

Effect of Waste Dump on Ground Water Quality using Electrical Restivity Method in Engr. A.A Kure Modern Market Minna, Niger State

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ABSTRACT

Groundwater contamination resulting from indiscriminate solid waste disposal poses a significant environmental and public health challenge in many urban areas of Nigeria. This study investigated the effect of solid waste dumping on groundwater quality at the Engr. Abdulkadir Abdullahi Kure Ultra-Modern Market, Minna, Niger State, using electrical resistivity methods. Vertical Electrical Sounding (VES) employing the Schlumberger array and two-dimensional (2D) resistivity imaging using the Wenner array were utilized to delineate subsurface lithology, assess aquifer protective capacity, and identify possible leachate migration pathways. The results revealed three to four geoelectric layers consisting of topsoil, weathered/fractured layers, and fresh basement rock. Resistivity values of the top layer ranged from 251.2 to 481.0 Ωm , while the second layer recorded lower resistivity values between 88.9 and 162.7 Ωm , indicating zones affected by leachate infiltration. Longitudinal conductance values ranged from 0.03578 to 0.06363 mho, suggesting poor aquifer protective capacity and high vulnerability to contamination. The 2D resistivity sections identified low-resistivity anomalies extending to depths of approximately 10–15 m, indicating significant leachate migration within the subsurface. The study confirms that improper waste disposal practices have adversely affected groundwater quality within the study area. The findings highlight the need for improved waste management systems, continuous groundwater monitoring, and protective measures to safeguard groundwater resources and public health.

Keywords: Groundwater Contamination, Electrical Resistivity, Vertical Electrical Sounding, Wenner Array, Leachate Migration, Aquifer Protective Capacity, Solid Waste Dumpsite, Minna, Nigeria..

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Introduction

Background to the Study

Around the world, groundwater is a significant component of the water supplies, especially in arid areas. Since it is of great quality and needs little to no preparation before use, it is utilized for household tasks. According to, biological pollutants such as bacteria, fungus, and other organisms are naturally filtered and attenuated as water seeps into or permeates through the soil [1]. Another reason groundwater is used domestically is that the public's needs for clean water are egregiously unmet by the water distribution system that is in place. The availability of fresh groundwater has significantly diminished as a result of careless management and/or disposal

of hazardous contaminants [2]. The setback of ecological contamination is a major concern of earth scientists today, and investigators from other associated disciplines across the world (International Solid Waste Association [3].

According to Ige, with increased social-economic development, trash production has risen disproportionately in Nigerian cities [4]. Rapid industrialization and unchecked urban population growth have a significant negative impact on the environment by producing large amounts of toxic solid waste [5]. Municipal waste items, primarily home trash, are routinely thrown away inappropriately on land surfaces, in drainage ditches, and along

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river and stream channels, putting the groundwater at risk of contamination. Solid waste disposal sites are a crucial component of the hydrological structure of the soil, posing a serious risk of contaminating both the groundwater and downstream surface water [6]. Consequently, there is a need to comprehend and measure the hydraulic behavior of landfills.

Fluvial water percolation and pollutant penetration into the soil beneath waste dumps are the two main causes of groundwater pollution. The putrefaction of municipal solid wastes produces a liquid called noxious waste [7]. When the leachate, an aqueous liquid that leaks and affects groundwater quality, reaches the groundwater table, contamination occurs. It is impossible to overstate the ecological degradation and health risk associated with exposed dumpsites [8].

Assessment of the location and level of pollution in the spaces in lanes held by landfills is a necessary and regular need in urban areas [9]. Applying geotechnical, hydrogeology, and geophysical methods provides a substantial way to estimate and classify pollutants produced by urban residues (household and/or industrial), in this environment. The geoelectrical approach has been discovered to be particularly suitable for these kinds of ecological investigations [10]. This is due to the fact that leachate from landfills typically has an ionic intensity that is much higher than that of groundwater. As a result, as soon as the leachate enters the aquifer, a significant difference in electrical properties will be felt. The methods will recognize these regions as an irregularity, which enables the detection of the leachate trail. In accordance with the documentation provided geology, hydrogeology, geotechnical, and geophysical methodologies have been utilized to study landfills [11].

Environmental pollution is currently a serious concern for earth scientists and researchers from related fields of study around the world. Untreated waste dumped carelessly endangers public health because it creates unsanitary conditions that have negative consequences on city dwellers. Domestic solid waste is likely to be mixed with fecal material in areas with a shortage of sanitary services, which complicates the health hazards [12]. The majority of these waste disposal locations are found close to human settlements, where there are numerous wells and boreholes, in open areas. The environment and the welfare of the populace would be negatively impacted by the careless disposal and improper management of residential and industrial garbage. One in five African infants die from transmissible infections linked to a deficient ecological environment, with acute respiratory illnesses and diarrhea being the two primary causes of death [13]. Poor water quality and sanitation are linked to diseases like typhoid, cholera, guinea worm, trachoma, bilharziasis, polio, hookworm, and tapeworm [14].

The intrusion of leachates through the soil at a waste disposal site leads to groundwater contamination. When rain falls on a landfill site, leachates are produced, which percolate through the trash and carry pollutants as they drain down [15]. The frequently weak aquifer that is present in basement complex habitats is typically exposed to outside and nearby outside pollutants [10]. It has been confirmed that as soon as an aquifer is severely

depleted or contaminated, the damage is almost irreparable and the costs of cleaning up the contamination are very high [16]. The primary source of water for household needs in the study region and its environs is groundwater, which is obtained by hand-dug boreholes and wells at depths occasionally as low as 5 meters. The hydrological connection between the dangerous compounds in the groundwater and leachate plumes makes the pollution clear [17].

In the fields of geo-environment, hydrogeology, engineering, and contaminated hydrology, direct current (DC) electrical resistivity exploration geophysical techniques are popular and have shown to be successful and reliable. The use of 2-D electrical imaging techniques to scan areas with moderate to challenging geology has been improved [18]. A more accurate representation of the subterranean in two dimensions (2-D) can be obtained by mapping variations in the observed resistivity in both the vertical and horizontal trend. Electrical conductivity/resistivity of groundwater chemistry produces intrinsic properties (electrical conductivity/resistivity) of groundwater chemistry that gives information on contamination, reasonably economical, and optimization of the required amount of observation wells are some of the benefits of using electrical resistivity methods for contaminant studies on thin resources of groundwater [19]. The study's goal is to use vertical electrical sounding and Wenner techniques in combination with geoelectric technology to locate and map the leachate trail from an unregulated solid waste disposal location in Kure Market Minna, North-central Nigeria.

Statement of the Research

The indiscriminate dumping of solid waste in proximity to groundwater sources poses a significant threat to the quality of groundwater, leading to contamination by leachates that can permeate into the aquifer, causing changes in the physical, chemical, and biological characteristics of the water [4]. This can result in the presence of harmful pollutants, such as heavy metals, pathogens, and organic compounds, which can have severe impacts on human health, the environment, and the economy, highlighting the need for effective waste management strategies to mitigate this critical issue.

Justification for the Study

The dumping of solid waste in proximity to groundwater sources catastrophically compromises water quality, triggering a cascade of chemical, microbiological, and physicochemical contaminants that imperil human health, environmental sustainability, and economic viability by irreversibly degrading aquifers and polluting the vital resource.

Location of the Study Area

Engr. Abdulkadir Abdullahi Kure Ultra-Modern Markets Chanchaga (Figure 1), the metropolitan area of Minna, Niger State, Nigeria covers 72 km² located between the 6°30'E to 6°40'E Longitude and 9°30'N to 9°35'N Latitude. The 2006 population of Chanchaga Local government was projected for 2020 to approximately 309,154 population using the average growth rate of 3.06% based on the recommended National Population Commission exponential method of projection as a result of the inadequacies of Nigeria's Census data, the exponential method will give high variance [20].



Figure 1: Minna showing study areas [21]

Scope of the Study

The study will provide critical insights into the influence of waste dumping activities on groundwater quality. The study is structured to assessing the effect of solid waste dump in Engr A.A Kure market on the groundwater quality using electrical resistivity method.

Aim and Objectives of the Study

The aim of the research is to investigate the effect of solid waste dump on groundwater quality using electrical resistivity methods within the study area.

The specific objectives of the study are to:

1. produce resistivity logs of the investigated site
2. determine the resistivity layers, thickness and depth of the study area
3. investigate the behaviour of leachate migration in the subsurface of the study area.

Significant of the Study

This study is a very important and relevant study in our society today, because most people in the study area do not have a steady source of pipe borne water supply, therefore they mainly depend on well water as their major source of water supply for their daily domestic use. The outcome of this study will help physical planners and health workers coordinate their activities in relation to environmental health policy issues. It will also guide stakeholders from the environment, health water resource ministries and community-based organizations with the best options for public campaign towards maintaining a clean environment. In addition, it is also hoped that the research outcome will contribute to the existing body of knowledge on the subject matter.

