH 5.0-8.3). Such water would be corrosive and therefore would attack carbonate minerals as wells as borehole materials. The relatively high salinity of the water can be explained as being due to localized hydrogeological processes going on in the study area rather than seawater intrusion. In the same vein, Esu *et al* (1999) inferred the groundwater temperature to be in the order of 24 to 27^0C. The total dissolved solids (TDS) varied from 72.8 to 300.5ml/ and 1050mg/l respectively. Generally, the chloride content of the groundwater is low, varying from 3.4 to 72.5mg/l. This is an indication that the groundwater under study is from shallow depth or low residence time.

2.8 Fluid Components of near-surface materials

Fluids occupy the void space between the solid components in the geological materials. The void space can include pores, vugs, cracks, faults, fractures, and can be interconnected or disconnected. The two fluids that occur naturally in the near-surface region are water and air.

The water contained in near-surface materials, referred to as *groundwater*, contains dissolved inorganic and organic components. The chemical composition of the water is most commonly described in the groundwater literature in terms of the total dissolved solids (TDS) given in units of milligrams of solute per litre (or kilogram) of water, mg/l. This is also referred to using the equivalent units of parts per million, ppm, that is, 1g of solute per 10^6 of solution. Another commonly used concentration unit is molarity M which is the number of moles of solute in 1m^3 of solution, expressed using the units mol/m^3. To convert from mg/l or ppm to molarity requires knowing the identity and formula weight of the contained solutes:

$$\text{molarity} = \frac{milligrams\ per\ litre}{1000 * formula\ weight} \qquad 2.8$$

In Table 2.4 is a list of various categories of groundwater and the corresponding TDS (Freeze and Cherry, 1979). For comparison, TDS in water is 5 to 10 mg/l, and in seawater is approximately 35 000 mg/l.

The pH of groundwater is also important aspect of its composition as pH determines the solubility of minerals and thus the concentration of chemical species in the water. While pH = 7 is defined as neutral, natural rainwater has a pH = 5.7, so is slightly acidic. The pH of natural waters can range from values as low as 3 in regions affected by acid mine drainage, to 8.1 in seawater.

Table 2.4 Simple classification scheme for water using TDS (from Freeze and Cherry, 1979)

Category	TDS (mg/L) or ppm
Fresh	0 – 1000
Brackish	1000 - 10 000
Saline	10 000 - 100 000
Brines	100 000+

The specific chemical composition of the groundwater, that is, the identity of the dissolved species, is slightly variable and is determined over time by the geochemical processes involving the interaction of the water with the solids. In general, the major constituents (greater than 5 mg/l) are bicarbonate, calcium, chloride, and magnesium: these occur mainly in ionic form. In the near-surface, with repeated cycles of wetting and drying, it is often the case that the groundwater is not in equilibrium with the surrounding solid. This makes the prediction of water chemistry very difficult, and direct sampling of the water is often the only way to accurately determine the composition.

The other fluid occurring naturally in the near-surface of the earth is air, which coexists with the water as a separate gas phase in the vadose or unsaturated zone, and as a dissolved phase in the water in both vadose and in the water-saturated region. The electrical and elastic properties of the air are so different from those of water that the presence of air can result in a large change in geophysical properties.

The fluid phase of interest in many near-surface studies these days is neither water nor air, but a contaminant that has been introduced from surface or subsurface sources. A contaminant can be defined as any substance occurring due to human activities that degrades water quality with respect to a defined standard. Once a certain parameter occurs above permissible limit, there is pollution. There is a wide range of contaminants; Fetter (1993) gives an extensive list of synthetic organic chemicals, hydrocarbons, inorganic cations and anions, pathogens, and radionuclides that have been identified as groundwater contaminants.

In considering the geophysical properties and detection of groundwater contaminants, it is useful to refer to two major categories; aqueous phase and immiscible phase contaminants. An aqueous phase contaminant is one where the pore water contains dissolved ionic species (e.g., inorganic cations and anions such as arsenic) or miscible fluids (e.g., ethanol). Immiscible phase contaminants exist as separate fluids within the pore space. Liquid immiscible contaminants, also referred to as nonaqueous phase liquids (NAPLs), are defined on the basis of their density relative to water. Light nonaqueous phase liquids (LNAPLs), such as benzene, are less dense than water and will float on the top of the saturated zone. Dense nonaqueous phase liquids (DNAPLs), such as perchloroethene, are denser than water and will migrate into the saturated zone. Immiscible vapour phase contaminants originating from volatile organic compounds can occur in the vadose zone. While the physical properties of these vapour phases do not differ significantly from those of air, they can alter the physical properties of the vadose zone system (e.g., through changing residual water saturation).

2.9 Tomography

The fundamentals of the electrical resistivity tomography (ERT) method have been described by several authors. Briefly, two stainless steel electrodes are used to inject a direct electrical current (I, in amperes) into the soil, while two other electrodes are used to measure the resulting potential difference (ΔV, in volts) (Dumont *et al*.,2018). The common arrays used are Schlumberger, Wenner and dipole-dipole, depending on application and the resolution desired (Loke,1999). Electrical tomography has many applications in geology, hydrogeology and environmental studies. Examples include: determination of the depth and thickness of geological strata, detection of lateral changes and locating anomalous geological conditions, locating buried wastes (e.g., landfill), mapping saltwater intrusion and contaminated plumes (Pomposiello *et al*.,2012). This electrical resistivity imaging survey is widely used to control the depth, extent and geometry of the landfill. Frequent monitoring of landfill leachate with this technique allows early leak detection. In subsurface imaging (SSI), also known as electrical resistivity tomography (ERT), typical 50 electrodes are laid out in two strings of 25, with electrodes connected by a multi-core cable to a switching box and resistance metre, or a single cable connecting 72 or more electrodes. The whole data acquisition procedure is software - controlled from a laptop computer (Reynolds,2011).

The value of tomographic methods is that they can be used whether variations are vertical or lateral or when there are no discontinuities, though resolution is usually poor and often the methods are complex to carry out.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

3.1.1 Equipment for Resistivity Survey

The geoelectrical resistivity survey within the study area involved the use of the GEOTRON (Model G41) resistivity meter and OHMEGA resistivity meter (Figs. 3.1a and b).

The GEOTRON (Model G41) resistivity meter has potential and current electrodes, 4 reels of cables of 700m long for current electrodes and 200m for potential electrodes, measuring tape, GPS, data reporting sheet, field note book, pen, pencil and geologic hammers for the collection of field resistivity data. The South African made resistivity meter (GEOTRON G41) has a very high precision in giving accurate results and has the advantage of instantly converting resistivity values to apparent values, making data collection easy and with less time. This is a great advantage over other resistivity meters where field resistivity values are multiplied with the Geometric factor (K) to obtain apparent values, which is usually time - consuming.

The OHMEGA Ω is a high-quality portable earth resistance meter capable of accurate measurement over a wide range of conditions. It has a maximum power output of 36 watts, manual selection of current in steps up to 200 mA, a choice of sample time / signal length averaged and three frequency settings. The OHMEGA receiver incorporates automatic gain steps, which provide a range of measurements from 0.001 Ω to 360k Ω. The instrument is powered by a large capacity internal rechargeable battery providing several days of use without recharging in average terrain conditions. External power can be by way of any 12 VDc source, the most common type being a vehicle battery (with caution as some trucks use

24VDc). The OHMEGA resistivity (Ω) is housed in an impact-resistant Peli Case, the case benefits form a lifetime guarantee.

Fig. 3.1a: A GEOTRON (Model G41) Resistivity Meter

Fig. 3.1b: OHMEGA Resistivity Meter

3.2 Methods

The Schlumberger configuration was used with current electrode spacing (AB/2) ranging between a minimum value of 1.5m and maximum value of 150m in some areas with enough space and 80m in some places with limited space. The potential electrode spacing (MN/2) ranged between a minimum value of 0.5m to a maximum value of 30m for areas with much space and 10m for areas with limited space. The GEOTRON G41 resistivity meter (plate 1 A and B) has the components of a voltmeter and ammeter installed together. It can be used to carry out Spontaneous Potential (SP) survey, Electrical resistivity survey using Schlumberger, Wenner and Pole- Dipole survey configurations. There is a special control switch to be used for any choice of these surveys. There is also a control switch to turn on and off the meter and another to take measurements when the meter is on. It has 4 sockets, 2 for the connection of current pins tied to current cables and the other 2 for the connection of potential pins tied to the potential cables. In the 4- point configuration such as the Schlumberger used here, current is being introduced into the earth surface by means of the 2 current electrodes A-B(Fig.2.6a) planted on the ground and connected to the resistivity meter by means of the 2 cables earlier mentioned, and the current input is measured by the ammeter in the resistivity meter. The potential drop or impedance to current flow known as resistance is then recorded by the voltmeter through the potential electrodes also planted on the ground and connected to the resistivity meter, and these records are both modified to give the resistivity of the subsurface below the survey station. The further the current electrode spacing, the deeper the depth of penetration but the poorer the resolution. The Schlumberger array was used to collect Vertical Electrical Sounding (VES) data along profile lines with survey stations placed at equal intervals (30m) apart. The coordinates of each station were taken using the global positioning system (GPS) equipment and the results are shown in Table 3.1.

Four- point Multiple Vertical Electrical Sounding (MVES) such as the Schlumberger array run at constant stations interval along a profile is synonymous with Electrical Resistivity Tomography (ERT) and gives subsurface layered resistivity images in two dimensions when modelled. The advantage of this survey type is that it allows the subsurface variation of resistivity values to be modelled both vertically and laterally, thus giving a clear resistivity image of the subsurface in 2D. Vertical electrical sounding (VES) – also called depth sounding or sometimes electrical drilling – is used when the subsurface approximates to a series of horizontal layers, each with a uniform but different resistivity (Musset and Khan,2000). As the distance between the current electrodes is increased, so the depth to which the current penetrates is increased. For a depth sounding, measurements of the resistance ($\partial V/I$) are made at the shortest electrode separation and then at progressively larger spacings. At each electrode separation a value of apparent resistivity (ρ_a) is calculated using the measured resistance in conjunction with the appropriate geometric factor for the electrode configuration and separation being used. The values of apparent resistivity are plotted on a graph('field curve'), the X- and Y- axes of which represent the logarithmic values of the current electrode half-separation (AB/2) and the apparent resistivity (ρ_a), respectively. The resistivity data was modelled using the computer resistivity iteration and inversion software called IPI2WIN, which is quite efficient in modelling resistivity data both by plotting apparent resistivity values against half-current electrode spacing (AB/2), and also generating pseudo and resistivity cross sections to give the resistivity image of the subsurface in resistivity profiling.

Table 3.2a: Coordinates of VES Stations at Uyo Dumpsite

Label	Longitude (E)	Latitude (N)
P1VES1	$7^{0}56^{l}1.303^{ll}$	$5^{0}2^{l}31.051^{ll}$
P1VES2	$7^{0}56^{l}1.812^{ll}$	$5^{0}2^{l}32.025^{ll}$
P1VES3	$7^{0}56^{l}2.457^{ll}$	$5^{0}2^{l}33.135^{ll}$
P2VES4	$7^{0}56^{l}0.398^{ll}$	$5^{0}2^{l}32.773^{ll}$
P2VES5	$7^{0}56^{l}1.043^{ll}$	$5^{0}2^{l}33.628^{ll}$
P2VES6	$7^{0}56^{l}1.518^{ll}$	$5^{0}2^{l}34.857^{ll}$
P3VES7	$7^{0}55^{l}59.325^{ll}$	$5^{0}2^{l}33.454^{ll}$
P3VES8	$7^{0}55^{l}59.885^{ll}$	$5^{0}2^{l}34.462^{ll}$
P3VES9	$7^{0}56^{l}0.291^{ll}$	$5^{0}2^{l}35.708^{ll}$
P4VES10	$7^{0}55^{l}57.861^{ll}$	$5^{0}2^{1}36.303^{11}$
P4VES11	$7^{0}55^{l}58.369^{ll}$	$5^{0}2^{l}35.708^{ll}$
P4VES12	$7^{0}55^{l}59.014^{ll}$	$5^{0}2^{l}36.048^{ll}$

Table 3.2b: Coordinates of VES Stations at Ikot Ekpene Dumpsite

Label	Longitude (E)	Latitude(N)
P5VES13	$7^{0}42^{l}41.345^{ll}$	$5^{0}10^{l}30.682^{ll}$
P5VES14	$7^{0}42^{l}41.914^{ll}$	$5^{0}10^{l}30.953^{ll}$
P5VES15	$7^{0}42^{l}42.599^{ll}$	$5^{0}10^{l}31.39^{ll}$
P6VES16	$7^{0}42^{l}40.792^{ll}$	$5^{0}10^{l}31.51^{ll}$
P6VES17	$7^{0}42^{l}41.061^{ll}$	$5^{0}10^{l}31.873^{ll}$
P6VES18	$7^{0}42^{l}41.949^{ll}$	$5^{0}10^{l}31.873^{ll}$
P7VES19	$7^{0}42^{l}41.476^{ll}$	$5^{0}10^{l}31.873^{ll}$
P7VES20	$7^{0}42^{l}41.061^{ll}$	$5^{0}10^{l}32.197^{ll}$
P7VES21	$7^{0}42^{l}41.476^{ll}$	$5^{0}10^{l}32.376^{ll}$

Table 3.2c: Coordinates of VES Stations at Oron Dumpsite

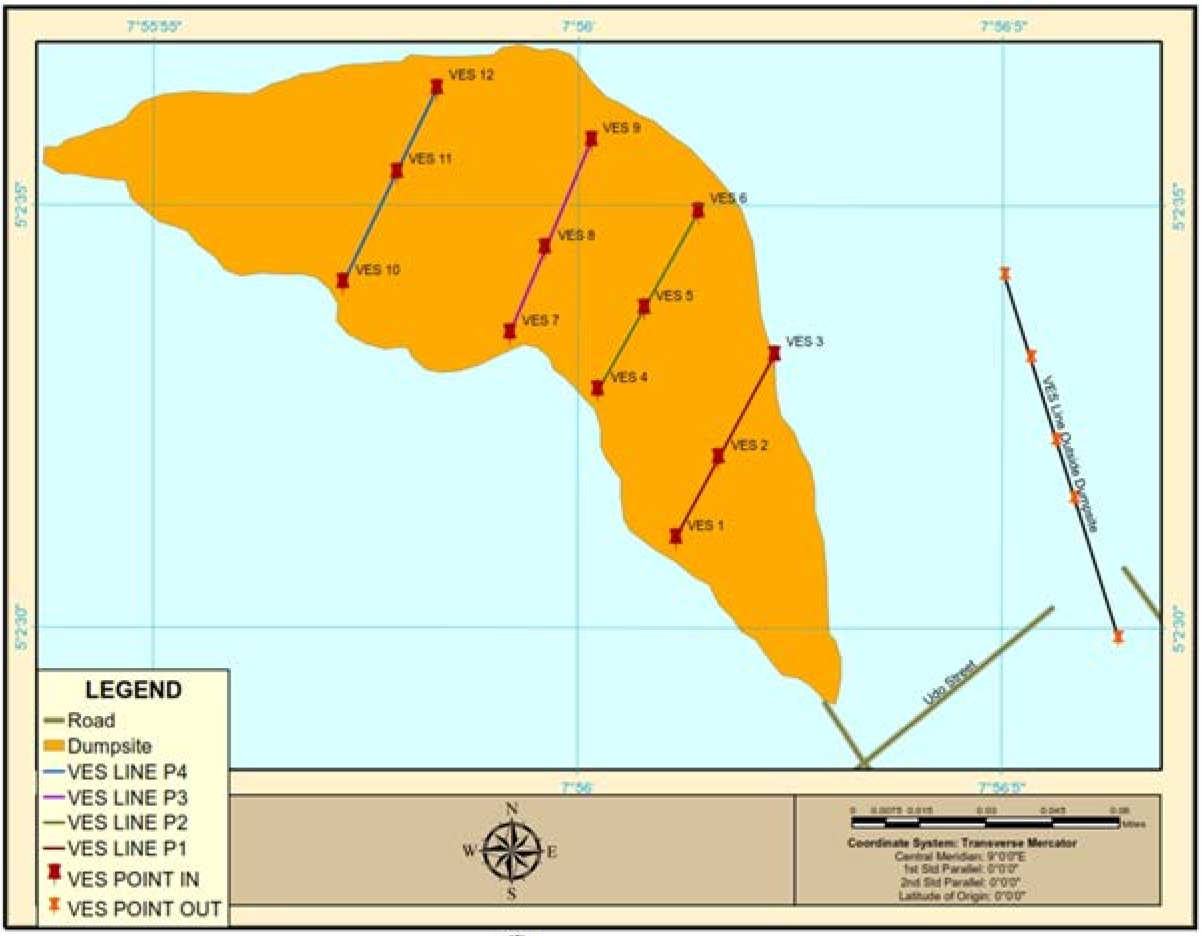
Label	Longitude (E)	Latitude (N)
P8VES22	$7^{0}56^{l}1.303^{ll}$	$5^{0}2^{l}31.051^{ll}$
P8VES23	$7^{0}56^{l}1.812^{ll}$	$5^{0}2^{l}32.025^{ll}$
P8VES24	$7^{0}56^{l}2.457^{ll}$	$5^{0}2^{l}33.135^{ll}$
P9VES25	$7^{0}56^{l}0.398^{ll}$	$5^{0}2^{l}32.773^{ll}$
P9VES26	$7^{0}56^{l}1.043^{ll}$	$5^{0}2^{l}33.628^{ll}$
P9VES27	$7^{0}56^{l}1.518^{ll}$	$5^{0}2^{l}34.857^{ll}$
P10VES28	$7^{0}55^{l}59.325^{ll}$	$5^{0}2^{l}33.454^{ll}$
P10VES29	$7^{0}55^{l}59.885^{ll}$	$5^{0}2^{l}34.462^{ll}$
P10VES30	$7^{0}56^{l}0.291^{ll}$	$5^{0}2^{l}35.708^{ll}$

3.2.1 Vertical Electrical Sounding

The vertical electrical sounding (VES) was carried out at three different sites within Akwa-Ibom State, Nigeria (Fig. 3.2 a-c) using two different resistivity meters namely; the GEOTRON (Model G41) and the OHMEGA resistivity meters. The Schlumberger electrode configuration having a maximum current electrode spread of 150 m was used. The apparent resistivity values obtained from the measurement were plotted against half the current electrode spacing on a bi-logarithmic graph in order to determine the apparent resistivities and thicknesses of various layers penetrated. This technique has been functional in groundwater exploration by various investigators such as Onwuemesi and Egboka (2006), Anudu *et al.* (2008), Oseji and Ujuanbi (2009), Okoro *et al.* (2010), Anakwuba *et al.* (2014), Ezeh (2011), Nfor, *et al.*(2007), Anizoba *et al.* (2015) and others. The generated curves from resistivity data were made possible by resistivity inversion software IPI2WIN after using the conventional manual curve - matching as a control to the modelled data. The software has been used in many similar research works and has proven very effective for groundwater investigation and vulnerability studies. The profile line data were also modelled with the help of the software to generate pseudo cross- sections that gave clear images of the subsurface in 2D.

In March 2014, a total of 8 Soundings along 2 profile lines (separated by 60m apart) were covered in Uyo dumpsite, and 4 Soundings along 2 profile lines each because of limited space for traversing, were covered in Ikot Ekpene and Oron Urban dumpsites respectively. There was also one sounding at each of the locations serving as the ‘Control’. GPS coordinates for each station were taken and appropriately documented and were helpful in modelling and development of surveyed area maps with field data.

In August 2016, a total of thirty (30) Soundings were run along ten (10) profiles (Fig. 3.2-3.4): 4 profiles at Uyo, 3 each at Ikot Ekpene and Oron. The field results are presented in the Appendix I.



(i)

(ii)

Fig. 3.2a: Map showing (i) the sounding points and (ii) pictures of Uyo dump site

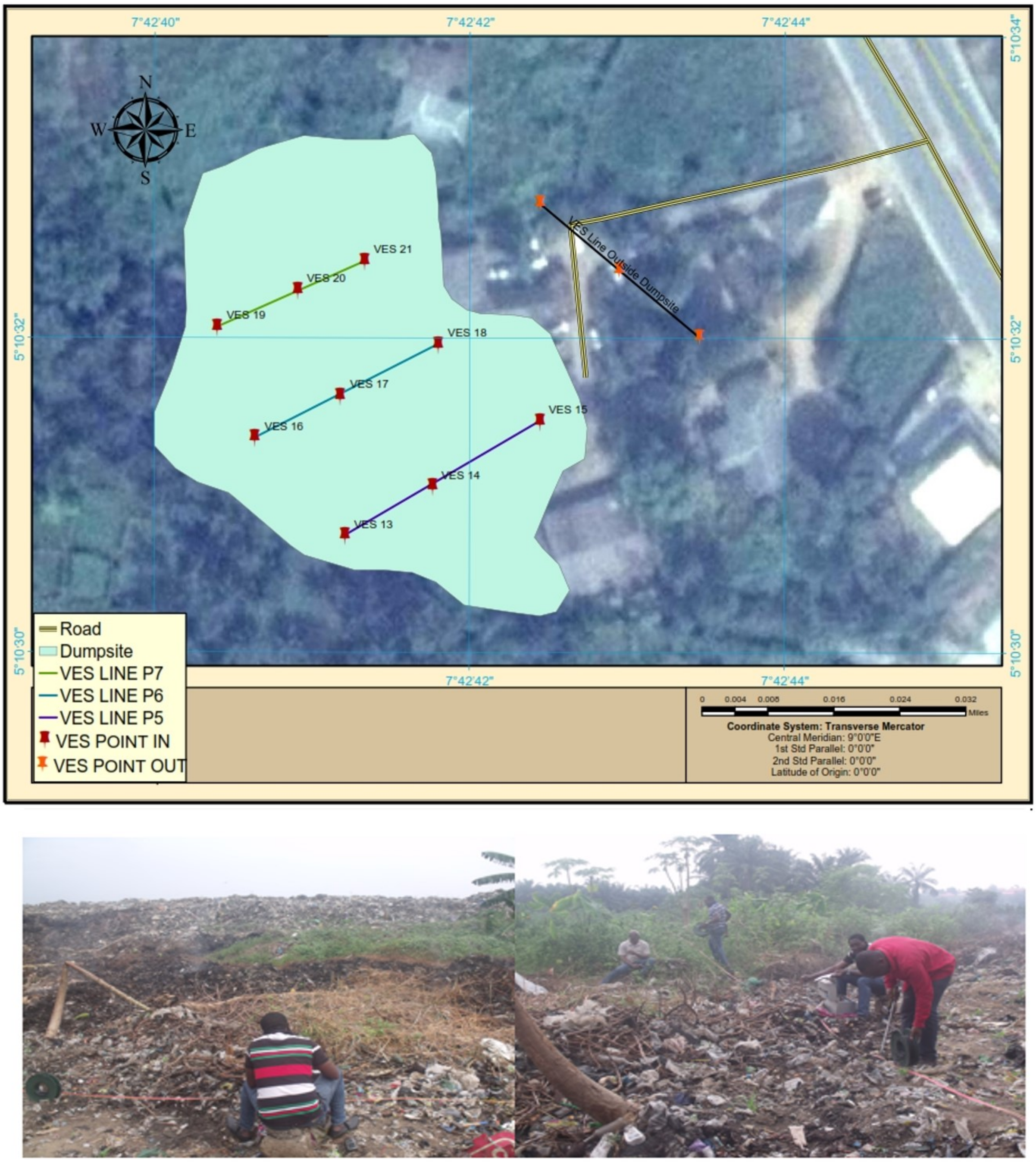


Fig. 3.2b: Map showing the Sounding points and pictures of Ikot Ekpene dump site

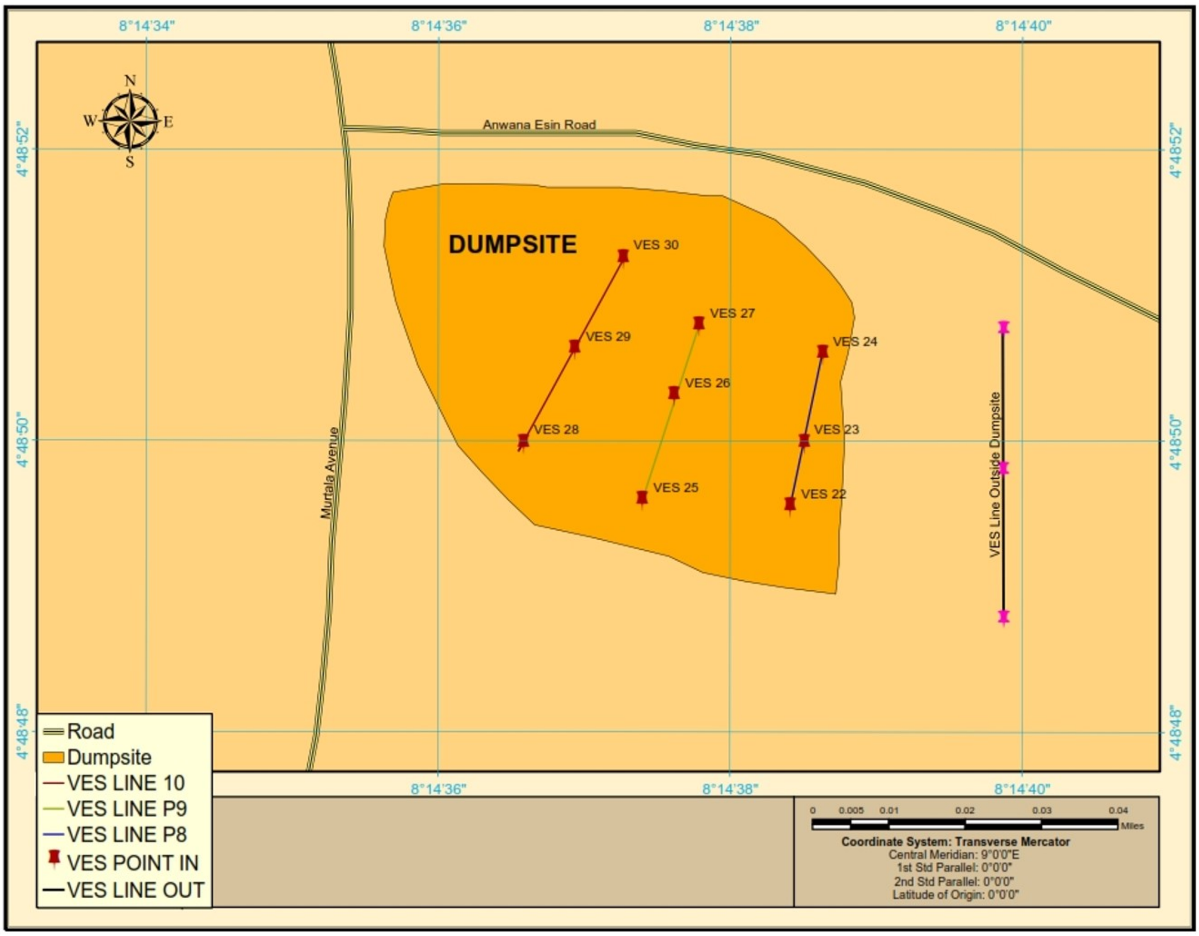


Fig. 3.2c: Map showing the Sounding points and pictures of Oron dumpsite

Fig. 3.3: Vertical Electrical Sounding (VES) layout within the study area

Fig. 3.4: Field procedures and data acquisition during Resistivity Survey.

3.2.2 Tomography

Tomography is ground resistivity imaging, which presents in 2D the resistivity variation of subsurface rocks, both laterally and with depth. The CVES (Continuous Vertical Electrical Sounding) or MVES (Multiple Vertical Electrical Sounding) using the Schlumberger configuration was used for the study. The CVES or MVES approach was conducted along four profile lines in the field. A map of the survey area (the dumpsite) was developed (Fig.3.2) and points for the VES stations were marked on the map with coordinates recorded. The same coordinates for the VES stations were then marked on land and the Schlumberger configuration with maximum current electrode spread of up to 150m as the space permitted. Soundings were conducted at each VES point until the entire survey or profile line was covered. The process continued until all four profile lines were covered (Fig.3.2a). This process of continuous VES along a profile line, probes the subsurface resistivity of rocks both vertically and horizontally and thus implies simultaneous VES and HRP (Horizontal Resistivity Profiling) investigation.

The data from this survey was then modeled to image the subsurface resistivity of rocks along the profile line. Anomalies within the subsurface can be detected based on the colour contrast in relation to their assigned values. It is this Subsurface Resistivity Imaging (SSI) that we refer to as Electrical Resistivity Tomography (ERT) (Reynolds, 2011).

3.2.3 Dar Zarrouk Parameters

According to Maillet, 1974; Niwas and Singhal, 1981, the Dar-Zarrouk parameters are longitudinal conductance and transverse resistance. These parameters are characterized by a geologic unit of layer resistivity (ρ) and layer thickness (h). From these two properties, two electrical parameters for each layer can be derived. These are longitudinal conductance and transverse resistance generally called Dar-Zarrouk parameters. These Dar-Zarrouk parameters were estimated across the study area.

3.2.3a Longitudinal Conductance

According to Maillet, (1974); Niwas and Singhal, (1981) defined longitudinal conductance as the sum of all the thickness/resistivity ratios of n-1 layers which overlie a semi-infinite substratum of resistivity, ρ_n, such that:

$$S = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \frac{h_3}{\rho_3} \ldots \ldots \ldots + \frac{h_{n-1}}{\rho_{n-1}} \ (\Omega^{-1}) \qquad \textbf{3.1}$$

Where,

$h_1, h_2, \ldots h_{n-1}$ *are* the thickness and

$\rho_{1}, {}_{2}, \ldots \rho_{n-1}$ are the resistivity values of successive layers.

Hence:

$$S = \frac{h}{\rho} = h\sigma \qquad \textbf{(Maillet, 1974)} \qquad \textbf{3.2}$$

Where,

S is longitudinal conductance and σ is conductivity.

The sum of all $S(\sum {}^{h_i}/_{\rho_i})$ is called Dar-Zarrouk functions. When longitudinal conductance (S) increases in value from one sounding point to the next, it indicates an increase in the total thickness of the sedimentary section. The values of longitudinal conductance of the aquifer are classified based on its protective capacity into poor, weak, moderate and good (Henriet , 1976; Oladapo *et al.*, 2004). Areas with poor and weak longitudinal conductance values are vulnerable to contamination from infiltration from contaminants such as dumpsite leachate and/or leakage of buried underground storage facility.

3.2.3b Transverse Resistance

This is the product of the layer's resistivity and its thickness. It is a geophysical parameter, proportional to product of the resistivity (ρ) and thickness (h) of the aquifer. For n-1 layers of resistivity (ρ_n), transverse resistance,

$$T = \boldsymbol{h_1\rho_1 + h_2\rho_2 + h_3\rho_3 \ldots\ldots\ldots + h_{n-1}\rho_{n-1}}\ (\boldsymbol{Ohm - m^2}) \qquad \textbf{3.3}$$

Where $\boldsymbol{\rho_{1,\ 2\ldots.}\ \rho_{n-1}}$ are the resistivity values and $\boldsymbol{h_1, h_2 \ldots h_{n-1}}$ are the thickness of successive layers. The transverse resistance parameter for the saturated zone of the aquifer makes it possible to delineate the most favourable and prolific zones, with the objective of hydrogeological exploration. Hence:

$$\boldsymbol{T = h\rho} \qquad \textbf{(Maillet, 1974)} \qquad \textbf{3.4}$$

The sum of all **(hρ)** is called Dar Zarrouk variables. When the value of transverse resistance (T) increases from one sounding point to another, it means generally that the thickness of the resistive layer in the section (gravel, basalt etc) also increases. The increase in T might be caused by increase in the resistivity values. High transverse resistance assumes that the aquifer may likely have high transmissivity with quantifiable groundwater potentials characterized by high yield of the aquifer units.

3.2.4 Layer Characteristics/Parameters

For the interpretation and understanding of the geologic model, some parameters related to different combination of thickness and resistivity of geoelectrical layer are necessary (Zohdy et al. 1974; Maillet 1947). These parameters are the Dar Zarrouk parameters (longitudinal conductance and transverse resistance) and hydraulic parameters (hydraulic conductivity, transmissivity, erodibility or parallel flow within each lithologic layer, the reflection coefficient (RC) and fractured contrast (FC)).

3.2.4a Hydraulic Conductivity

Hydraulic conductivity, symbolically represented as $\boldsymbol{K}$, is a property of soils and rocks, that describes the ease with which a fluid (usually water) can move through pore spaces or fractures. It depends on the intrinsic permeability of the material, the degree of saturation, and on the density and viscosity of the fluid.

According to Mbipom et al. (1996), the study area falls within the Sedimentary area of Nigeria and is overlain by Tertiary coastal plain sands of the Niger Delta sedimentary sequence known as the Benin Formation. As a result, the hydraulic conductivity (K) of the leachate layers across the area was estimated using equation generated by Heigold et al.

(1979); $\boldsymbol{K = 386.40 R_{rw}^{-0.93283}}$ (After, Heigold et al. 1979) **3.5**

Where, K = Hydraulic conductivity; R_{rw} = *Apparent r*esistivity of the layer.

3.2.4bTransmissivity/ Transmissibility

Transmissibility (or transmissivity) is a property closely related to hydraulic conductivity that describes the capacity of a specific water-bearing unit of a given thickness, such as an aquifer, to transmit water. Transmissibility is most simply defined as the effective hydraulic conductivity of an aquifer or other water-bearing unit multiplied by the thickness of that unit. However, the leachate transmissivity (T_L) of the leachate layers across the area was estimated using the relation generated by Niwas and Singhal, 1981:

$$\boldsymbol{T_L = K_L h_L} \qquad \mathbf{3.6}$$

Where, T_L = Leachate transmissivity; K_L = Leachate hydraulic conductivity; h_L=Leachate thickness.

3.2.4c Erodibility

Erodibility (or erodability) property of the layer is determined with respect to the geoelectrical parameters generated within the study area. It is good to note that erodibility can be defined as the inherent yielding or nonresistance of soils and rocks to erosion. Hence, a high erodibility implies that the same amount of work exerted by the erosion processes leads to a larger removal of material. Because the mechanics behind erosion depend upon the competence and coherence of the material, erodability is treated in different ways depending on the type of surface that eroded. The erodability of the overburden layers within the study area were calculated using the equation below,

$$\boldsymbol{K_z} = \frac{\boldsymbol{b}}{\left[\sum_{i=1}^{m}(\boldsymbol{b_i}/\boldsymbol{K_i})\right]} \qquad \text{(After, Freeze and Cherry, 1979)} \qquad \mathbf{3.7}$$

Where, $\boldsymbol{K_z}$ = erodibility or parallel flow within each lithologic layer; K_i= hydraulic conductivity of each individual layer of thickness; b_i =individual layer of thickness; b = Overall thickness of the sequence.

3.2.4d Reflection Coefficient and Fractured Contrast

Other parameters deduced within the study area are the reflection coefficient (RC) and fractured contrast (FC). The equations for calculating them are given as follows:

$$\boldsymbol{RC} = \frac{\boldsymbol{\rho_n} - \boldsymbol{\rho_{n-1}}}{\boldsymbol{\rho_n} + \boldsymbol{\rho_{n-1}}} \qquad \text{(After, Obiora et al., 2016)} \qquad \mathbf{3.8}$$

$$\boldsymbol{FC} = \frac{\boldsymbol{\rho_n}}{\boldsymbol{\rho_{n-1}}} \qquad \text{(After, Obiora et al., 2016)} \qquad \mathbf{3.9}$$

Where, RC = Reflection Coefficient; ρ_n= the resistivity of the n^{th} layer; ρ_{n-1}= the layer resistivity overlying the n^{th} layer; FC = Fractured Contrast

3.3 Hydrogeochemical Analyses

The fundamental task is to obtain samples that are representative, diagnostic, and characteristic of the aquifer and to analyse them with minimal change in composition. To achieve this, the tap was allowed to run for about ten (10) minutes to clear the path of the casing in order to collect water from the aquifer.

A two (2) litres plastic container was used for the water collection. The plastic container was previously washed with detergent and dried. At the point of collection, the container was rinsed three times with the sample to be collected. Duplicate samples were collected and labelled A and B. Sample A was stabilized using three drops of Hydrochloric acid to prevent the metals from adsorbing on the surface of the container. It was filtered with 0.45mm filter paper and the sample was used for cation analysis.

Sample B which was not filtered was used for anion and microbial analyses. The samples were preserved using a plastic cooler with ice to maintain the temperature such that there would be no change in the constituent of the sample. The water was then taken to the laboratory of Akwa Ibom State Water Company, Uyo Headquarters, within 48hours for analyses. Cation analysis was done using Atomic Absorption Spectrometer (AAS), while the anions were analysed using the Ultraviolet (UV) Spectrophotometer. Microbial analysis was done using the filter membrane method. Some parameters were analysed using titrimetric method. Temperature, pH and turbidity were measured in the field insitu using the portable pH meter (ADWA Instruments, AD 130, waterproof portable pH Meters), turbidity was measured using turbidimeter (Aquafast AQ4500 Turbidity Meter), and temperature was measured using mercury-in-glass thermometer.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Qualitative Interpretations of Geoelectrical Results

The geoelectrical curves generated across the study areas (Fig. 4.1 – Fig. 4.2), vary considerably throughout the entire areas. Uyo resistivity curves show typically H-curves which are quite common in a sedimentary environment for multilayer structures of three or more layers (Fig. 4.1a). At Ikot Ekpene, there are hybrid of K and H curves, A and K curves while one VES station has H-curve. At Oron, it is predominantly K-curves, with one VES station having A-curve and hybrid KHK-curve.