Literature Review

Geological Review

Niger State, situated in central Nigeria, boasts a rich and diverse geological history, evident in its varied and contrasting landscapes. Understanding this geological tapestry is crucial, not only for appreciating the state's natural beauty. This comprehensive exploration delves into the fascinating geological makeup of Niger State, spanning ancient Precambrian formations to younger sedimentary basins. The basement complex is a major

geological feature underlying approximately half of Niger State, Nigeria. It consists of ancient igneous and metamorphic rocks formed over 2 billion years ago. These rocks are typically hard, crystalline, and resistant to weathering.

Niger State, is known for its distinct and varied landscapes, which are as a result of its rich and varied geological past. It is essential to comprehend this geological tapestry not only in order to enjoy the natural beauty of the state but also for resource development, land use planning, and environmental sustainability. This thorough investigation explores the Niger State's diverse geological composition, which ranges from older sedimentary basins to ancient Precambrian formations. About half of Niger State is covered by the basement complex, a significant geological structure. It is composed of rocks that were produced more than two billion years ago, both igneous and metamorphic. Usually, these rocks are crystalline, hard, and weather-resistant [22].

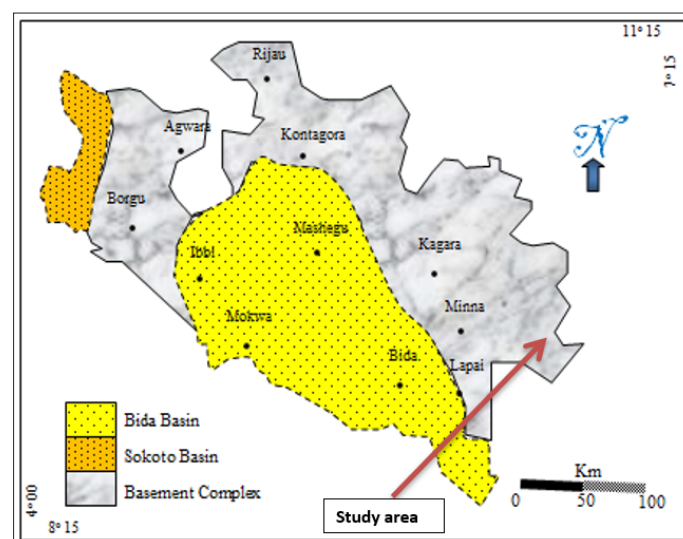


Figure 2: Geology Map of Niger State [23]

The Basement Complex: The basement complex, forming the foundation of approximately half of Niger State, is a story etched in ancient rock, spanning over 2.2 billion years. These robust igneous and metamorphic rocks hold the key to understanding not only the state's majestic landscapes but also its valuable resources and potential challenges.

- a. The Precambrian Older Granite
- b. The Migmatite/Gneiss Complex
- c. Undeformed Acidic and Basic Dykes.
- d. The Low-grade Schist Belt

The Older Granite: The Older Granite in Niger State represents a significant component of the state's geological makeup, forming part of the basement complex, which underlies about half of the state. This ancient formation holds historical, economic, and environmental significance. The Older Granite is not uniformly distributed throughout the basement complex. It typically appears as isolated, dome-shaped or oval-shaped bodies scattered across the region. These exposed areas often form hills and ridges, contributing to the diverse topography of

Niger State. Some notable examples of these formations include the Paiko and Minna Batholiths [24].

The formation comprises:

- a) The migmatite granite;
- b) The granitic gneiss;
- c) The early on pegmatitic and fine-grained granite;
- d) The uniform to coarse porphyry granite;
- e) Pegmatitic aplites that are to some extent distorted with veins of quartz; and
- f) Undeformed pegmatite, two-micaceous granites and quartz intrusion.

The Migmatite/Gneiss Complex: The Migmatite-Gneiss Complex forms a significant portion of the basement complex underlying approximately half of Niger State, Nigeria. This complex, composed primarily of migmatites and gneisses, showcases a fascinating history of metamorphic processes that transformed ancient rocks over billions of years. Migmatites are unique metamorphic rocks characterized by the presence of both igneous-looking (light-colored) and metamorphic (darker-colored) bands. This distinct banding pattern reflects the partial melting of pre-existing rocks, often gneisses, under high temperatures Amadi et al, [25]. The molten material infiltrates the surrounding rock, forming the lighter bands, while the unmelted remnants remain as darker bands. Gneisses, on the other hand, exhibit a banded or foliated texture due to the alignment of mineral grains under pressure during metamorphism. The specific minerals present in the gneisses within the complex vary, including common minerals like quartz, feldspar, mica, and amphibole [26].

The Low-grade Schist Belt: The Low-Grade Schist Belt comprises metamorphosed sedimentary and volcanic rocks that have undergone low-grade metamorphism. This means they experienced moderate heat and pressure compared to other metamorphic formations within the basement complex. As a result, the original textures and minerals of the rocks have been partially altered, but not entirely destroyed. The most common rock types within the belt are phyllites, fine-grained metamorphic rocks with a pronounced foliation (layered appearance). Other prevalent rock types include mica schists, characterized by the presence of mica minerals like muscovite and biotite, and quartzites, hard, non-foliated rocks primarily composed of quartz [23,27].

Undeformed Acidic and basic Dykes: The basement complex of Niger State, beyond its dominant igneous and metamorphic rocks, also features undeformed acidic and basic dykes. These intrusive features, injected into pre-existing rocks, offer valuable insights into the state's geological history and resource potential. Acidic Dykes, primarily composed of light-colored minerals like quartz and feldspar, these dykes are often classified as aplite's or pegmatites. They may contain valuable minerals like tin, columbite, and tantalum. Basic Dykes: Typically composed of darker-colored minerals like pyroxene and amphibole, these dykes are often classified as dolerites or basalts. They may hold potential for construction materials like crushed rock [28].

Solid Waste and Groundwater Contamination

Dumping of solid waste on land is the main frequent waste

techniques of disposal across Nigeria. Groundwater forms an important part of the water resources across the world particularly in the arid regions. It is used for household functions because it is of high value and required slight or no remedy prior to usage. Musa et al, said that bacteria, fungi and further biological contaminants are in nature filtered and attenuated as the water infiltrate or permeate throughout the soil [29]. The lackadaisical administration and/or discarding of harmful substances, fresh groundwater supplies are decreased greatly.

The menace of groundwater contamination by any leachate is resolved by the following factors:

1. **Depth to water table:** If there is low water table (far below the ground surface), water will turn out to be partly filtered as it permeates through the soil downward. Water table that is high (near to the surface), the contaminants can go into the groundwater unswervingly devoid of filtration through the soil.
2. **Concentration of contaminants:** An elevated contaminants concentration in leachate will make groundwater contamination more possible.
3. **Permeability of the geologic strata:** Extremely leaky geologic stratum permit leachate to rapidly infiltrate through, getting slight filtration down the way. Strata consisting of moderately impervious resources for instance silt and clay serves as natural impediment to leachate and consequently inhibits the descending leachate percolation

General Principle of Electrical Resistivity

The resistivity method has its origin in the 1920's due to the work of the Schlumberger brothers. Since then, quantitative interpretation, conventional sounding surveys are normally used. In this method, the centre point of the electrode array remains fixed, but the spacing between the electrodes is increased to obtain more information about the deeper sections of the subsurface. The resistivity method measures the apparent resistivity of the subsurface, including effects of any or all of the following: soil type, bedrock fractures, contaminants, and ground water. A change in electrical resistivity may suggest changes in composition, layer thickness, or pollution levels. The resistivity is useful for detecting lateral and vertical changes in subsurface electrical properties at the same time. According to Gomiz-Ortiz et al., electrical resistivity imaging is a geophysical prospecting technique designed for the investigation of areas of complex geology: this involves measuring a series of resistivity profiles, using a computer to control measurements between selected sets of an electrode array [30]. Since increasing separation between electrodes provides information from increasingly greater depths, the measured apparent resistivity can be processed to provide an image of true resistivity against depth. The principal applications of this technique are found in definition of aquifer boundary units, such as aquitards, bedrock, faults and fractures, the detection of voids in karst regions, the mapping of saltwater intrusions into coastal aquifers, the identification of contaminated groundwater plumes, the detection of mineralized zones, and the exploration of sand and gravel resources among others.

Several standard electrode arrays are available, with different horizontal and vertical resolution, penetration depth and signal-

to-noise ratio. The dipole-dipole array gives good horizontal resolution but may have a poor signal-to-noise ratio because the potential electrodes are outside of the current electrodes. The Wenner array is usually applied for a good vertical resolution, but may also provide a reasonable horizontal resolution. This method has greater signal-to-noise ratio than the dipole-dipole method because the potential electrodes are placed between the two current electrodes. In order to combine the benefits derived from the standard electrode arrays and/or different electrode spacing in some field profiles, both of them could be obtained independently, and then combined in a mixed array that has been jointly inverted and interpreted.

The relevance of electrical surveys is to identify the subsurface resistivity distribution by making measurements on the ground surface. The true resistivity of the subsurface can be quantified from these measurements. The ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock. Electrical resistivity surveys have been used for many decades in hydrogeological, mining and geotechnical investigations. More recently, it has been used for environmental surveys.

The resistivity measurements are normally made by injecting current into the ground through two current electrodes (C1 and C2), and measuring the resulting voltage difference at two potential electrodes (P1 and P2). From the current (I) and voltage (V) values, an apparent resistivity (ρ_a) value is calculated using:

$$\rho_a = k V/I \quad (2.1)$$

where,

k is the geometric factor which depends on the arrangement of the four electrodes. Resistivity meters normally give a resistance value, $R = V/I$, so in practice the apparent resistivity value is calculated by:

$$\rho_a = k R \quad (2.2)$$

The calculated resistivity value is not the true resistivity of the subsurface, but an "apparent" value which is the resistivity of a homogeneous ground which will give the same resistance value for the same electrode arrangement. The relationship between the "apparent" resistivity and the "true" resistivity is a complex relationship. According to Rosqvist et al, an inversion of the measured apparent resistivity values using a computer program must be carried out to determine the true subsurface resistivity [31].

Electrical Resistivity Survey: The idea of resistivity surveying was first marked by Conrad Schlumberger near the beginning of this century by injecting electrical currents into the ground and mapping the resulting potential field distribution as a technique for mapping subsurface geology [32]. Since then, measurement of terrain resistivity has been applied to a variety of geological problems vis-à-vis, determination of rock lithology and bedrock depth, location and mapping of aggregates and clay deposits, mapping groundwater extent and salinity, detecting pollution plumes in groundwater, mapping areas of high ice content in permafrost regions, locating geothermal areas, mapping archaeological sites, Oyedediran and Iroegbeachu [33].

The propagation of electric current in rocks and minerals may be in three ways: electronic (Ohm) conduction, electrolytic conduction and dielectric conduction. Most geologic materials are composed of minerals which are electrically insulators at the temperature some rocks conduct usually encountered in the near surface environment. Typically, electricity only through fluid filled pores and fractures while some are electrically conductive due to high content of magnetic substances.

Electronic conduction is the normal type of current conduction in metallic materials which contain free electrons. In electrolytic conduction, current is carried by ions at comparatively slow rate. Dielectric conduction takes place in poor conductors or in insulators which have very few or no free charge carriers [34].

Review of Previous Work

There exist numerous geophysical researches that have been done by various researchers on landfills and refuse dumpsites. Their outcomes revealed that geophysical methods can be utilized in landfills and refuse dumpsites investigation as a result of its capacity to identify modifications connected to variants in conductivity.

Akankpo and Igboekwe conducted Survey by electrical resistivity scheme in Uyo [35]. Akwa Ibom, Nigeria. The data of five Schlumberger Vertical Electrical Soundings (VES), with a maximum of AB/2=500 m, were analyzed using Hemkler computer program. In general, there exists a common feature in the resistivity variation pattern of high-low-high-low-high in the area. Furthermore, the high amount of resistivity at mechanic village 60700 Ωm perhaps was connected to the waste oil put down because of the vehicle repair activities. Likewise, they clarified that a contrast of the values of resistivity and the types of curves at the dumpsites (Udo and Eka Streets) and other sites illustrate that the two dumpsites had a type H curve representing zones of contamination, whilst other areas had a type K curve representing uncontaminated areas. They concluded that there was a wide range of resistivity variation ranging from 2.0 to 60700 m. Based on the survey results, the resistivity values less than 75 m showed contamination due to waste at Eka street and Udo Street. Also, the high resistivity value at mechanic village (60700 m) may be related to the waste oil deposit due to the automobile repair activities. A comparison of the resistivity values and the curve types at the dumpsites (Eka Street and Udo Street) and other locations show that the two dumpsites have an H curve type indicating contaminated zones, while other locations have a K curve type indicating non contaminated zones.

A resistivity survey of direct current was conducted in Akure South-western Nigeria by Bayode et al. [36]. A direct current electrical resistivity survey using the Schlumberger Vertical Electrical Sounding (VES) and dipole – dipole profiling techniques have been used to map structurally controlled pollution plume around the Otutubiosun dumpsite, Akure, southwestern Nigeria. It was established that the resistivity of topsoil and rate of thickness varied from 5 – 107 Ωm and 0.2 Ωm – 2.7 Ωm correspondingly. The fractured/fresh basement constituted the basement bedrock. The weathered layer and the fractured/faulted zones constituted the major aquifer units in the

study area. Topsoil resistivity and thickness values ranged from 5 – 107 ohm-m and 0.2 – 2.7 m respectively. The weathered layer resistivity values vary from 4 – 35 ohm-m while its thickness ranged from 1.1 – 12.9 m beneath the dumpsite. The depth to the bedrock varied from 2.2 – 13.1 m. The resistivity values of the fractured/fault zones ranged from 2 – 55 ohm-m and the thickness vary from 10 – 30 m. The 2-D resistivity structures showed that zones with relatively low resistivity values (< 35 ohm-m) with a depth range of 1.1 – > 15 m for topsoil, weathered layer and fractured/faulted basement zones were suspected to be due to leachate saturation. Due to the observed relatively shallow water table of 0.5 – 2.0 m around the dumpsites the groundwater around the dumpsites was suspected to have been polluted. This study revealed that subsurface geologic structures within the bedrock (fractures/faults) control the migration of leachate plume around the area investigated.

Ibitola et al., carried out vertical electric sounding in Ibadan, South-western Nigeria [37]. A total of four Vertical Electrical Sounding (VES) stations were established using Schlumberger configuration. Two VES (1 and 2) were carried out on the landfill site at Ajakannga in Oluyolo Local Government, while the other two (VES 3 and 4) were carried out at Aba-Eku in Ona Ara Local Government. The Schlumberger electrode configuration employed for the survey was carried out with measurement beginning with electrode spacing, AB/2, equal to 1m and the maximum electrode spacing, AB/2, of 100m was used for both VES 1 and 2, at each landfill sites. VES 1 and 2 were about 50m from each other at Ajakannga, while VES 3 and 4 were about 75m at Aba-Eku. This showed that an incorporated study of qualitative and quantitative elucidation gave the lithologies of the underground for VES that have top soil (0.5 - 1.0 m) and resistivity varies from 9.2 - 68.3 Ω m, clayey soil (2.0 m - 11.3 m) with resistivity ranges from 2.2 - 12.30 Ω m, lying atop of the novel basement of unidentified thickness of the individual refuse sites. The product of the VES data presents a qualitative clayey and topsoil lithology (aquitarde) that had a low resistivity region < 100 Ohm-m, underlain by extreme resistive basement. They concluded that combining the two explanations acquired from the map of digital elevation and geophysical survey was applied for the founding the health and environmental vulnerabilities linked to passage of groundwater in the underground (saturated and vadose regions) down the two refuse sites. A proper analysis of both interpretations revealed the lithology of the subsurface for VES 2 at Ajakanga dumpsite in Oluyole L.G.A with clayey topsoil (1.0 m), Resistivity 68.3 Ohm-m, clayey soil 11.3 m, resistivity 12.3 Ohm-m, overlying the fresh basement of unknown thickness. The VES 2 of Ajakanga, has its lithology interpreted as clay layer of thickness 2.0 m, with resistivity 17 ohm-m, clayey layer 4.9 m, resistivity 8.7 ohm-m overlying the fresh basement of unknown thickness VES 2 as Aba-Eku has its lithology interpreted as topsoil layer 0.5 m, with resistivity 9.2 ohm-m, clayey layer 0.7 m, resistivity 2.2 Ohm-m weathered layer 0.5 m, resistivity 22.2 ohm-m, overlaying the fresh basement of unknown thickness. Deductively from the VES data, it is observed that the lithologies (vadose zone, top soil and clay soil at the Aba-Eku and Ajakannga are highly contaminated, due to their resistivities which range from 0.5-17.0 which falls within the published resistivities values of solid waste contaminated substrate of 1.5 to 20.2 Ohm-m.

Raman and Sathiyarayanan conducted research on quality assessment of ground water in Pallavpuram municipal solid waste dumpsite in Chennai [38]. Groundwater samples in and around the dumpsites area were studied to assess the impact of municipal solid waste in groundwater resources in the area. Groundwater samples were collected from the different bore holes in and around the dumpsites. The water samples in all five locations had mild to high iron concentration and mild to high acidity. The researcher therefore concluded that the presence of such dumpsites is a potential source of pollution to the groundwater. It showed the effect of the dumpsite on the subsurface layers. From their results, it was obvious that a contaminant leachate plume percolated through the dumpsite and infiltrated the clay beds near the aquifers as the depth of investigation increased. However, the groundwater aquifers were not directly contaminated, but the pollution effect of the plume on other sand aquifers within the subsurface needed to be investigated further by increasing the survey profiles around the dumpsite. Furthermore, the use of the ADMT 200S Digital Terameter which utilized a ground sensor for this study significantly minimized the operational difficulties that would have been encountered if the conventional VES method that involves extensive layout of cables had been employed. This instrument can also be used in a very confined space to implement VES survey as it allows deep penetration of current into subsurface depths without moveable electrodes. Apart from the operational convenience this method offers in contaminant studies, it adds the advantage of producing high resolution results in real time.