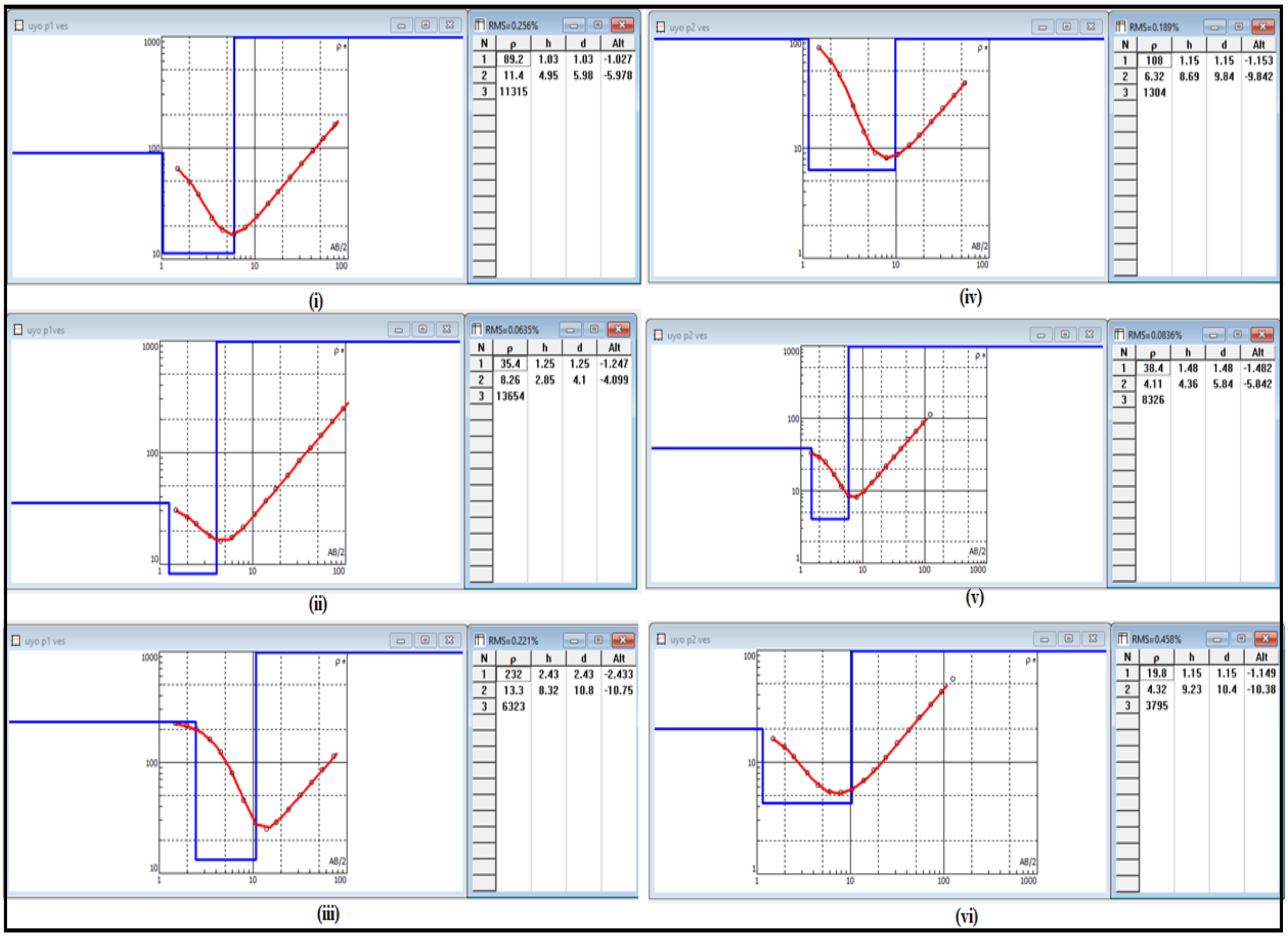


Fig.4.1a:VES results in Uyo study site**:** Geoelectric curves for Profile 1 **(**i-iii): and Profile 2 **(**iv-vi)

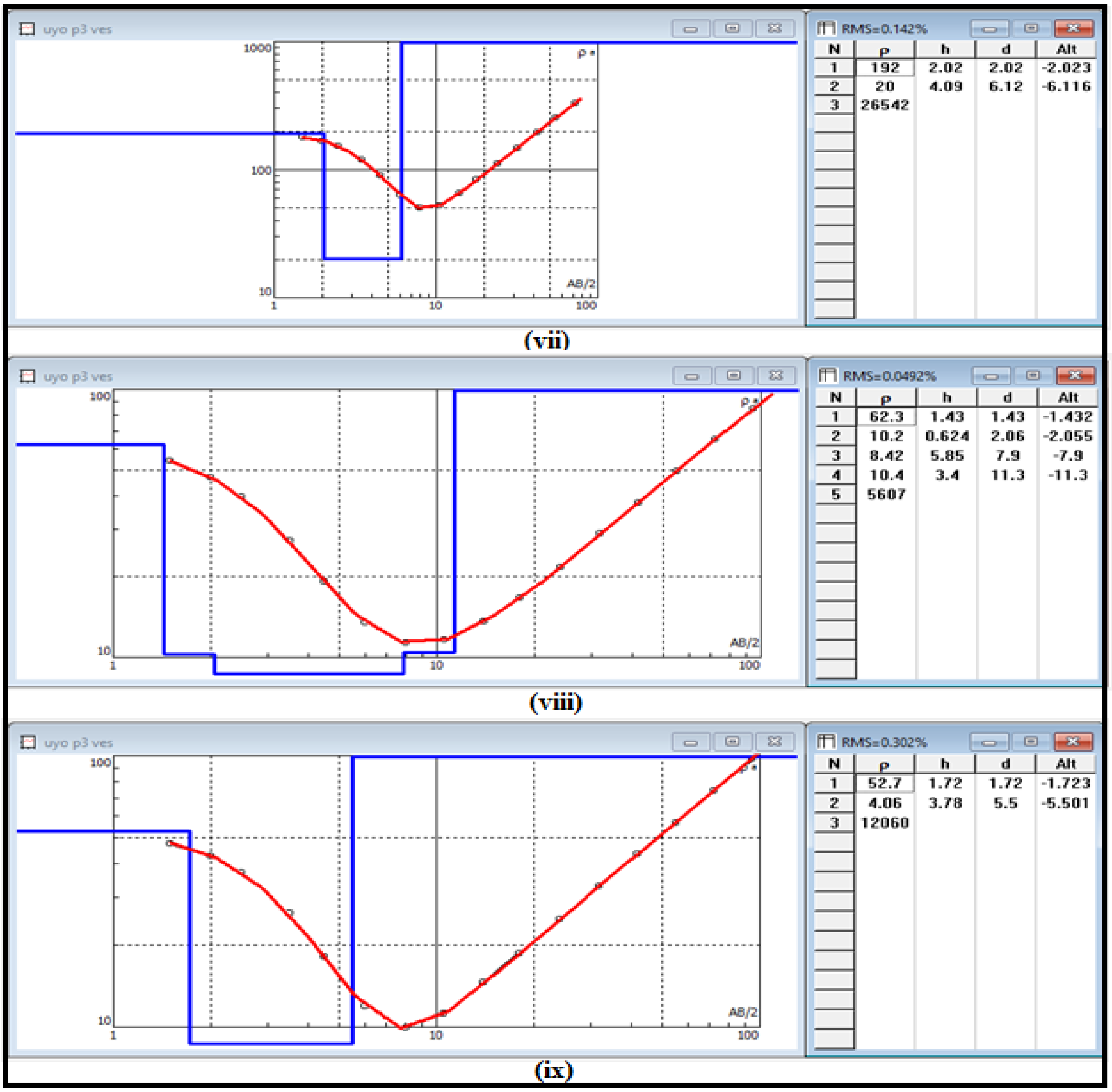


Fig.4.1b VES results in Uyo study site (**vii**-ix) Geoelectric Curves for Uyo Profile 3

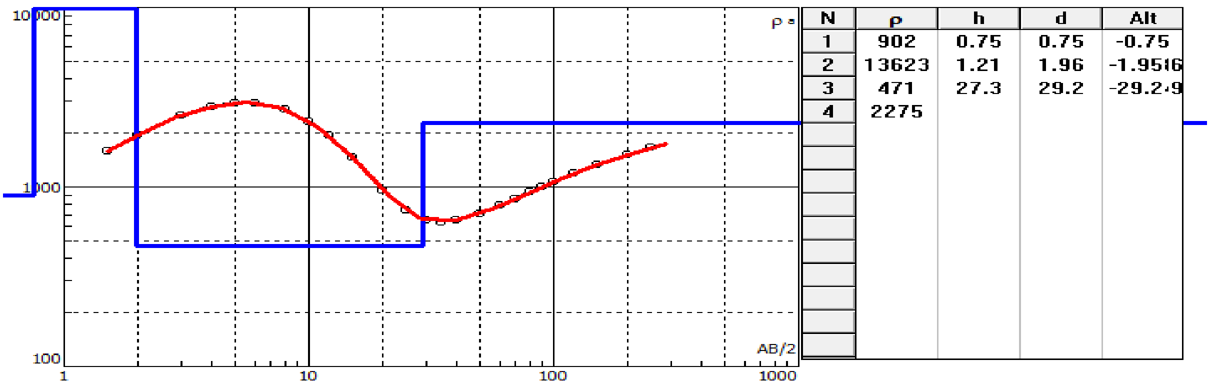


Fig. 4.2a: : Geoelectric Curve for VES Control at Uyo

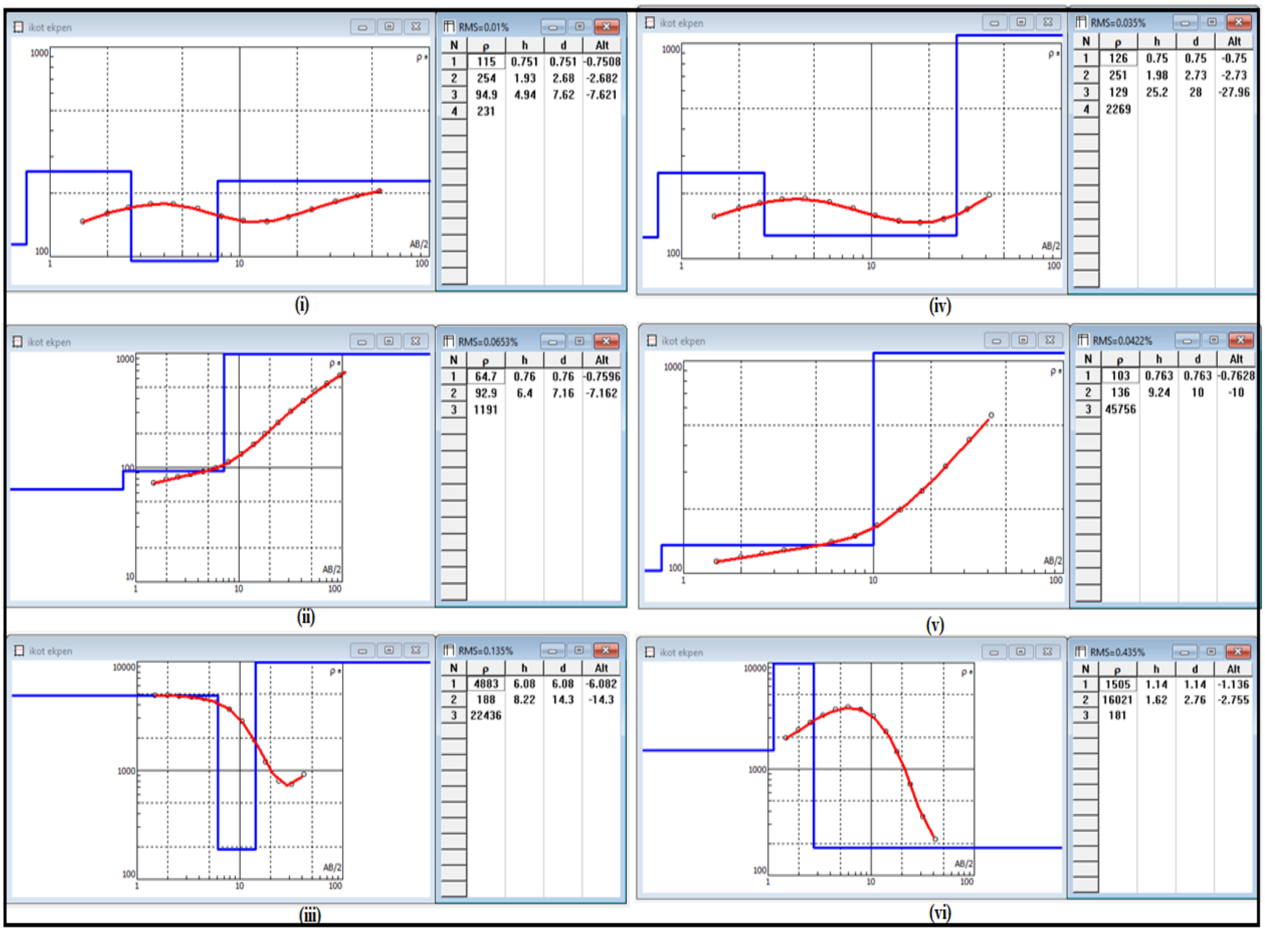


Fig.4.1b: VES results in Ikot Ekpene study site**:** Geoelectric Curves for Profile 5**(**i-iii); and Profile 6 **(**iv-vi)

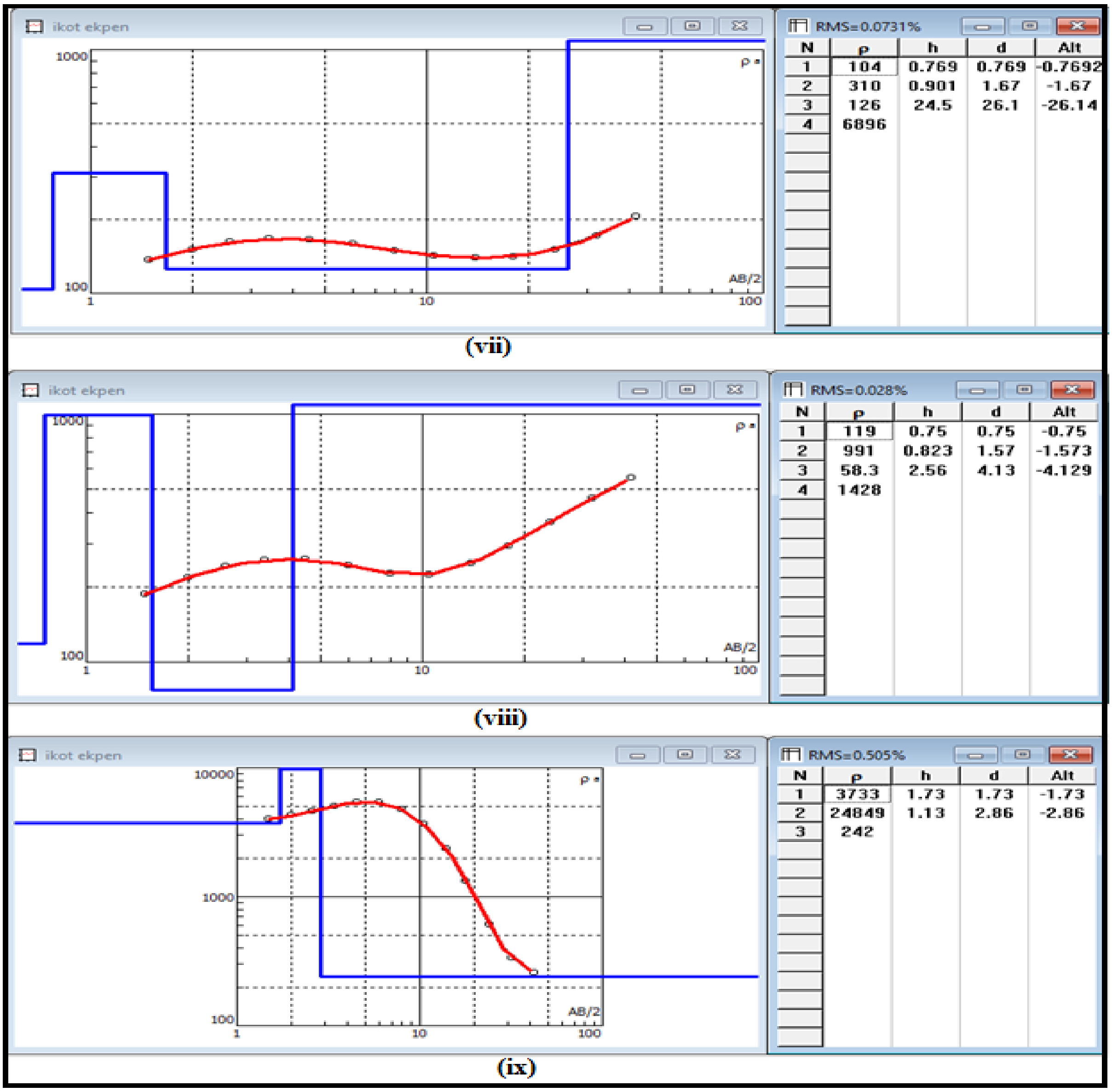


Fig.4.1b: VES results in Ikot Ekpene study site - Geoelectric Curves for Profile **7(vi**i-ix)

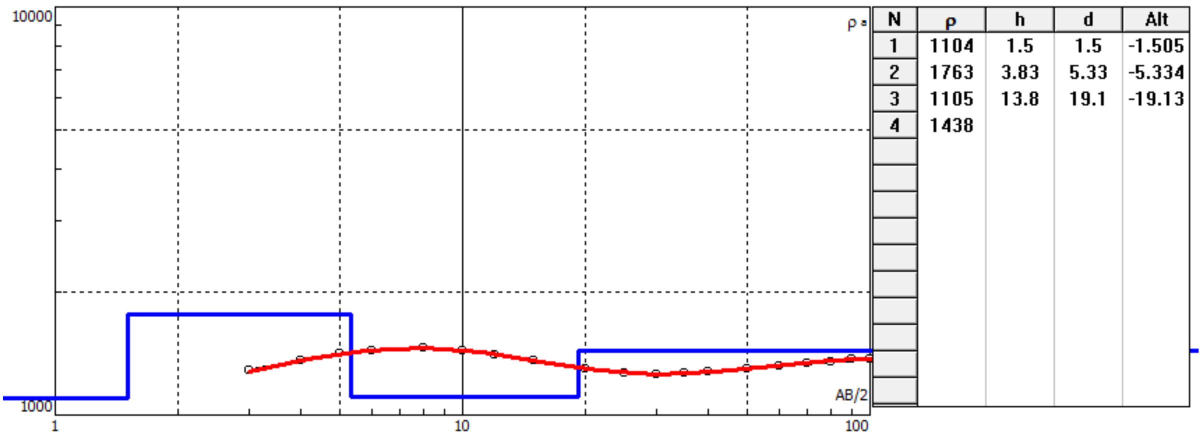


Fig. 4.2b: : Geoelectric Curve for VES Control at Ikot Ekpene

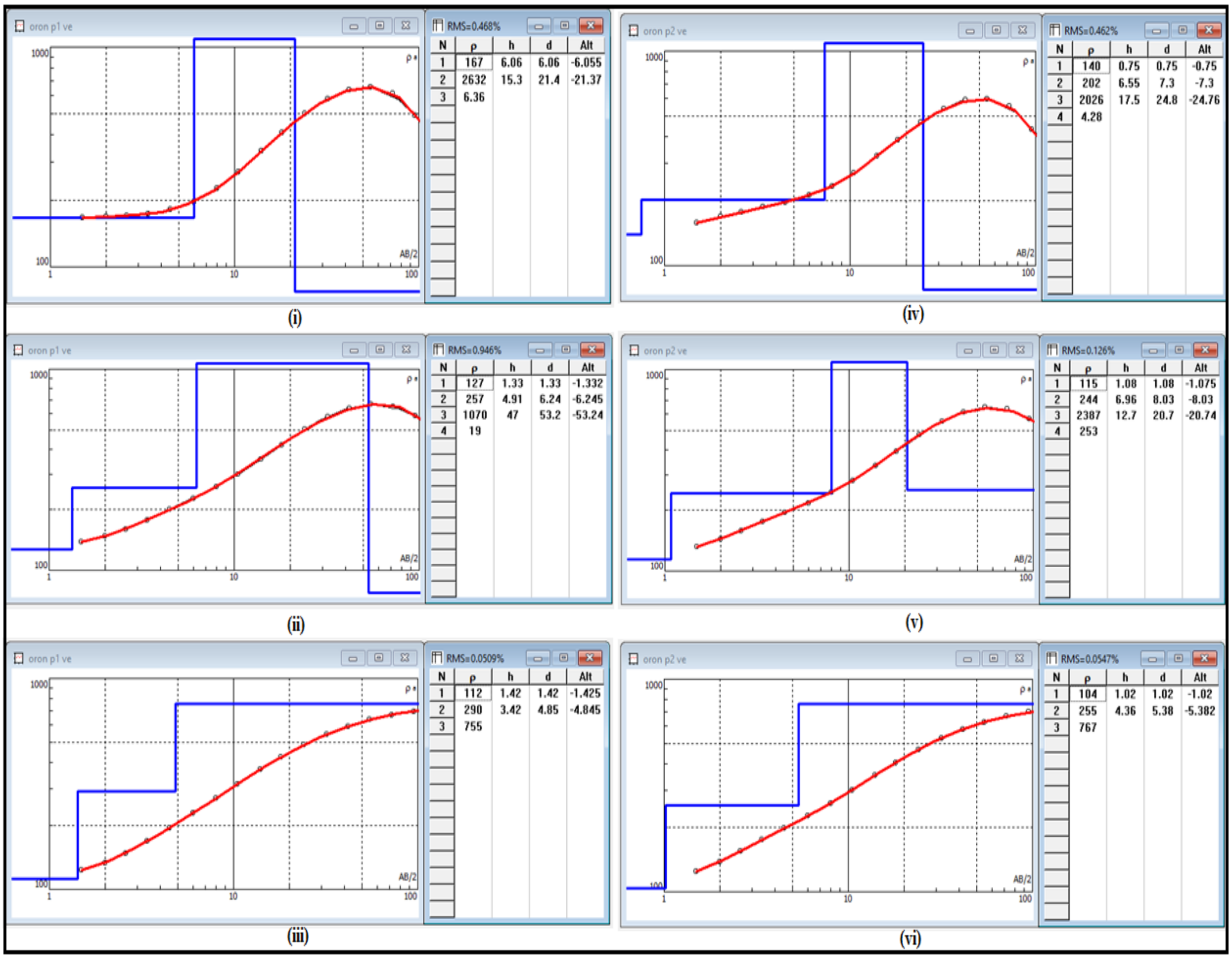


Fig.4.1c: VES results in Oron study site **:** Geoelectric Curves for Profile 8 **(**i-iii): and Profile 9 **(**iv-vi)

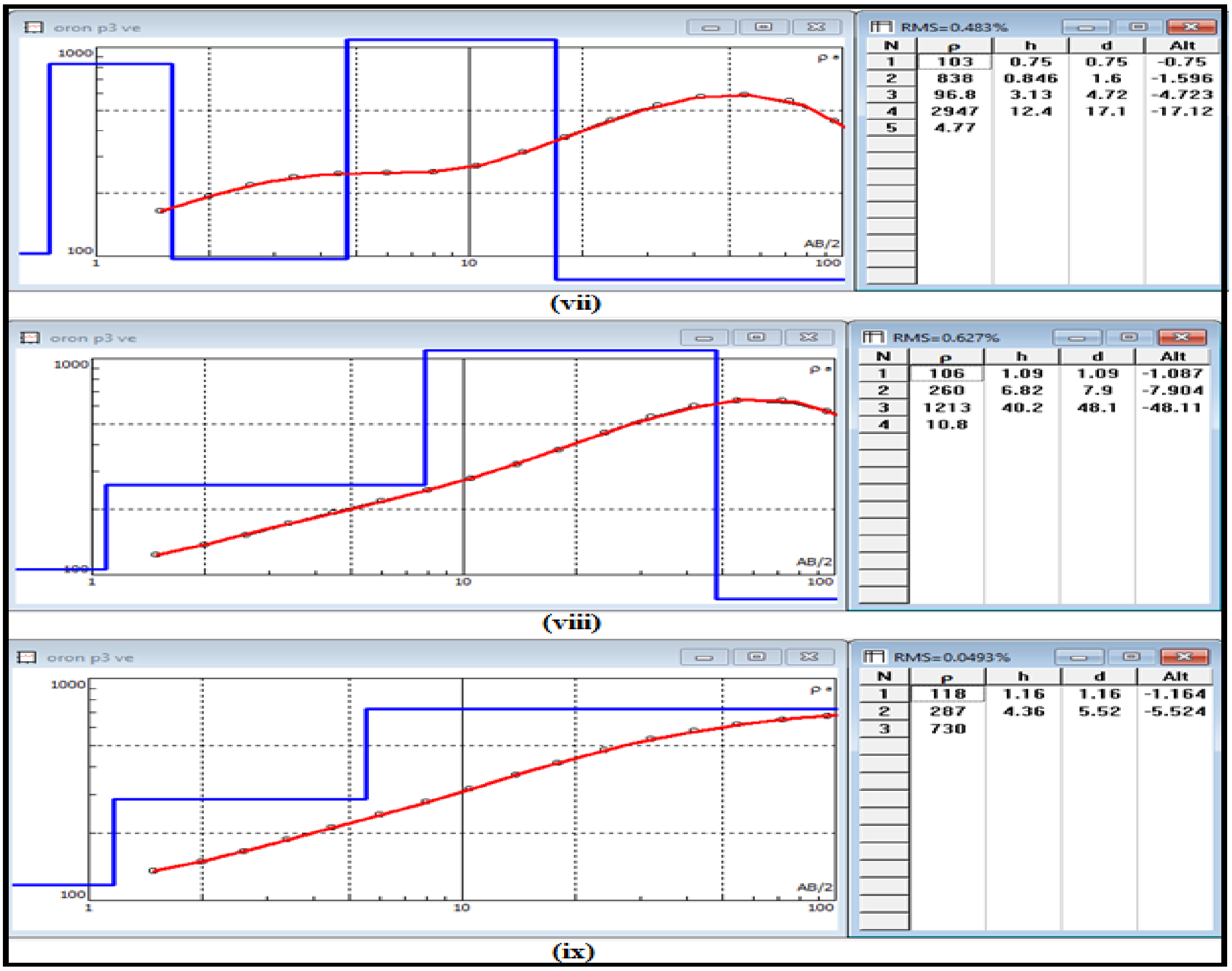


Fig.4.1d **:** VES results in Oron study site **-** Geoelectric Curves for Oron Profile 10**(vi**i-ix)

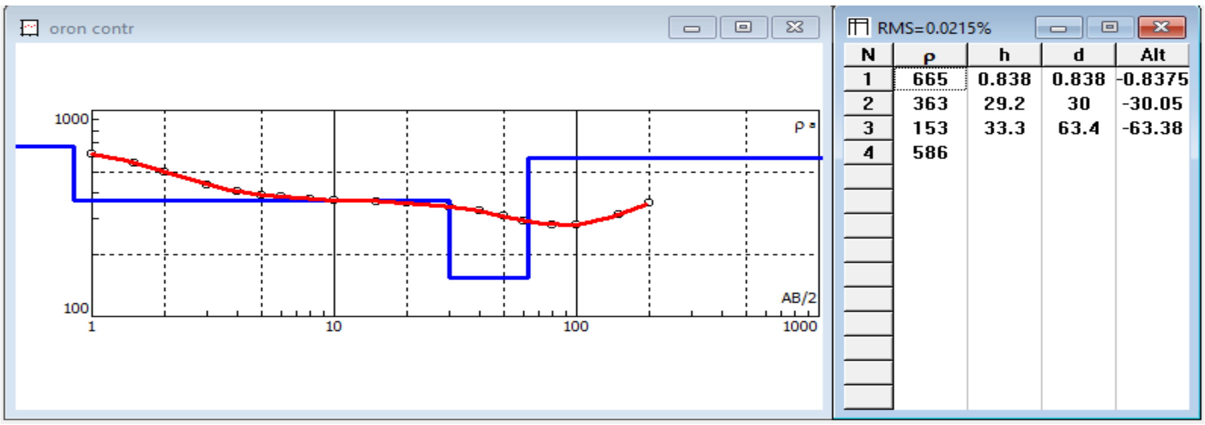


Fig. 4.2c: Geoelectric Curve for VES Control at Oron

4.2 Quantitative Interpretations of Geoelectrical Results

4.2.1 Interpretations of VES Results

The results of the VES interpretations in conjunction with the borehole data within the study area show that Uyo is mainly of three layers namely; top lateritic sand, leachate contaminated sand, and dry fine to medium-grained sand layers, except one Station that is up to five layers of the same characterization with the former. Ikot Ekpene and Oron are of three to four layers, except one Station at Oron is of five layers down to the depth of investigation. The results of the soundings together with geological data were used to construct a cross-section of the study area (Fig.4.3). The top layers thickness and resistivity range between 0.7 – 6.06m and 19.8 - 4883Ωm respectively and they are characterized by lateritic sand (Appendix 1). The second layer thickness and resistivity range between 0.64 – 22.2m and 4.06 - 24849Ωm respectively and they are delineated as mainly of fine to medium-grained sand (Appendix 1). This is interpreted as the leachate contaminated layer across the study area on the basis of the abnormally low resistivity values. The third layer consists mainly medium-grained sand with admixture of clay; its thickness and resistivity range between 2.56 – 47.0m and 6.36 - 45756Ωm respectively (Appendix 1).

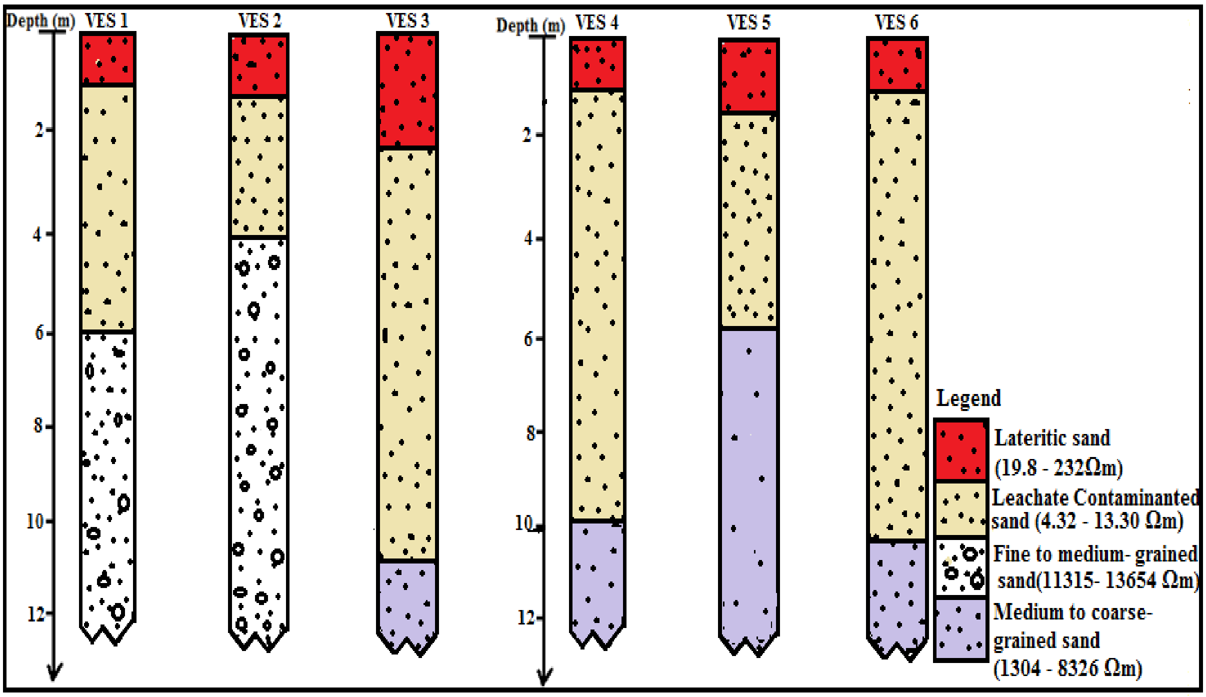


Fig.4.3a: Cross-section of the VES at Uyo**:** along Profile 1(1-3); along Profile 2(4-6)

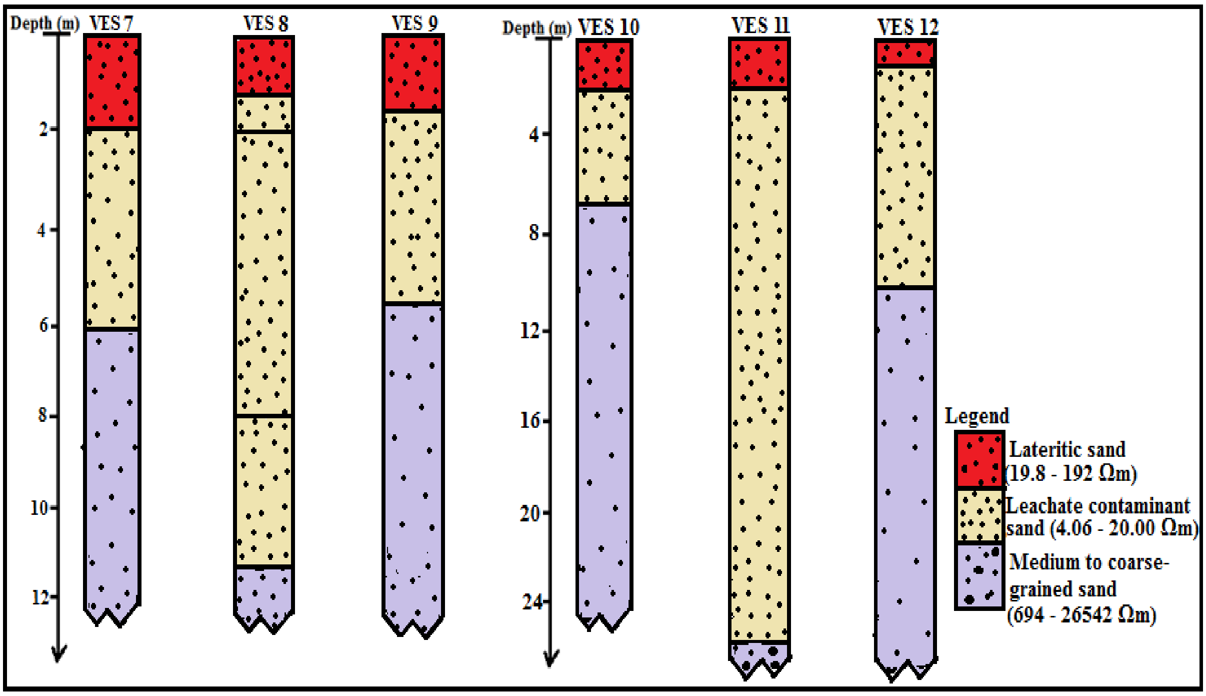


Fig.4.3b: Cross-section of the VES at Uyo**:** along Profile 3(7-9); along Profile 4(10-12)

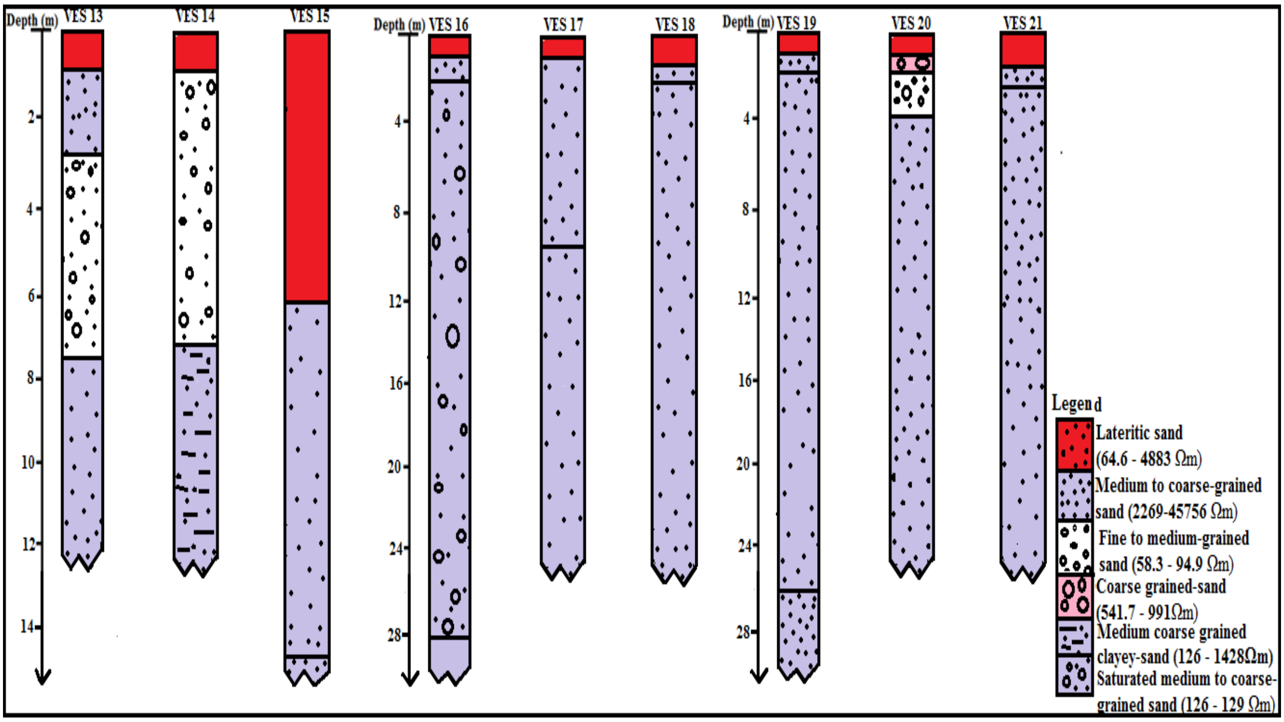


Fig.4.3c: Cross-section of the VES at Ikot Ekpene**:** along Profile 5(13-15); along Profile 6(16-18); along Profile 7(19-21)

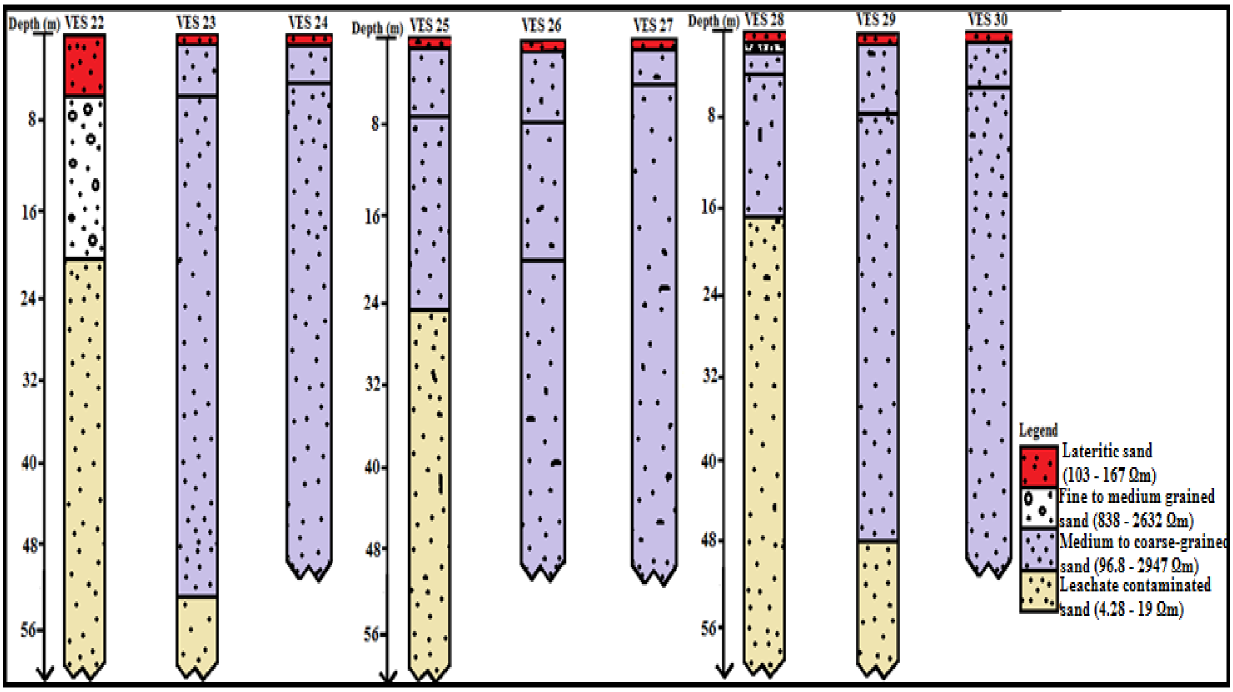


Fig.4.3d: Cross-section of the **VES** at Oron**:** along Profile 8(22-24); along Profile 9(25-27); and along Profile 10(28-30)

4.3 Correlation of Geo-electric Cross Sections

4.3.1 Geo-electric Correlation at Uyo

Fig. 4.4a-b shows a true variation of the different layers delineated through VES in Uyo. The lithologic facies are sandy lateritic overburden (19.80 – 232.00 Ohm-m), leachate contaminated sand (4.06 – 20.00 Ohm-m), dry fine to medium grained sand (11315 – 13654 Ohm-m) and medium to coarse grained sand (1304.00 – 26542.00 Ohm-m). Thin lateritic sand units which overlie the leachate contaminated sand units, signify that the study area is of unconfined region and there is possibility of flow of leachate plume down the subsurface.

4.3.2 Geo-electric Correlation at Ikot Ekpene

Fig. 4.4c shows a true variation of the different layers delineated through VES in Ikot Ekpene. The lithologic facies are sandy lateritic overburden (64.60 – 3733.00 Ohm-m), medium to coarse-grained sand (126 – 24849 Ohm-m), fine to medium grained sand (58.30 – 94.90 Ohm-m). Thin lateritic sand units which overlie the medium to coarse-grained sand units, signify that the study area is more of unconfined region.