Jegede et al. employed survey by electrical resistivity to observe the movement of leachate plumes in the underground at ancient cemetery and Tsamiya refuse dumpsite in Zaria, Nigeria [16]. The resistivity survey was carried out using the ABEM Lund Imaging System, a computer controlled multi-electrode system. The data acquisition was carried out as a number of parallel continuous vertical electrical soundings (CVES). The Wenner- α array was used throughout, employing cables with 5 meters between each electrode take-out, 42 electrodes and the ES464 electrode selector. The electrode spacing ranged from 2.5 m to 5.0 m, profile lengths ranged from 100 m to 200 m. Eight (8) imaging profiles were acquired and interpreted using the Rapid 2-D Resistivity and IP inversion software. Ten months were utilized in studying the movement of plume of leachate in underground for these two areas. They discovered that plume leachate travels quicker in lateral path than vertical bearing. The use of different geophysical techniques for the examination of pollution of groundwater sites is a reasonably latest improvement.

They concluded that the horizontal and vertical extent of leachate plumes was delineated by the geo-electrical imaging as a response to the varying electrical resistivity in the contaminated area. The migration rate of 2.50 m/month and 2.05 m/month, in the lateral direction as well as 0.67 m/month and 0.53 m/month in the vertical direction, in the Old Cemetery and Tsamiya dumpsites, respectively were obtained. The rate of migration was found to depend on the compaction of the soil texture, the presence of loose soil, fractures, depressions, undulations and dipping topography. The rate of migration was higher in the old cemetery dumpsite than in the Tsamiya dumpsite. The rate

of migration in the horizontal direction was higher than that in the vertical direction in both sites by a very significant margin of 1.83 m/month and 1.42 m/month in the old cemetery and Tsamya dumpsites respectively. The vertical motion was impeded by the presence of clay as revealed by the inverted resistivity models with resistivity values in the range of 46.4 to 100 Ωm and 82.0 to 100 Ωm in the old cemetery and Tsamya dumpsites respectively.

Olafisoye et al, investigated groundwater contaminants at Aarada waste disposal site using geophysical and hydro-physicochemical approach [39]. The VES was carried out using Schlumberger electrical array. The Campus Tiger resistivity meter was employed for resistance measurements. A total of seven electrical soundings were established, with maximum half current electrode spacing (AB/2) of 65 m. The field data was interpreted by applying partial curve matching technique with the help of master curves and sets of auxiliary charts. From the preliminary interpretation, initial estimates of the resistivity and thickness of the various geoelectric layers at each VES location were determined. These geoelectric parameters were then employed as starting models for the computer-aided iteration using Resist software. The partial curve matching technique carried out on the seven VES revealed a 3 layered model with H type curve (resistive-conductive-resistive). The result obtained from the interpreted VES data revealed leachate plumes at the subsurface in the study area. The electrical resistivity (Vertical Electrical Sounding) method was used to investigate the contamination level and extent in the study area. The analysis of the VES survey revealed that leachate spread out in all direction originating from the part of the refuse dumps with older wastes deposit polluting the nearby hand dug wells it comes in contact with to a distance less than 10m from the waste body. The geo-electric sections of the interpreted VES data delineated the leachate extent to a maximum depth of 5.4 m in the subsurface.

Rafiu and Mallam investigated the impact of a waste disposal site on soil and groundwater in Dusten-Kura Gwari, Minna, Niger state, Nigeria [40]. Twenty Vertical Electrical Sounding were carried out along two profiles inside the dump comprising sixteen VES and another four outside the dump to serve as control. Twenty VES points were measured using Schlumberger array with the aid of ABEM Terrameter SAS 4000 and its accessories. A maximum current electrode separation of AB/2 of 80 m was used in this study. The apparent resistivity from the survey was processed by a computer software program called Winresist. The resistivity values for all VES in the dump had low resistivity (25.6 Ωm - 85.1 Ωm), while that of control sit ranged between (190.9 Ωm – 233.6 Ωm). The result of well water and soil within the study area showed elevation in some of the parameters analysed which made the water unsafe for drinking. Vertical The VES delineated three to five geologic layers which infer geologic units. The fractured/fault zones constitute the major aquifer units. Which host groundwater and leachate. The migration of the leachate is being controlled by the fractured/fault zones, thus polluting the groundwater around the refuse dump. The concentrations of heavy metals were found to be higher at the centre of the dump and decrease slightly at a distance of 10 m to 60 m down slope.

George et al., worked on Integrated Approach to Investigate the effect of Leachate on Groundwater around the Ikot Ekpene

Dumpsite in Akwa Ibom State, Southeastern Nigeria [41]. The hydro-chemical results of some species conform to WHO standards, while some were found to be relatively higher due to dissolution, leaching, and draining of leachate related contaminants in the soil. The correlation indices of the ion pairs showed no significant effect on the paired ions, indicating that the significant value of some of the individual ions was not geologic but due to precipitation from the leachate residue. In general, the effect of leachate was more dominant in the immediate groundwater pathway near the dumpsite than aquifer repositories away from it. The cross plots of the water resistivity and bulk resistivity show exponential increase for the different layers. The result showed on the average transitions of resistivity variations from resistive zone to conductive zone. The resistivity increases diagonally downward from Agric. Secretariat (closed to dumpsite) to the Local Gov't Area Secretariat (away from dumpsite). Similarly, conductivity increases diagonally from the deeper layer of VES at the Local Gov't Area Secretariat to the surficial layer at the Agric. Secretariat. The observation in this profile explained the effect of massive percolation of tissue fluid (leachate) into the subsurface within the dumpsite environment. The borehole water at Agric. Secretariat appeared to be influenced by fluid emanated from garbage dumped in the dumpsite. The distribution of the bulk and fluid conductivities as changes from place to place and within the depths penetrated in the profile.

Rafiu and Mallam carried out investigation of solid waste disposal site and its relationships with groundwater in Angwan Jukpa, Minna, Niger state, Nigeria [42]. The result of the interpreted North central Nigeria was carried using Schlumberger array of Vertical Electrical Sound Thirty VES were collected at the site, twenty were collected during the dry season along three profile, two of the profiles were drawn inside the waste dump comprising of sixteen (16) VES, eight (8) on each of the profile while four (4) VES points were carried out at a distance of about 300 metres away from the waste dump to serve as control. Ten (10) VES points were also collected during the wet season, eight (8) on the waste dump and another two at a distance not less than 300 metres away from the waste dump. The VES data were interpreted curves delineated three to five layers. The area with low resistivity values were delineated as contaminated zone.

Rafiu and Mallam carried out vertical electrical resistivity evaluation at solid waste disposal site, Dusten kura, Minna, Niger state [43]. An ABEM Terrameter SAS4000 and its accessories were employed to carry out a total of twenty (20) Vertical Electrical Soundings (VES using Schlumberger array with maximum current electrode separation of AB/2 of 80 m. Sixteen (16) VES were carried at the edges of refuse disposal site along two profiles and another four (4) at a distance of 200 m away from the refuse dump to serve as the control. The results of interpretation of VES data show three subsurface layers: the topsoil, weathered layer and the fractured/fresh basement rock. The topsoil resistivity and thickness values range from (22.2-50 Ωm) and (1-6 m) respectively. VES point 5 in profile A and VES point 5 and 7 in profile B are more prone to contamination, thus groundwater at these points is not fit for consumption. Interpretation of geo-electric soundings of refuse dump yielded information on groundwater pollution as shown

by the curve types, measured resistivity values. The results reveal that the quality of groundwater at this site was affected as a result of domestic dumping. Therefore, combination of vertical electrical soundings is a vital tool for investigating groundwater pollution.

Rafiu and Mallam carried out research on detection of leachate plumes migration using vertical electrical sounding method at Kpangungun, Minna, Niger state, Nigeria [44]. The result revealed second and third layers to be mainly clayey sand and lateritic soils of low resistivity values which varied with distance; an indication of leachate migration. The interpretation of electrical resistivity models revealed regions of very low resistivity (14.8 -25.3 Ωm) to be from an average depth of 4.5 m to an average depth of 17.8 m for profile A; and to a maximum depth of 11.3 m for profile B. These regions of very low resistivity could be contamination zones of the subsurface beneath the profiles resulting from leachate seeping into the soil and or groundwater from the waste dump. The result of the heavy metal determination revealed that concentration of heavy metals (water sample collected from hand dug well and soil sample collected at the waste dump site) was more than that of profile C (water sample collected from hand dug well away from the waste dump site). In terms of WHO, guideline for drinking water quality, Lead, Chromium and Cadmium were above the guideline values in both water samples [45].

Rafiu and Mallam worked on investigation of contamination plumes at mechanic road, Bosso waste disposal site using geophysical approach [46]. The results from the sounding data indicated that the area was generally underlain by three to four geoelectric sections which included top soil, Sandy clay, weathered basement, and Fresh basement. Based on the result obtained, the fractured and the weathered basement formed the aquiferous zone within the study area. The resistivities of these zones vary from 12.7 to 475.2 Ωm , while the thickness varied from 0.9 to 7.8 m. Depth to this zone varies from 0.9 to 8.6 m. The result of water analysed in this area is found to be contaminated by Lead, Chromium and Cadmium with level of contamination exceeding WHO regulated guidelines.