4.3.3 Geo-electric Correlation at Oron

Fig. 4.4d shows a true variation of the different layers delineated through VES in Oron. The lithologic facies are sandy lateritic overburden (103 – 167.00 Ohm-m), dry fine to medium grained sand (838 – 2632 Ohm-m), medium to coarse grained sand (96.80 – 2947.00 Ohm-m) and leachate contaminated sand (4.77 – 19.00 Ohm-m). Thick sand units which overlie the leachate contaminated sand units, signifying that the study area is of unconfined region and there is possibility of flow of leachate plume down the subsurface.

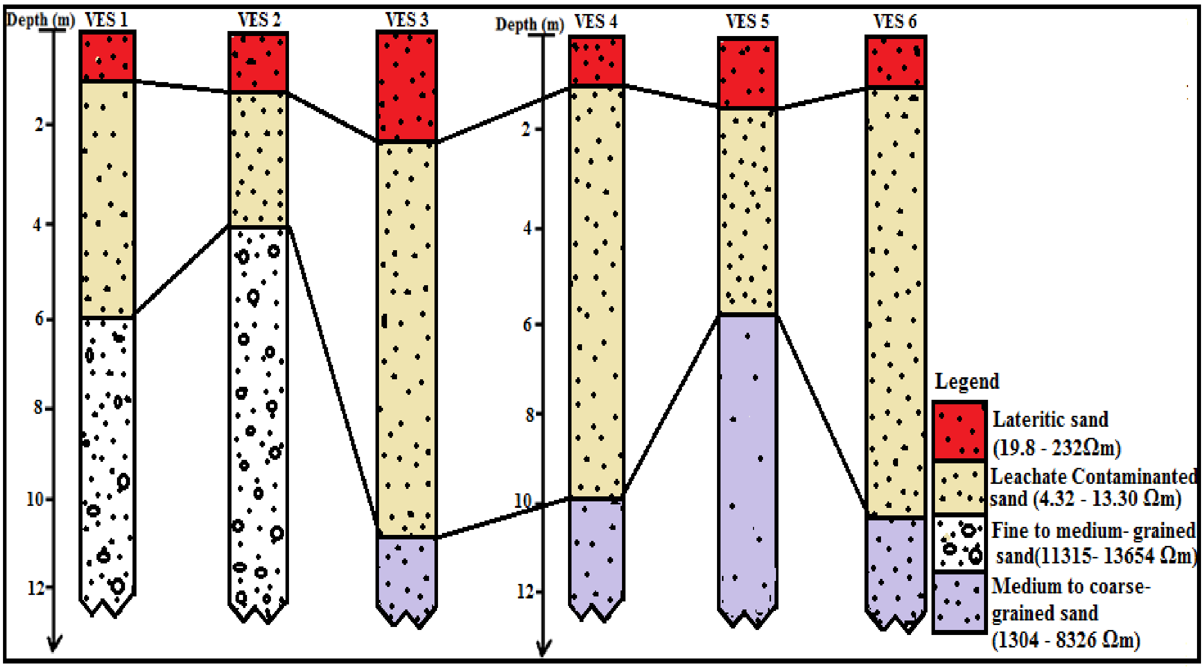


Fig. 4.4a: Correlation along Profile 1 and 2 at Uyo

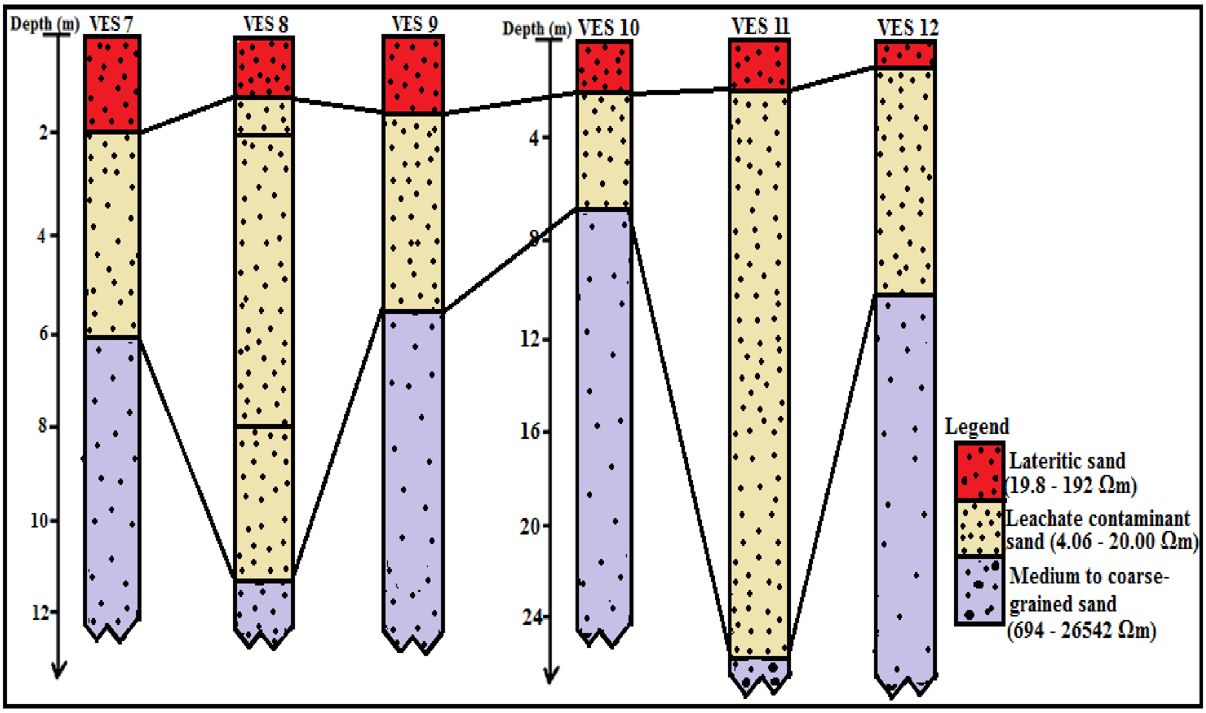


Fig. 4.4b: Correlation along Profile 3 and 4 at Uyo

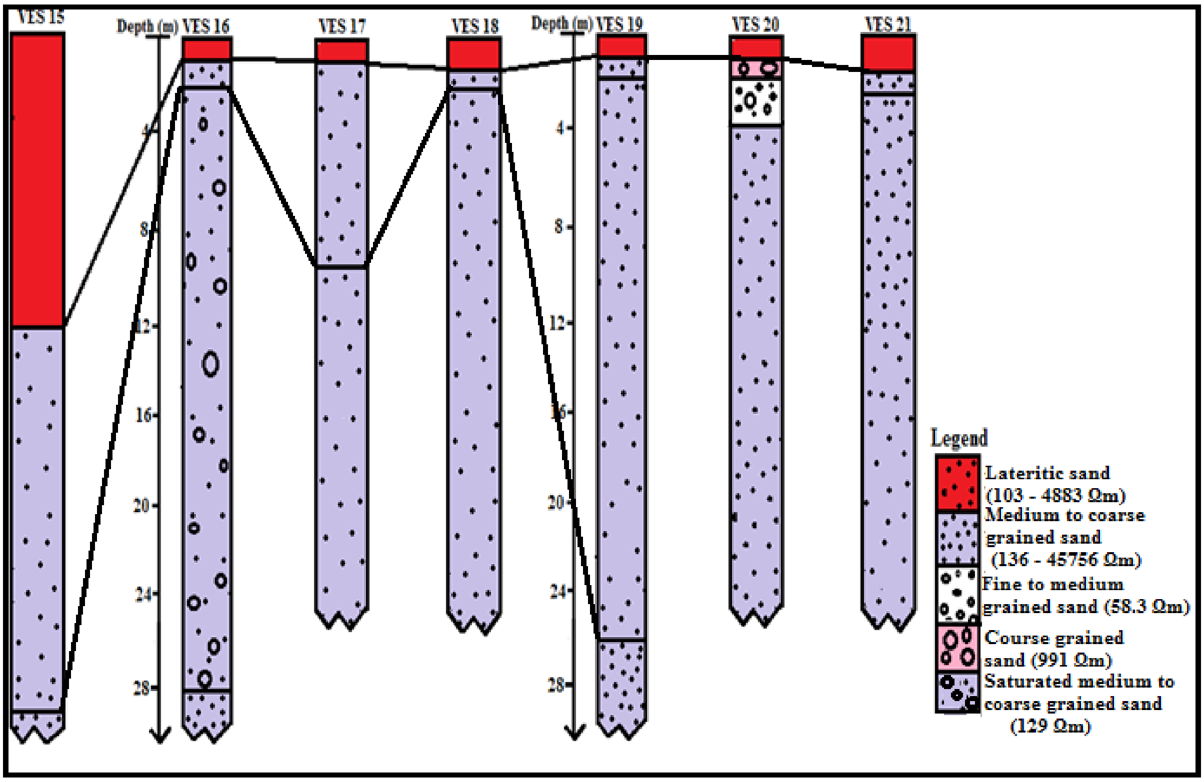


Fig. 4.4c: Correlation along Profile 5, 6 and 7 at Ikot Ekpene

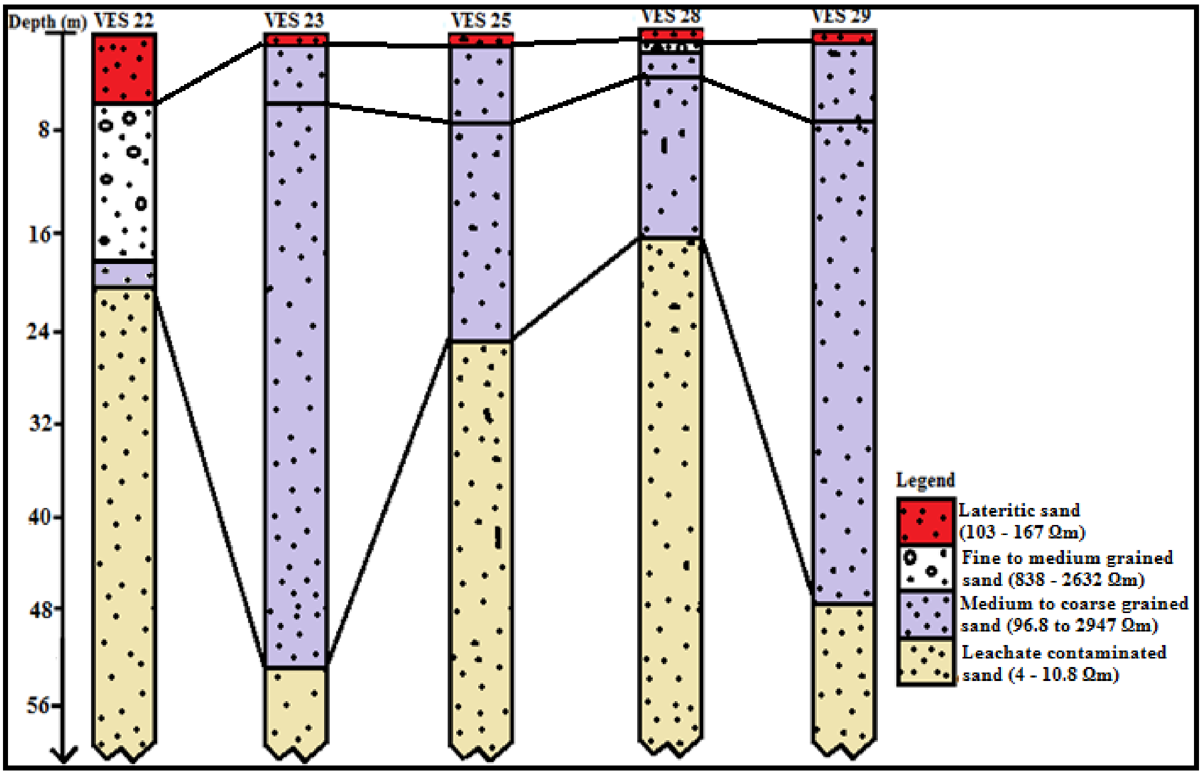


Fig. 4.4d: Correlation along Profile 8, 9 and 10 at Oron

4.4 Geoelectrical Tomography

According to Wunderlich *et al* (2018), geoelectric data are analysed in a tomographic inversion process leading to images of the subsurface in terms of resistivity (electric resistivity tomography [ERT]). The inversion of geoelectric data is nonunique. Therefore, electric resistivity tomography (ERT) usually results in different subsurface models that fit observed apparent resistivity values equally well. The interpretation of the pseudo cross-sections generated within the study area is based on colour codes depicting variation in apparent resistivity values of the subsurface (Fig. 4.5). The black colour represents very low apparent resistivity values followed by the blue colour code (Fig 4.5). The green colour code represents moderate apparent resistivity values followed by the yellow colour code with higher apparent resistivity values. The highest resistivity values are represented by the red colour code. These interpretations align with the already interpreted leachate-prone zones in the subsurface. It has abnormally low apparent resistivity values; which will present itself as plumes of black and light blue colours, while areas with green, yellow and red colour codes represent areas of no vulnerability to contamination.

More so, areas with high porosity and permeability are more likely to be percolated by leachates and thus more prone to contamination. The amount and depth of percolation of the leachates serve as an index to qualitative evaluation of porosity and permeability of the transmitting medium such as sediments.

4.4.1 Uyo Profiles

The resistivity tomography shows the thickness and depth of each layer in Uyo profiles 1-4 (Fig. 4.5a-d). In Fig. 4.5b, the resistivity cross-section shows three blocks representing VES 1,2,3, each has three layers. The low resistivity values of the second layer at Uyo dumpsite (6.32 Ωm,4.11 Ωm and 4.32 Ωm,) shows that it is the leachate contaminated layer. The leachate plume is represented by the black colour with the lowest resistivity of less than 10Ωm in Fig 4.5a-d. The thickness of the plume for Uyo Profile 1 ranges between 4-8m in depth. The tomography shows that the plume has migrated from VES 1 to a little beyond VES 2 a distance of more than 30m in the subsurface. The resistivity values for the second layer in VES 1,2 and 3 are 11.4,8.26 and 13.3Ωm in the resistivity model for Uyo dumpsite.

4.4.2 Ikot Ekpene Profiles

At Ikot Ekpene, the resistivity tomography is represented in Fig. 4.5e-g: Based on the resistivity values of 58.3Ωm and above for layer 3(VES 20, profile 7), Ikot Ekpene dumpsite has very minimal leachate plume.

4.4.3 Oron Profiles

For the Oron dumpsite, the resistivity tomography is represented in Fig. 4.5h-j. The black colour which connotes leachate plume is very prominent between VES 9 and VES 10 (Fig. 4.5h-j). Fig. 4.5h-j represents the resistivity tomography for the Oron dumpsite. The leachate plume is shown by the black colour between VES 2 and VES 3 profiles. (Figs 4.5h-j). The low resistivity value of 6.84 Ωm in layer 3 clearly shows the leachate contaminated zone.

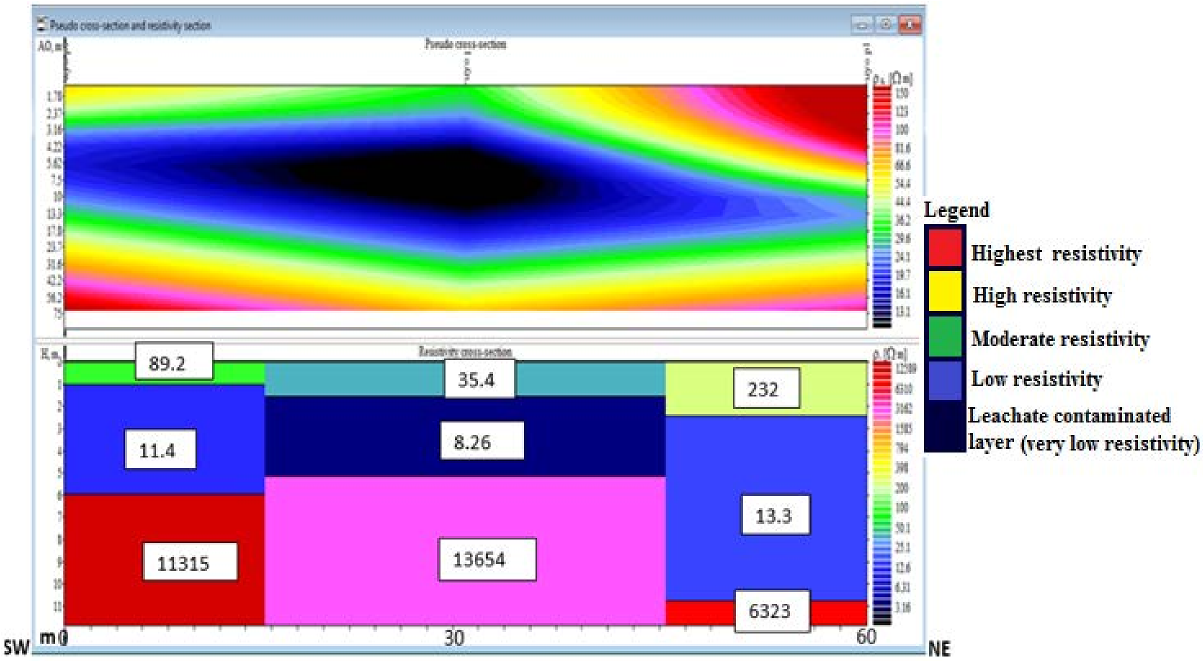


Fig. 4.5a: Geoelectrical Tomography of Uyo Profile 1

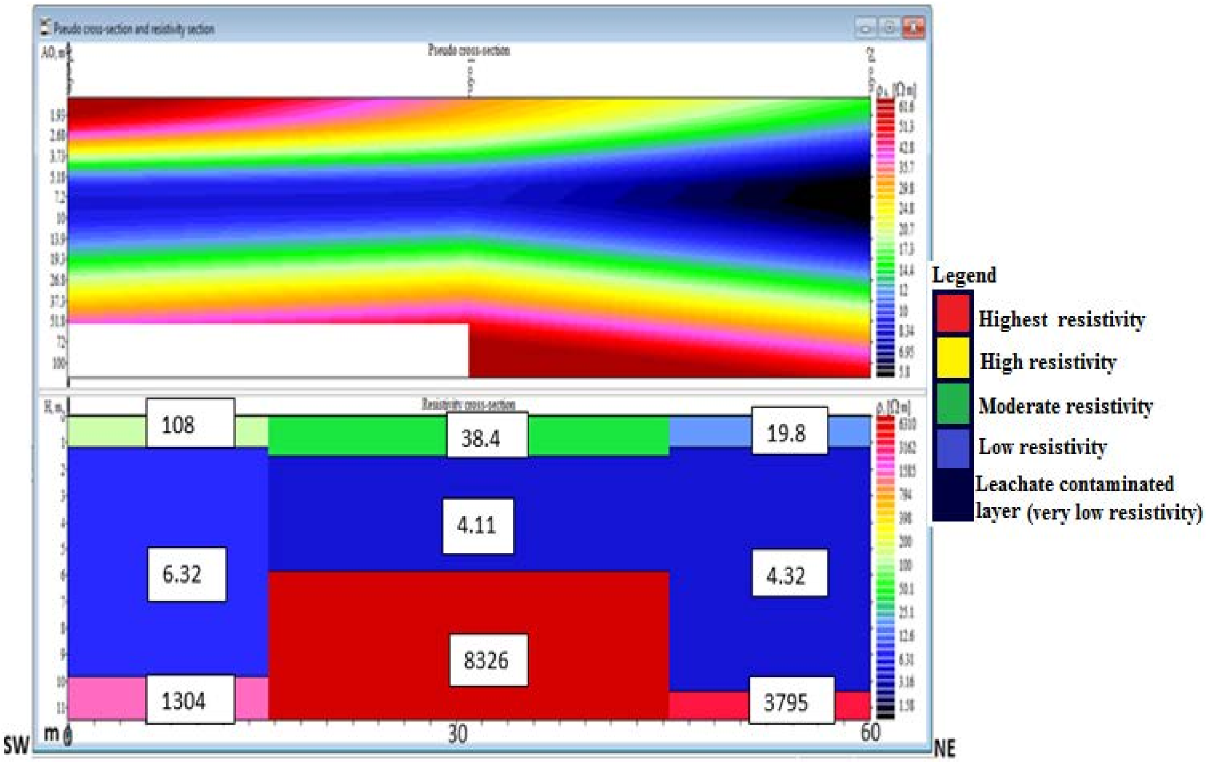


Fig. 4.5b: Geoelectrical Tomography of Uyo Profile 2

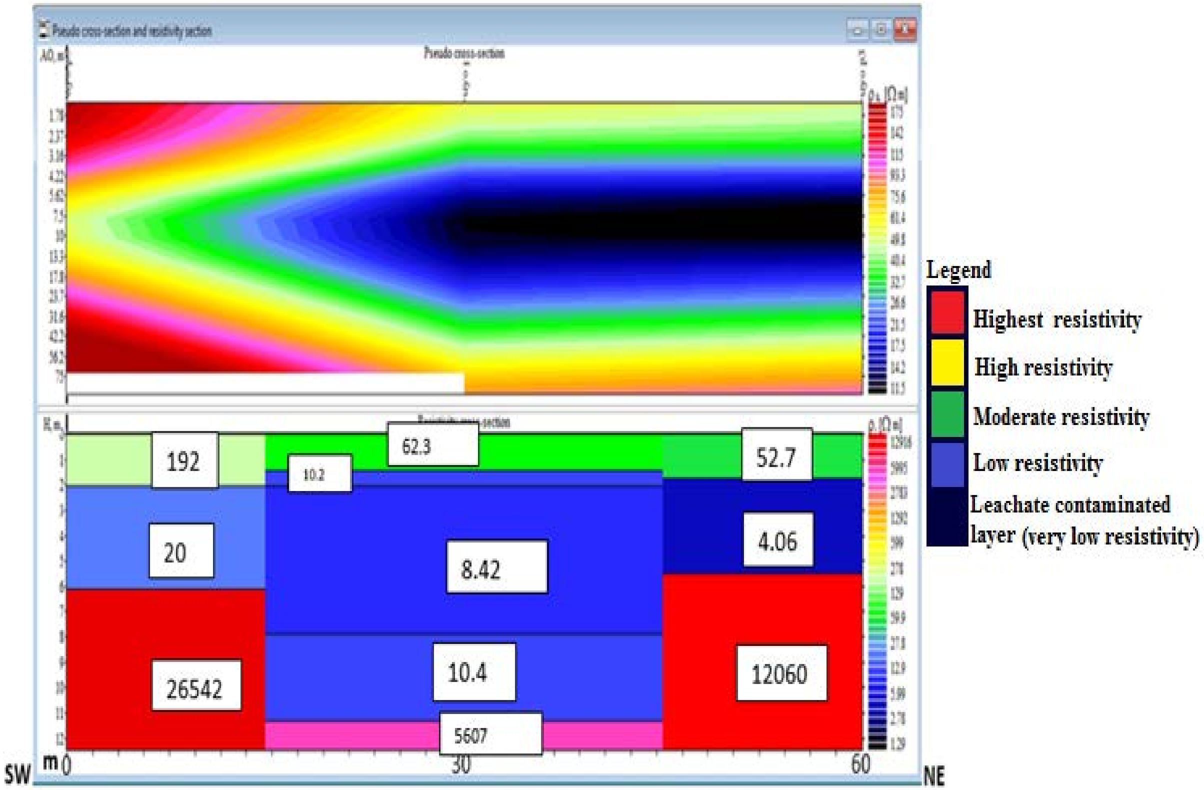


Fig. 4.5c: Geoelectrical Tomography of Uyo Profile 3

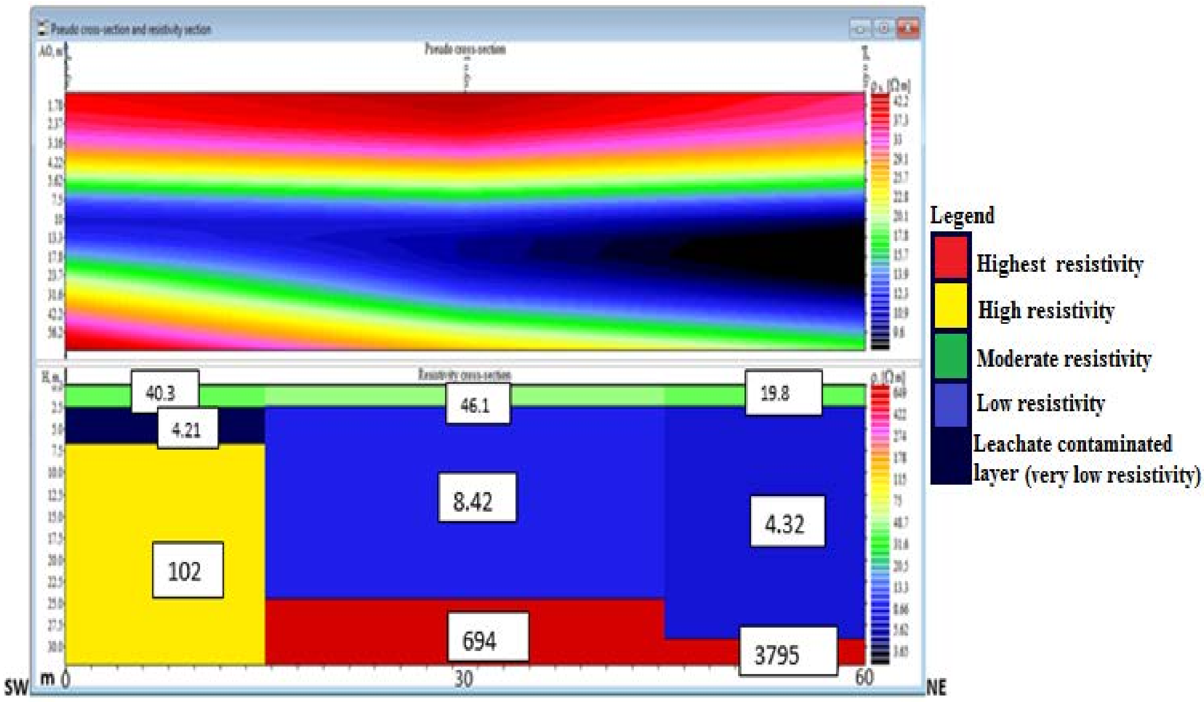


Fig. 4.5d: Geoelectrical Tomography of Uyo Profile 4

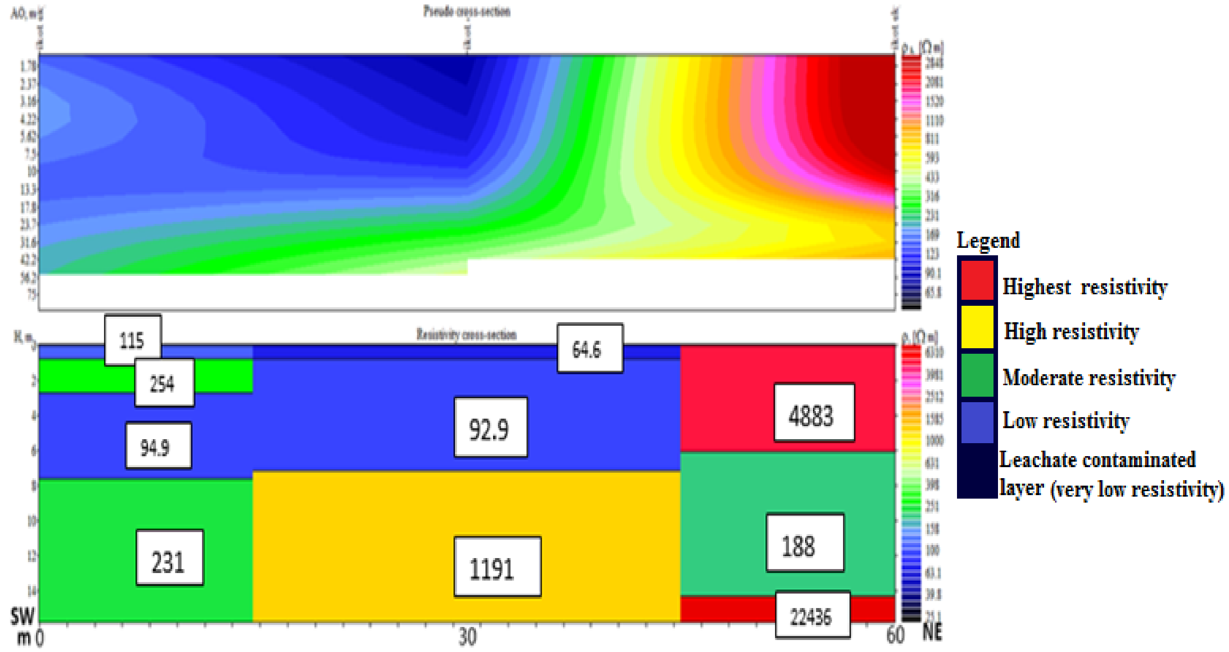


Fig. 4.5e: Geoelectrical Tomography of Ikot Ekpene Profile 5

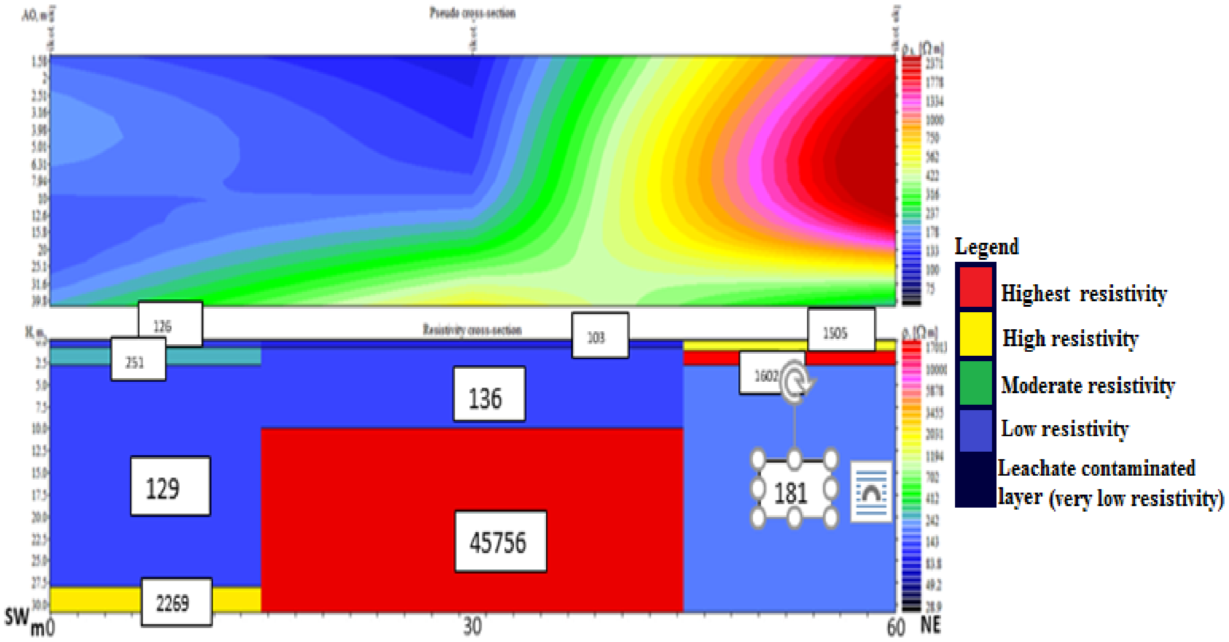


Fig. 4.5f: Geoelectrical Tomography of Ikot Ekpene Profile 6

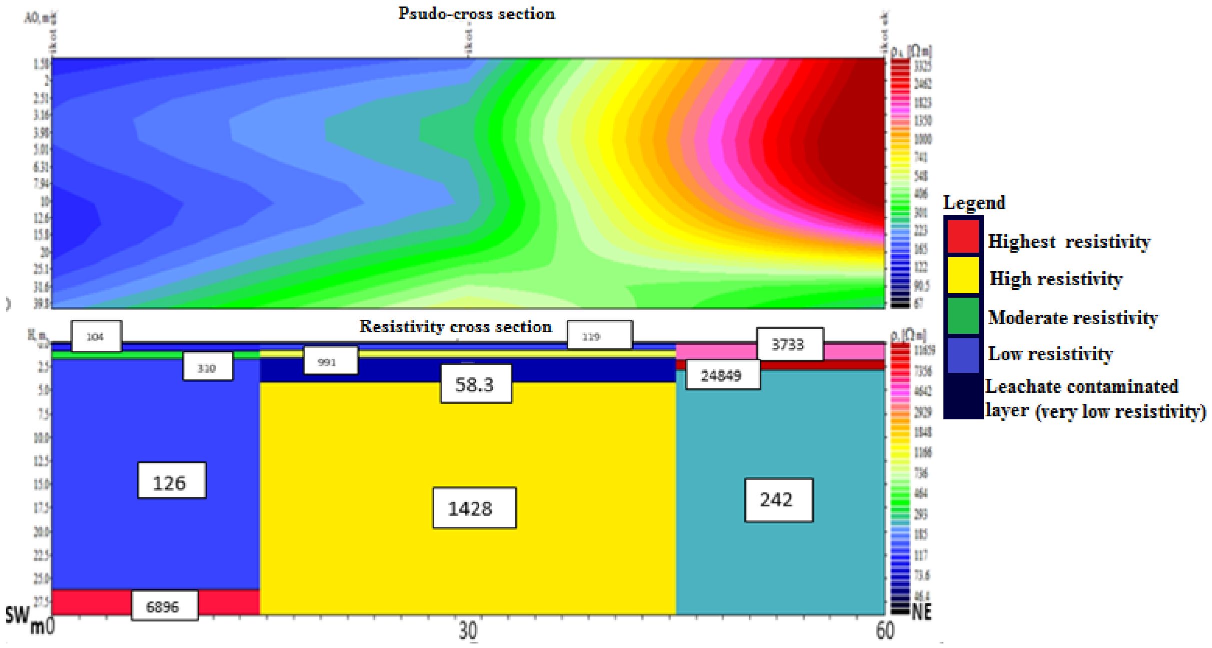


Fig. 4.5g: Geoelectrical Tomography of Ikot Ekpene Profile 7

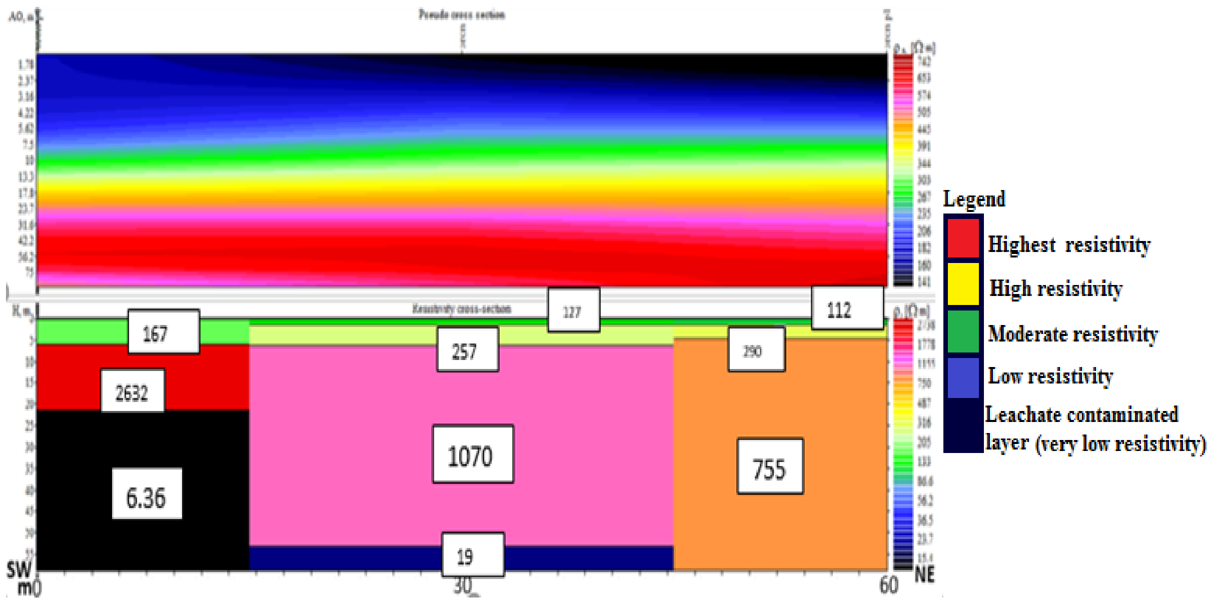


Fig. 4.5h: Geoelectrical Tomography of Oron Profile 8

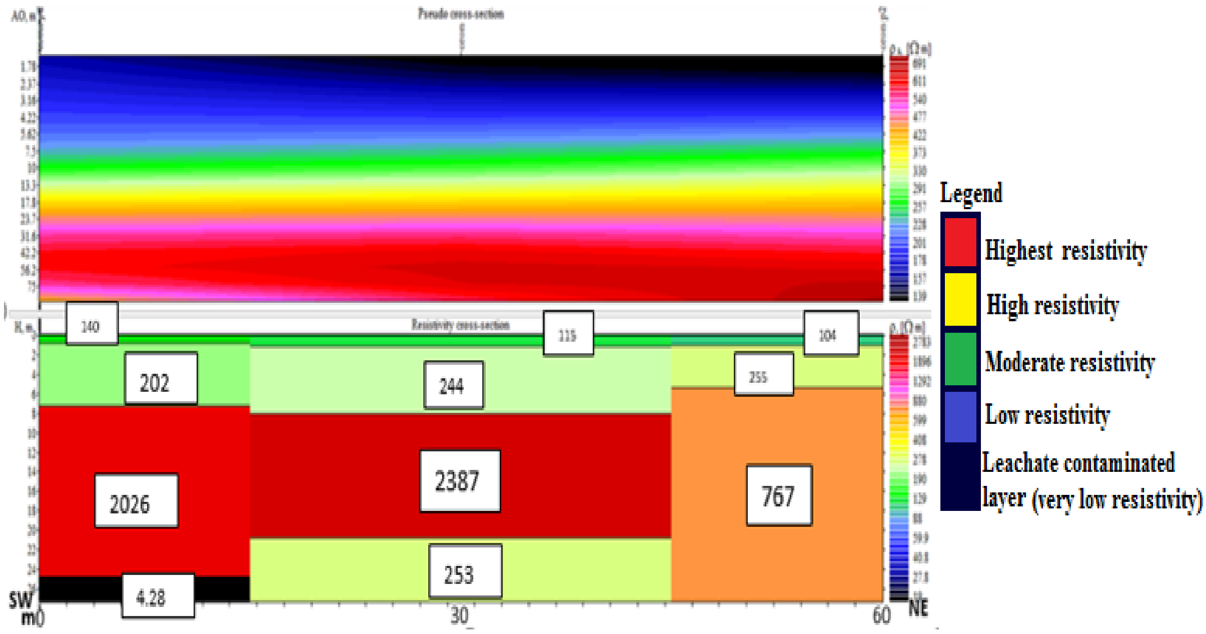


Fig. 4.5i: Geoelectrical Tomography of Oron Profile 9

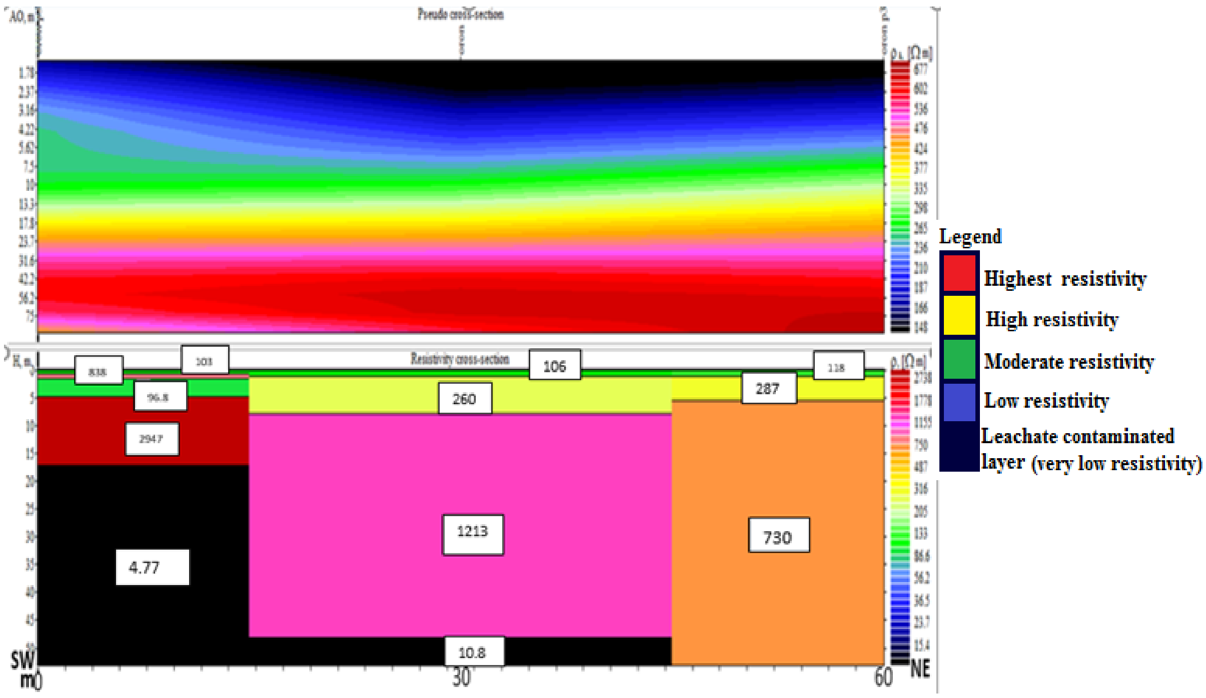


Fig. 4.5j: Geoelectrical Tomography of Oron Profile 10

4.5 Geological Characteristics and Profiles

The geology of the study area is predominantly sands that range from fine to coarse-grained, which may occur as brownish clay-mixed sand to clean white sand. These are some characteristics of the Benin Formation underlying this area. The entire profile therefore shows sands of varying composition based on their resistivity attributes.

Resistivity (VES) Control along CCC lane in Uyo (Fig. 4.5) and lithologic log from borehole show that the area is entirely underlain by sand at least to a depth of about 63m.

4.6 Estimation of Layer Characteristics/Parameters

The computed layer parameters for the leachate zone interpreted from VES data are presented in Table 4.2. The results show that the values of various parameters range from low to high within the area: For Uyo dumpsite, leachate resistivity vary from 4.06-20.00Ωm; leachate thickness from 2.85-22.20m; longitudinal conductance from 0.204500-2.636580 mhom. For Oron dumpsite, leachate resistivity varies from 4.26-19.00Ωm; leachate thickness from 26.80-62.90m; longitudinal conductance from 1.410526-13.186580.

4.6.1 Da-Zarrouk Parameters Maps of the Area

The distribution map of the longitudinal conductance and transverse resistance of the leachate zone in both Uyo and Oron dumpsites were generated. In Uyo area, Fig. 4.6a depicts that the eastern part of the area possesses higher longitudinal conductance (1.20-2.00 mhom) while at the western part of the area, there are lower values of longitudinal conductance (0.20-1.100 mhom). However, at Oron area, Fig. 4.6b depicts that the eastern part of the area possesses lower longitudinal conductance (0.30 - 6.9 mhom) while at the western part of the area, there are higher values of longitudinal conductance (7.20 - 13.80 mhom).

Table 4.2: Estimated Leachate layer Parameters for the Study Area

Dumpsite/ Profile	VES Point	ρ_l (Ohm-m)	h (m)	S(mhom)	T (m-Ohm)	C (mho)	K_l (m/day)	T_l (m^2/day)	K_z (m/day)	RC
UYO	1	11.40	4.95	0.434211	56.4300	0.08772	39.91394	197.5740	399.2094	-0.77336
P1	2	8.26	2.85	0.345036	23.5410	0.12107	53.90768	153.6369	756.4044	-0.62162
	3	13.30	8.32	0.625564	110.6560	0.07519	34.56803	287.6060	283.8217	-0.89156
	4	6.32	8.69	1.375000	54.9208	0.15823	69.19970	601.3454	1206.1770	-0.88943
P2	5	4.11	4.36	1.060827	17.9196	0.24331	103.3777	450.7268	2871.4350	-0.80663
	6	4.32	9.23	2.136574	39.8736	0.23148	98.68220	910.8367	2509.5430	-0.64179
	7	20.00	4.09	0.204500	81.8000	0.05000	23.62639	96.6319	134.5287	-0.81132
P3	8	9.67	3.29	0.340228	31.8143	0.10341	46.53736	153.1079	523.1242	-0.73128
	9	4.06	3.78	0.931034	15.3468	0.24631	104.56490	395.2553	2948.9360	-0.85694
	10	4.21	4.18	0.992874	17.5978	0.23753	101.08530	422.5366	2241.6450	-0.81083
P4	11	8.42	22.20	2.636580	186.9240	0.11877	52.95150	1175.5230	474.8026	-0.69112
	12	4.32	9.25	2.141204	39.9600	0.23148	98.68220	912.8104	2503.6040	-0.64179
ORON	22	6.36	58.60	9.213836	372.6960	0.15723	68.79363	4031.3070	865.3287	-0.41274
P8	23	19.00	26.80	1.410526	509.2000	0.05263	24.78434	664.2203	104.3551	-0.42424
P9	25	4.26	55.20	12.957750	235.1520	0.23474	99.97812	5518.7920	1877.5230	-0.60846
	28	4.77	62.90	13.186580	300.0330	0.20964	89.96940	5659.0750	1508.9210	-0.44438
P10	29	10.80	31.90	2.953704	344.5200	0.09259	41.97865	1339.1190	310.9530	-0.57647
Average		8.45	18.86	3.114470	143.4344	0.15596	67.80010	1351.1800	1265.900	-0.68440

Key: ρ_l = Leachate resistivity; h= Leachate thickness; S=Longitudinal Conductance; T= Transverse Resistance; C=conductivity; K_l= Hydraulic Conductivity of Leachate; T_l= Transmissivity of Leachate; K_z= Erodibility of Leachate (Parallel flow within each lithologic layer); RC=Reflection Coefficient; FC=Fractured Contrast.

Furthermore, at Uyo area, Fig. 4.7a depicts that the southern parts mostly possess higher transverse resistance (85-185.00 m-ohm-m) while at the eastern - western part of the area, there are lower values of transverse resistance (5.00 - 80.00 m-ohm-m). However, at Oron area, Fig. 4.7b depicts that the northern parts of the area possess higher transverse resistance (310.00 - 520.00 m-ohm-m) while at the southern part of the area, there are lower values of transverse resistance (200.00 - 300.00 m-ohm-m).

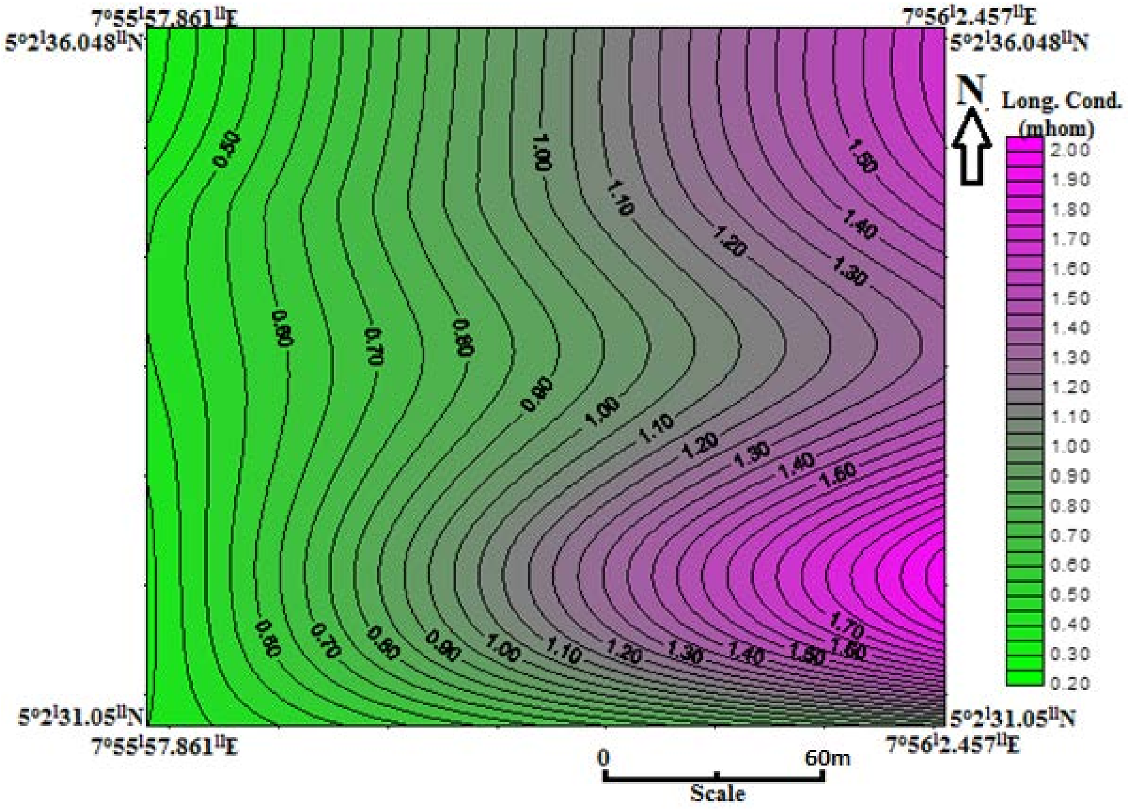


Fig.4.6a: Longitudinal Conductance of Leachate in Uyo area (Contour Interval~0.05mhom)

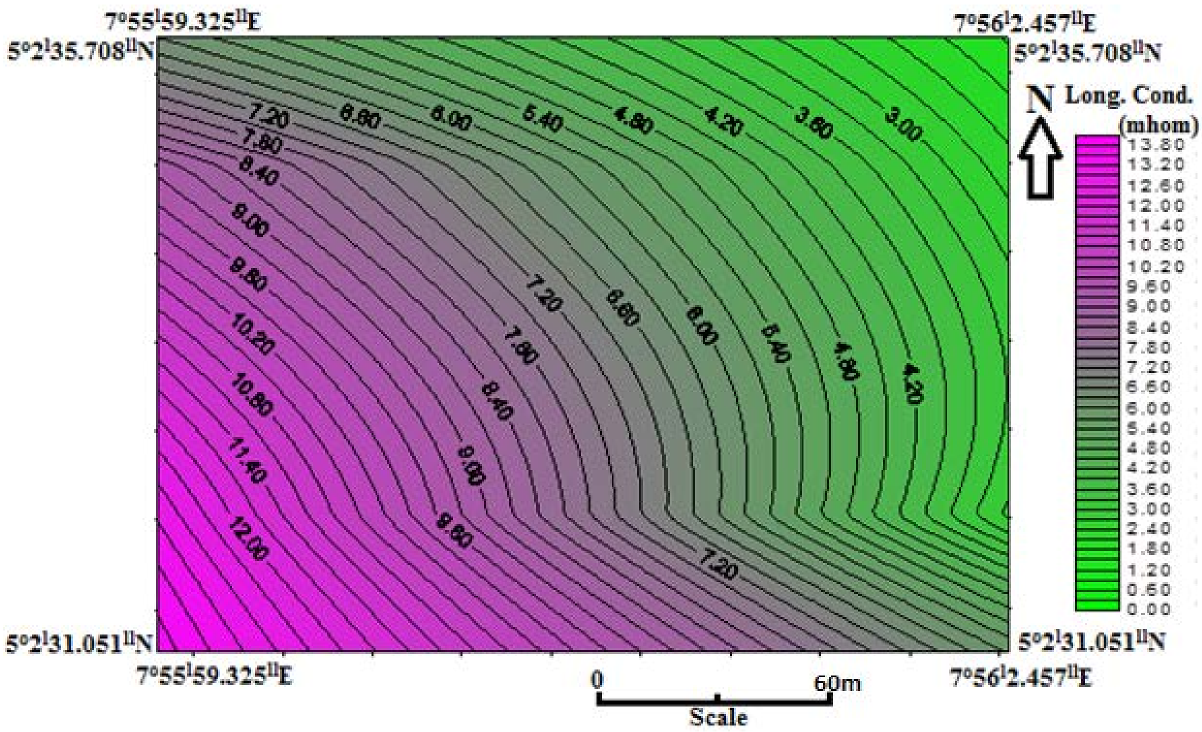


Fig.4.6b: Longitudinal Conductance of Leachate in Oron area (Contour Interval~ 0.05mhom)

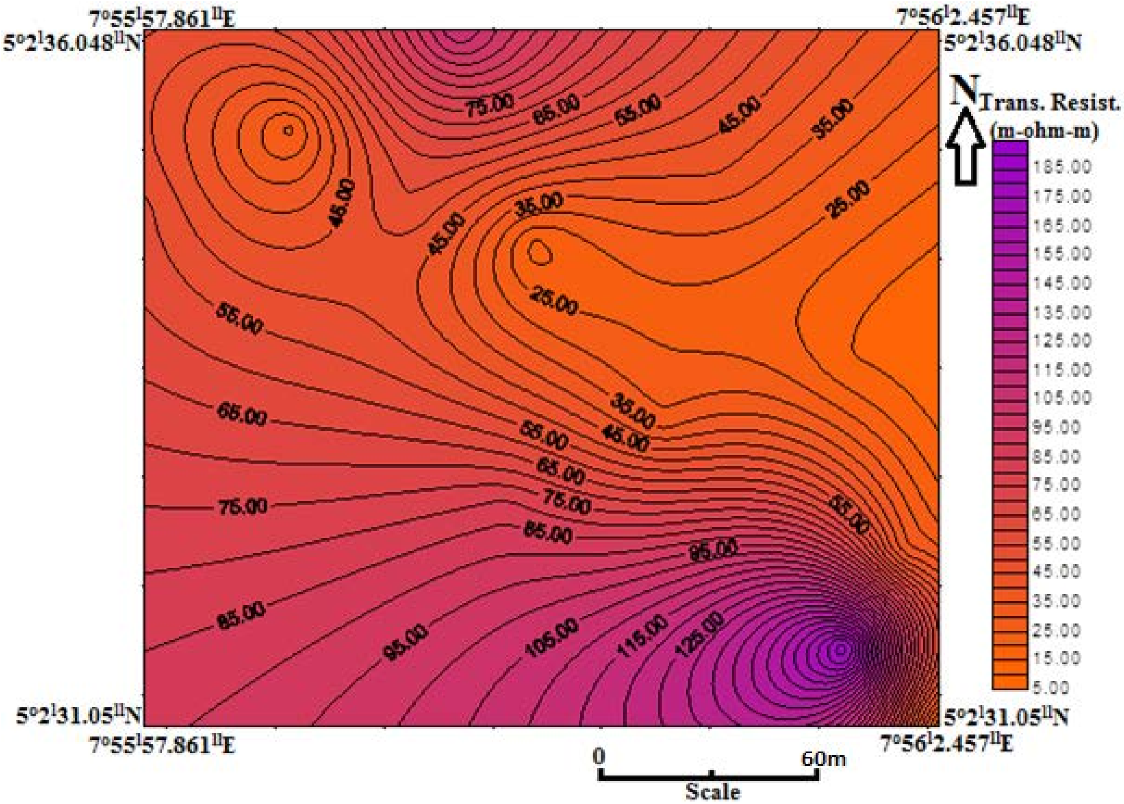


Fig.4.7a: Transverse Resistance of the Leachate at Uyo area (Contour Interval~ 5m-Ohm-m)

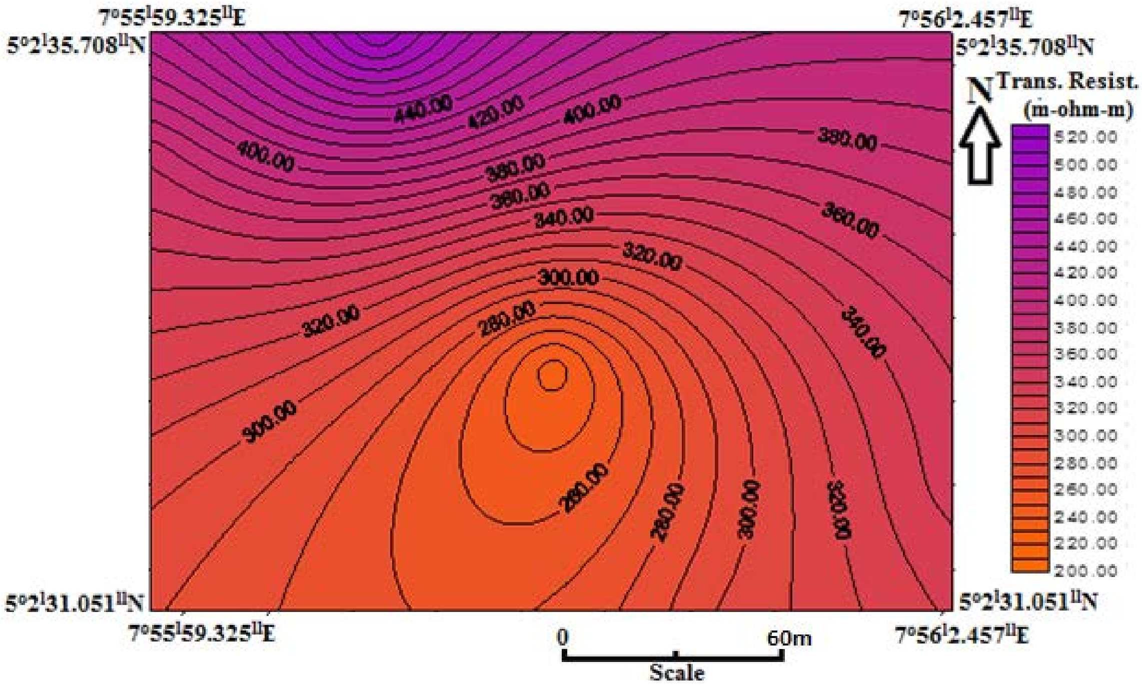


Fig.4.7b: Transverse Resistance of the Leachate at Oron area (Contour Interval~10m-ohm-m)

4.6.2 Leachate Resistivity map

In Uyo area, the obtained results (Table 4.2) show that the value of resistivity of the leachate layer (Fig. 4.8a) is relatively low (4.11 to 20 Ohm-m) compares with the resistivity of the overlying layer (Fig. 4.8b) which is relatively high (10 to 230.00 Ohm-m). At Oron area, the value of resistivity of the leachate layer (Fig. 4.8c) is relatively low (4.26 to 19.00 Ohm-m) unlike the resistivity of the overlying layer (Fig. 4.8d) which is relatively very high (700 to 3100.00 Ohm-m). Some of these resistivity values obtained here aligned with those by Ganiyu *et al*. (2015) at Lapite dumpsite in Ibadan, southwestern Nigeria; where their result revealed the extent of leachate plumes with resistivity values less than 10 ohm-m.

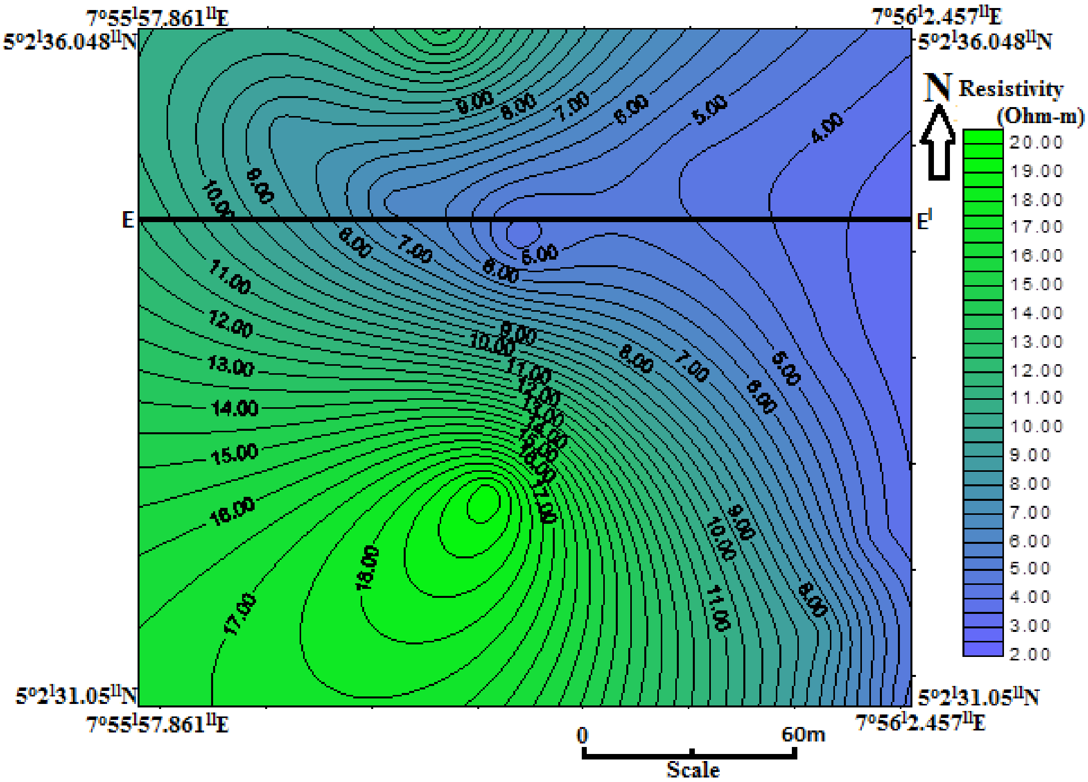


Fig.4.8a: Resistivity of the Leachate layer in Uyo area (Contour Interval~ 0.5Ohm-m)

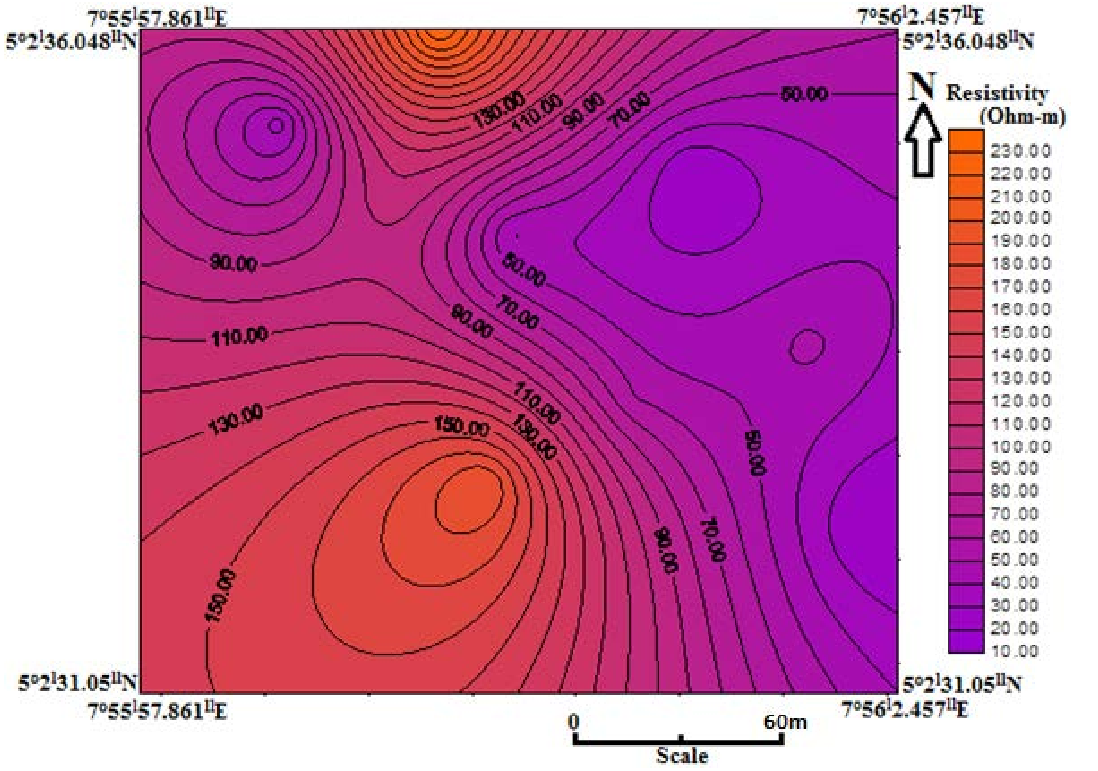


Fig.4.8b: Resistivity of the overlying layer in Uyo area (Contour Interval~10 Ohm-m)

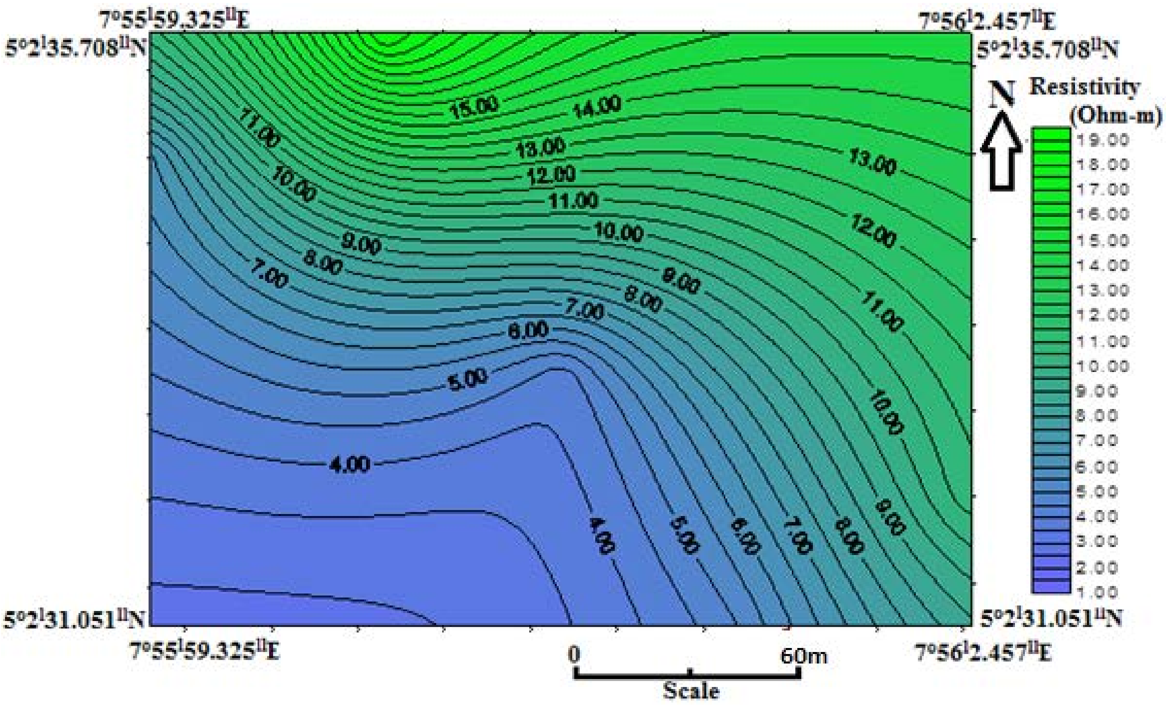


Fig.4.8c: Resistivity of the leachate layer in Oron area (Contour Interval~0.5 Ohm-m)

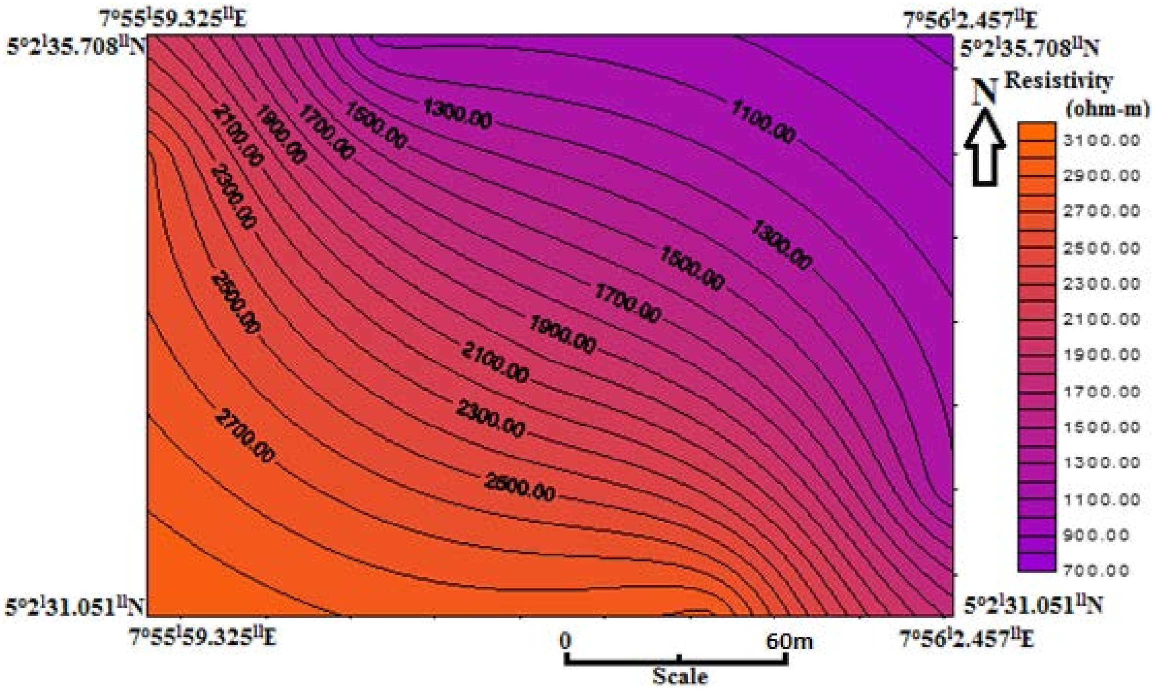


Fig.4.8d: Resistivity of the overlying layer in Oron area (Contour Interval~100 Ohm-m)

4.6.3 Leachate Thickness map

Using the leachate thickness, as derived from the interpretation of resistivity soundings data, the map showing leachate thickness distributions were constructed within the study area (Fig. 4.9). The distribution of aquifer thickness values at contour interval of 2m indicates that two distinct zones can be identified within the area (Fig. 4.9). At Uyo dumpsite (Fig. 4.9a), the violet colour occurs mostly within area which reveals the existence of relatively low thickness of the leachate unit (1 to 10m), while the yellowish colour occurs in a limited portion in the southern part which corresponds to relatively moderate- low thickness of the leachate unit (11 to 22m).

However, at Oron area (Fig. 4.9b), the violet colour occurs mostly within the northeastern area which reveals the existence of relatively moderate- high thickness of the leachate unit (25 to 43m), while the yellowish colour occurs in the southwestern region which corresponds to relatively high thickness of the leachate unit (44 to 67m). Generally, the Oron area is characterized by a leachate zone, which is not favourable for good groundwater exploitation.

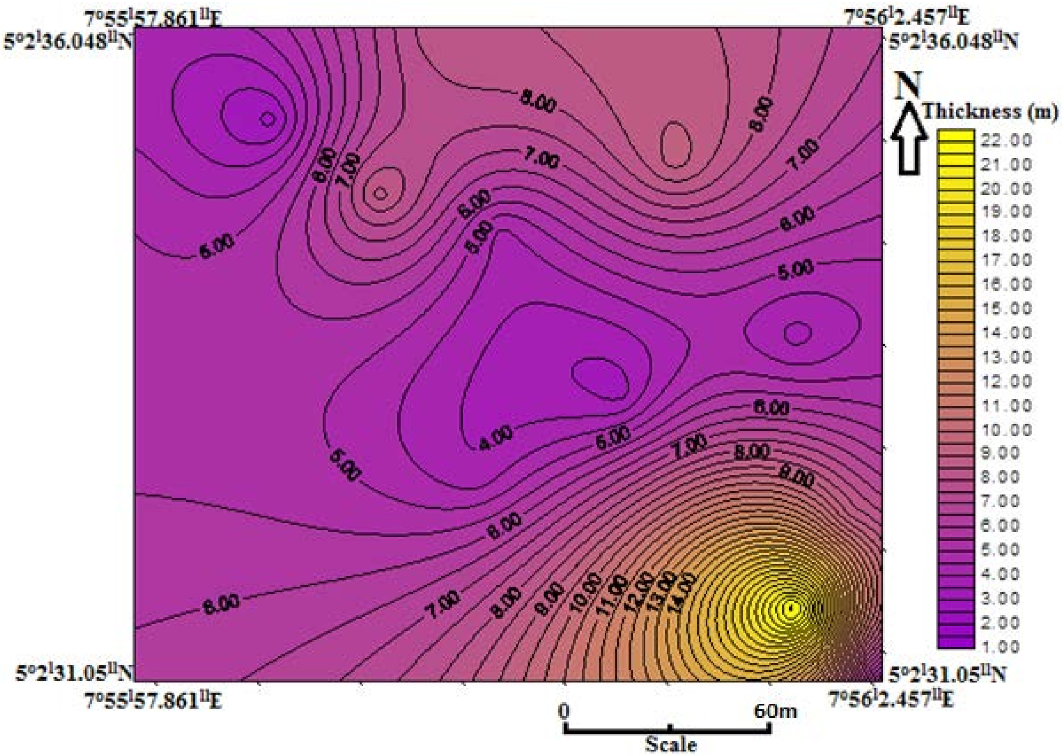


Fig.4.9a: Thickness of the Leachate in Uyo Area (Contour Interval~0.5m)

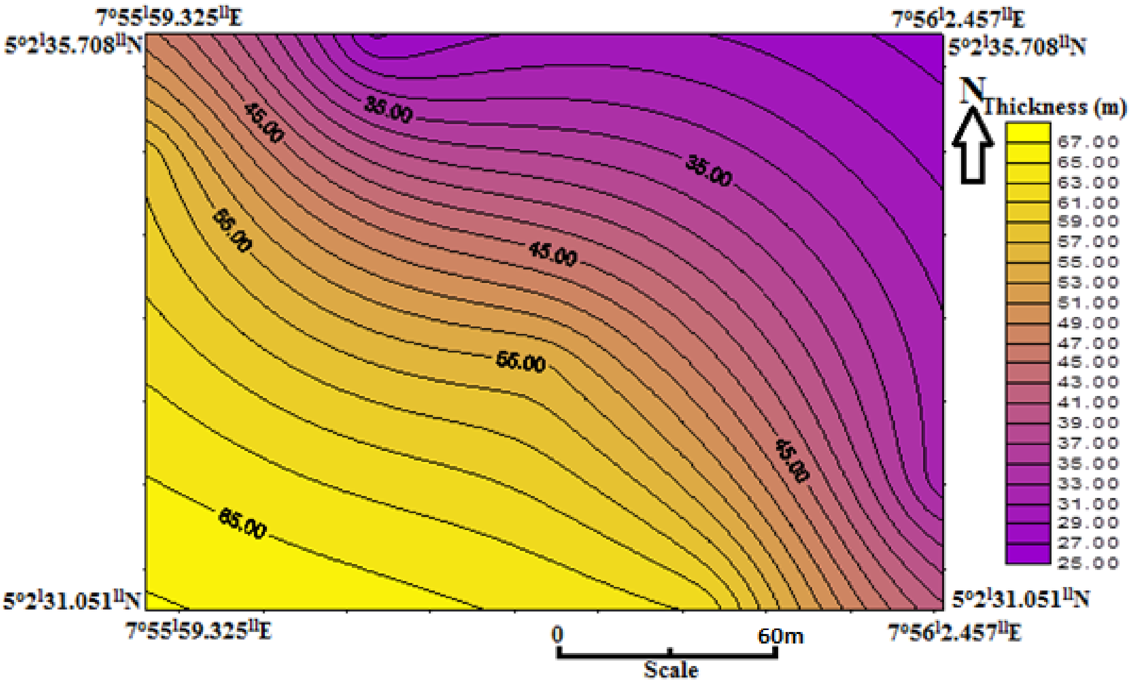


Fig. 4.9b: Thickness of the Leachate in Oron Area (Contour Interval~1.0m)

4.6.4 Hydraulic Conductivity

The hydraulic conductivity of leachate (K_L) calculated from VES result at Uyo area (Fig. 4.10a) ranges from 23.63 m/day to 104.56 m/day. At the western area possesses relatively lower hydraulic conductivity of the leachate unit (23.63 – 65.00 m/day), while the pinkish colour at the eastern part corresponds to relatively higher hydraulic conductivity of the leachate unit (70 – 104.56 m/day).

At Oron dumpsite (Fig. 4.10b), the northeastern area possesses relatively lower hydraulic conductivity of the leachate unit (24.78 – 68.79 m/day), while the pinkish colour at the southwestern part corresponds to relatively higher hydraulic conductivity of the leachate unit (70 – 99.98 m/day).

Few of these values compared well with those obtained by Ekwe and Opara (2012) from interpreted VES data around Owerri and its environs, Southeastern Nigeria for leachate plume; which the hydraulic conductivity of the area were deduced to vary between 6.19 and 24.7 m/day. Fig.4.10 shows clearly the distribution of hydraulic conductivity within the study area. The map signifies that there are two clear zones which can be identified within the area.