Omale et al, conducted the appraisal of leachate contamination of groundwater at three most important refuse dumping sites in Minna (Barkin-Sale, FM and Albishiri) [47]. The geo-electrical technique (induced polarization and vertical electrical sounding) and physical chemical analysis of sampled water were used for measuring the leachate contamination of the resources underground. There were 18 IP and VES locations at Albishiri, 18 IP and VES locations at Barkin-Sale and 350 IP and VES locations at FM sites correspondingly. The outcome illustrated that the region was in general, underlain by three patterns of geology (top soil (laterite), fractured/weathered basement and novel basement) matching the geo-electric prototypes. Conversely, wherever the basement had witnessed intense fracturing which led to the basement rocks weathering, five- and four-layer prototypes were achieved. Leachate plume discharge and contamination was at changeable depth and moisture content. The degree of contamination by leachate at the research region was put at 0.3 m, 0.6 m and 0.7 m for each year for the Barkin-Sale, FM and Albishiri sites in that order.

Ganiyu et al, worked on assessment of groundwater contamination around active dumpsite in Ibadan southwestern Nigeria using integrated electrical resistivity and hydro-chemical methods [48]. Two-dimensional (2D) electrical resistivity survey was carried out within the dumpsite using Campus Tigre Terameter. Nine traverses were mapped out within the dumpsite and a control traverse at about 500 m away from the refuse dumpsite using the Wenner array configuration. The electrode separation distance for each traverse ranged from $a = 5 - 30$ m with a station interval of 5 m. The Wenner electrode array had one current electrode (C1) followed by two potential electrodes, (P1 and P2) and ends with second current electrode (C2). The current and potential electrodes were maintained at a regular fixed distance from each other (starting at $a = 5$ m) and were progressively moved along the traverse line. The geometric factor (K) for the Wenner array equals $2\pi a$. Measurements commenced at one end of the traverse line with electrode spacing $a = 5$ m at electrode positions 1, 2, 3 and 4. Each electrode (C1, P1, P2 and C2) was shifted a distance of 5 m, the active electrode positions being 2, 3, 4 and 5. The resistivity inverse model of traverse 1 showed continuous spread of leachate plume from horizontal distance of 8–82 m in the north – south direction with resistivity values below 10 X m, an indication of leachate plume accumulation up to 12 m depth below the surface and probably may have reached the water table due to weathered basement below the basin shaped leachate plume. The leachate migration on this traverse originated from the northern end of the traverse where it extended to the surface. The resistivity values throughout the traverse section were mostly less than 100 X m. The result also showed inverse model section for traverse 3, wherein low resistivity anomalies below 10 X m, an indication of leachate plume migration occur at horizontal distances 10–35 and 41–85 m along the traverse. Following this plume was weathered zone at depth 12–15 m with resistivity values ranging from 17 to 132 X m indicating that the deeper layers were prone to groundwater contamination as dumpsite ages. Relatively high resistivity anomaly of resistivity values 17–79 X m to a depth of about 5 m occurs close to the surface suggesting presence of clayey sand mixed with non-degradable waste material. The integrated approach of electrical imaging methods investigation was employed to investigate groundwater contamination around Ajakanga dumpsite. The integrated methods led to a better understanding of the site than could have been achieved with the use of a single investigative method. The interpretation of 2D resistivity models of traverses within Ajakanga dumpsite showed low resistive zones with true resistivity values less than 20 X m as indicative of leachate plume and 15.9 m as maximum depth of investigation.

Agbalagba and Osimobi carried out Geophysical Investigation of Groundwater Contamination levels in Obiaruku Waste Dumpsite Using Vertical Electrical Sounding Method [49]. The materials used for data acquisition included, Terameter (SAS 1000), which is the main instrument used to send current into the ground so as to measure the resistance of the soil strata, electrodes, wire cables, sledge hammer, measuring tapes, cutlass for clearing and battery for powering the Terameter. The Vertical electrical sounding technique using the Schlumberger array approach was adopted for this investigation. The interpreted data showed that four geoelectric layers underlie the study area. The vertical

electrical sounding curves showed AA, HK, AH, AA and HA types for VES I to VES V respectively. The average resistivity values obtained ranged from 234 Ωm to 3475.1 Ωm for VES I; 229.2 Ωm to 8817.2 Ωm for VES II; 1514.3 Ωm to 3864.8 Ωm for VES III; 115.6 Ωm to 3864.8 Ωm for VES IV; 36.8 Ωm to 3101.1 Ωm for VES V. Locations 3 was analyzed to have the be best aquifer where boreholes could be sited with aquifer thickness of 22.5 m, though the close proximity to the dump site call for further investigation. It was observed from the result that VES II (on the dumpsite) had a relatively low resistivity at the top of the soil profile, thus pollutants could emerge from the landfill top and migrate downwards to contaminate the water table. The results obtained indicate that the leachates from the dump sites have increased the conductivity of the soil, thereby lowering the resistivity. Considering the implications of this groundwater source contamination and the health implications on the populace, recommendations were made.

Shehu et al, carried out Geoelectrical investigation for groundwater potential and aquifer protective capacity of overburden units at unions Site, Gidan-kwano campus, federal university of technology, Minna, North Central, Nigeria [50]. The interpretation revealed three distinct geologic layers. These include topsoil with resistivity values ranged between 11.41 and 1009 ohm-m and the thickness was relatively thin and ranged between 1 and 6m. The weathered/fractured layer had resistivity values from 11 to 963 ohm-m with thickness varied from 1 to 45 m indicating high degree of weathered/fracture and/or water saturation, The fresh basement had resistivity values that ranged between 12 and 2983 ohm-m. All the sounding points were characterized by A, H and Q curve types. The area was categorized into high, medium and low groundwater potential zones. Twenty-five (25) VES points were delineated as ground water zones having weathered/fractured resistivity values between 100 and 963 Ωm and thickness ranging from 5 – 45 m. The characteristic longitudinal unit conductance ranged from 0.01 to 1.84 m and about 70 % of the VES points fell within the poor rating, suggesting a generally poor overburden protective capacity around the study area.

Yusuf et al, carried out an Investigation of groundwater quality and soil cultivation viability using geophysical and geochemical Approach at a dumpsite in Mokwa, Niger State, Nigeria [51]. Electrical Profiling (EP) method for horizontal or lateral variations of resistivity at the farm site. In the Wenner array configuration, the spacing between successive electrodes (a) remained constant and all electrodes were moved for each reading. The four electrodes were collinear and the separations between adjacent electrodes were equal (a) with MN in between AB. The choice of this electrode spacing was primarily based on the depth of the anomalous resistivity features (high crop yielding and farm infrastructural viable locations) to be mapped. ABEM Terrameter SAS 4000 was used for Vertical Electrical Soundings (VES). The study location comprised six profiles within the dumpsite and two other profiles outside the dumpsite. Forty VES points were established, thirty points within the dumpsite and another ten points in another location outside the dumpsite to serve as control. The resistance values displayed by the terameter were recorded on recording sheets and later used

to compute apparent resistivity. The results obtained showed that the fractured and the weathered basement constitute the aquifer zones within the study location. These zones were characterized by dominant low resistivity zones <75 Ωm due to the delineated leachate invasions up to the depth of 20 m which indicate very poor soil and groundwater quality. The research was developed as a spatial decision Support System and an aid to support decision making. Geo-electrical imaging was very useful in mapping resistivity variations at Masallachi Idi dumpsite. Leachate was inferred from the inverse model sections as well as the VES data. The results revealed leachate migration into the subsurface as well as its ingress into the surrounding soils and groundwater up to the depth of 20 m. Three dominant geologic features (claystones, sandstones and conglomerates) were delineated at various locations among others like; weathered basement, fresh basement, fractured and aquifer zones.

Temitope et al. conducted a geophysical investigation of groundwater pollution at Ikoto and Oru dumpsites in Ogun State, Nigeria [52]. They used an electrical resistivity survey to detect the level of pollution and the conductivity of underground layers. The survey involved passing a known electrical current through the ground through current electrodes, measuring the potential of the electrical field, and calculating the apparent resistivity. The Vertical Electrical Sounding (VES) data were acquired using the ABEM Terameter, with four electrodes arranged using the Schlumberger configuration array. The data was interpreted using WINRESIST to identify the curve types of each study area. On Oru dumpsite, leachate pollution was observed in VES1 and VES2, while VES3 and VES4 were leachate-free. On Ikoto dumpsite, leachate pollution was observed in VES4 (layer 2), while VES1, VES2, and VES3 had no leachate flow. The study highlighted the need for better monitoring and management of groundwater pollution in Nigeria. The leachate present in VES4 could infiltrate into the groundwater table through the highly porous and permeable material in the subsurface layer of the location. They concluded that Electrical Resistivity Method using Vertical Electrical Sounding (VES) successfully delineated subsurface stratigraphy as preliminary investigations to underground water contamination through leachate migration in Oru and Ikoto, Ogun State, southwestern Nigeria. Oru dumpsite consisted of topsoil, sand, dry sand, clay, weathered layer, and fresh basement, indicating that the dumpsite was located on weathered layer. Other locations around the dumpsite were located on fresh basement. Low resistivity values of VES1 and VES2 revealed the presence of subsurface leachate pollution on the dumpsite, while the high resistivity values of VES3 and VES4 compared to VES1 and VES2 implied absence of pollutants as these areas were less porous and impermeable due to their stratigraphy (strong overburden layer). The survey further revealed that the dumpsite in Ikoto consist of topsoil, sand, Sandstone, weathered layer, fractured layer, indicating that the dumpsite was located on fractured layer. The low resistivity values in VES4 revealed the presence of the leachate pollution on the dumpsite which could directly penetrate into the subsurface water due to high porosity and permeability of the under lying layers (Aquiferous). On the other hand, other locations around the dumpsite are located on weathered layer and sandstone. The resistivity values of VES1, VES2 and VES3 were regularly

increased compared to VES4, this implied absence of pollution but may be present with time due to the stratigraphy of the study area.

Alkali et al, carried out geoelectrical investigation of groundwater potential, at bosso campus, Minna, Niger State, Nigeria [53]. The sounding interpretation results were used to generate geoelectric section. The corresponding geologic sections were also generated which revealed the existence of three subsurface layers. These layers comprised the top soil, weathered/fractured basement and fresh basement. The results showed that the area is generally unsuitable for borehole drilling due to the absence of adequate aquifers and the dominance of highly resistive fresh basement rock. These findings underscored the need for detailed subsurface evaluations before groundwater resource development in the area to avoid unproductive drilling. The results of this analysis were presented as curves of apparent resistivity versus depth, from the digitalized curves obtained from the IP2WIN software, Sulfer 11 was used to generate iso-resistivity map at different depth. The analysis of results showed that the area is not appropriate for borehole drilling.

Nwakwo and Udo worked on Investigation of groundwater aquifer contamination due to leachate intrusion using a high-resolution real-time resistivity technique at a dumpsite around the university of Port-Harcourt environs, Choba, Rivers State, South-South, Nigeria [54]. The result revealed groundwater aquifers at depths of 40-70 m and 100 m, capped at the top and bottom by clay beds. These were zones of lower conductivities (higher resistivities) ranging from 10.3 mS/m to 11.1 mS/m at the 40-70 m depth zone and 11.1 -11.5 mS/m at the 100 m depth. A higher conductivity (lower resistivity) that permeated the subsurface layers from the topsoil through the different lithologic layers down to the depth of about 190m occurred within the subsurface. This conductivity pattern represented a deviation from normal conductivities for an uncontaminated lithology. It showed the effect of the dumpsite on the subsurface layers. The results obtained clearly showed that a contaminant leachate plume percolated through the dumpsite and infiltrated the clay beds without a direct contamination of the delineated aquifers. Although the identified groundwater aquifers were not directly contaminated, the pollution effect of the plume on other sand aquifers within the subsurface around the dumpsite may need to be further investigated. Using the ADMT 200S Digital Terameter and a ground sensor, real time 2D/3D resistivity maps were obtained. The results obtained showed a high conductivity pattern that permeated the subsurface layers from the topsoil through the different lithologic layers down to the depth of about 190 m, revealing the migration of a leachate plume through the subsurface beds, although the groundwater sand aquifers present at depths of 40-70 m and 100 m were not directly contaminated. They also demonstrated that the VES resistivity technique employed in the study was one that provided operational convenience during field work in addition to the advantage of producing high resolution results in real time.

Coker et al., carried out investigation of groundwater contamination from Akanran open waste dumpsite, Ibadan, south-western Nigeria, using geoelectrical and geochemical

techniques [55]. The results of soil analysis show that clay ranges between 9.61 - 18.8 %, silt between 9.27 – 19.7 % and an average bulk density of 1.48 (relatively high for a sandy loam) which suggests that infiltration of the leachate was minimal. The pH of the water sample analysis obtained was 6.9, suggesting acidic concentrates in the groundwater of the study area. However, this pH value for drinking water was within the permissible level of 6.5 – 8.5 indicating that the groundwater in the study area was suitable for drinking and also for other purposes. A Nitrate level of 2.56 mg/l in the water sample fell within 50.0 mg/l, and nitrite level of 0.09 mg/l which was moderate when compared to the permissible level limit of 0.20 mg/l. The concentration of heavy metals in a hand-dug well sample from Akanran dumpsite were Zn (1.81 mg/l), Cu (0.38 mg/l), Cr (0.003 mg/l) which were within the permissible level limit and Pb (0.21 mg/l) which recorded high metal concentration which may suggest that the dumpsite contain waste metals which may leach down the soil. In conclusion, the groundwater in the area of the survey was safe for drinking, domestic purpose and agricultural use; and there were high toxicity level and possible leaching of lead.

Alao et al, worked on investigation of groundwater vulnerability to open dumpsites and its potential risk using electrical resistivity and water analysis [56]. The electrical Resistivity Technique was adopted for acquiring geophysical field data using the Schlumberger array. A total of twenty-nine (29) VES points were investigated within the dumpsite with $(AB/2) = 70$ m maximum spread. Minimum of four electrodes was used for Schlumberger configuration during the field data acquisition. An Ohm-mega Ω resistivity Meter was used to acquire geophysical field data within the dumpsite. The subsoil depth profile of three to five geological layers was observed. A total of seventeen (17) VES points taken along West–East azimuth was examined. The first layer (topsoil) resistivity was highly variable ranging from 4.8 Ω m to 611 Ω m. The VES points (A5 – A13) located within the dumpsite were marred with low resistivity values, which indicate high electrical conductivity, while the VES points (A1 - A5 and A14 – A17) located off the dumpsite were characterized by high subsurface resistivity values. That is; the dumpsite subsurface was highly conductive (low tolerance), while the off-dumpsite was highly resistive which implied that the groundwater systems and the subsoil are heavily impacted by the dumpsite leachates noted that the dumpsite leachates released into the environment hardly remain at the surface, but seeped down the soil to the water-bearing unit. The weathered unit resistivity values were found to be within the range of 2.9 Ω m – 19 Ω m, while fractured unit resistivity varies between 67 Ω m and 444 Ω m, which grossly contradicted the ambient resistivity values.

Materials and Methods

Materials

The materials that were used for this research are

1. ABEM SAS 4000 Terrameter
2. Reel Cables
3. Electrodes
4. Pegs
5. Hammer
6. Masking tape

Wenner Array

This is a robust array that was popularized by the pioneering work carried by the university of Birmingham research group. Many of the early 2-D surveys were carried out with this array. Because of its sensitivity horizontally, the Wenner array is relatively used for vertical changes in the subsurface resistivity below the centre of the array. However, it is less sensitive to horizontal changes in the subsurface resistivity. In general, the array is good in resolving vertical changes (horizontal structures), but relatively poor in detecting horizontal changes (narrow vertical structures). 2D survey measures the resistivity changes both in vertical direction, as well as in the horizontal direction along a common survey line at the same time [57]. 2D electrical imaging doesn't only give more accurate results and save time, it is also cost effective. 2-D imaging survey involves about 100 to 1000 measurements.

Schlumberger

The Electrical resistivity method is widely used in the study of lateral and vertical variations in conductivities of the subsurface layer and also in the direction of 2-dimensional bodies of anomalous electrical conductivity, Oyelami et al., [58]. The application of this method of geophysical prospecting involves the measurement of potential difference across two measuring electrodes when current flows through the subsurface between two current electrodes on a generalized four electrode system of various configurations. The potential created can be from natural earth field or created artificial by passing a dc electric current in the ground. Natural potentials are associated with oxidizing sulphide ores, corrosion of metals, water of different chemical composition in contact through pores and any other electrochemical sources, Cristina et al., [59]. The electrical resistivity method employs the use of artificial potential that drops across two potential electrodes system in determining the resistivity of the subsurface formation. The resistivity of a material can be defined as the resistance of conducting cylinder with a cross section of unit area (A) and with a length (L)

$$\rho \propto A/L \quad (3.1)$$

$$\rho = RA/L \quad (3.2)$$

where

R = electrical resistance, ρ = resistivity in ohm-meters. The electrical property of natural earth material particularly its resistivity varies and it is governed solely by their content (water). The resistivity of rock is therefore a function of porosity and chemical properties of the water filling the pore spaces rather than the conductivity of the mineral grains that the rock itself is recomposed. Thus, massive rocks such as granites are poor conductors (unless they are fractured) while gravels and clean sands have a relatively lower resistivity if filled with water and sands saturated with saline water have lowest resistivity [60].

There are several methods of geophysical survey but the electrode configuration used for this project is the Schlumberger array. This makes use of four electrodes. Here, measurement of apparent resistivity is made by keeping the potential electrodes fixed about the mid-point of the array while the current electrodes are systematically spaced in opposite directions, [61]. As a result of its simplicity in interpretation and poor sensitivity to lateral variation of resistivity, it is used for Vertical Electrical Sounding (VES).

Methods of Investigation

The methods of investigation that were used for the purpose of this research are Wenner (Horizontal profiling method 2-D) and Schlumberger (Vertical Electrical Sounding). The Horizontal profiling method is used to study the lateral variation in resistivity of an area. Constant separation traversing (CST). The principle of horizontal profiling is based on the fact that the subsurface is inhomogeneous and that electrical properties vary from one place to another over an area thus, the lateral variation can be studied. The resistivity measurement is carried out by the use of collinear four electrode array configuration in which the entire electrode array is moved after taking measurement to successive stations, Abiola et al., [62]. The depth of investigation in resistivity surveying is proportional to electrode spacing. The choice of electrode array and spacing is often based on consideration of the ease of measurement and time, depth of investigation and the sensitivity to lateral variations and anomaly resolution).