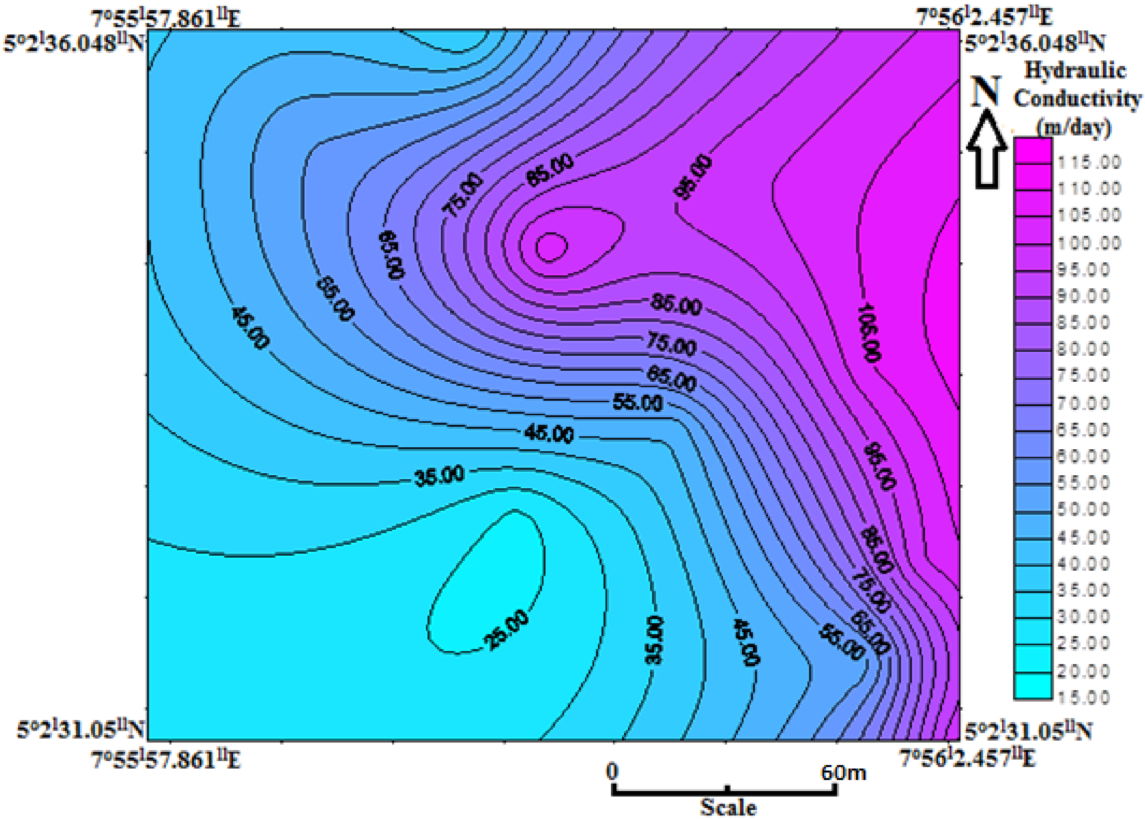


Fig. 4.10a: Hydraulic Conductivity of the Leachate in Uyo Area (Contour Interval~5.0m/day)

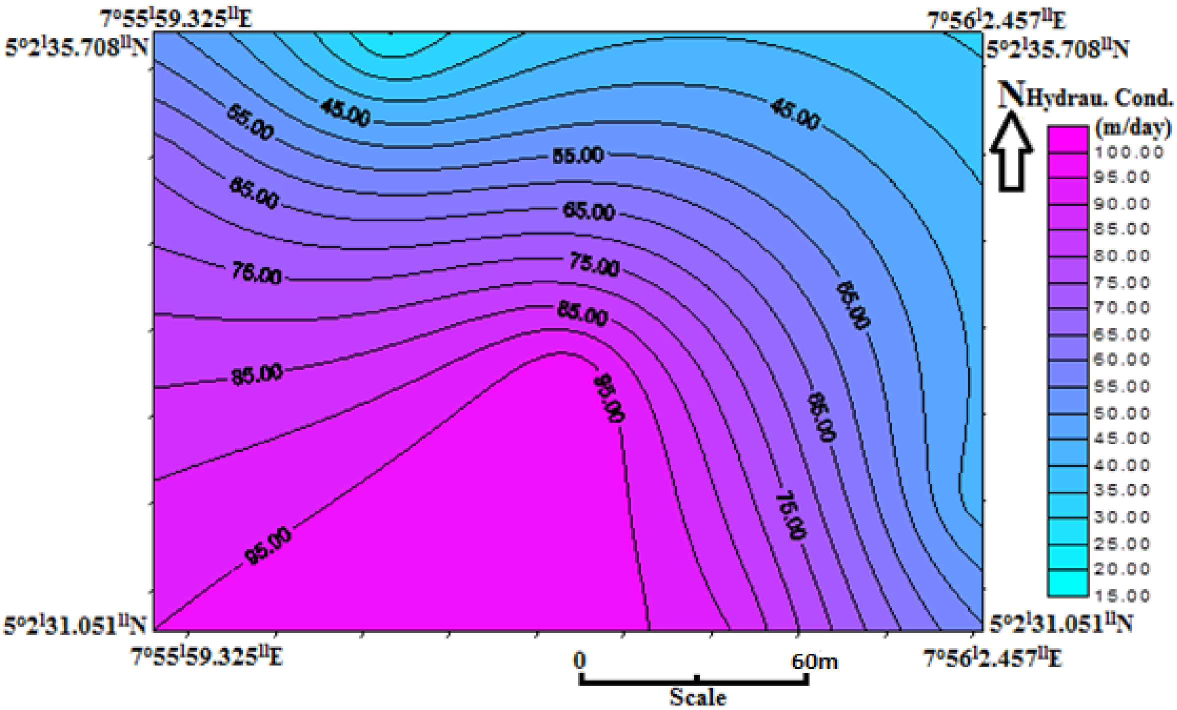


Fig. 4.10b: Hydraulic Conductivity of the Leachate in Oron Area

(Contour Interval~5.0m/day)

4.6.5 Transmissivity

The transmissivity of leachate (T_L) calculated from VES result ranges from 96. 63 to 1175.52m^2/day at Uyo (Fig. 4.11a), while at Oron area, the transmissivity of leachate ranges from 664.22 to 5659.08m^2/day (Fig. 4.11b). Some of these values compared well with those obtained by Ekwe and Opara (2012) from interpreted VES data around Owerri and its environs, Southeastern Nigeria for leachate plume; which the transmissivity of the area were deduced to vary between 51.39 and 5659.08 m^2/day. Fig.4.11 shows clearly the distribution of transmissivity within the study area.

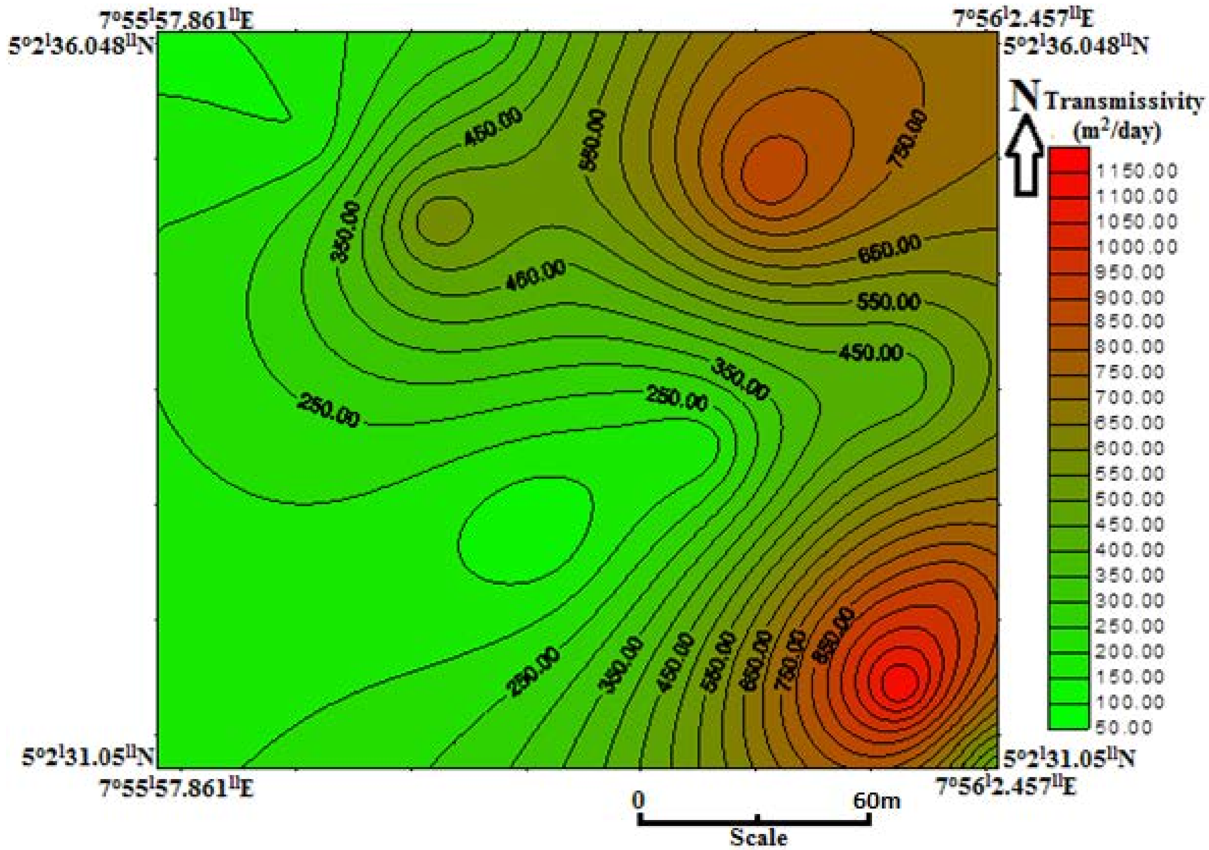


Fig. 4.11a: Transmissivity of the Leachate at Uyo (Contour Interval: 50m^2/day)

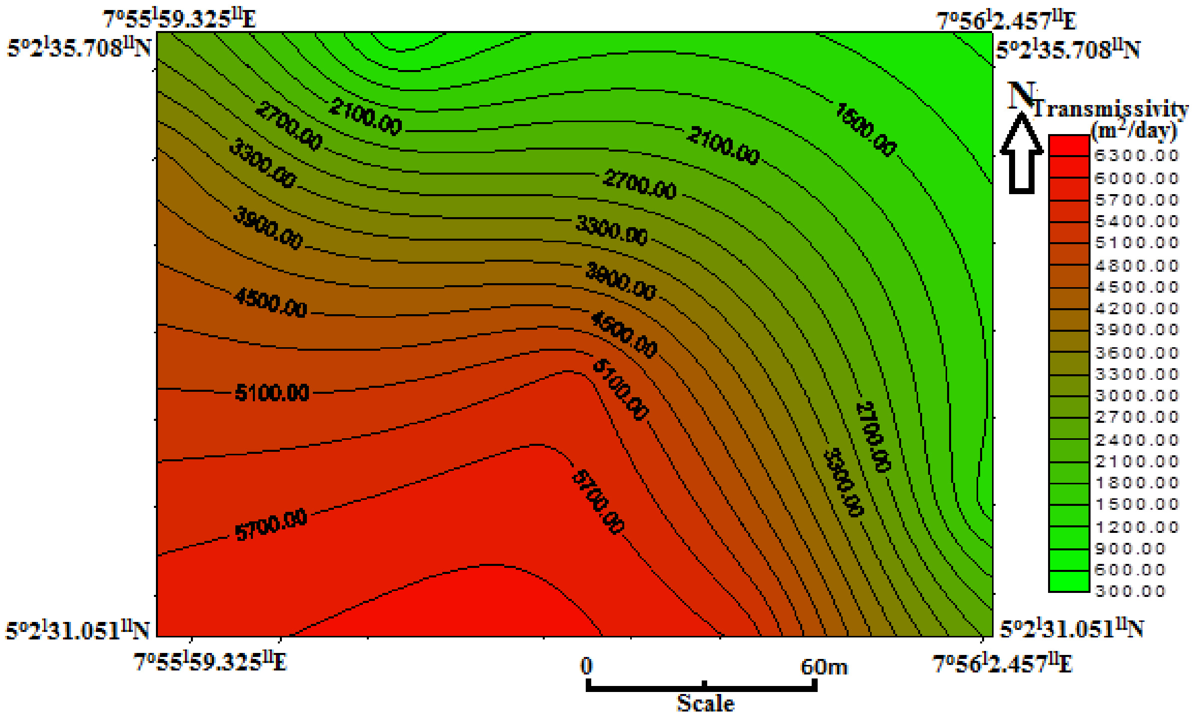


Fig. 4.11b: Transmissivity of the Leachate at Oron area (Contour Interval: 300m^2/day)

4.6.6 Erodibility of the Leachate

The obtained results show that the value of erodibility within the area is between 134.53 and 2948.94 m/day at Uyo area while that of Oron area ranges between 104.36 and 1877.52 m/day. The leachate erodibility distribution maps were produced across the study area (Fig. 4.12). At Uyo area, two distinct zones were interpreted namely; a relatively high erodibility (1400 to 2948.94 m/day) and a relatively moderate erodibility (134.53 to 1206.18 m/day). More so, at Oron area, two distinct zones were interpreted namely; a relatively high erodibility (900 to 1877.52 m/day) and a relatively moderate erodibility (104.36 to 865.33 m/day).

Considering the average erodibility of the leachate units at Uyo area to be 1404.44 m/day, and that of Oron area to be 933.42 m/day, the study area can be classified as having a relatively high erodibility of the leachate units. This implies that the same amount of work exerted by the erosion processes leads to a larger removal of material within the area. This is possible because the mechanics behind erosion depend upon the competence and coherence of the material.

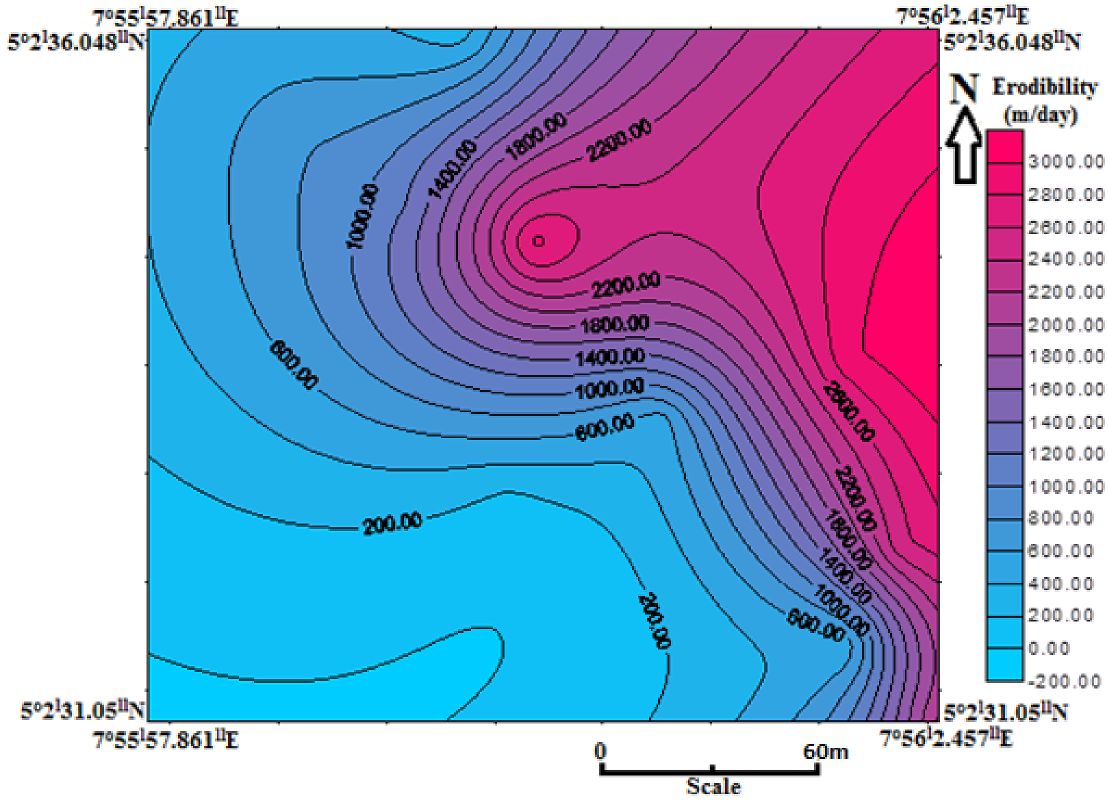


Fig. 4.12a: Erodibility of the Leachate at Uyo area (Contour Interval: 200m/day)

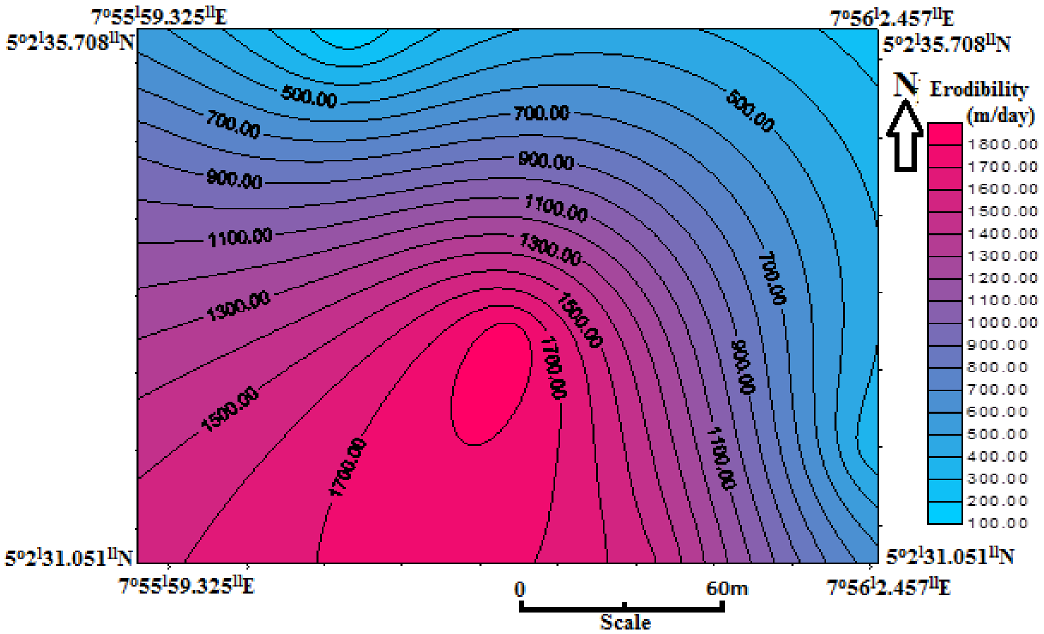


Fig. 4.12b: Erodibility of the Leachate at Oron area (Contour Interval: 100m/day)

4.6.7 Borehole data

The lithology data from boreholes proximal to the dumpsite are shown in Fig 4.13 and Table 4.3. The lithological units within the study area are lateritic sand, fine to medium- grained sand, clayey sand, and medium to coarse-grained sand (the aquifer unit within the study area).

In addition, to be able to determine the groundwater flow direction in the study area, static water levels of water boreholes around the dumpsite were measured. The process involved opening each well head and inserting the electric water level sounder meter. Once the sensitive end of the cord from the meter touches the groundwater surface, it makes a sound. The water depth is measured from the length of the cord at that point. The location and coordinates of each well were also taken and the data presented on Table 4.3.

Table 4.3 Location of water boreholes used for static water level (SWL).

S/N	Latitude	Longitude	Elevation (m)	Static Water Level (m)	Absolute Water Level (m)
1	$N05^{0}02^{1}30.1^{11}$	$E\ 007^{0}\ 56^{1}11.2^{11}$	91	42.9	48.1
2	$N\ 05^{0}\ 02^{1}\ 27.5^{11}$	$E\ 007^{0}\ 56^{1}\ 06.9^{11}$	42	38.6	3.4
3	$N\ 05^{0}\ 02^{1}\ 29.3^{11}$	$E\ 007^{0}\ 56^{1}\ 03.2^{11}$	54	28.3	25.7
4	$N\ 05^{0}\ 02^{1}\ 27.3^{11}$	$E\ 007^{0}\ 56^{1}\ 01.7^{11}$	58	36.6	21.4
5	$N\ 05^{0}\ 02^{1}\ 28.7^{11}$	$E\ 007^{0}\ 55^{1}\ 59.9^{11}$	39	36.6	2.4
6	$N\ 05^{0}\ 02^{1}\ 22.7^{11}$	$E\ 007^{0}\ 56^{1}\ 01.2^{11}$	48	37.8	10.2
7	$N\ 05^{0}\ 02^{1}\ 22.6^{11}$	$E\ 007^{0}\ 55^{1}\ 57.4^{11}$	68	38.1	29.9
8	$N\ 05^{0}\ 03^{1}\ 11.6^{11}$	$E\ 007^{0}\ 55^{1}\ 47.4^{11}$	43	35.5	7.5
9	$N\ 05^{0}\ 02^{1}\ 25.1^{11}$	$E\ 007^{0}\ 55^{1}\ 59.2^{11}$	66	39.6	26.4
10	$N\ 05^{0}\ 02^{1}\ 16.5^{11}$	$E\ 007^{0}\ 55^{1}\ 40.5^{11}$	71	46.7	24.3

N/B: Absolute water level = Elevation – Static Water level

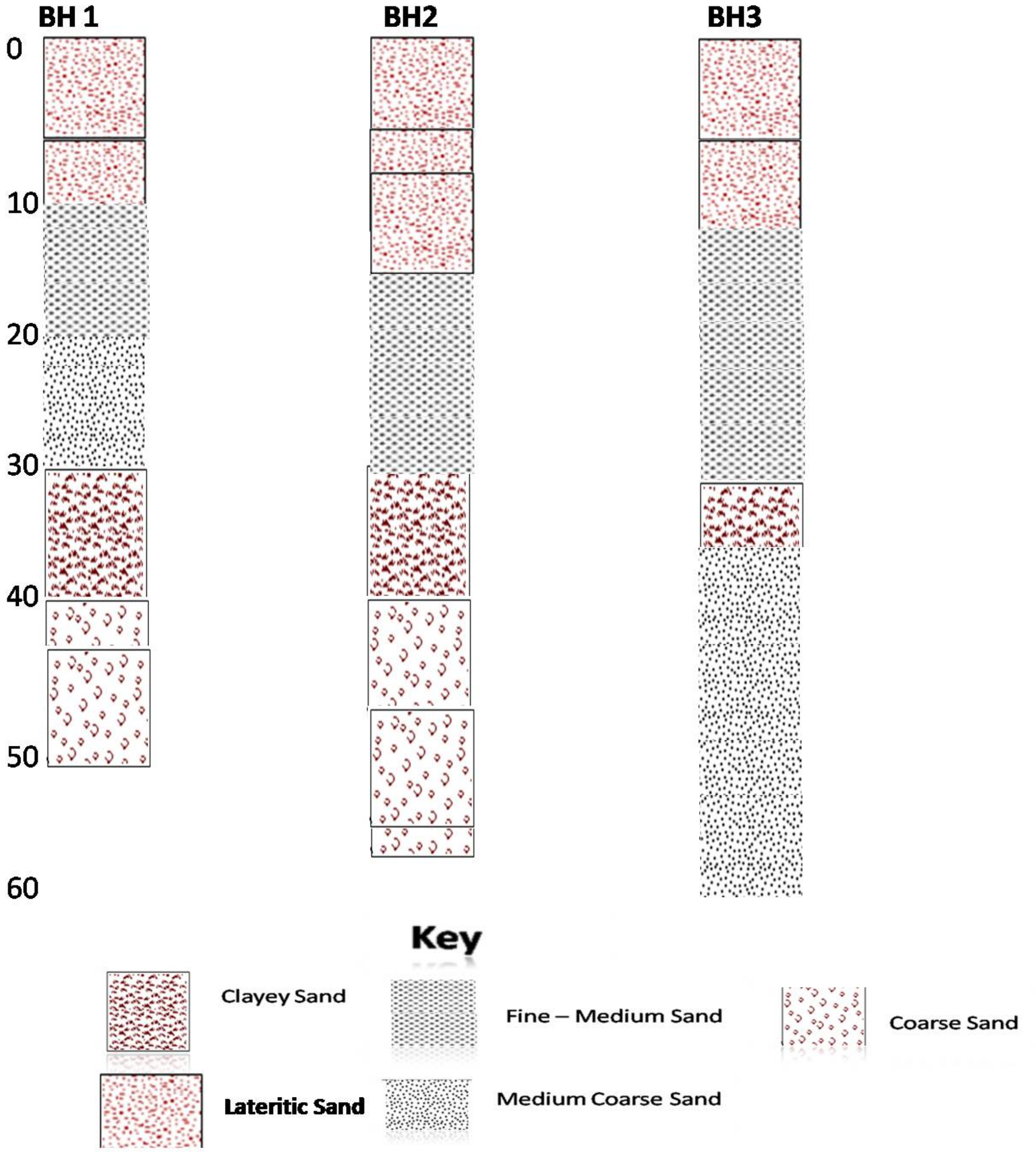


Fig.4.13: Lithologic Profiles of boreholes near Uyo dumpsite

4.7 Hydrogeochemical Characteristics

The quality parameters of the groundwater samples were compared with WHO guidelines (WHO 2017) and Nigerian Standard for Drinking Water Quality (NSDWQ)for drinking purpose (Tables 4.4 and 4.5). Based on these results, the following deductions were made:

The hydrogeochemical analyses reveal that few water samples from boreholes surrounding the dumpsites exhibit elevated Total Dissolved Solids (TDS), reduced pH and high electrical conductivity. Significantly, of the heavy metals, Cadmium is above the permissible limit (Samples DS3 and DS4). The dumpsite is encroaching albeit with minimal impact at the time of study. The acidic pH is a pointer to things that will happen that have not yet manifested. Both the acidic pH and high Cadmium are signs that things are getting wrong with the groundwater. There are a lot of anthropogenic influences adding Cadmium to the groundwater.

The pH data are not within the allowable limits of 6.5-8.5 for drinking and domestic use. The recorded low values are in the range 3.7-5.8. Low pH values are attributed to humic acid from decaying vegetative matter (Edet, 2017). Drinking low pH water (<4.0), could lead to redness and irritation of the eyes. In addition, such low pH values affect the degree of corrosion of metals as well as disinfection efficiency, which may have indirect effect on health (WHO,1996). Therefore, it is recommended that neutralizing filter containing calcite or ground limestone be used to raise the pH of the groundwater before use by the population.

Also, the result of the analysis shows high amount of dissolve Oxygen in samples DS3 and DS4. This perhaps is due to high microbial activity within the environment as shown on Table 4.6.

The concentration of dissolved solids (TDS)may affect the taste of water. Water that contains more than 1000mg/l is unsuitable for many industrial uses. The presence of high levels of TDS may also be objectionable to consumers owing to excessive scaling in water pipes, heaters, boilers and household appliances.

At Ikot Ekpene dumpsite, the low pH is recorded too. However, there is no mineralization of Cadmium; The anthropogenic influences that should have added Cadmium to the groundwater is not prevailing, obviously because this dumpsite was no more active even as at the time of study.

Table 4.4a: Results of Hydrogeochemical Analysis around Uyo Dumpsite

Parameters	66 Udo St (DS1)	H. Garden (DS2)	64 Udo St (DS3)	58 Udo St. (DS4)	68 Udo St. (DS5)	NSDWQ	W.H.O. (2017)
Appearance	Clear	Clear	Clear	Clear	Clear	Clear	
Colour (HU)	5	5	5	5		15	
Odour	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	
Temperature ^{0}c	27.7	31	29.4	29.2	22.7	Ambient	
pH	5	5.8	3.93	3.7	3.82	6.5-8.5	6.5-8.5
Turbidity (NTU)	1.03	20.1	0.5	0	1.17	5`	
Iron (Fe^{3+})mg/l	0.07	0.08	BD	0.16	0.25	0.3	0.3
Salinity %	0.9	1.3	0	0.1	0.1	0.5	
Electrical Conductivity μs/cm	1813	2059	40	131.4	231	1000	1000
Total Dissolved Solid mg/l	857	1242	16.4	79.3	110.1	500	1000
Residual Chlorine (d_2) mg/l	----	-------	--------	-------	--------	0.2-0.25	
Manganese mg/l	0.08	0.08	0.035	0	BD	-	0.4
Nitrates (No_3) mg/l	0.027	0.336	0.06	-0.02(BD)	0.4	50	50
Nitrite (No_2) mg/l	0.018	0.018	0.006	0.001	0.013	0.2	3
Ammonia (NH_3) mg/l	0.07	0.04	0	0	0	0	0.2
Phosphate (po_1^3) mg/l	0.033	0.001	0.025	0.043	0.006	3.5	
Suspended Solid mg/l	0.4	2.4	8	15	BD	10	
Total silica (SiO_2) mg/l	--------	---------	0.029	0.002	0.035	17	
Sulphate (SO_4) mg/l	11.2	11.2	5	3	5	1000	500
Total Hardness mg/l	72	34	36	46	32	500	
Calcium Hardness (Ca^2) mg/l	70	82	14	20	30	75	
Magnesium Hardness mg/l	2	BD	BD	BD	BD	0.2	
Acidity mg/l	0.8	0.48	0.04	0.64	0.08	4.5-8.2	
Total Alkalinity mg/l	13.2	15.6	4.8	4.88	24	100-200	
Chloride (Cl) mg/l	0.83	0.78	0.6	0.1	0	250	
Methyl Alkalinity mg/l	13.2	15.6	4.8		2.4	100-200	
Aluminium ($A1^{3+}$) mg/l	---------	---------	0.01	0.04	0	0.2	0.1-0.2
Selenium (Se) mg/l	-------------	----------	0.101	0.04	0	-	0.01
Chromium (Cr)	0.002	0	0	0.01	0.01	0.05	0.05
Cadmium (Cd) mg/l	0	0	1	1	0.004	0.003	0.003
Copper (Cu)mg/l	0.813	0.824	0.17	0.12	0.17	1	2.0
Cyanide (CN) mg/l	---------	----------	0.005	0	0.006	0.01	0.17
Lead (Pb) mg/l	0.0007	0.0007	0.6	0	0.003	0.01	0.01
Arsenic (As) mg/l	---------	---------	0.03			0.01	0.01
Barium mg/l	-------------	----------	7	7	BD	0.7	0.7
Dissolved Oxygen (0_2) mg/l	0.77	0.78	43.4	10.8	1.2	- 1.0-5.0	

Table 4.4b: Results of Hydrogeochemical Analysis around Ikot Ekpene and Oron Dumpsites

Parameters	IK (DS6)	Murtala Way Oron (DS7)	NSDWQ	W.H.O. (2013)
Appearance	Clear	Clear	Clear	
Colour (HU)	5	5	15	
Odour	Acceptable	Acceptable	Acceptable	
Temperature ^{0}c	22.9	25.7	Ambient	
pH	3.86	4.15	6.5-8.5	6.5-8.5
Turbidity (NTU)		0.28	5`	
Iron (Fe^{3+}) mg/l	BD	0.08	0.3	0.3
Salinity %	0.5	0.06	0.5	
Electrical Conductivity us/cm	1022	1224	1000	1000
Total Dissolved Solid mg/l	480	574	500	1000
Manganese mg/l	BD	BD	-	0.1
Nitrates (No_3) mg/l	0.015	0.01	50	0.09
Nitrite (No_2) mg/l	BD	BD	0.2	0.013
Ammonia (NH_3) mg/l	0	0	0	0.2
Phosphate (po_4^3) mg/l	0.031	0.05	3.5	
Suspended Solid mg/l	17	BD	10	
Total silica (Sio_2) mg/l	BD	BD	17	
Sulphate (so_1^2) mg/l	3	BD	1000	500
Total Hardness mg/l	220	130	500	
Calcium Hardness (Ca^2) mg/l	140	34	75	
Magnesium Hardness mg/l	80	96	0.2	
Acidity mg/l	0.04	0.8	4.5-8.2	
Total Alkalinity mg/l	12	62.4	100-200	
Chlorine Demand mg/l			0.2-0.25	
Chloride (Cl) mg/l	0.1	BD	250	250
Aluminium ($A1^{3+}$) mg/l	BD	BD	0.2	0.1-0.2
Selenium (Se) mg/l	0.02	BD	-	0.01
Chromium (Cr^{61})	BD	0	0.05	0.05
Cadmium (Cd) mg/l	0	0	0.003	0.003
Copper (Cu^{2+}) mg/l	0	BD	1	2
Cyanide (CN) mg/l	0	BD	0.01	0.17
Lead (Pb) mg/l	BD	BD	0.01	0.01
Zinc (Zn) mg/l	0.01	BD	3	
Arsenic (As) mg/l			0.01	0.01
Barium mg/l	BD	BD	0.7	0.7
Fluoride (F) mg/l	0	BD	1.5	
Mercury (Hg) mg/l			-	
Dissolved Oxygen (0_2) mg/l	1	1.1	1.0-5.0	

Table 4.5: Control Result of Hydrogeochemical Analysis away from Uyo Dump Site

Parameters	45 Calabar/ Itu Road Uyo/S1	Ewet Housing Uyo/S2	Ikot Abia Idem Ik/S4	Nkanga Road Ik/S5	EffiongEsang Oron/S6	NSDWQ
Appearance	Clear	Clear	Clear	Cloudy	Clear	Clear
Colour (HU)	5	5	5	5	5	15
Odour	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
Temperature ^{0}c	31.7	26.1	26	27.1	31.9	Ambient
pH	5.7	5.09	5.58	6.67	5.19	6.5-8.5
`Turbidity (NTU)	1.19	4.72	0.31	12.2	0.83	5`
Iron (fe^{3+})mg/l	BD	0.18	0.64	0.11	0.02	0.3
Salinity %	0	0	0	0	0	0.5
Electrical Conductivity us/cm	45.48	63.6	20.9	40.2	24.6	1000
Total Dissolved Solid mg/l	18.8	30.9	8.4	16.4	9.7	500
Manganese mg/l	BD	0.018	BD	0.025	0	-
Nitrates (No$_2$)	BD	0.06	BD	0.06	0.65	50
Nitrite (No$_2$)	0	0.014	0.07	0.004	0.008	0.2
Ammonia (NH_3)	0.02	BD	0	0	BD	0
Phosphate (PO_1^3) mg/l	BD	0.252	0.0023	0.089	0.136	3.5
Suspended Solid mg/l	20	BD	BD	12	17	10
Total silica (Sio$_2$) mg/l	BD	0.048	BD	0.034	BD	17
Sulphate (so_1^2) mg/l	0	8	2	8	8	250
Total Hardness mg/l	148	18	56	14	44	500
Calcium Hardness (Ca^2)	48	52	58	16	48	75
Magnesium Hardness mg/l	100	0	BD	BD	BD	0.2
Acidity mg/l	4	0.12	0.08	4	8	4.5-8.2
Total Alkalinity mg/l	13.2	6	18	9.6	25.2	100-200
Chlorine Demand mg/l	-	0.8	-	-	-	0.2-0.25
Chloride (CT) mg/l	BD	0.5	0.1	0.8	0.6	250
Aluminium ($A1^{3+}$) mg/l	0.02	0	0	0.05	BD	0.2
Chromium (Cr^{61})	0.01	0.31	BD	0	0.01	0.05
Cadmium (Cd) mg/l	0	0	BD	0.04	0.005	0.003
Copper (Cu^{2+})mg/l	0.01	0	0.16	0.001	0.02	1
Cyanide (n) mg/l	0.001	0.03	0	0.16	0.001	0.01
Lead (pd) mg/l	BD	-	BD	0.004	BD	0.01
Zinc (Zn) mg/l	0.05		0.05	0.08	0.01	3
Arsenic (As) mg/l	-		-	-	BD	0.01
Barium mg/l	BD	4	BD	6	0.06	0.7
Fluoride (F) mg/l	0	BD	BD	BD	-	1.5
		-	-	-		-
Dissolved Oxygen (0$_2$) mg/l	0.9	0.2	0.2	0.1		1.0-5.0

4.8 Bacteriological Characteristics

The result of the analyses shows that all samples except that of Ikot Abia Idem had high level of bacteriological pollution with E. Coli and Total Coliform counts above permissible limit of the W.H.O. (Table 4.6). This is very harmful for health and therefore proper borehole treatment should be carried out to safeguard human health.

The most common and widespread health risk associated with drinking water is microbial contamination, the consequences of which mean that its control must always be of paramount importance (WHO, on guidelines for drinking water quality, 2008).

Diseases related to contamination of drinking water constitute a major burden on human health. Interventions to improve the quality of drinking water provide significant benefits to health (WHO, 2008).

Table 4.6a Test for total coliform

Report of water culture in (CFU) per 100ml at 48hrs

SAMPLE / LOCATION	MEDIA		DILUTION FACTOR	AVERAGE	TOTAL	NSDWQ	
	NUTRIENT	MACKONKEY AGAR				E.coli	Total Coliform
58 Udo Str.	84	88	10^{-2}	59	590	0	10
64 Udo Str.	40	6	10^{-2}	23	230	0	10
68 Udo Str.	72	50	10^{-2}	61	610	0	10

PARAMETER	DS1 (Ik. Club)	DS2 (Murtala Way)	DS3 (64 Udo)	DS4 (58 Udo)	DS5 (68 Udo)	WHO STANDARD
Faecal Coliform (E.Coli)	Nil	Nil	$23x10^2$	$59x10^2$	$61x10^2$	O/100ml
Total Coliform	$1x10^2$	$4x10^3$	$1x10^2$	$6x10^2$	$1x10^2$	O/100ml

Note: Total Coliform = E.coli + other coliforms.

Table 4.6b: Control Result of Water Culture at 48 Hours in (CFU) Per 100ml

Samples	NA	MAC	Factor	Average	Total	W.H.O.
Ikot Abia Idem	0	0	10^{-2}	0	0	0
Nkanga Road Nkap	0	10	10^{-2}	5	5×10^2	0
Effiong Esang 87	2	0	10^{-2}	1	1×10^2	0
45 Itu Road	5	0	10^{-2}	2	$2 x10^2$	0
Ewet Housing	0	0	10^{-2}	0	0	0
Akpabio Street	20	4	10^{-2}	12	12×10^2	0

(cfu-coliform forming unit)

4.9 Discussions and Geologic Implications

4.9.1 VES Curves and its implications

The VES curves generated at Uyo and Oron areas are typically H and K-curves, which imply that the interpreted VES Curves are quite common in a sedimentary environment for multilayer structures of three or more layers. The interpreted VES in conjunction with the borehole data within the study area reveal the following layers: top lateritic sand, leachate contaminated sand, and dry fine to medium-grained sand layers. These are some characteristics of the Benin Formation which this area is entirely made up of. The entire profile therefore shows sands of varying composition based on their resistivity attributes. In line with this, Mbipom *et al*. (1996) established that the study area falls within the sedimentary area of Nigeria and is overlain by Tertiary coastal plain sands of the Niger Delta sedimentary sequence known as the Benin Formation. They observed that Benin Formation consists of fine to medium, coarse-grained sands which sometimes are poorly sorted. Also, Ugbaja and Edet (2004) observed that the coastal plain sands are made of alternating sequences of gravels and sands of different grain sizes, silt, clay and alluvium.

4.9.2 Interpreted Pseudo Cross- Section and its Implications

Subsequently, the interpretation of the pseudo cross- sections generated within the study area align with the already interpreted leachate-prone zones in the subsurface within the study area, such that, it has abnormally low apparent resistivity values; which it will present itself as plumes of black and light blue colours and will mean areas of high contamination; while areas with green, yellow and red colour codes will represent areas of no vulnerability to contamination. More so, areas with high porosity and permeability are more likely to be percolated by leachate and thus more prone to contamination. The amount and especially the depth of percolation of the leachate can serve as an index to qualitative evaluation of porosity and permeability of the transmitting medium such as sediments.

In addition, the leachate migration path within the study area trend in the NW-SE direction. This signifies that the migration pattern of the plume coincides with the dominant groundwater flow direction of the area (Fig.4.14).

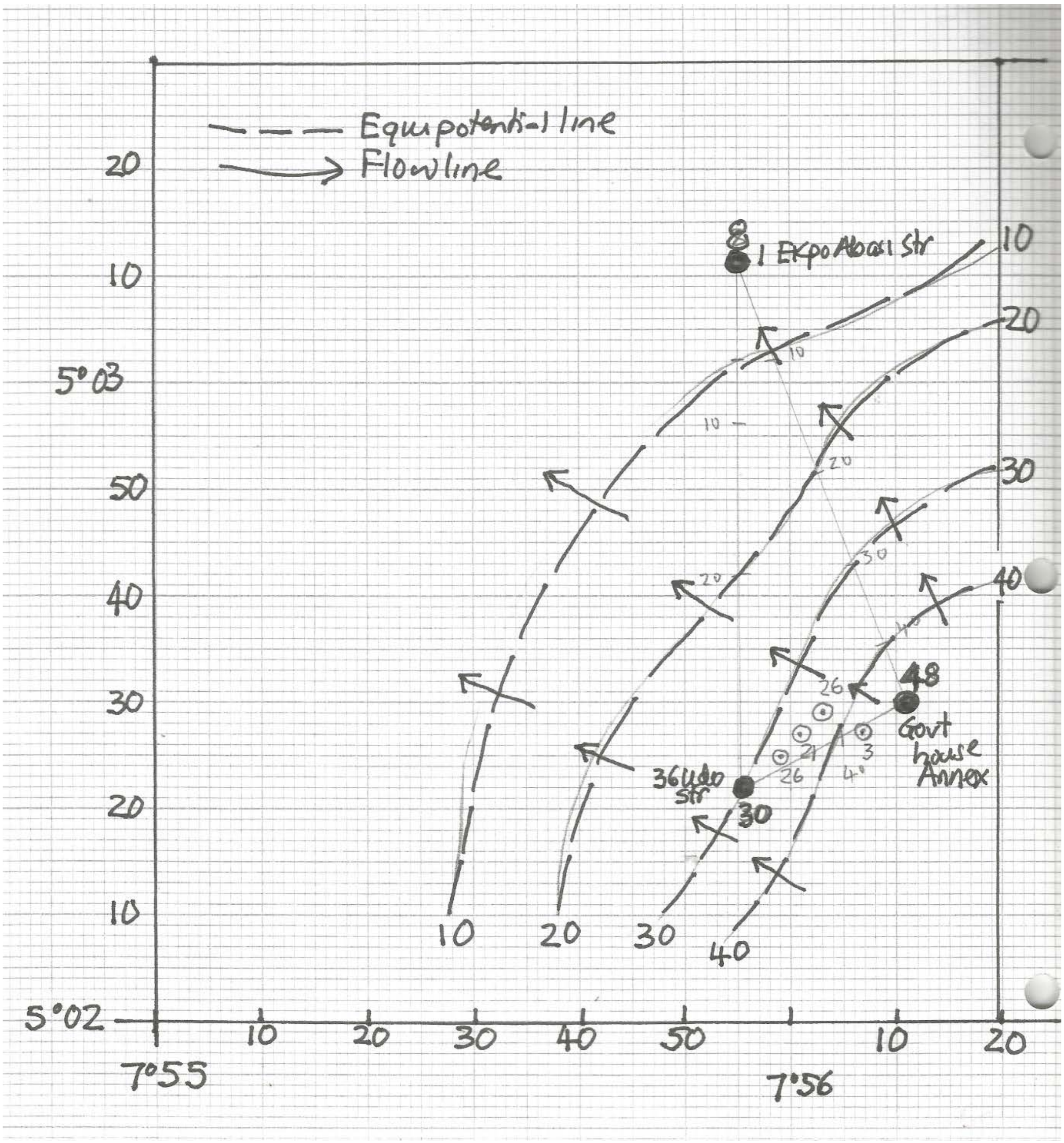


Fig. 4.14: Groundwater flow direction in the Study Area.