Field procedure

Schlumberger Array: The field work was carried out at Engr AA Kure Market, Minna. Schlumberger array was used in the study area using a current electrode separation (AB) of 60 metres located on four profiles (A, B, C and E) VES with one point on each profile. Direct current was introduced into the ground and the resulting potential difference was measured across two electrodes. The ratio of the potential difference was displayed by the terrameter as a resistance and electrode spacing was increasing noting the centre point of the electrode array fixed. The software used to generate VES graph curves is WINRESIST

Wenner Array: The Wenner method was also used in the field, four electrodes were set up in a straight line with evenly spaced intervals (C1, P1, P2, C2), were connected cables to a resistivity meter, take resistance readings for each electrode spacing, record data, repeat measurements for accuracy, and calculate apparent resistivity using the formula $\rho_a = 2\pi aR$ to determine soil resistivity and layering. The software used is called DIPROWIN and SUFFER.

The apparent resistivity values were evaluated by multiplying the resistances with the corresponding geometric factors, k.

Soil Corrosiveness

Soil corrosiveness refers to the capacity of soil to cause deterioration in materials, particularly metals, buried underground. This property is influenced by various factors, including soil resistivity, moisture content, pH levels, chloride and sulfate concentrations, and organic matter content. Soils with low resistivity, typically below 100 Ωm , are considered highly corrosive because they facilitate the flow of electrical currents, which accelerate electrochemical reactions such as rusting. On the other hand, soils with high resistivity are less likely to cause corrosion. The pH level of the soil also plays a critical role, with highly acidic or alkaline soils being more corrosive. Chlorides and sulfates further exacerbate corrosiveness by promoting the breakdown of protective oxide layers on metal surfaces [63].

Corrosive soils can significantly impact infrastructure, such as pipelines, storage tanks, and foundations, as well as

groundwater quality by interacting with pollutants in the soil. Electrical resistivity surveys are commonly used to assess soil corrosiveness, as they provide a reliable method for understanding the soil's ability to conduct electrical currents and its potential to cause corrosion.

Table 1: Resistivity Range and Corrosiveness [64]

Resistivity Range	Corrosiveness
<100 Ωm	Highly corrosive
100–250 Ωm	Moderately corrosive
250–500 Ωm	Slightly corrosive
>500 Ωm	Low corrosiveness (non-corrosive)

Aquifer Protective Capacity

Aquifer protective capacity refers to the ability of overlying soil and rock layers to prevent contaminants from reaching the aquifer. It is an essential hydrogeological parameter, particularly in assessing groundwater vulnerability in areas with potential sources of pollution, such as waste dumpsites. The protective capacity of an aquifer is influenced by the thickness and resistivity of overburden layers. Higher resistivity and thicker layers generally provide better protection, while low resistivity values indicate a higher risk of contamination due to increased permeability and reduced barrier potential. (Henriet, 1976). According to Henriet, the resistance [65]

$$R = \sum_{i=1}^n \frac{\rho_i}{h_i} \quad (3.3)$$

Where ρ_i is resistivity of the layer (Ω-m)
 h_i is the thickness of the layer (m)

Since conductance (S) is the reciprocal of the resistance

$$S = \frac{1}{R} = \sum_{i=1}^n \frac{h_i}{\rho_i} \quad (3.4)$$

Where:

S= Longitudinal conductance (mho)

ρ_i = Thickness of the layer (m)

h_i = Resistivity of the layer (Ω -m)

Table 2: Protective capacity and Longitudinal Conductance [62]

Protective Capacity	Longitudinal Conductance (mho)
Poor	< 0.1
Weak	0.1– 0.19
Moderate	0.2–0.69
Good	0.7–4.9
Very Good	5.0–10.0
Excellent	> 10.0

The longitudinal conductance (S) is often used as an index to assess aquifer protective capacity. It is calculated using the formula:

Protective Capacity (P)

$$S = h_i / \rho_i \quad (3.5)$$

But commonly expressed for multi-layers earth as:

$$S = \frac{1}{R} = \sum_{i=1}^n \frac{h_i}{\rho_i} \quad (3.6)$$

where, h_i = thickness of the layer (in meters)

ρ_i = resistivity of the layer (in ohm-meters)

s = longitudinal conductance, which is used as a proxy for protective capacity

Result and Discussion

Geoelectrical Section

The Geoelectrical section (VES curve) as shown in Figure 3.1, provides information about the subsurface layer resistivity, depth and thickness as well as curve type of the investigated site and are tabulated in table 3.1 while remaining curves presented in appendices.

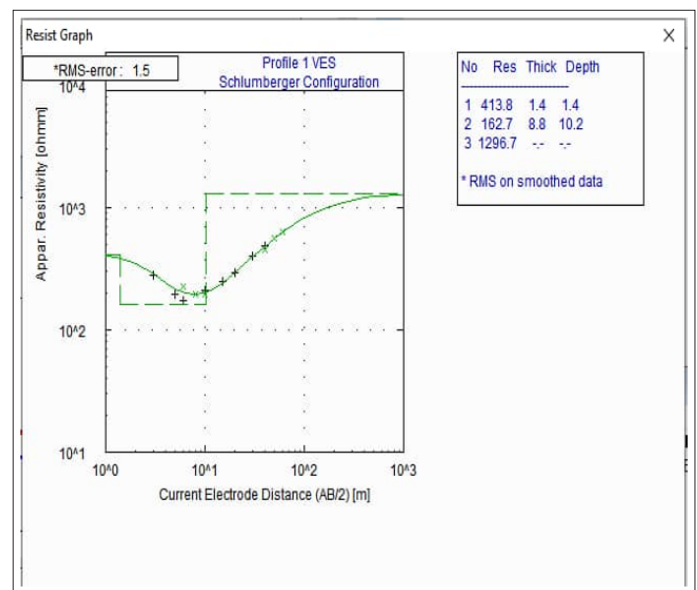


Figure 3.1: Geoelectrical section of VES Profile 3

Table 3.1 shows the results obtained from each geoelectric section across profiles 1 to 4 which revealed that the investigated site is underlain by three (3) to four (4) geoelectric subsurface layers. The top layer has resistivity value ranging from 251.2 to 481.0 Ωm, its depth and thickness ranges from 0.7 to 1.7 m and 0.7 to 1.7 m respectively which corresponds to the geoelectrical parameters of fadama mud, weathered laterite and fresh laterite. The second subsurface layer has resistivity value of 88.9 to 162.7 Ωm, its depth and thickness ranges from 3.0 to 10.8 m and 2.3 to 9.8 m respectively. The third layer resistivity is from 193.6 to 1296.7 Ωm; its depth and thickness are undefined. Low resistivity values (e.g., 96.1 Ω, 88.9 Ω) indicate conductive contaminants, while thin layers with high resistivity values (e.g., 251.2 Ω, 481 Ω) represent less conductive materials. Thick layers with low resistivity values (e.g., 342.8 m, 2635.3 m) indicate contaminant plumes. The HA curve type suggests layered structures with high-resistivity layers overlying low-resistivity layers, potentially indicating contaminant layers. The contamination risk appears to be moderate to high, particularly at stations 1, 3, and 4. The low resistivity values (96.1 Ω, 88.9 Ω) and thick layers (342.8 m, 2635.3 m) suggest the presence of conductive contaminants, potentially indicating a contaminant plume.

Table 3.1: Resistivity, depth, thickness of the layers and curve type

VES	Longitude	latitude	No. of	Layer Resistivity,				Layer Depth,			Layer Thickness		
Station	(0)	(0)	Layers	ρ (Ω)				(m)			(m)		
				ρ^1	ρ^2	ρ^3	ρ^4	d_1	d_2	d_3	h_1	h_2	h_3
1	6.3259 E	9.325 N	4	251.2	96.1	193.6	1303.5	0.7	3	7.5	0.7	2.3	4.5
2	6.3140 E	9.3715 N	3	481	130.3	2635.3	∞	1.7	5.9	∞	1.7	4.2	∞
3	6.3144 E	9.3710 N	3	413.8	162.7	1296.7	∞	1.4	10.2	∞	1.4	9.8	∞
4	6.3142 E	9.3742 N	4	305.6	88.9	342.8	1531.1	0.7	3.2	10.8	0.7	2.5	7.5

Soil Corrosiveness and Aquifer Protective Capacity

Soil Corrosiveness is generally inversely related to resistivity, low resistivity implies high corrosiveness, while high resistivity implies low corrosiveness. Table 3.2 shows the computed soil corrosiveness from the data.