4.9.3 Computed Layer Parameters and its implications

The computed layer parameters for the overburden and leachate of the interpreted VES data (Table 4.2) show that the values of various parameters range from low to high across Uyo and Oron areas: longitudinal conductance (0.20 – 2.00 mhom at Uyo and 0.30 – 13.80 mhom at Oron); transverse resistance (5.00 to 185.00 m-ohm at Uyo and 200.00 - 520.00 m-ohm); and others. Also, at Uyo, comparing the resistivity of the leachate layer (4.11 to 20 Ohm-m) and the resistivity of the overlying layer (10 to 230.00 Ohm-m), it means that the resistivity of the overlying layer is greater than that of the leachate layer. This also implies that the conductivity of the leachate layer at Uyo (Fig. 4.15a) is invariably high compared to that of the overlying layer which is relatively low. Also, at the Oron area, the resistivity of the leachate layer (4.26 to 19.00 Ohm-m) differs strongly from the resistivity of the overlying layer (700 to 3100.00 Ohm-m). This implies that the conductivity of the leachate layer at Oron (Fig. 4.15b) is invariably high compared to that of the overlying layer which is relatively low. Hence, these resistivity values obtained in this study aligned with those obtained by Ganiyu *et al*. (2015) at Lapite dumpsite in Ibadan, southwestern Nigeria; where their result revealed that the extent of leachate plumes with resistivity values less than 10 ohm-m.

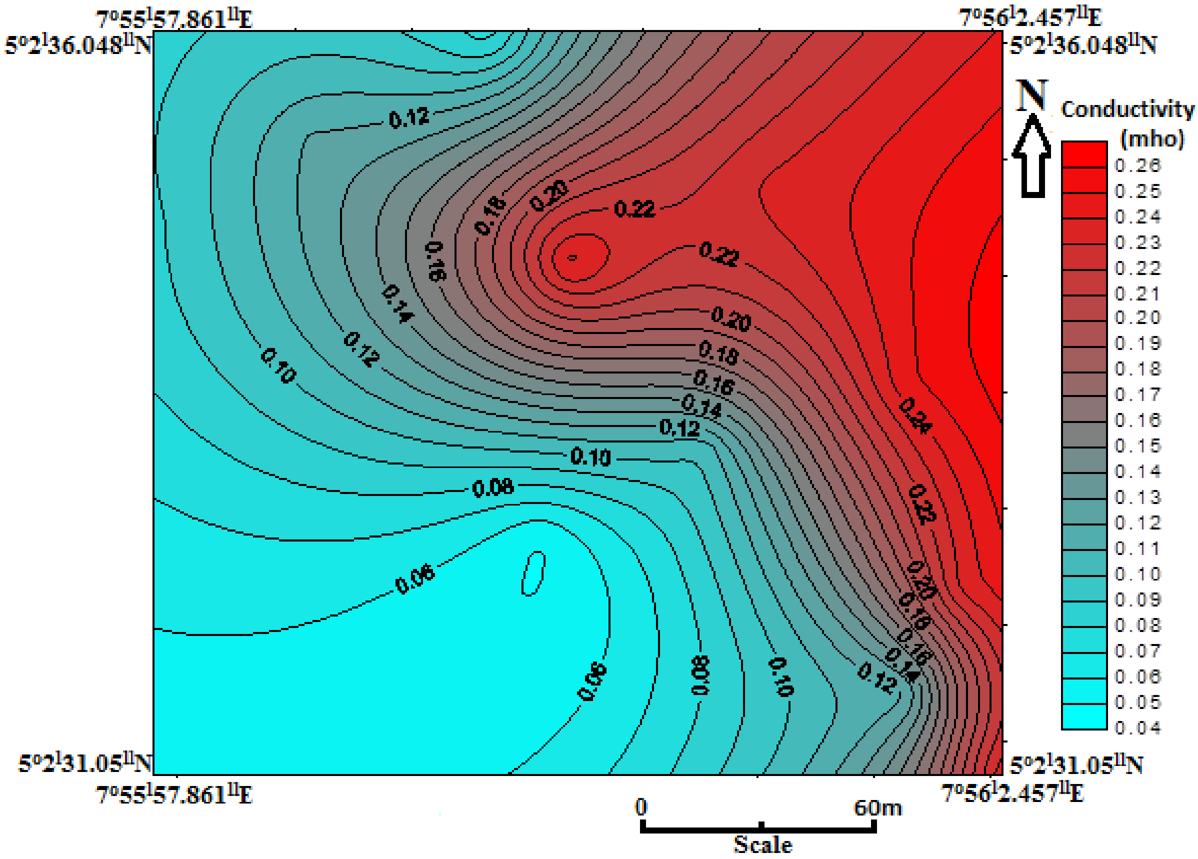


Fig. 4.15a: Conductivity of the Leachate in Uyo area (Contour Interval: 0.01mho)

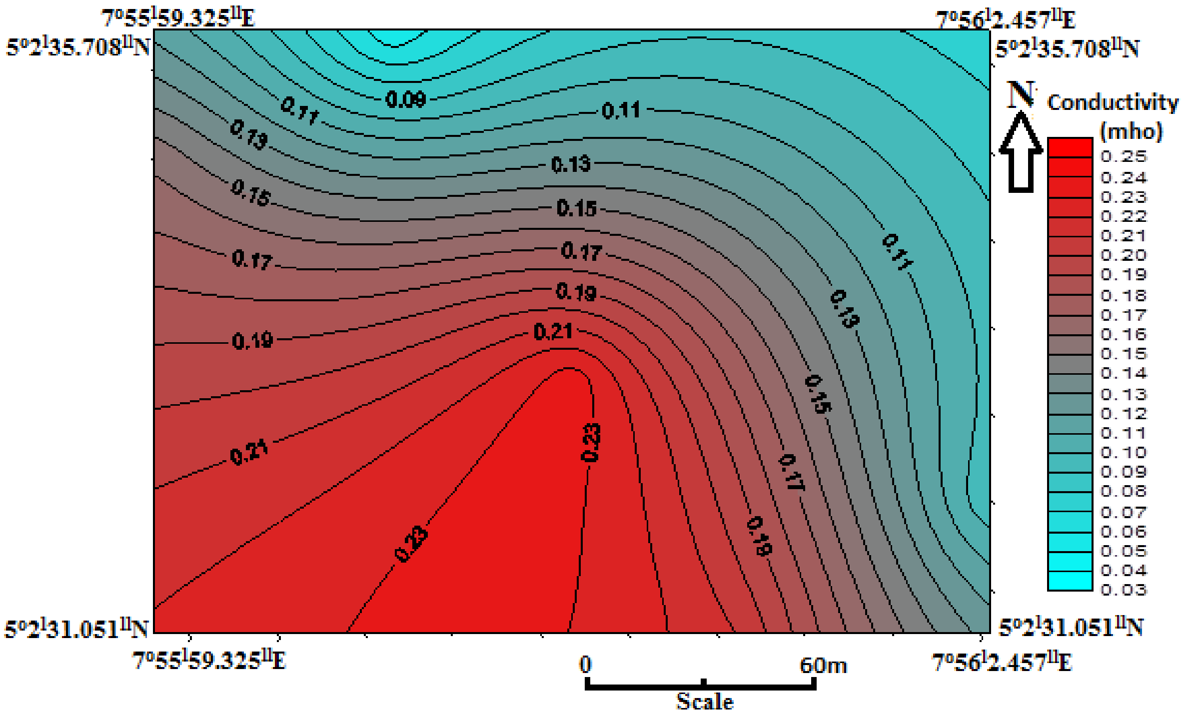


Fig. 4.15b: Conductivity of the Leachate in Oron area (Contour Interval: 0.01mho)

Considering the leachate thickness across the study area (Fig. 4.9); at Uyo dumpsite (Fig. 4.9a), the violet colour occurs mostly within the northern area which reveals the existence of relatively low thickness of the leachate unit (1 to 10m), while the yellowish colour occurs in a limited portion in the southern part which corresponds to relatively moderate -low thickness of the leachate unit (11 to 22m). However, at Oron area (Fig. 4.9b), the violet colour occurs mostly within the northeastern area which reveals the existence of relatively moderate- high thickness of the leachate unit (25 to 43m), while the yellowish colour occurs in the southwestern region which corresponds to relatively high thickness of the leachate unit (44 to 67m). Generally, the Oron area is characterized by a thick leachate zone, which is not favourable for good groundwater potential.

Furthermore, the hydraulic conductivity at Uyo area (Fig. 4.10a) ranges from 23.63 m/day to 104.56 m/day. At Oron dumpsite (Fig. 4.10b), the northeastern area possesses relatively lower hydraulic conductivity of the leachate unit (24.78 – 68.79 m/day), while the pinkish colour at the southwestern part corresponds to relatively higher hydraulic conductivity of the leachate unit (70 – 99.98 m/day). Few of these values compared well with those obtained by Ekwe and Opara (2012) from interpreted VES data around Owerri and its environs, Southeastern Nigeria for leachate plume; which the hydraulic conductivity of the area were deduced to vary between 6.19 and 24.7 m/day. Fig.4.10 shows clearly the distribution of hydraulic conductivity within the study area. The map signifies that there are two clear zones which can be identified within the area. In addition, the transmissivity of leachate zone at Uyo area ranges from 96. 63 to 1175.52m^2/day (Fig. 4.11a), while at Oron area, the transmissivity of leachate ranges from 664.22 to 5659.08m^2/day (Fig. 4.11b). Some of these values compared well with those obtained by Ekwe and Opara (2012) from interpreted VES data around Owerri and its environs, Southeastern Nigeria for leachate plume; with the range of transmissivity of the area obtained to be between 51.39 and 5659.08 m^2/day.

More so, considering the average erodibility of the leachate units at Uyo area to be 1404.44 m/day, and that of Oron area to be 933.42 m/day, the study area can be classified as having a relatively high erodibility of the leachate units. This implies that the same amount of work exerted by the erosion processes leads to a larger removal of material within the area. This is possible because the mechanics behind erosion depend upon the competence and coherence of the material.

4.9.4 Leachate Level and its implication

4.9.4.a Elevation and Leachate level Maps

The elevation maps of Uyo and Oron dumpsites (Fig. 4.16) were produced for effective correlation with the leachate level maps. Nevertheless, the leachate levels across Uyo and Oron dumpsites were computed by subtracting depths to leachate layer deduced from the sounding curves from surface elevations obtained during the data acquisition (Table 4.7). Thus, maps of the leachate levels with respect to elevations were generated in order to depict the flow direction of the leachate plume across the study area (Fig. 4.17). At Uyo area (Fig. 4.18a), the flow direction of the leachate plume is predominantly in NW-SE direction and hydrogeologically, this is the dominant groundwater flow direction in this area (Fig.4.13). Also, the thickness of the leachate level increases along this flow direction within this area. Subsequently, the flow direction of the leachate plume at Oron area (Fig. 4.18b) is predominantly in NE-SW direction and hydrogeologically, this is the groundwater flow direction of the area. Hence, the thickness of the leachate level increases along this flow direction within this area. Also, cross sections G-G^{l} at Uyo in Fig. 4.18a and H-H^{l} at Oron (Fig. 4.18b) were taken along the flow directions in order to unveil the sinks and peaks of the flow direction (Fig. 4.20).

.

Table 4.7a: Leachate level with respect to mean sea level (MSL) at Uyo Dumpsite

VES Point	Latitude	Longitude	Elevation (m)	Depth (m)	Leachate level w.r.t. MSL (m)
1	5.041959	7.933695	52	1.03	50.97
2	5.042229	7.933837	99	1.25	97.75
3	5.042537	7.934016	41	2.43	38.57
4	5.042437	7.933695	83	1.15	81.85
5	5.042674	7.933623	59	1.48	57.52
6	5.043016	7.933755	74	1.15	72.85
7	5.042626	7.933146	88	2.02	85.98
8	5.042906	7.933301	69	1.43	67.57
9	5.043252	7.933414	70	1.72	68.28
10	5.043418	7.932739	72	2.47	69.53
11	5.043252	7.93288	71	2.32	68.68
12	5.043347	7.933059	68	1.15	66.85
Average			70.5	1.63	68.87

Table 4.7b: Leachate level with respect to mean sea level (MSL) at Oron Dumpsite

VES Point	Latitude	Longitude	Elevation (m)	Depth (m)	Leachate level w.r.t. MSL (m)
22	5.041958	7.933695	65	21.4	43.6
23	5.042229	7.933837	48	53.2	-5.2
24	5.042437	7.933444	63	24.8	38.2
27	5.042626	7.933146	56	17.1	38.9
28	5.042906	7.933301	60	48.1	11.9
Average			58.4	32.92	25.48

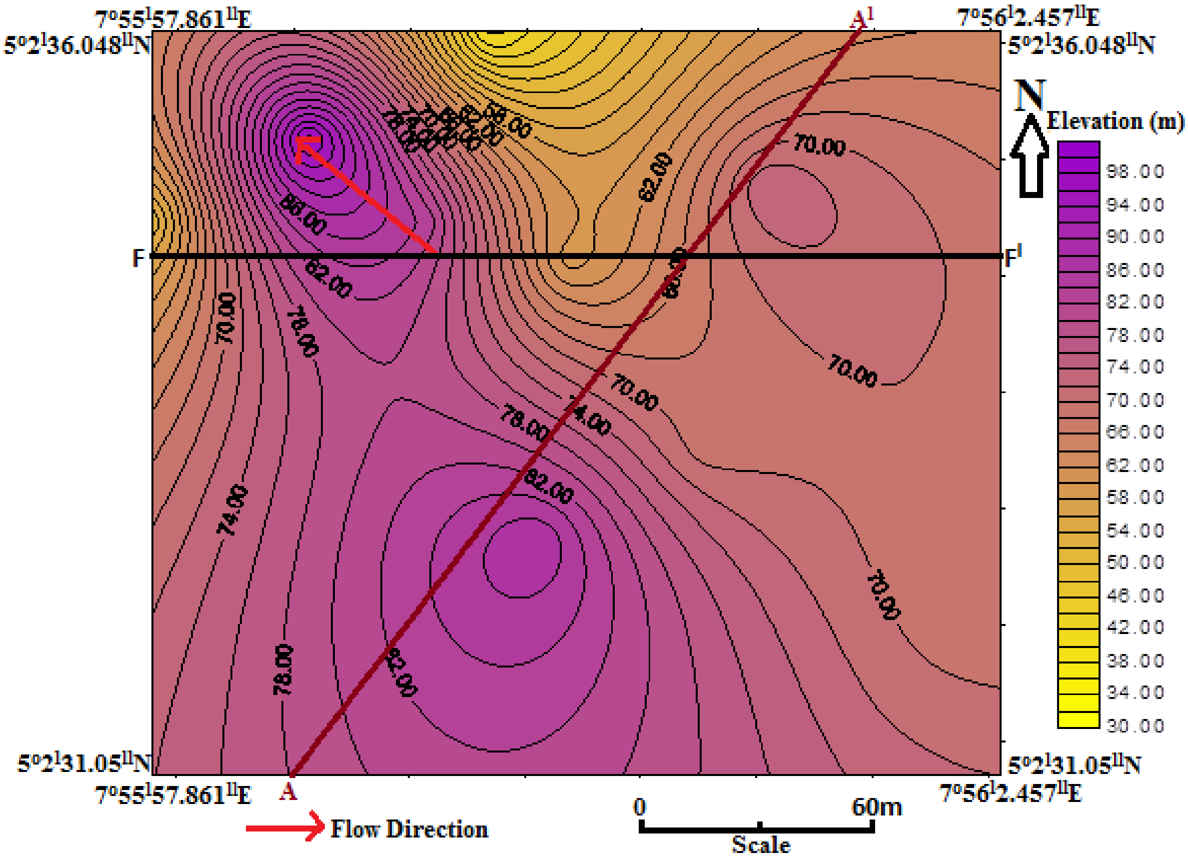


Fig 4.16a: Elevation Map for Uyo area (contour interval ~2m)

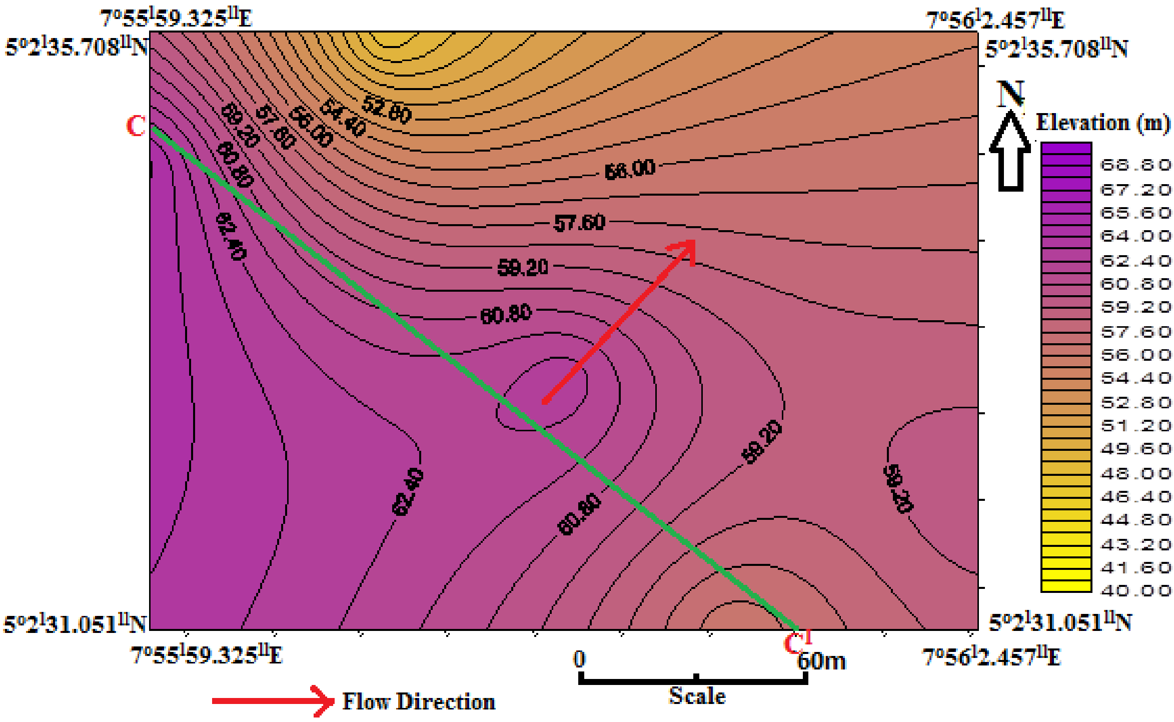


Fig. 4.16b: Elevation map at Oron area (contour interval ~ 0.8m)

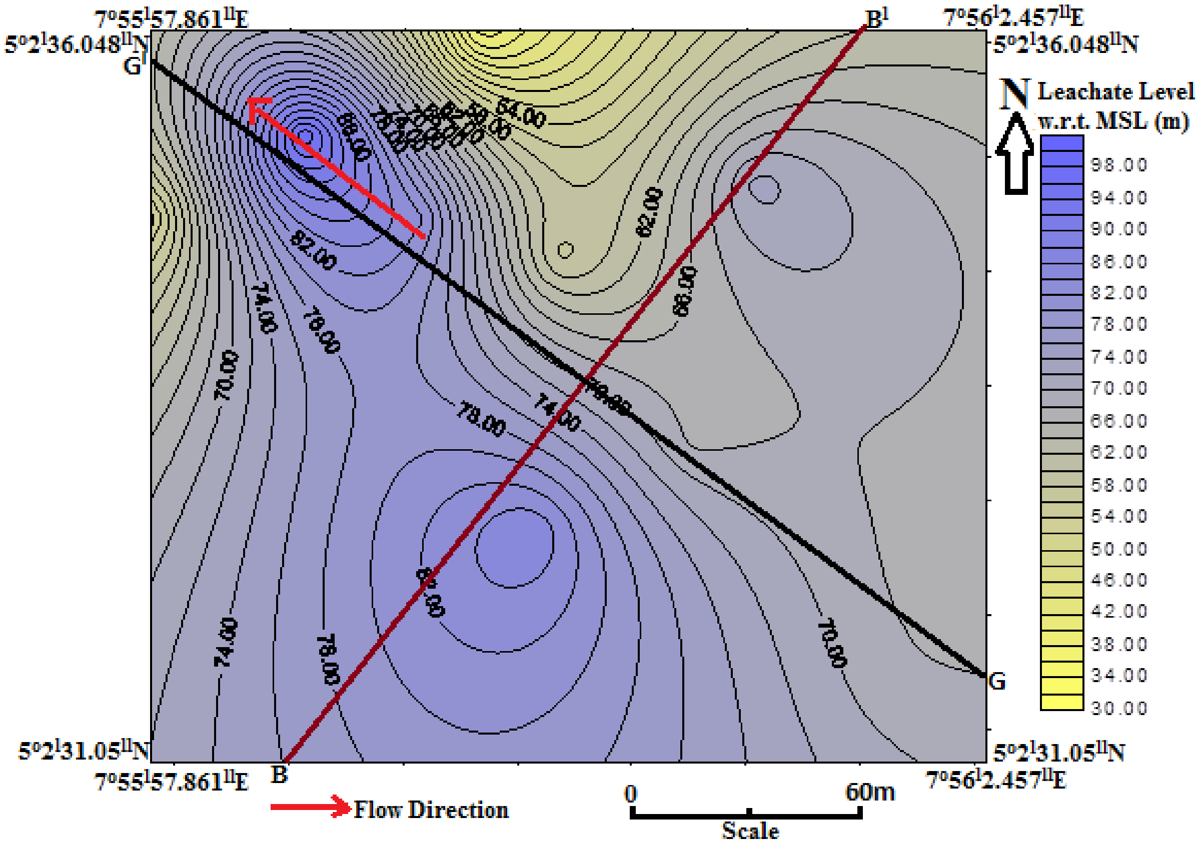


Fig. 4.17a: Leachate level map w.r.t. MSL for Uyo area (contour interval~2m)

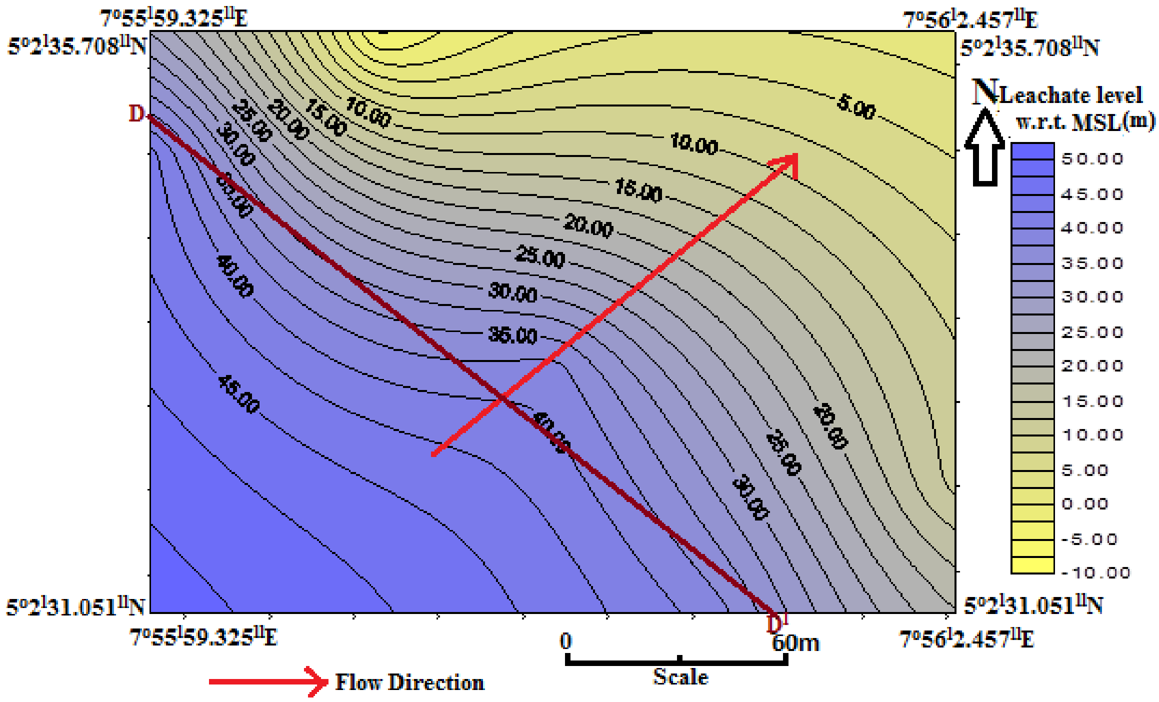


Fig.4.17b: Leachate level map w.r.t. MSL at Oron area (contour interval ~2.5m)

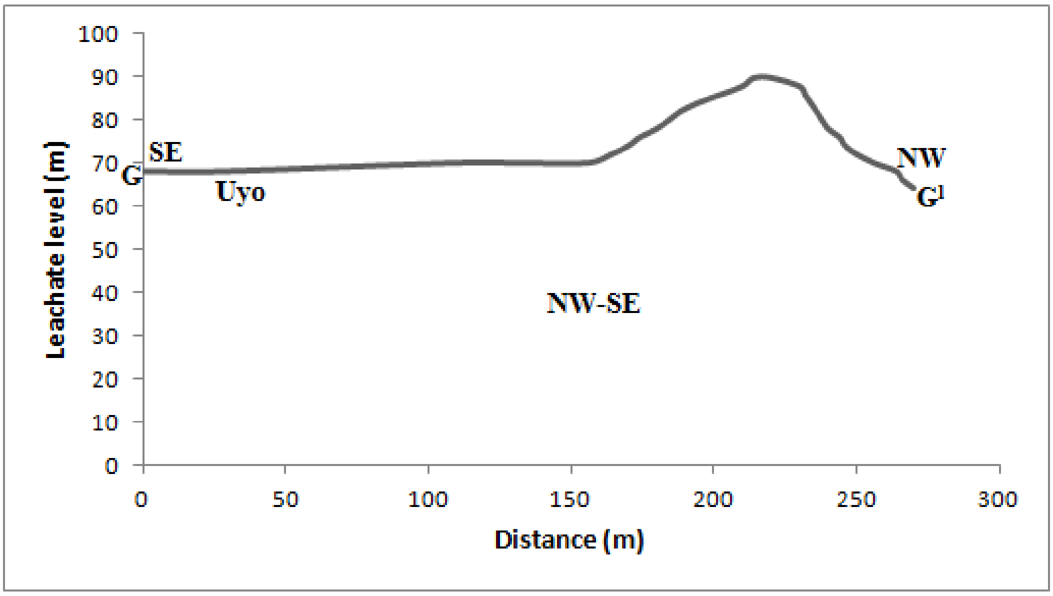


Fig. 4.18a: Cross -section showing the direction of leachate flow in Uyo Dumpsite

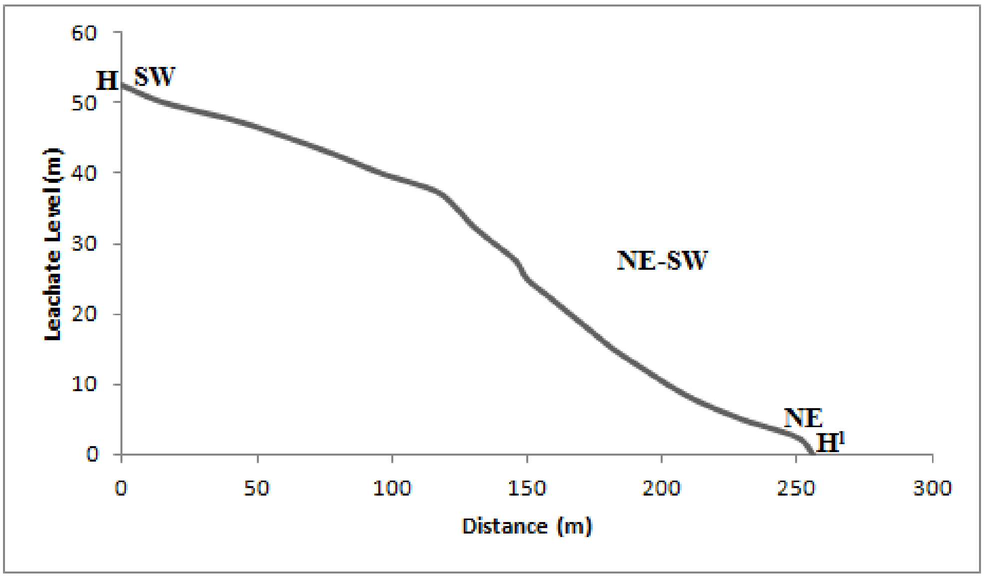


Fig. 4.18b: Cross- section showing the direction of leachate flow in Oron Dumpsite

4.9.4b Hydrogeological Risk implication associated with Leachate Level

Different cross sections were taken at both the elevation map (Fig. 4.16) and leachate level map (Fig. 4.17) at Uyo and Oron areas respectively. At Uyo, profiles running from A-A^{l} at Fig. 4.16a and B-B^{l} at Fig. 4.17a were superimposed in order to estimate the groundwater risk factor (Fig. 4.18) obtainable in this area. Here, it was observed that the leachate level follows the topography which implies that the topography controls the configuration of the leachate level (Fig. 4.18). Also, the gap between the leachate level and the average static water level in Uyo area is 25m since the depth of the sink leachate level and the static water level is 65m and 38m respectively (Fig. 4.18a). This implies that the vertical movement of leachate (contaminate) will be slow thereby allowing physical (filtration), chemical and biochemical processes to remove contaminants before reaching the aquifer. Also, from the hydrogeochemical analysis, some of the indicator parameters at Uyo are very low and may not indicate much contamination from the dumpsite.

Furthermore, at Oron, profiles running from C-C^{l} at Fig.4.16b and D-D^{l} at Fig. 4.17b were superimposed in order to estimate the groundwater risk factor (Fig. 4.19b) obtainable in this area. Here, it was also observed that the leachate level follows the topography which implies that the topography controls the configuration of the leachate level (Fig. 4.19b). More so, Fig. 4.19b shows an intersecting pattern such that the static water level crisscrosses the leachate level surface at 35m. This implies that the sink of the leachate level is beyond the groundwater level which has contaminated the groundwater at in-situ already, as such; it is very risky for the users in this area.

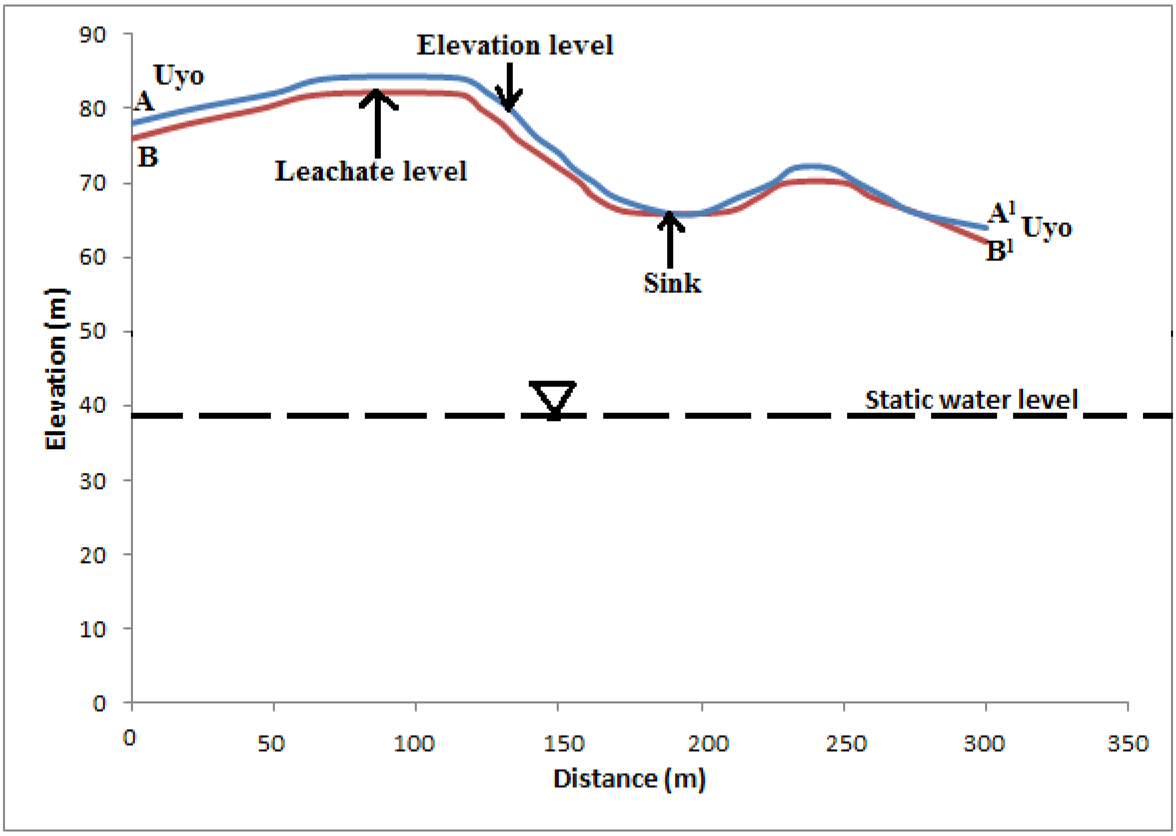


Fig. 4.19a: Risk Map of leachate level within Uyo Dumpsite

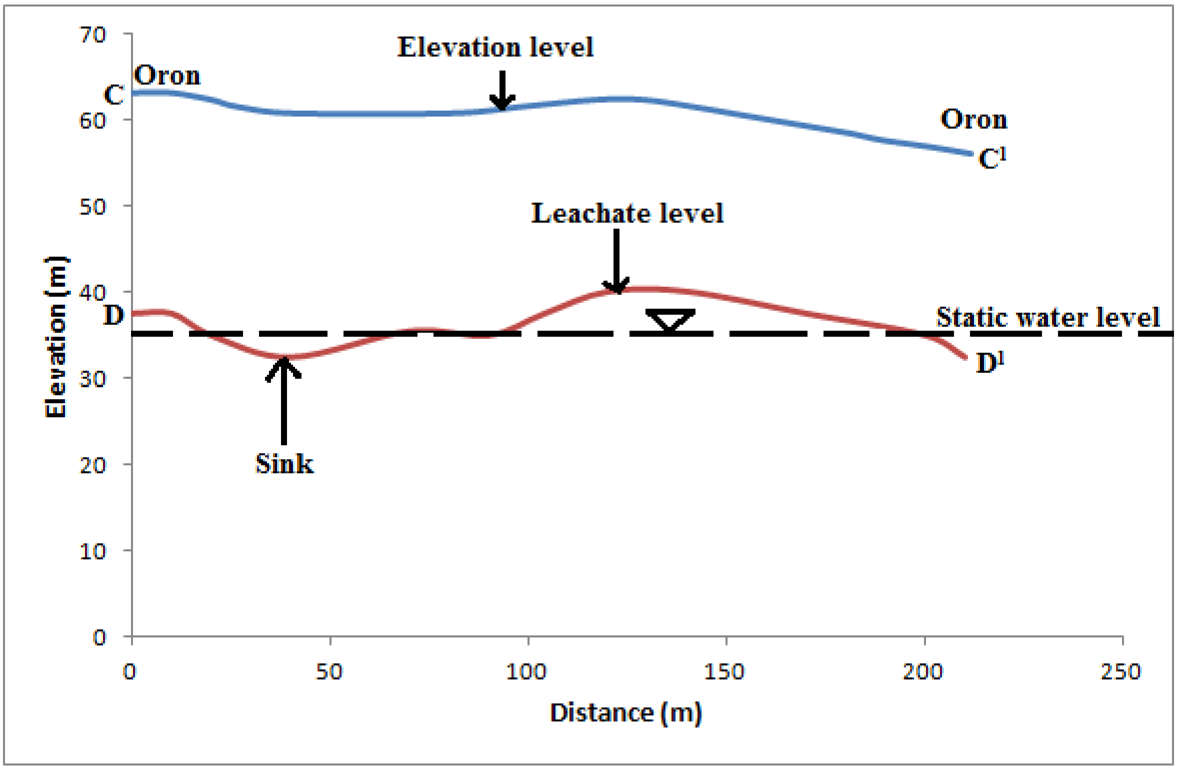


Fig. 4.19b: Risk Map of leachate level within Oron Dumpsite

4.9.5 Resistivity and Litho-Correlation Implications

Litho-correlations of formations encountered in boreholes (Fig. 4.20) proximal to the Uyo dumpsite shows intercalations of materials of relatively low porosity and permeability. Implication is that vertical movement of leachate (contaminate) will be slow, thereby allowing physical (filtration), chemical and biochemical processes to remove contaminants before reaching the aquifer according to the static water level. This also shows that there are intercalations of materials of relatively low porosity and permeability, occuring below the approximate location of the dumpsite in the area.

The results show a wide range of resistivity variations ranging from 4.06Ωm to 45756Ωm reflecting the variation in origin of the materials in the dumpsites. Cross sections were taken at the same distance at Uyo dumpsites namely; E-E^{l} at Fig. 4.21a and F-F^{l} at Fig. 4.21b reveal that both there is existence of structural depression named sink at an approximate horizontal distance of 110m (Fig. 4.21). This may serve a place of accumulating any leachate in the area.

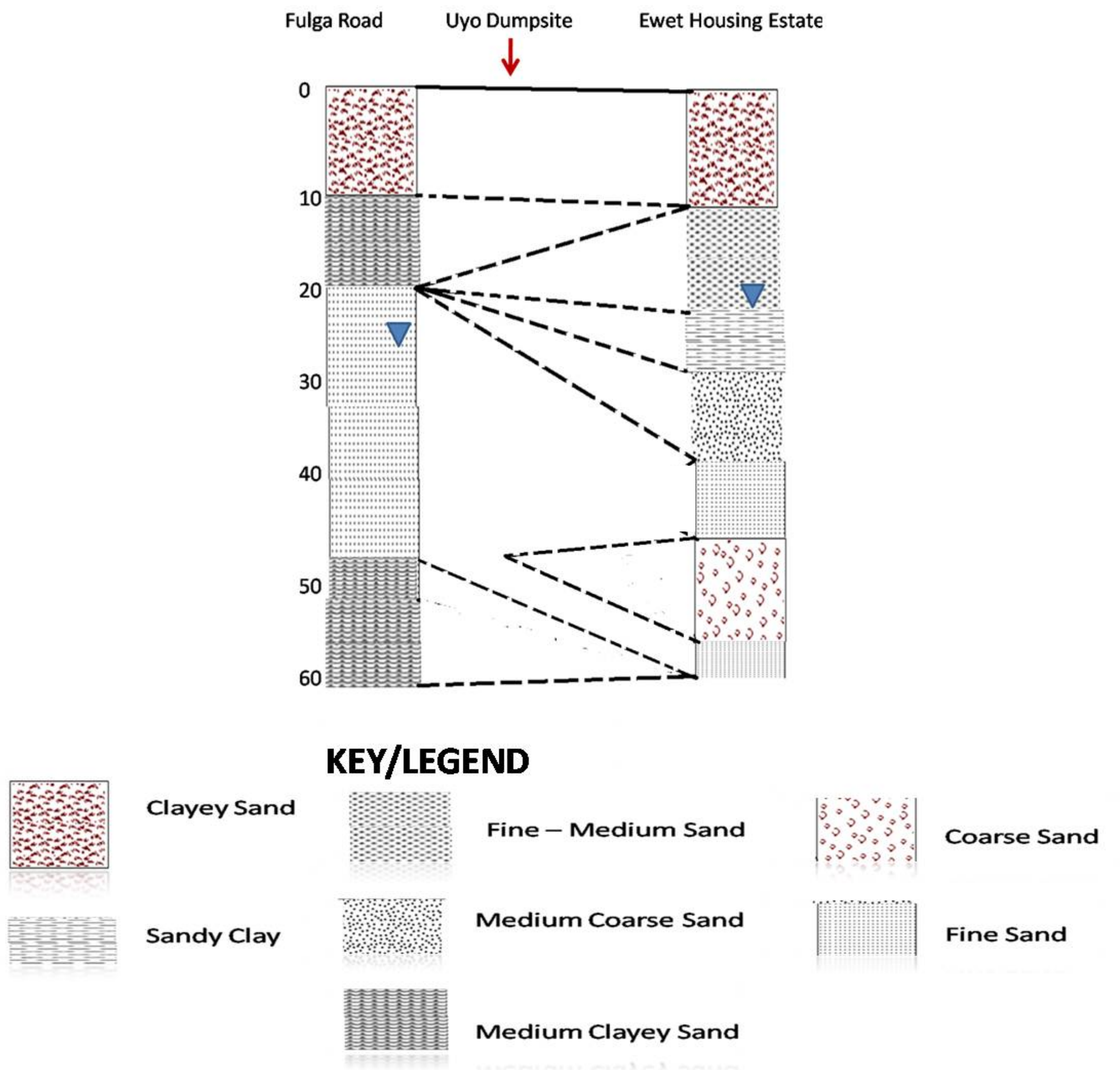


Fig. 4.20 : Litho-Correlation within the Study Area. Above shows intercalations of materials of relatively low porosity and permeability, especially below the approximate location of the dumpsite.

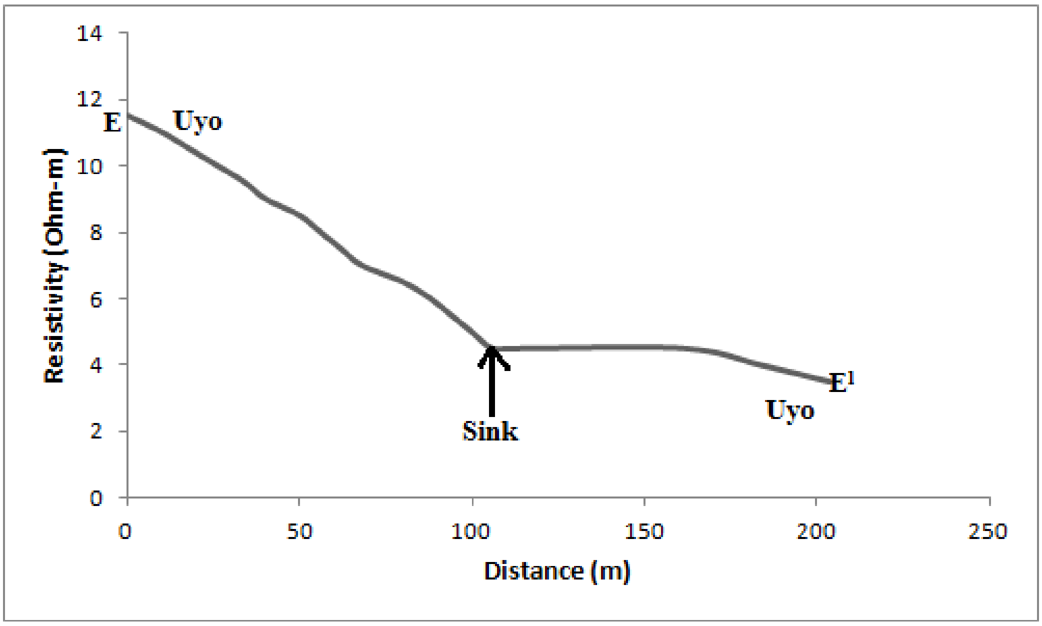


Fig. 4.21a: Cross -section showing the resistivity of leachate layer in Uyo Dumpsite

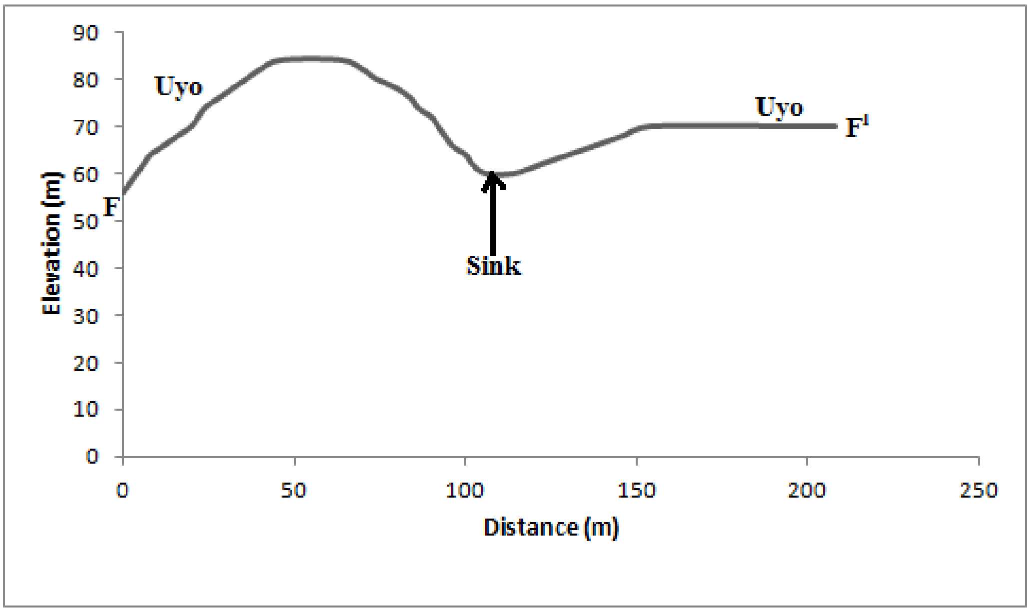


Fig. 4.21b: Cross- section showing the elevation in Uyo Dumpsite

CHAPTER FIVE

SUMMARY, CONCLUSIONS, SUGGESTION FOR FURTHER WORK AND CONTRIBUTION TO KNOWLEDGE

5.1 Summary

This research work is summarized as follows:

The results of qualitative interpretation reveal that the VES curves generated at Uyo dumpsite is basically H-curves. The VES results in conjunction with the borehole logs showed mainly three or four lithologic layers namely: top lateritic sand, leachate contaminated sand, dry, fine to medium-grained sand and medium to coarse-grained sand layers. The leachate contaminated layer has thickness range of 0.64-22.20m and resistivity values range from 4.06 -20.0Ωm. The computed layer parameters show that the values of various parameters range from low to high: longitudinal conductance (0.204500-2.636580S); transverse resistance (15.3468 – 186.9240Ωm^2) and leachate thickness (2.85 – 22.20m). The hydraulic conductivity of the leachate at Uyo dumpsite ranges from 23.62639 – 104.56490m/day while the transmissivity ranges from 96.6319 – 1175.5230m^2/day. The hydrogeochemical analyses revealed that all water samples from boreholes proximal to Uyo dumpsite had low pH while few water samples exhibited elevated total dissolved solids (TDS), Cadmium, electrical conductivity and dissolved oxygen. The leachate migration path around Uyo dumpsite trend predominantly in NW- SE direction.

The VES curves generated at Oron dumpsite are K, A, and the hybrid curve KHK. The interpretation showed three to five layers, the leachate contaminated layer being the third layer. The computed layer parameters range as follows: leachate thickness (18.86 – 62.90m); longitudinal conductance (1.410526 – 13.186580S); transverse resistance (143.4344 – 509.2000). The hydraulic conductivity of leachate at Oron dumpsite ranges from 24.78434 – 99.97812m/day while the transmissivity ranges from 664.2203 – 5659.0750m^2/day. Water samples from boreholes proximal to Oron dumpsite exhibited low pH, high electrical conductivity and dissolved oxygen. The leachate migration path trend predominantly in the NE-SW direction. The result reveals intersecting pattern such that the static water level crisscrosses the leachate level surface at 35m.

5.2 Conclusions

This study reached the following conclusions:

1. Vertical electrical sounding (VES) has guided the estimation of leachate resistivity, thickness, hydraulic conductivity, transmissivity, longitudinal conductance and transverse resistance
2. Oron dumpsite is more contaminated than Uyo. This is buttressed by the following:

(i) At Oron dumpsite, the leachate level actually meets the static water level.

(ii) Oron dumpsite has lower resistivity values.

(iii) Oron dumpsite has lower erodibility.

(iv) Oron dumpsite has higher leachate transmissivity

(v) Oron dumpsite has greater leachate thickness than Uyo.

(vi) Geologically Oron is underlain by Alluvial Sand while Uyo is underlain by more consolidated materials of lower porosity and permeability

3. The risks associated with the present poor system of waste management is very high as it constitutes threat to surface and groundwater resources. The groundwater of the study area may not have been seriously contaminated as at the time of study; but there is no guarantee that this may not reverse in the future.

5.3 Suggestions for further Work

There is a growing need for characterization of the near-surface region, with information required about the physical, chemical, and biological properties and processes in the subsurface. While traditional methods of drilling and direct sampling can provide highly accurate information, they are limited in terms of spatial coverage, in both the size of the sampled volume and the density of the sampling. In addition, when dealing with contaminated sites where there is a great need for accurate characterization, all methods of direct sampling run the risk of further spreading the contaminant, a potential hazard to both workers and to the environment.

Groundwater protection policy and strategy should be based on the concept that prevention of pollution is always less expensive than aquifer rehabilitation, which is a costly, time-consuming and technically demanding task. It may often be more efficient to invest in preventive processes within the catchment than to invest in major treatment infrastructure to manage a hazard. As it is neither physically nor economically feasible to test for all drinking-water quality parameters, the use of monitoring effort and resources should be carefully planned and directed at significant or key characteristics. However, it is anticipated that in the future much more use may be made of geophysics for monitoring contamination of the groundwater using permanently installed geophysical sensors in water boreholes and perhaps both within and on the ground surface.

One public health implication of this work is that no new water supply wells should be placed in areas of abnormally low resistivity until the reason for this low resistivity can be resolved.

5.4 Contribution to Knowledge

i. The study evaluated layer parameters including Dar Zarrouk parameters of the Study Area.

ii. The study allows for comparative assessment of data in geographically different, but geologically similar areas of Uyo, Ikot Ekpene and Oron.

iii. The Risk Map Model is a very significant tool for assessing the contamination status in the Study Area.

iv. The study has also designated areas affected and not affected by the dumpsites.

v. The data generated in this study, will guide planners and managers of environment in the future siting of waste ‘facility’ in the State.

REFERENCES

Abdullahi, N.K., Osazuwa, I.B., and Sule, P.O., (2011). Application of geophysical techniques in the investigation of groundwater contamination: A case study of Municipal solid waste leachate. Journal of Applied Sciences 4(1): 7-25.

Aderemi, A.O., Oriaku, A.V, Adewumi, G.A. and Otitoloju, A.A., (2011). Assessment of groundwater contamination by leachate near a municipal solid waste landfill. African Journal of Environmental Science and Technology, 5(11): 933-940.

Agunwamba, J.C., (1998). Solid waste management in Nigeria: problems and Issues. Environmental Management. New York, 22(6): 849-856.

Ajayi, O., and Umoh, O.A(1998). Quality of groundwater in the Coastal plain sands of Akwa Ibom State, Nigeria. Journal of African Earth Sciences, 27(2): 259-275.

Ahmed, A.M., and Sulaian, W.N., (2001). Evaluation of groundwater and soil pollution in a landfill area using electrical resistivity imaging survey. Environmental Management, 28(5): 655-63.

Akankpo. (2011). Monitoring Groundwater Contamination using Surface Electrical Resistivity and Geochemical Methods: Journal of Water Resource and Protection, Scientific Research Publishing. Provided by ProQuest LLC,1-6.

Akpabio. And Ekpo, E. (2008). Geoelectric Investigation for Groundwater Development of Southern part of Nigeria. Pacific Journal of Science and Technology. 9(1): 219-226.

Akpabio, E.M., and Ekandem, E. M., (2009). Water uncertainties in Southeastern Nigeria: why Government should be interested in management. International Journal of Sociology and Anthropology, 1(2): 038-046.

Akpabio, E.M., (2003). Variability of water quality from boreholes in Akwa Ibom State, Nigeria, In: Akpabio, E.M., and Ekandem, E. M., (2009). Water uncertainties in Southeastern Nigeria: why Government should be interested in management. International Journal of Sociology and Anthropology, 1(2) 038-046.

Amadi,A.N. (2011). Assessing the Effects of Aladimma Dumpsite on Soil and Groundwater using Water Index and Factor Analysis. Applied Sciences,5(11): 763-770.

Amah, E.A., Ugbaja, A.N., and Esu, E.O., (2012). Evaluation of groundwater potentials of the Calabar coastal aquifers. Journal of Geography and Geology, 4(3).

Anakwuba, E.K., Nwokeabia, C.N., Chinwuko, A.I., and Onyekwelu, C.U., (2014). Hydrogeophysical assessment of some parts of Anambra basin, Nigeria. International Journal of Advanced Geosciences, 2(2) : 72-81.

Anizoba, D. C. Chukwuma, G. O., Chukwuma, E. C., & Chinwuko, E. C. (2015). Determination of Aquifer Characteristics from Geo-electrical Sounding data in parts of Anambra State, Nigeria. International Journal of Innovation and Applied Studies, **11** (4), 832-843.

Anudu, G. K., Onwuemesi, A. G., Ajaegwu, N. E., Onuba, L. N., & Omali, A. O. (2008). Electrical resistivity investigation for groundwater in the basement complex terrain: a case study of Idi-ayunre and its environs, Oyo State, southwestern Nigeria. Natural and Applied Sciences Journal, **9** (2), 1-11.

Appleyard, S.J. (1996). Impact of liquid-waste disposal on portable groundwater resources near Perth. Environmental Geology, 28,106-110.

Aristedemou, E. and Thomas-Betts, A., (2000). DC resistivity and Induced polarization investigations at a waste disposal site and its environments. Journal of Applied Geophysics, 44: 275-302.

Awokunmi, E. E., Asaolu, S. S., and Ipinmoroti, K. O. (2010). Effect of leaching on heavy metals concentration of soil in some dumpsites. African Journal of Environmental Science and Technology, 4(8) : 495-499.

Atekwana, E.A, Sauck, W.A., and Werkema, D.D.,(2000). Investigations of geoelectric signatures at a hydrocarbon contaminated site (In) Butler, D.K. (2005) Near-Surface Geophysics, ; SEG Investigations in Geophysics series No. 13, 732.
Auken, E., Pellerin, L., Christensen, N.B., and Sorensen. (2006). A survey of current trends in near-surface electrical and electromagnetic methods. Geophysics, 71(5) : 249-260.

Back, W., (1960). Origin of hydrochemical facies of groundwater in the Atlantic Coastal Plain.
International Geological Congress, 21st, Copenhagen, Proceedings, pt. 1: 87-95.

Back, W., (1966). Hydrochemical facies and groundwater flow patterns in northern part of Atlantic Coastal Plain: US Geological Survey Professional Paper 498-A, 42pp.

Baedecker, M.J., and Apgar, M.A., (1984), Hydrochemical studies at a landfill in Delaware, in Groundwater Contamination, edited by J. Bredehoeft, National Academy Press, Washington, DC,127-138.

Bell, F.G., and Jermy, C.A., (1995), A seepage problem associated with an old landfill in the greater Durban area. In: Meju, M.A. (2006). Geoelectrical Characterization of covered landfill sites: a process-oriented model and investigative approach. H. Vereecken et al. (eds.), Applied Hydrogeophysics, 319-339. Springer, Printed in the Netherlands.

Benson, A.K., Payne, K.L., and Stubben, M.A., (1996). Mapping groundwater contamination using dc resistivity and VLF geophysical methods. Geophysics 62(1), 80-86.

Benson, R.,Glaccum,R., and Noel, M.(1983). Geophysical techniques for sensing buried waste and waste migration. (In): Kayabali, K.,Yuksel,F.A., and Yeken,T.,(1998). Integrated use of hydrochemistry and resistivity methods in groundwater contamination caused y a recently closed solid waste site. Environmental Geology 36(3-4). (c) Springer- Verlag. 227-234.

Bernstone, C. And Dahlin, T.(1999). Assessment of two automated DC resistivity data acquisition systems for landfill location surveys: Two case studies. In: Dahlin, T.,Rosqvist,H.,and Leroux, V.,(2010). Resistivity – IP mapping for landfill applications, First Break, 28(8),.101-105. 2010 EAGE www.firstbreak.org

Beyene,H.,and Banerjee,S.(2011). Assessment of the pollution Status of the Solid Waste Disposal Site of Addis Ababa City with some selected Trace Elements, Ethiopia. World Applied Sciences Journal 14(7):1048-1057, 2011.

Bhalla, G., Kuman, A., and Bansal, A., (2011). Assessment of groundwater pollution near municipal solid waste landfill. Asian Journal of water, Environment and pollution, 8(1).

Birks,J., and Eyles, C.A.(1997). Leachate from landfills along the Niagara Escarpment, in Environmental Geology of Urban Areas, edited by N. Eyles, Geological Association of Canada,24:347-363.

Buselli,G., and Kanglin, Lu(2001). Groundwater contamination monitoring with multichannel electrical and electromagnetic methods. Journal of Applied Geophysics, 48(1): 11-23.

Buselli,G., Barber, C., Davis, G.B., and Salama, R.B.,(1990). Detection of groundwater contamination near waste disposal sites with transient electromagnetic and electrical methods, In: Meju, M.A. (2006). Geoelectrical Characterization of covered landfill sites: a process-oriented model and investigative approach. H. Vereecken et al. (eds.), Applied Hydrogeophysics, 319-339. Springer, Printed in the Netherlands.

Butler, D.K., (2005). Near-Surface Geophysics. Investigations in Geophysics No.13. Society of Exploration Geophysicists. 732.

Butler, D.K., (2005). What is near-surface geophysics, In: Bridle, R., (2016). Near-surface modelling and imaging. The Leading Edge, **35**(11)938-939, http://dx.doi.org/10.1190/tle35110938.1.

Butu, A.W., and Mshelia, S.S. (2014). Municipal Solid Waste Disposal and Environmental Issues in Kano Metropolis, Nigeria. British Journal of Environmental Sciences, 2(2) :10-26

Carlson, N., Bouzid, N., and Byrd, R., (2015). Environmental applications of the IP method: Surveys of subsurface waste. The Leading Edge, 34(2)260.

Carpenter, P.J., Calkin, S.F., and Kaufmann, R.S.(1991). Assessing a fractured landfill cover using electrical resistivity and seismic refraction techniques, Geophysics, 56, 1896-1904.

Carpenter,P.J.,Ding,A.,and Cheng, L.(2012). Identifying Groundwater contamination using Resistivity Surveys at a Landfill near Maoming, China. Nature Education Knowledge 3(7):20.

Cartwright, K., and Sherman, F.B., Jr., (1972). Electrical Earth Resistivity Surveying in landfill investigations. Engineering and Soils Engineering Symposium Proceedings 10th Annual Meeting, Moscow, 77-92.

Christensen, T.H., Cossu, R., and Stegmann, R. (1992). Landfill of waste. Elsevier Science publisher Ltd, England.

Code of Practice: Environmental Risk Assessment for Unregulated Waste Disposal Sites. Environmental Protection Agency (2007), Ireland.

Dahlin,T.,Rosqvist,H.,and Leroux, V.,(2010). Resistivity – IP mapping for landfill applications, First Break, 28(8)101-105. 2010 EAGE www.firstbreak.org

De Wiest, R.J.M.(1965). Geo-hydrology. John Wiley and Sons, New York, 366P.

Dobrin, M.B., (1976). Introduction to Geophysical Prospecting, 3rd ed.,McGraw-Hill Book Company INC. U.S.A.

Desa , N.D.,Mejus , L.,Abd Rahman, M.,Samuding, K., Mostapa, R., and Dominic,J.A.,(2009). Study on subsurface contamination flow path distribution using Electrical Resistivity Imaging (ERI) technique at waste disposal site, Taiping, Malaysia. In: Proceedings of SEG Houston 2009 International exposition and annual meeting.

Dumont, G., Robert, T., and Nguyen, F., (2018). Electrical resistivity tomography and distributed temperature sensing monitoring to assess the efficiency of horizontal recirculation drains on retrofit bioreactor landfills. Geophysics 83(2) : B13-B23.

Edet, A.E., (2017). Hydrogeology and groundwater evaluation of a shallow coastal aquifer, southern Akwa Ibom State (Nigeria). Springer Open. (7) 5:2397-2412.

Edet, A.E., (1993). Groundwater quality assessment in parts of Eastern Niger Delta. Environmental Geology, Sprinker-Verlag: 22:41-46.

Edet, A.E., Abdelaziz R., Merkel, B.,Okereke, C.S.,and Nganje, T.(2014). Numerical Groundwater Flow Modelling of the coastal plain sand aquifer, Akwa Ibom State, SE Nigeria. Journal of Water Resource and Protection, 6: 193-201.

Edet, A.E., Nganje, T.N., Ukpong, A.J., and Ekwere, A.S. (2011). Groundwater Chemistry and quality of Nigeria: A status review. African Journal of Environmental Science and Technology 5(13), 1152-1169.

Edet, A.E., and Okereke, C.S, (2002). Delineation of shallow groundwater aquifers in the Coastal plain sands of Calabar area (Southern Nigeria) using surface resistivity and hydrogeological data. Journal of African Earth Sciences, (35) 3,433-443.

Egong, E. J., Ndubuisi-Nnaji, U. U., and Ofon, U. A. (2016). Bacteriological Health Status of Adjoining Dumpsite Soils in Uyo, Akwa Ibom State, Nigeria. Journal of Advances in Biology & Biotechnology, 9(4): 1-8.

Ehirim, C.N., Ebeniro, J.O., and Ugwu, D.A.(2009). A Geophysical and Hydro-physiochemical Study of the Contaminant Impact of a Solid Waste Landfill (SWL) in Port Harcourt Municipality, Nigeria. Pacific Journal of Science and Technology. (10)2,596-603.

Eja, M.E., Alobi, N.O. Ikpeme, E.M, Ogri, O.R., and Inyang, A.O.(2010).Environmental and Public health-related Assessment of Solid-Waste management in Uyo, Akwa Ibom State, Nigeria. World Journal of Applied Science and Technology, (2)1,110-123.

Ekeocha, N.E.,Okereke, I.D.,and Okonkwo,S.E.(2012). Electrical Resistivity Investigation of Solid Waste Dumpsite at Rumuekpolu in Obio Akpor L.G.A.,Rivers State, Nigeria. International Journal of Science and Technology, (1)11:631-637

Ekot,M.O.(2012).Post-Consumer Clothing and Textile Waste Disposal Practices of Families in Uyo Metropolis, Akwa Ibom State, Nigeria. mildredobot@yahoo.com P1-14. www.educationforsustainabledevelopment.org/data/papers.

Ekwe, A.C., and Opara, A. I.(2012). Aquifer Transmissivity from Surface Geo-electrical Data: A Case Study of Owerri and Environs, Southeastern Nigeria. Journal Geological Society of India, 80:123-128.

Enikanselu,P.A.(2008). Detection and Monitoring of Dumpsite-Induced Groundwater Contamination using Electrical Resistivity Method. The Pacific Journal of Science and Technology. 9(1):254-262.

Essien,O.E.,and Bassey,E.D.(2012). Spatial Variation of borehole water quality with depth in Uyo Municipality, Nigeria. International Journal of Environmental Science, Management and Engineering Research 1(1):1-9.

Esu,E.O.,and Okereke,C.S. and Edet, A.E.(1999). A regional hydrostratigraphic study of Akwa Ibom State, Southeastern Nigeria. Global Journal of pure and applied sciences, (5)1, 89-96.

Esu,O.E., and Okereke,C.S.,(2002). Delineation of shallow groundwater aquifers in the coastal plain sands of Calabar area (Southern Nigeria) using surface resistivity and hydrogeological data. J.Afr. Earth Sci.,35: 433-443.

Everett, L.G.,Wilson, L.G., and Hoylman, E.W.,(1984). Vadose zone monitoring for hazardous waste sites: Pollution Technology Review, 112, Noyles Data Corporation, New Jersey, 358 p, In: Meju, M.A. (2006). Geoelectrical Characterization of covered landfill sites: a process-oriented model and investigative approach. H. Vereecken et al. (eds.), Applied Hydrogeophysics, 319-339. Springer, Printed in the Netherlands.

Ezeh, C. C. (2011). Geoelectrical studies for estimating aquifer hydraulic properties in Enugu State, Nigeria. International Journal of the Physical Sciences, **6** (14), 3319-3329.

Fang,H.Y.,(1995). Engineering behaviour of urban refuse, compaction control and slope stability analysis of landfill, In: Meju, M.A. (2006). Geoelectrical Characterization of covered landfill sites: a process-oriented model and investigative approach. H. Vereecken et al. (eds.), Applied Hydrogeophysics, 319-339. Springer, Printed in the Netherlands.

Farquhar,G.J.(1989). Leachate: production and characterization. Canada Journal of Civil Engineering 16:317-325.

Fetter, C.W.,(1993). Contamination hydrogeology: Macmillan Publishing Co. Prentice – Hall, Inc.

Freeze, R.A., and Cherry, J.A., (1979). Groundwater. Prentice Hall, 604 pp., (In): Kovalevsky,V.S.,Kruseman,G.P., and Rushton,K.R. for UNESCO (2004). Groundwater Studies ,An International guide for hydrogeological investigations, IHP-VI, Series on Groundwater No.3. United Nations Educational Scientific and Cultural Organization, Paris,423P.

Ganiyu, S. A., Badmus, B. S., Oladunjoye, M. A., Aizebeokhai, A. P. and Olurin, O. T. (2015). Delineation of leachate plume migration using electrical resistivity imaging on Lapite dumpsite in Ibadan, Southwestern Nigeria. Geosciences, 5(2):70 – 80.

Geoffrey, I.N.,(2005). The urban informal sector in Nigeria: towards economic development, environmental health, and social harmony. Global Urban Development Magazine 1(1). In: Babayemi, J.O., and Dauda, K.T.,(2009). Evaluation of Solid Waste Generation, Categories and Disposal Options in Developing Countries: A Case Study of Nigeria. Journal of Applied Sciences&Environmental Management, (13)3,83-88.

George, N.J.,Ubom,A.I.,and Ibanga,J.I.(2014). Integrated Approach to Investigate the Effect of leachate on groundwater around the Ikot Ekpene Dumpsite in Akwa Ibom State, Southeastern Nigeria. International Journal of Geophysics,2014: 1-12.

George,N.J.,Evans,U.F.,Akpan,A.E.,Obot,I.B., and Ikot,A.N.(2010). A Study of Superficial Sediments and Aquifers in Parts of Uyo Local Government Area, Akwa Ibom State, Southern Nigeria, Using Electrical Sounding Method, E-Journal of Chemistry, 7(3),1018-1022.

Heigold, P.C., Gilkeson,R.H., Cartwright, K., and Reed, P.C.(1979). Aquifer transmissivity from surficial electrical methods. Groundwater , 17(4) : 338-345.

Henriet, J. P. (1976). Direct application of Dar Zarrouk parameters in groundwater surveys. Geophysics Prospecting, 24, 344–353

Hughes,L.,Figgins,S., and Tinlin,R.,(1989). The use of electrical geophysics in groundwater exploration and mapping groundwater contamination. In: Kayabali,K.,Yuksel,F.A.and Yeken,T.,(1998). Integrated use of hydrochemistry and resistivity methods in groundwater contamination caused by a recently closed solid waste site. Environmental Geology 36(3-4). (C)Springer – Verlag, 227-234.

Jackson, P.D., and McCann,D.M.,(1994). Non-destructive geophysical site investigation – an aid to the redevelopment of sites in Urban areas with groundwater problems,(In): Geophysics for Civil Engineers: The Institution of Civil Engineers,1Great George Street London SW1P3AA.

Jegede, S.I.,Iserhien-Emekeme,R.E., Iyoha,A.,and Amadasun,C.V.O.,(2013). Near-surface Investigation of Groundwater Contamination in the Regolith Aquifer of Palladan, Zaria, using Borehole log and Tomography Techniques. Research Journal of Applied Sciences, Engineering and Technology 6(4): 537-544.

Jegede,S.I.,Osazuwa,I.B., Ujuanbi,O.,and Chiemeke,C.C.(2011). 2D electrical imaging survey for situation assessment of leachate plume migration at two waste disposal sites in the Zaria basement complex, Pelagia Research Library, Advances in Applied Science Research, 2(6):1-8.

Jegede,S.I.,Ujuanbi,O.,Abdullahi,N.K.,and Iserhien-Emekeme,R.E.(2012). Mapping and monitoring of leachate plume migration at an open Waste Disposal Site using non-invasive methods. Research Journal of Environmental and Earth Sciences 4(1):26-33.

Jimmy,G.N.,Otu, A.A., Asuquo, U.A.,(2013). Preliminary Geophysical Investigation to delineate the groundwater conductive zones in the coastal region of Akwa Ibom State, Southern Nigeria of Akwa Ibom State, Southern Nigeria , around the Gulf of Nigeria. International Journal of Geosciences,4:108-115.

Karlik,G., and Kaya,A.,(2001). Investigation of groundwater contamination using electric and electromagnetic methods at an open waste-disposal site: a case study from Isparta,Turkey. Environmental Geology, (40)6.

Kaya,M.A.,Ozurlan,G., and Sengul,E.(2007). Delineation of soil and groundwater contamination using geophysical methods at a waste disposal site in Canakkale, Turkey. Environmental Monitoring and Assessment. 2007 Dec; 135(1-3): 441-6. Sprinker-Link.

Kayabali,K.,Yuksel,F.A., and Yeken, T.,(1998). Integrated use of hydrochemistry and resistivity methods in groundwater contamination by a recently closed solid waste site. Environmental Geology 36(3-4). Springer-Verlag, 227-234.

Kearey,P.,Brooks,M., and Hill, I.(2002). An introduction to Geophysical Exploration, 3rd edition. Blackwell Scientific Ltd, Oxford, UK.

Keller,G.V., and Frischnechk, F.C.,(1966). Electrical methods in geophysical prospecting.

Pergamon Press, Oxford,91-135.

Khesin,B.,(2005). Physical methods and approaches in environmental studies – Use of geophysical methods for the solution of environmental problems in Israel; HAIT Journal of Science and Engineering B,(2) 1-2,95-124.

Kinnear,J.A., Binley,A.,Duque,C.,and Engesgaard, P.K,(2013). Using geophysics to map areas of potential groundwater discharge into Ringkobing Fjord, Denmark: The Leading Edge,(32)7, 792-796.

Knight, M.J., Leonard, J.G.,and Whitely, R.J.,(1978) . Lucas Heights solid waste landfill and downstream leachate transport – a case study in environmental geology, Bull. Int., Assoc. Eng. Geol., 18,45-64.

Kelly,W.F.,(1976). Geoelectrical Sounding for delineating groundwater contamination. Groundwater,14,1:6-10.

Kovalevsky, V.S.,Kruseman, G.P., and Rushton, K.R. (2004). Groundwater Studies, An International guide for hydrogeological investigations, IHP-VI, Series on Groundwater No.3. United Nations Educational Scientific and Cultural Organization, Paris,423P.

Kumar, S., Smith, S.R., Fowler, G., Velis, C., Kumar, S.J., Arya, S.,Rena, A., Kumar, R., and Cheeseeman, C.,(2017). Challenges and opportunities associated with waste management in India. Royal Society Open Science, 4 (3) : 1-11.

Laine, D.L.,Parra, J.O., and Owen, T.E.(1982). Application of an automatic earth resistivity system for detecting groundwater migration under a municipal landfill, In: Meju,M.A.(2006). Geoelectrical Characterization of covered landfill sites: a process-oriented model and investigative approach. H.Vereecken et al. (eds.), Applied Hydrogeophysics, 319-339. Springer, Printed in the Netherlands.

Lanz E, Jemmi L, Muller R, Green A, Pugin A, and Huggenberger P (1994).

Integrated studies of Swiss waste disposal sites : results from georadar and other geophysical surveys. In: Soupios, P.,Papadopoulos, N., Papadopoulos, I., Kouli, M., Vallianatos, F., Sarris, A., and Manios, T.,(2007). Application of integrated methods in mapping waste disposal areas. Environmental Geol. DOI 10.1007/s00254-007-0681-2. Springer-Verlag 2007.

Lee,G.F., and Jones,R.A.,(1991). Municipal Solid Waste Management: Long-term Public Health and Environmental Protection, Workshop Lecture Notes, National Water Well Association National Outdoor Conference, Las Vegas, NV, May (1991).

Leton, T.G., and Omotosho., (2004). Landfill operations in the Niger Delta region of Nigeria . Engineering Geology 73(1-2): 171-177. In: Babayemi, J.O., and Dauda, K.T.,(2009). Evaluation of Solid Waste Generation, Categories and Disposal Options in Developing Countries: A Case Study of Nigeria. Journal of Applied Sciences& Environmental Management, 13(3):83-88.

Ling, C., and Zhang, Q.,(2017). Evaluation of surface water and groundwater contamination in
a MSW landfill area using hydrochemical analysis and electrical resistivity tomography: a case study in Sichuan province, Southwest China. Environ Monit Assess 189 : 140.

Loke, M.H.(1999). Time-lapse resistivity imaging inversion. Proceedings of the 5th Meeting of the Environmental and Engineering Geophysical Society European Section, Em1.

Lopes,D.D.,Silva,S.M.,Fernandes,F.,Teixeira,R.S., Celligoi, A., and Dall'Antonia,L.H.,(2012). Geophysical technique and groundwater monitoring to detect leachate contamination in the surrounding of a landfill. - - Londrina (PR - - Brazil). Journal of Environmental Management 2012 Dec 30; 113: 481-7 , Elsevier Ltd.

Maillet R. E. (1974). The fundamental equations of electrical prospecting. Geophysics, 12: 529-556.

Masasan, J.A., and Quinn-young, C.T.,(1977). Visual Geography of Nigeria. Evans Brothers Limited, London. In: Obianwu, V.I.George, N.J., and Okiwelu, A.A.(2011). Preliminary Geophysical deductions of Lithological and Hydrological conditions of the North-Eastern sector of Akwa Ibom State, Southeastern Nigeria. Research Journal of Applied Sciences, Engineering and Technology 3(8): 806-811.

Matias,M.S.,Marques DA Silva M, Ferreira, P., and Ramalho, E.,(1994). A geophysical and hydrogeological study of aquifers contamination by a landfill. In: Kayabali,K.,Yuksel,F.A., and Yeken, T.,(1998). Integrated use of hydrochemistry and resistivity methods in groundwater contamination by a recently closed solid waste site. Environmental Geology 36(3-4). Springer-Verlag, 227-234.

Mazak,O.,Kelly,W.E., and Landa,I. (1987). Surface geoelectrics for groundwater pollution and protection studies. In: Kayabali,K.,Yuksel,F.A., and Yeken, T.,(1998). Integrated use of hydrochemistry and resistivity methods in groundwater contamination by a recently closed solid waste site. Environmental Geology 36(3-4). Springer-Verlag, 227-234.

Mbipom, E.M., Okwueze, E.E., and Onwuegbuche, A.A.,(1996). Estimation of transmissivity using VES data from the Mbaise area of Nigeria. Nigeria Journal of physics, 85:28-32.

Meju, M.A.,(2000). Geoelectrical investigation of old/abandoned, covered landfill sites in urban areas : model development with a genetic diagnosis approach. Journal of Applied Geophysics 44: 115-150, In: Meju,M.A.(2006). Geoelectrical Characterization of covered landfill sites: a process-oriented model and investigative approach. H.Vereecken et al. (eds.), Applied Hydrogeophysics, 319-339. Springer, Printed in the Netherlands.

McKinney., and Schoch, R.M., (2003). Environmental Science, Systems and Solutions, 3rd Edition. Jones and Bartlet Publishers, Inc.

Ministerial Conference on Environment and Development in Asia and the Pacific 2000. Kitakyushu, Japan, 31 August – 5 September 2000. (http:www.unescap.org/mced2000/pacific/background/pollution).

Mor,S., Ravinda,K.,Dahiya,R.P. and Chaudra,A.,(2006). Leachate characterization and assessment of groundwater pollution near municipal solid waste landfill site. Environ Monit Assess,118(1-3): 435-456.

Morgan, C.O., and Winner, M.D. Jr(1962). Hydrochemical facies in the "400-foot" and " 600-foot" sands of the Baton Rouge area, Louisiana , In: Short papers in geology, hydrology, and topography. US Geological Survey Professional Paper 450-B: 120-121.

Morof,O.O., and Adeyemi, G.O.(2014). Geophysical and Hydrochemical evaluation of groundwater potential and character of Abeokuta area, Southwestern Nigeria. Journal of Geography and Geology: 6 (3): 162-177.

Mosuro,G.O.,Omosanya,K.O.,Bayewu,O.O.,Oloruntola,M.O.,Laniyan,T.A.,Atobi,O., Okubena, M., Popoola, E.,and Adekoya, F.,(2017). Assessment of groundwater vulnerability to leachate infiltration using electrical resistivity method. Springer.com. Applied Water Science, 7: 2195-2207.

Musset,A.E., and Khan Aftab, M., (2000). Looking into the Earth. Cambridge University Press, Cambridge, UK.

Nagarajan,R., Thirumalaisamy,S. And Lakshumanan, E.,(2012). Impact of leachate on groundwater pollution due to non-engineered municipal solid waste landfill sites of erode city, Tamil Nadu, India. Iranian Journal of Environmental Science and Engineering, 9(1): 35 5.

Nfor, B. N., Olobaniyi, S. B., & Ogala, J. E. (2007). Extent and distribution of groundwater resources in parts of Anambra state Southeastern, Nigeria. Department of geology, Delta State University Abraka, Delta State , Nigeria. Journal of Applied Sciences and Environmental. **11** (2), 215 – 221.

Niwas, S., and Singhal D.C. (1981). Aquifer transmissivity of porous media from Dar-Zarrouk parameters in porous media. Journal of Hydrology, 82: 143-153.

Nwankwo,C.N., and Emujakporue, G.O.(2012). Geophysical Method of Investigating groundwater and sub-soil contamination: A case study. American Journal of Environmental Engineering, 2(3):49-53.

Nwajide, C.S. (1990). Cretaceous Sedimentation and Paleogeography of the Central Benue Though. In: Ofoegbu, C.O; (Ed.), The Benue. Tough structure and Evolution International Monograph Series, Braunschweig, pp. 19-38.

Obianwu, V.I.George, N.J., and Okiwelu, A.A.(2011). Preliminary Geophysical deductions of Lithological and Hydrological conditions of the North-Eastern sector of Akwa Ibom State, Southeastern Nigeria. Research Journal of Applied Sciences, Engineering and Technology 3(8): 806-811.

Obiora, D. N., Ibuot, J. C., George, N. J. (2016). Evaluation of aquifer potential, geoelectric and hydraulic parameters in Ezza North, Southeastern Nigeria, using geoelectric sounding. Int. J. Environ. Sci. Technol.,13: 435–444.

Obot, I.B., George, N.J.,and., Obianwu,V.I., and Akpan, A.E.(2010). Assessment of shallow aquiferous units and their coefficients of anisotropy in the coastal plain sands of Southern Ukanafun Local government area, Akwa Ibom State, Southern Nigeria.

Ogbonna, D.N.,Ekweozor, I.K.E.,Igwe, F.,(2002). Waste management: A Tool for Environmental Protection in Nigeria. AMBIO A Journal of the Human Environment 31(1) :55-57.

Ogwueleka. (2009). Municipal solid waste characteristics and management in Nigeria. Iran Journal of Environmental Health, Science& Engineering, 6(3):173-180.

Okafor, P., and Mamah, L.I.,(2012). Integration of geophysical techniques for groundwater potential investigation in Katsina-Ala, Benue State, Nigeria. The Pacific Journal of Science and Technology,13(2): 463-474.

Okey, E. N., Umana, E. J., Markson, A. A., and Okey, P. A. (2013). Municipal solid waste characterization and management in Uyo, Akwa Ibom State, Nigeria. Sustainable Development and Planning VI 639; WIT Transactions on Ecology and The Environment, 173, 1-10.

Okoro, E. I., Egboka, B. C. E., & Onwuemesi, A. G. (2010). Evaluation of the aquifer characterics of Nanka Sands using hydrogeological method in combination with vertical electrical sounding (VES). Journal of Applied Sciences, 14(2):5-9.

Oladapo, M. I., Mohammed, M. Z., Adeoye, O. O. and Adetola, O. O. (2004). Geoelectric investigation of the Ondo State Housing Corporation Estate; Ijapo, Akure, Southwestern Nigeria. Journal of mining and geology,40:41-48.

Olagunjoye,M.A.,Olayinka,A.I.,and Amidu,S.A.(2011). Geoelectrical Imaging at an Abandoned Waste Dump Site in Ibadan, Southwestern Nigeria. Journal of Applied Sciences, 11:3755-3764.

Olaniyan, I.O.,Ayinla,I,A., and Bashir Abdul(2012). Hydrochemical Analysis of Leachate Characteristics from Landfill sites in Kaduna, Nigeria. Journal of Environmental Science, Toxicology and Food Technology, (2) 1: 48-53.

Olobaniyi,S.B.,Ogala,J.E., and Nfor,N.B., (2007). Hydrogeochemical and bacteriological investigation of groundwater in Agbor area, Southern Nigeria. Journal of Mining and Geology, 43(1), 79-89.

Olofsson,B., Jernberg, H.,and Rosenqvist, A.,(2005). Tracing leachates of waste sites using geophysical and geochemical modelling. Environmental Geology (49)5:720-732.

Oluwemimo,O.,(2007). Social systems, institutions and structures: urbanization, poverty and changing quality of life. Paper presented at the training session of the foundation for environmental development and education in Nigeria, Thursday, February 22, 2007. In: : Babayemi, J.O., and Dauda, K.T.,(2009). Evaluation of Solid Waste Generation, Categories and Disposal Options in Developing Countries: A Case Study of Nigeria. Journal of Applied Sciences&Environmental Management, (13)3:83-88.

Orlando, L., and Marchesi, E., (2001). Georadar as a tool to identify and characterize solid waste dump deposits. J Appl Geophys 48:163-174, In: Soupios, P.,Papadopoulos, N., Papadopoulos, I., Kouli, M., Vallianatos, F., Sarris, A., and Manios, T.,(2007). Application of integrated methods in mapping waste disposal areas. Environmental Geol. DOI 10.1007/s00254-007-0681-2. Springer-Verlag 2007.

Osazuwa, I.B., and Abdullahi,N.K.,(2008). Electrical Resistivity and Induced Polarization Investigation at an open solid waste dumpsite. Case study: Kaduna, Nigeria. Journal of Environmental Hydrology, (16) 29,1-6.

Osei,J., Nyame, F.K.,Armah,T.K.,Osae,S.K.,Dampare,S.B.,Fianko,J.R., Adomako,D., and Nash,B.(2010). Application of Multivariate Analysis for identification of pollution sources in the Densu Delta Wetland in the vicinity of a landfill site in Ghana. Journal of Water Resource and Protection, 2010,2,1020-1029.

Oseji, J.O.,and Ujuanbi, O.,(2009). Hydrogeological investigation of groundwater potential in Emu Kingdom, Ndokwa land of Delta State, Nigeria. International Journal of Physical Sciences, 4(5): 275-284.

Otitoju,O., Akpanabiatu, M.I., Otitoju,G.T.O., Ndem, J.I., Uwah,A.F., Akpanyung, E.O., and Ekanem, J.T. (2012). Heavy Metal Contamination of green leafy vegetable gardens in Itam road construction site in Uyo, Nigeria. Research Journal of Environmental and Earth Sciences, (4) 4:1- 371.

Outreach Department, National Water Resources Institute, Kaduna, Nigeria (1997).

Onwuemesi, A.G.,and Egboka, B.C.E.,(2006). 2-D Polynomial curve fitting techniques on watertable, and hydraulic gradients estimations in parts of Anambra basin, Southeastern Nigeria. Natural and Applied Sci. Journal. 7 (2) :6-13.

PAI Associate International, 1982. The state of the Environment in Nigeria. Monograph series, no.2, Solid Waste Management in Fifteen Cities. FMHE, Nigeria.

Payal,S.,(2000). Deep Trouble. The Hidden Threat of Groundwater Pollution. In: Jegede,S.I., Iserhien-Emekeme,R.E., Iyoha,A.,and Amadasun,C.V.O.(2013). Near-surface Investigation of groundwater contamination in the Regolith Aquifer of Palladan, Zaria, using borehole log and Tomography Techniques.

Petters, S.W., and Ekweozor, C.M., (1982). Petroleum geology of Benue Trough and Southern Chad Basin, Nigeria. AAPG. Bull.,66:1141-1149.

Pomposiello, C., Dapena, C., Favetto, A., and Boujon, P.,(2012). Application of Geophysical Methods to Waste Disposal Studies

Porter,K.S.,and Stimmann, M.W.(1988). Protecting ground water: A guide for the pesticide user. In: Jegede,S.I., Iserhien-Emekeme,R.E., Iyoha,A.,and Amadasun,C.V.O.(2013). Near-surface Investigation of groundwater contamination in the Regolith Aquifer of Palladan, Zaria, using borehole log and Tomography Techniques. Research Journal of Applied Sciences, Engineering and Technology 6(4): 537-544.

Pugh, M., (1997). The path to affordable landfills. Journal of Waste Management, 1999, 58-59.

Pujari,P.R., Pardhi, P.,Muduli,P.,Harkare,P., and Nanoti,M.V.,(2007). Assessment of Pollution near landfill site in Nagpur, India, by resistivity imaging and Ground Penetrating Radar. Environmental Monitoring and Assessment, (131)1-3, 489-500, PubMed: 17295117.

Ramaanathan,R.M., and Fayose, E.A.,(1989). Cretaceous Transgression and Regression in Calabar Flank, South-eastern Nigeria, In: Obianwu, V.I.George, N.J., and Okiwelu, A.A.(2011). Preliminary Geophysical deductions of Lithological and Hydrological conditions of the North-Eastern sector of Akwa Ibom State, Southeastern Nigeria. Research Journal of Applied Sciences, Engineering and Technology 3(8): 806-811.

Reynolds,J.M.,(2011). An introduction to Applied and Environmental Geophysics,2nd Edition. John Wiley &Sons Ltd., UK.

Ritter,L., Solomon., Sibley,P.,Hall,K.,Keen,P.,Matta,G., and Linton, B.,(2002). Sources, pathways, and relative risks of contaminants in surface water and groundwater: a perspective prepared for the Walkerton inquiry. Journal of Toxicology and Environmental Health A. 2002 Jan 11; 65(1):1-142.

Rushbrook, P.(1997). Encouraging better landfilling in middle- and lower-income countries. Proc. Sardina 97, Sixth International Landfill Symposium, Italy.

Samsudin, A.R., Rahim,B. E.,Yaacob, W.Z.W.and Hamzah,U.,(2006). Mapping of contaminated plumes at municipal solid waste disposal sites using geoelectric imaging technique: case studies in Malaysia. Journal of Spatial Hydrology, 6(2), 13-22.

Sauck, W.A.,(2000). A model for the resistivity structure of LNAPL plumes and their environs in sandy sediments. J ApplGeophys 44:151-165. In : Soupios, P.,Papaopoulos, N., Papadopoulos, I., Kouli, M., Vallianatos, F., Sarris, A., and Manios, T.,(2007). Application of integrated methods in mapping waste disposal areas. Environmental Geol. DOI 10.1007/s00254-007-0681-2. Springer-Verlag 2007.

Schmoll, O.,Howard,G.,Chilton, J., and Chorus, I.,(2006). Protecting Groundwater for Health. Published on behalf of the World Health Organization by IWA Publishing, Alliance House, 12 Caxton Street, London, SWIH 0QS, UK.

Seaber, P.R., (1962). Cation hydrochemical facies of groundwater in the Englishtown Formation, New Jersey, In: Short papers in geology, hydrology, and topography. US Geological Professional Paper 450-B, 124-126.

Sharma, P.V.,(1997). Environmental and engineering geophysics, Cambridge University Press, Cambridge. In: Martinho ,E., and Almeida,F.,(2006). 3D behaviour of contamination in landfill sites using 2D resistivity/IP imaging: case studies in Portugal. Environmental Geology 49: 1071-1078. Springer-Verlag.

Shemang,E.M., Mickus,K.and Same,M.P.,(2011). Geophysical Characterization of the Abandoned Gaborone Landfill, Botswana: Implications for Abandoned Landfills in Arid Environments. International Journal of Environmental Protection, 1,:,1-12, World Academic Publishing.

Shemang, E.M., Molwalefhe,L., Chaoka, T.R., Moswell,E., and Nondo,M.(2006). Geophysical Investigation of the old Gaborone Dumpsite, Botswana. Journal of Applied Sciences &Environmental management, Vol. 10, No.3,87-92.
Sheriff,R.E.(2013). Encyclopedic dictionary of Applied Geophysics, 4th Edition. Society of Exploration Geophysicists, Tulsa, Oklahoma, U.S.A.

Simsek,C., Gemici,U., and Filiz,S.(2008) An assessment of surficial aquifer vulnerability and groundwater pollution from a hazardous landfill site, Torbali/Turkey. Geosciences Journal, 12(1):69-82.

Simsek,C., Kinkal,C., and Gunduz, O.,(2006). A solid waste disposal site selection procedure based on groundwater vulnerability, (In): Simsek,C., Gemici,U., and Filiz, S.(2008). An assessment of surficial aquifer vulnerability and groundwater pollution from a hazardous landfill site, Torbali/Turkey. Geosciences Journal, 12(1)69-82.
Singh, A., Sharma, S.P., Akca, I., and Baranwal, V.C., (2018). Fuzzy constrained Lp-norm inversion of direct current resistivity data. Geophysics, 83(1) : E11-E24.

Singh, R.P. (2000). Effect of waste-water disposal and extent of industrial pollution in and around Kanpur, Uttar Pradesh, India. Bulletin of Engineering Geology Environment, 60:31-35.(C) Springer-Verlag.

Singh, U.K., Kumar, M., Chauhan,R., Jha,P.K., Ramanathan, A., Subramanian, V.,(2008). Assessment of the impact of landfill on groundwater quality: a case study of the Pirana Site in Western India. Environmental Monitoring and Assessment. 2008 Jun; 141(1-3): 309-21. Sprinker-Link.

Society of Exploration Geophysics, SEG (2005). http://dx.doi.org/10.1190/1.9781560801719.ch 10.

Soupios,P.,Papadopoulos,Kouli,M.,Georgaki,I.,Vallianatos,F.,and

Kokkinou,E.(2006). Investigation of waste disposal areas using electrical methods : a case study from Chania, Crete, Greece. Environmental Geology, 51(7):1249-1261.

Soupios, P.,Papadopoulos, N., Papadopoulos, I., Kouli, M., Vallianatos, F., Sarris, A., and Manios, T.,(2007). Application of integrated methods in mapping waste disposal areas. Environmental Geol. DOI 10.1007/s00254-007-0681-2. Springer-Verlag 2007.

Soupios, P., Papadopoulos, M., Kouli, I., Georgaki, I., Valianatos, F. and Kokkinou, E. (2007). Investigation of waste disposal areas using Electrical methods: A case study from Chania, Crete, Greece. Environmental Geology, 51(7) :693-700

Spiegel, R., (1990). Statistics,2nd Edition, McGraw Hill, New York.

Steeds, J.E., Slade, N.J., and Reed,M.W.(2000). Technical Aspects of Site Investigation, Vol. 1(of 11) overview. Environmental Agency, Rio House, Waterside Drive, Aztec West, Almonds –bury, BRISTOL, BS 32 4 UD. 91P.

Szalai, S., and Szarka, L.,(2008). On the classification of surface geoelectrical arrays. Geophysical prospecting, 56: 159-175.

Stollar,R.L. and Roux,P.(1975). Earth Resistivity Survey – A method for defining groundwater contamination. Groundwater ,13,2:145-150.

Telford,W.M.,Geldart,L.P., and Sheriff,R.E.(2004). Applied Geophysics, 2nd edition. Cambridge University Press, Cambridge, UK.

Tijani ,M.N., Jinno, K., and Horoshiro, Y.,(2004). Environmental impact of heavy metals distribution in water and sediments of Ogunpa River, Ibadan Area, Southwestern Nigeria; In: Mosuro,G.O.,Omosanya,K.O.,Bayewu,O.O.,Oloruntola,M.O.,Laniyan,T. Atobi,O.,Okubena,M.,Popoola,E.,and Adekoya,F.,(2017). Assessment of groundwater vulnerability to leachate infiltration using electrical resistivity method. Springer.com. Appl Water Sci(2017).

Ugbaja,A.N. and Edet, A.E.,(2004). Groundwater pollution near shallow waste dumps in Southern Calabar, South-eastern Nigeria. Global Journal of Geological Sciences, 2,2 : 199-206.

Ugwu,S.A., and Nwosu, J.I.(2009). Effect of waste dumps on groundwater in Choba using Geophysical method. Journal of Applied Sciences and Environmental Management, March, 2009, 13 (1) :85-89.

Ukpong, E. C. , Antigha, R. E. , and Moses, E. O. (2013). Assessment Of Heavy Metals Content In Soils And Plants Around Waste Dumpsites In Uyo Metropolis, Akwa Ibom State . The International Journal of Engineering and Science (IJES), 2(7) :75-86.

Umoren, I.A., (1992). Aquifer characteristics in Mkpat Enin local government area using VES technique, In: Obianwu, V.I.George, N.J., and Okiwelu, A.A.(2011). Preliminary Geophysical deductions of Lithological and Hydrological conditions of the North-Eastern sector of Akwa Ibom State, Southeastern Nigeria. Research Journal of Applied Sciences, Engineering and Technology 3(8): 806-811.

Underwood,W.D.,(2005). Environmental Geophysics, www.dragonfire.ws/ch.3, 7P.

United States Environmental Protection Agency, Office of Solid Waste and Emergency Response,542-F-08-007, December ,2008

Ulrych TJ, Lima OAL, Sampaio EES (1994). In search of plumes: a GPR odyssey in Brazil. In : Soupios, P.,Papadopoulos, N., Papadopoulos, I., Kouli, M., Vallianatos, F., Sarris, A., and Manios, T.,(2007). Application of integrated methods in mapping waste disposal areas. Environmental Geol. DOI 10.1007/s00254-007-0681-2. Springer-Verlag 2007.

Urish,D.W.(1980). Salt Source Sleuthing in a coastal environment: A case study; American Geophysical Union, 61,46 : 955

Usen,U.U.,Akpabio,I.O., and Uko,E.D.(2007). Delineation of saline and freshwater interface in the aquifer of the coastal region of Akwa Ibom State, Nigeria. Bulletin of Pure and Applied Sciences – Geology.

Utom, A.U., Odoh, B. I., and Okoro, A.U. (2012). Estimation of Aquifer Transmissivity Using Dar Zarrouk Parameters Derived from Surface Resistivity Measurements: A Case History from Parts of Enugu Town (Nigeria). Journal of Water Resource and Protection, 4: 993-1000.

Visanathan, C., Trankler, J., Basnayake, B.F.A., Chiemchaisri, C.,Joseph, K., and Gonming, Z.,(2003). Landfill management in Asia – Notations about future approaches to appropriate and sustainable solutions. Proc. Sardina 03, Ninth International Landfill Symposium, Italy.

Wakida,F.T., and Lerner, D.N.,(2005). Non-agricultural sources of groundwater nitrate : a review and case study. Water Resources Jan, 39(1) : 3-16. Elsevier.

Warrick, A.W.,Young,M.H., and Wierenga,P.J.(1998). Probabilistic Analysis of Monitoring systems for detecting subsurface contamination plumes. GROUNDWATER, 36(6): 894-900.

Warner, D.L.,(1969). Preliminary Field Studies using Earth Resistivity Measurements for delineating zones of contaminated groundwater. Groundwater :7,1:9-16.

Whiteley, R.J., and Jewell, C.,(1992). Geophysical techniques in contaminated lands assessment: Do they deliver ? Explor. Geophys., 23,557-565. In: Meju,M.A.(2006). Geoelectrical Characterization of covered landfill sites: a process-oriented model and investigative approach. H.Vereecken et al. (eds.), Applied Hydrogeophysics, 319-339. Springer, Printed in the Netherlands.

Wightman,W.E., Jalinoos,F., Sirles,P., and Hanna, K.(2003)." Application of Geophysical Methods to Highway Related Problems." Federal Highway Administration, Central Federal Lands Highway Division, Lakewood, CO, Publication No. FHWA-IF-04-021, September, 2003. http://www.cflhd.gov/resources/agm/

World Health Organization WHO (2008). Guidelines for drinking-water quality, Vol.1Recommendations,3rd ed. WHO Library Cataloguing-in-Publication Data.

World Health Organization, (1996). pH in Drinking water. Guidelines for drinking water quality, 2nd edition, 2. Health criterion and other supporting information, WHO, Geneva.

Wunderlich, T., Fischer, P., Wilken, D., Hadler, H., Erkul, E., Mecking, R., Gunther, T., Heinzelmann, M., Vott, A., and Rabbel, W., (2018). Constraining electric resistivity tomography by direct push electric conductivity logs and vibracores: An exemplary study of the Fiume Morto silted riverbed (Ostia Antica, western Italy). Geophysics 83(3) : B87-B103.

Yaramanci, U., (1994). Relation of in-situ resistivity to water content in rock salts. Geophysical prospecting V.41, p.229-239. In: Pomposiello, C., Dapena, C., Favetto, A., and Boujon, P., (2012). Application of Geophysical Methods to Waste Disposal Studies.

Yin K., Tong, H., Giannis, A., Wang, J., and Chang, V.W., (2017). Multiple geophysical surveys for old landfill monitoring in Singapore. Environ Monit Assess 189:20.

Zohdy, A.A.R., Eaton, G.P., and Mabey, D.R., (1974). Application of Surface Geophysics to groundwater investigation. U.S.G.S. Techniques of Water-Resource Investigation, Book 2.

APPENDICES

Appendix I: 2016 DATA ACQUISITION

Table 1 : Summary of Interpreted Resistivity Data for Uyo Dumpsite

Sounding Location	Curve Type	Layer	Resistivity ρ_a (Ωm)	Thickness h (m)	Depth d(m)	Remarks
Uyo Dumpsite P1 VES 1 N 05^0 02^1 31.051^{11} E $07^0 56^1 01.303^{11}$	H	1	89.2	1.03	1.03	Top, Lateritic Sand
		2	11.4	4.95	5.98	Leachate Contaminated Sand
		3	11315	∞	∞	Dry Fine to medium-grained Sand
Uyo Dumpsite P1 VES 2 N $05^0 02^1 32.025^{11}$ E $07^0 56^1 01.812^{11}$	H	1	35.4	1.25	1.25	Top, Lateritic Sand
		2	8.26	2.85	4.1	Leachate Contaminated Sand
		3	13654	∞	∞	Dry Fine to medium-grained Sand
Uyo Dumpsite P1 VES 3 N $05^0 02^1 33.135^{11}$ E $07^0 56^1 02.457^{11}$	H	1	232	2..43	2.43	Top, Lateritic Sand
		2	13.3	8.32	10.8	Leachate Contaminated Sand
		3	6323	∞	∞	Medium to Coarse -grained Clayey-Sand
Uyo Dumpsite P2 VES 4 N $05^0 02^1 32.773^{11}$ E $07^0 56^1 0.398^{11}$	H	1	108	1.15	1.15	Top, Lateritic Sand
		2	6.32	8.69	9.84	Leachate Contaminated Sand
		3	1304	∞	∞	Medium to Coarse-grained Sand

Uyo Dumpsite P2 VES 5 N $05^{0}02^{1}33.628^{11}$ E $07^{0}56^{1}1.043^{11}$	H	1	38.4	1.48	1.48	Top, Lateritic Sand
		2	4.11	4.36	5.84	Leachate Contaminated Sand
		3	8326	∞	∞	Dry medium to coarse-grained Sand
Uyo Dumpsite P2 VES 6 N $05^{0}02^{1}34.857^{11}$ E $07^{0}56^{1}01.518^{11}$	H	1	19.8	1.15	1.15	Top, Lateritic Sand
		2	4.32	9.23	10.4	Leachate Contaminated Sand
		3	3795	∞	∞	Medium to Coarse-grained Sand
Uyo Dumpsite P3 VES 7 N $05^{0}02^{1}$ 33.454^{11} E $07^{0}55^{1}59.325^{11}$	H	1	192	2.02	2.02	Top, Lateritic Sand
		2	20	4.09	6.12	Leachate Contaminated Sand
		3	26542	∞	∞	Dry medium to coarse Sand
Uyo P3 VES 8 N $05^{0}2^{1}34.462^{11}$ E $07^{0}55^{1}59.885^{11}$	H	1	62.3	1.43	1.43	Top, Lateritic Sand
		2	10.2	0.624	2.06	Leachate Contaminated Sand
		3	8.42	5.85	7.9	Leachate Contaminated Sand
		4	10.4	3.4	11.3	Leachate Contaminated Sand
		5	5607	∞	∞	Medium to coarse-grained Sand
Uyo P3 VES 9 N $05^{0}2^{1}35.708^{11}$ E $07^{0}56^{1}0.291^{11}$	H	1	52.7	1.72	1.72	Top, Lateritic Sand
		2	4.06	3.78	5.5	Leachate Contaminated Sand
		3	12060	∞	∞	Dry Medium-grained Sand
Uyo P4 VES10	H	1	40.3	2.47	2.47	Top, Lateritic Sand

N $5^{0}2^{1}36.303^{11}$ E $07^{0}55^{1}$ 57.861^{11}		2	4.21	4.18	6.64	Leachate Contaminated Sand
		3	102	∞	∞	Medium-grained Clayey-Sand
Uyo P4 VES 11	H	1	46.1	2.32	2.32	Top, Lateritic Sand
N$05^{0}2^{1}35.708^{11}$ E $07^{0}55^{1}58.369^{11}$		2	8.42	22.2	24.5	Leachate Contaminated Sand
		3	694	∞	∞	Medium to Coarse Sand
Uyo P4 VES 12	H	1	19.8	1.15	1.15	Top, Lateritic Sand
N$0502^{1}36.048^{11}$ E $07^{0}55^{1}59.014^{11}$		2	4.32	9.25	10.4	Leachate Contaminated Sand
		3	3795	∞	∞	Dry medium to coarse-grained Sand

Table 2: Summary of Interpreted Resistivity Data for Ikot Ekpene Dumpsite

Sounding Location	Curve Type	Layer	Resistivity $\rho_a(\Omega m)$	Thickness h, (m)	Depth, d, (m)	Remarks
Ikot Ekpene Dumpsite		1	115	0.751	0.751	Top, Lateritic Sand
P5 VES 13 N$05^{0}10^{1}30.682^{11}$ E$007^{0}42^{1}41.345^{11}$	K-H	2	254	1.93	2.68	Medium to Coarse –grained Sand
		3	94.9	4.94	7.62	Fine to Medium -grained Clayey Sand
		4	231	∞	∞	Medium to Coarse-grained Sand
Ikot Ekpene P5 VES 14	A	1	64.6	0.758	0.758	Top, Lateritic Sand
N$05^{0}10^{1}30.953^{11}$ E $07^{0}42^{1}41.914^{11}$		2	92.9	6.4	7.16	Fine to medium -grained

						Sand
		3	1191	∞	∞	Medium to coarse-grained Sand
Ikot Ekpene P5 VES 15	H	1	4883	6.08	6.08	Top, Lateritic Sand
N $05^{0}10^{1}$ 31.39^{11} E $07^{0}42^{1}42.599^{11}$		2	188	8.22	14.3	Medium to Coarse-grained Sand
		3	22436	∞	∞	Very dry medium to coarse-grained Sand
Ikot Ekpene P6 VES 16	K-H	1	126	0.75	0.75	Top, Lateritic Sand
N $05^{0}10^{1}31.51^{11}$ E $07^{0}42^{1}40.792^{11}$		2	251	1.98	2.73	Medium to Coarse-grained Sand
		3	129	25.2	28	Saturated medium to Coarse-grained Sand (shallow aquiferous unit)
		4	2269	∞	∞	Dry medium to coarse-grained Sand
Ikot Ekpene P6 VES 17	A	1	103	0.763	0.763	Top, Lateritic Sand
N $05^{0}10^{1}31.873^{11}$ E $07^{0}42^{1}41.061^{11}$		2	136	9.24	10	Medium to coarse-grained Sand
		3	45756	∞	∞	Very dry medium to coarse-grained Sand
Ikot Ekpene P6 VES 18	K	1	1505	1.14	1.14	Top, Lateritic Sand
N$05^{0}10^{1}31.873^{11}$ E $07^{0}42^{1}41.949^{11}$		2	16021	1.62	2.76	Dry medium to coarse-grained Sand
		3	181	∞	∞	Medium to coarse-grained Sand
Ikot Ekpene P7 VES 19	K-H	1	104	0.769	0.769	Top, Lateritic Sand
N 05^{0} $10^{1}31.873^{11}$		2	310	0.901	1.67	Medium to coarse-grained

E 07^0 $42^1 41.476^{11}$						Sand
		3	126	24.5	26.1	Wet medium to coarse-grained Sand
		4	6896	∞	∞	Dry medium to coarse-grained Sand
Ikot Ekpene P7 VES 20 N $05^0 10^1 32.197^{11}$ E $07^0 42^1 41.061^{11}$	K-H	1	119	0.75	0.75	Top, Lateritic Sand
		2	991	0.823	1.57	Coarse grained Sand
		3	58.3	2.56	4.13	Fine to medium-grained Clayey Sand
		4	1428	∞	∞	Dry medium to coarse-grained Sand
Ikot Ekpene P7 VES 21 N $05^0 10^1 32.376^{11}$ E $07^0 42^1 41.476^{11}$	K	1	3733	1.73	1.73	Top, Lateritic Sand
		2	24849	1.13	2.86	Dry medium to coarse-grained Sand
		3	242	∞	∞	Medium to coarse-grained Sand

Table 3: Summary of Interpreted Resistivity Data for Oron Dumpsite

Sounding Location	Curve Type	Layer	Resistivity $\rho_a(\Omega m)$	Thickness (m)	Depth (m)	Remarks
Oron Dumpsite P8 VES 22 N$05^0 02^1 31.051^{11}$ E $07^0 56^1 1.303^{11}$	K	1	167	6.06	6.06	Top, Lateritic Sand
		2	2632	15.3	21.4	Fine to medium-grained Sand
		3	6.36	∞	∞	Leachate Contaminated Sand
Oron Dumpsite P8 VES 23	K	1	127	1.33	1.33	Top, Lateritic Sand
N $05^0 02^1 32.025^{11}$		2	257	4.91	6.24	Medium to Coarse-grained

E $07^{0}56^{1}1.812^{11}$						Sand
		3	1070	47	53.2	Medium - grained Sand, unconfined aquiferous unit
		4	19	∞	∞	Leachate Contaminated Sand
Oron Dumpsite P8 VES 24	K	1	112	1.42	1.42	Top, Lateritic Sand
N $05^{0}2^{1}33.135^{11}$ E $07^{0}56^{1}2.457^{11}$		2	290	3.42	4.85	Medium to Coarse-grained Sand
		3	755	∞	∞	Dry medium to coarse-grained Sand
Oron Dumpsite P9 VES 25	K	1	140	0.75	0.75	Top, Lateritic Sand
N $05^{0}2^{1}32.773^{11}$ E $07^{0}56^{1}0.398^{11}$		2	202	6.55	7.3	Medium to Coarse-grained Sand
		3	2026	17.5	24.8	Dry medium to coarse-grained Sand
		4	4.28	∞	∞	Leachate Contaminated Sand
Oron Dumpsite P9 VES 26	K	1	115	1.08	1.08	Top, Lateritic Sand
N$05^{0}2^{1}33.628^{11}$ E $07^{0}56^{1}1.043^{11}$		2	244	6.96	8.03	Medium to Coarse-grained Sand
		3	2387	12.7	20.7	Dry medium to coarse-grained Sand
		4	253	∞	∞	Medium to Coarse-grained Sand
Oron Dumpsite P9 VES 27	A	1	104	1.02	1.02	Top, Lateritic Sand
N $05^{0}2^{1}34.857^{11}$ E $07^{0}56^{1}1.518^{11}$		2	255	4.36	5.38	Medium to Coarse-grained Sand
		3	767	∞	∞	Medium to Coarse-grained Sand
Oron Dumpsite P10 VES 28	KHK	1	103	0.75	0.75	Top, Lateritic Sand
N $05^{0}2^{1}33.454^{11}$		2	838	0.846	1.6	Fine to medium

E $07^{0}55^{1}59.325^{11}$						-grained Sand
		3	96.8	3.13	4.72	Medium to Coarse-grained Sand
		4	2947	12.4	17.1	Dry medium to coarse-grained Sand
		5	4.77	∞	∞	Leachate Contaminated Sand
Oron Dumpsite P10 VES 29	K	1	106	1.09	1.09	Top, Lateritic Sand
N $05^{0}2^{1}34.462^{11}$ E $07^{0}55^{1}59.885^{11}$		2	260	6.82	7.9	Medium to coarse- grained Sand
		3	1213	40.2	48.1	Medium -grained Sand, unconfined aquiferous unit
		4	10.8	∞	∞	Leachate Contaminated Sand
Oron Dumpsite P10 VES 30	K	1	118	1.16	1.16	Top, Lateritic Sand
N $05^{0}2^{1}35.708^{11}$ E $07^{0}56^{1}0.291^{11}$		2	287	4.36	5.52	Medium to Coarse-grained Sand
		3	730	∞	∞	Dry medium to coarse -grained Sand

Appendix II: 2014 Data Acquisition

Table 4

Summary of interpreted resistivity data for Uyo Dumpsite Profile 1

Sounding Location	Curve type	Layer	Resistivity ρ_a (Ωm)	Thickness, h (m)	Depth, d (m)	Remarks
UYO DUMPSITE VES1 N05^{0}02^{l}30^{ll}, E007^{0}56^{l}06.5^{ll}	Q	1	817.6	2.6	2.6	Top, medium to coarse-grained lateritic sand
		2	717	0.526	3.13	Top, medium to coarse-grained lateritic sand
		3	142	∞	∞	fine to medium-grained clayey-sand
UYO DUMPSITE VES2 N05^{0}02^{l}31.6^{ll}, E007^{0}56^{l}06.0^{ll}	Q	1	3746	4.887	4.887	Top, medium to coarse-grained lateritic sand
		2	663.3	7.514	12.4	Top, medium to coarse-grained lateritic sand with high clay content
		3	126.4	∞	∞	fine to medium-grained clayey-sand
UYO DUMPSITE VES3 N05^{0}02^{l}32.3^{ll}, E007^{0}56^{l}05.9^{ll}	H	1	1833	9.71	9.71	Top, medium to coarse-grained lateritic sand
		2	139	73.3	83	Fine to medium-grained sands, unconfined aquiferous unit
		3	5600	∞	∞	Dry medium to coarse-grained sands
UYO DUMPSITE		1	16.46	1.502	1.502	Fine to medium-grained sands, highly contaminated with

VES4						leachate
N05^{0}02^{l}33.2^{ll}, E007^{0}56^{l}05.2^{ll}	A	2	38.31	15.39	16.89	Fine to medium- grained top lateritic sand that is contaminated with leachate
		3	39214	∞	∞	Dry medium to coarse-grained sand
UYO DUMPSITE VES5 N05^{0}02^{l}34.1^{ll}, E007^{0}56^{l}05.2^{ll}	H	1	45.97	1.545	1.545	Fine to medium- grained leachate contaminated sand
		2	13.4	5.726	7.271	Fine to medium-grained sands, highly contaminated with leachate
		3	6613	∞	∞	dry, Medium to coarse-grained sand

Summary of interpreted resistivity data for Uyo Dumpsite profile line 2,

Sounding Location	**Curve type**	**Layer**	**Resistivity ρa (Ωm)**	**Thickness, h (m)**	**Depth,d (m)**	**Remarks**
UYO DUMPSITE VES1 N05^{0}02^{l}29.7^{ll}, E007^{0}56^{l}04.8^{ll}	H	1	170.1	6.42	6.42	Fine to medium-grained top lateritic sand
		2	69.7	7.97	14.4	Fine to medium-grained sand contaminated with leachate
		3	269	∞	∞	Partially wet, fine to medium-

						grained sand.
UYO DUMPSITE VES2 N05^{0}02^{l}30.4^{ll}, E007^{0}56^{l}04.2^{ll}	H	1	151.9	16.56	16.56	Dry, fine to medium -grained top lateritic sand
		2	26.88	25.74	42.3	Fine to medium-grained sand of leachate contamination
		3	10711	∞	∞	Very dry medium to coarse-grained sand.
UYO DUMPSITE VES3 N05^{0}02^{l}31.2^{ll}, E007^{0}56^{l}03.8^{ll}	H	1	57.35	6.527	6.527	Top lateritic layer highly contaminated with leachate
		2	14.44	8.013	14.54	Fine to medium-grained sand layer highly contaminated with leachate
		3	22866	∞	∞	Highly compacted and dry layer of medium to coarse-grained sand.

Summary of interpreted resistivity data for Uyo Control

Sounding Location	**Curve type**	**Layer**	**Resistivity ρa (Ωm)**	**Thickness, h (m)**	**Depth, d (m)**	**Remarks**
UYO		1	902	0.75	0.75	Top lateritic soil
DUMPSITE		2	13623	1.21	1.96	Very coarse-grained and

VES1	K-H					dry sand
N05^{0}01^{l}18.5^{ll}, E007^{0}57^{l}07.9^{ll}		3	471	27.3	29.2	Saturated fine to medium-grained sand(shallow aquiferous unit)
		4	2275	∞	∞	Partially wet fine to medium-grained sand

Table 5:Summary of interpreted resistivity data for Ikot Ekpene Dumpsite profile line 1

Sounding Location	**Curve type**	**Layer**	**Resistivity ρ_a (Ωm)**	**Thickness, h (m)**	**Depth, d (m)**	**Remarks**
IKOT EKPENE DUMPSITE VES1 N05^{0}10^{l}30.5^{ll}, E007^{0}42^{l}42.2^{ll}	K	1	263	3.95	3.95	Fine to medium-grained top lateritic sand
		2	1869	34	37.9	Dry medium to coarse-grained sand
		3	15.9	∞	∞	leachate contaminated layer
IKOT EKPENE DUMPSITE VES2 N05^{0}10^{l}31.1^{ll}, E007^{0}42^{l}42.8^{ll}	K	1	16.03	15.111	15.111	Dry, fine to medium - grained top lateritic sand
		2	413.5	15.33	20.44	Fine to medium-grained sand of leachate contamination
		3	0.9084	∞	∞	Very dry medium to coarse-grained sand.
IKOT EKPENE DUMPSITE VES3 N05^{0}10^{l}31.5^{ll}, E007^{0}42^{l}43.8^{ll}	H-K	1	482.1	3.417	3.417	Top lateritic layer highly contaminated with leachate
		2	127.8	4.853	8.27	Fine to medium-grained sand layer highly contaminated with leachate
		3	22362	3.716	11.99	Highly compacted and dry layer of medium to coarse-grained sand.
		4	63.53	∞	∞	Clay or possibly shale layer

Summary of interpreted resistivity data for Ikot Ekpene Dumpsite profile line 2

Sounding Location	Curve type	Layer	Resistivity ρa (Ωm)	Thickness, h (m)	Depth, d (m)	Remarks
IKOT EKPENE DUMPSITE VES1 $N05^0 10^I 32.5^{II}$, $E007^0 42^I 42.5^{II}$	A	1	147	1.5	1.5	Fine to medium-grained top lateritic sand
		2	518	86.8	88.3	Dry medium to coarse-grained sand
		3	4980	∞	∞	Dry, moderately compacted medium to coarse-grained sand

Summary of interpreted resistivity data for Ikot Ekpene Control

Sounding Location	Curve type	Layer	Resistivity ρa (Ωm)	Thickness, h (m)	Depth, d (m)	Remarks
UYO DUMPSITE VES1 $N05^0 12^I 09.2^{II}$, $E007^0 42^I 01.2^{II}$	K-H	1	1104	1.5	1.5	Dry clayey sand
		2	1763	3.83	5.33	Dry medium to coarse-grained sand
		3	1105	13.8	19.1	Dry fine to medium-grained sand
		4	1438	∞	∞	Dry medium to coarse-grained sand

Table 6: Summary of interpreted resistivity data for Oron Urban Dumpsite profile line 1

Sounding Location	Curve type	Layer	Resistivity ρa (Ωm)	Thickness, h (m)	Depth, d (m)	Remarks
ORON URBAN		1	97	4.06	4.06	Fine to medium-grained

DUMPSITE	K					top sandy-clay
VES1 N04^{0}48^{l}56.7^{ll},		2	4097	8.69	12.8	Dry sands of medium to coarse-grained size
E008^{0}14^{l}29.7^{ll}		3	11.2	∞	∞	leachate contaminated layer
ORON URBAN DUMPSITE VES1 N04^{0}48^{l}58.8^{ll}, E008^{0}14^{l}29.3^{ll}	K	1	141	4.97	4.97	Fine to medium-grained top sandy-clay
		2	1264	47.8	52.8	Fine to medium-grained sand
		3	110	∞	∞	Fine to medium-grained sand, saturated with water.

Summary of interpreted resistivity data for Oron Urban Dumpsite profile line 2

Sounding Location	**Curve type**	**Layer**	**Resistivity ρa (Ωm)**	**Thickness, h (m)**	**Depth, d (m)**	**Remarks**
ORON URBAN DUMPSITE VES1 N04^{0}48^{l}56.0^{ll}, E008^{0}14^{l}30.2^{ll}	K	1	391	16.4	16.4	Top lateritic sand of medium to coarse-grained size
		2	1142	37.5	54	sand of medium to coarse-grained size
		3	278	∞	∞	Saturated sand of fine to medium-grained size
ORON URBAN DUMPSITE VES1 N04^{0}48^{l}55.6^{ll}, E008^{0}14^{l}28.8^{ll}	H-K	1	390.7	2.202	2.202	Sand of medium to coarse-grained size
		2	164.6	6.608	8.81	Partially wet, fine to medium-grained sand
		3	1637	17.61	26.42	Dry sand of medium to coarse-

						grained size
		4	7.306	∞	∞	Leachate contaminated layer
ORON URBAN DUMPSITE VES1 N04^{0}48^{I}54.5^{II}, E008^{0}14^{I}28.5^{II}	H-K	1	623.7	1.588	1.588	Top lateritic medium to coarse-grained sand
		2	245	8.029	9.617	Fine to medium-grained sand, partially wet
		3	1431	29.37	38.99	Sand of medium to coarse-grained size
		4	37.69	∞	∞	Leachate contaminated layer