Table 3.2: Soil Corrosiveness Level and Aquifer Protective Capacity

Profile	Layers	Resistivity (Ω m)	Soil Corrosiveness Level	Aquifer Protective Capacity
1	1	251.2	Slightly Corrosive	Moderate
	2	96.1	Highly Corrosive	Low
	3	193.6	Moderately Corrosive	Moderate
	4	1303.5	Slightly to non-corrosive	High
2	1	481	Slightly to non-corrosive	High
	2	130.3	Moderately Corrosive	Moderate
	3	2635.3	Low Corrosiveness (Non-Corrosive)	Very High
3	1	413.8	Slightly Corrosive	Moderate
	2	162.7	Moderately Corrosive	Low
	3	1296.7	Slightly to non-corrosive	High
4	1	305.6	Slightly Corrosive	Moderate
	2	88.9	Highly Corrosive	Low
	3	342.8	Slightly to non-corrosive	High
	4	1531.1	Low Corrosiveness (Non-Corrosive)	Very High

Table 3.2 summarizes the soil corrosiveness levels of four profiles based on their resistivity values. In Profile 1, the top layer is slightly corrosive with moderate aquifer protection, while the second layer is highly corrosive, offering low protection. The third layer is moderately corrosive with moderate protection, and the fourth layer is slightly to non-corrosive with high protection. In Profile 2, the first layer is slightly to non-corrosive with high protection, the second is moderately corrosive with moderate protection, and the third layer is non-corrosive, providing very high protection, Odewumi et al [66]. Profile 3 follows a similar trend, with the first layer being slightly corrosive and moderately protective, the second being moderately corrosive with low protection, and the third being slightly to non-corrosive with high protection. Lastly, in Profile 4, the top layer is slightly corrosive with moderate protection, the second is highly corrosive with low protection, the third is slightly to non-corrosive with high protection, and the fourth layer offers very high protection due to its low corrosiveness [67]. This variation highlights the influence

of resistivity on groundwater vulnerability to contamination. This analysis suggests that Stations 1 and 4 are more prone to corrosion compared to Profile 2 and 3.

Longitudinal Conductance and Aquifer Protective Capacity

The longitudinal conductance (S) values for all the VES stations as computed for equation 3.4 are less than 0.1 mho, which indicates poor aquifer protective capacity. This suggests that the aquifer is highly vulnerable to contamination from surface or near-surface sources [68].

Table 3.3: Longitudinal Conductance and Aquifer Protective Capacity

VES Station	Longitudinal Conductance (mho)	Protective Capacity Classification
1	0.04997	Poor

2	0.03578	Poor
3	0.06363	Poor
4	0.05229	Poor

Geological Cross-section of Profile 1

The section shows four distinct layers which are characterized as Top Soil (0-37 m), this layer is characterized by a low resistivity value of 251 Ohm-meter. Low resistivity typically indicates the presence of water-saturated materials like clay or silt.

Weathered Layer (0.37 – 3.0 m), this layer has a resistivity of 96.1 Ohm-meter, which is slightly lower than the top soil. It likely represents a zone of partially decomposed bedrock or soil mixed with weathered rock fragments.

Weathered/fractured Basement (3.0 – 7.5 m) this layer shows a higher resistivity of 194 Ohm-meter. This increase in resistivity suggests a decrease in water content and an increase in the proportion of solid rock material.

Fresh Basement (7.5 - 12 m) the final layer exhibits a very high resistivity of 1303 Ohm-meter. This indicates a zone of fresh, unaltered bedrock with minimal water content.

The resistivity values indicate a progression of contamination. The second layer 96.1 Ω m is classified as highly corrosive, signifying severe contamination due to the leachate infiltration, likely caused by the waste dump. The first layer 251.2 Ω m is slightly corrosive, showing moderate interaction with contaminants, while the third layer 193.6 Ω m is moderately corrosive, reflecting gradual attenuation of pollutants. The fourth layer 1303.5 Ω m, with its high resistivity, indicates non-corrosive conditions, suggesting minimal contamination at greater depths.

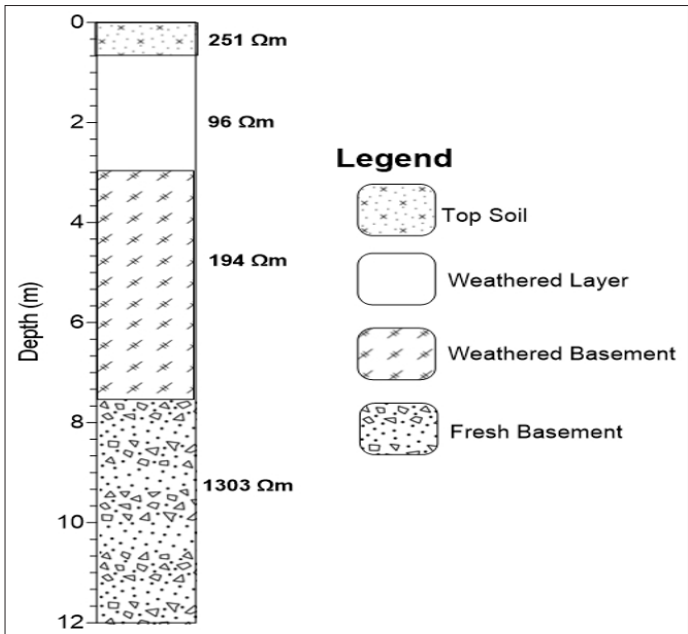


Figure 3.2: Resistivity log of Profile 1

Pseudo-sections and 2-D Resistivity Profile 1: The Field Data Pseudo-section shows the raw apparent resistivity measurements

collected from the ground using an electrode array, where variations in resistivity (color-coded) reveal initial subsurface heterogeneities.

The theoretical data Pseudo-section represents a model-generated pseudo-section derived from inversion or forward modeling, used to match and validate the field data for accuracy and consistency, highlighting areas where the model fits or diverges from the real measurements.

2-D Resistivity Structure: This section provides a clearer subsurface resistivity distribution with depth. The red areas (high resistivity) likely represent dry, compact materials or non-contaminated zones, while the yellow-green-blue zones indicate low resistivity. The low-resistivity zones at shallow depths suggest contamination due to leachate seepage from the waste dump, affecting groundwater quality. Depth of contamination, the low-resistivity areas extend down to about 10 –15 meters, which suggests that contamination could reach shallow aquifers, posing a risk to groundwater quality. The lateral spread of these zones indicates significant leachate migration.

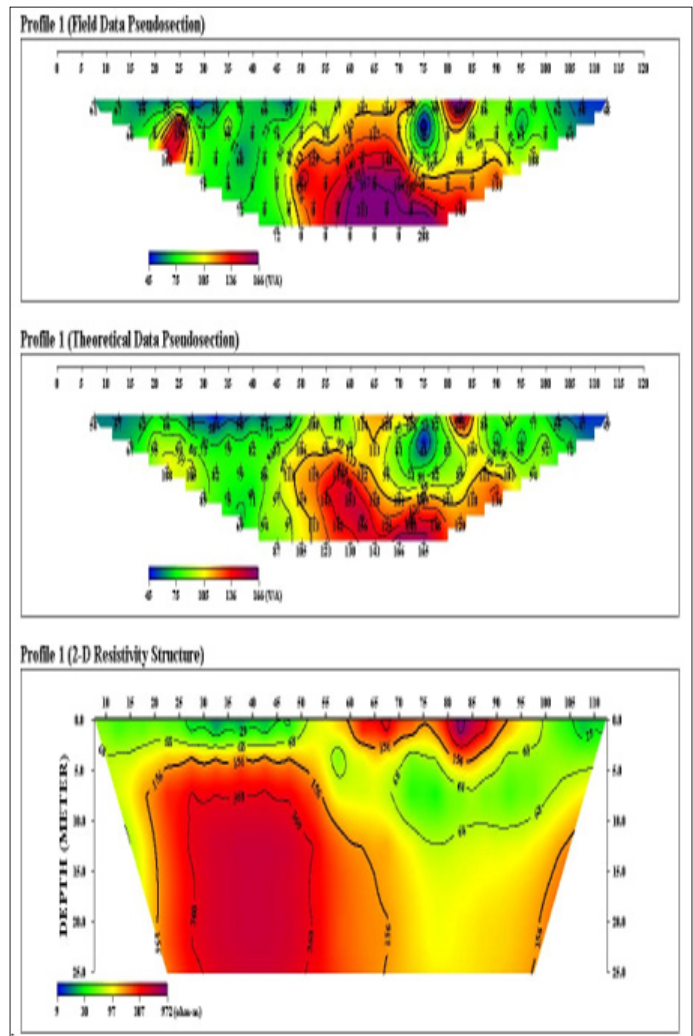


Figure 3.3: Pseudo-sections and 2-D Resistivity Profile 1

Geological cross-section of Profile 2

Top Soil (0 –1.80 m) with a low resistivity value of 481 Ohm-

meter, this layer is distinguished. Water-saturated materials, such as clay or silt, are usually indicated by low resistivity.

Weathered/Fractured Layer (1.80 – 5.90 m) this layer has a resistivity of 139 Ωm , which is slightly lower than the top soil. It likely represents a zone of partially decomposed bedrock or soil mixed with weathered rock fragments.

Fresh Basement (5.90 -10.0 m) this layer shows a very high resistivity of 2635 Ωm . This indicates a zone of fresh, unaltered bedrock with minimal water content.

The second layer 130.3 Ωm indicates moderate to high contamination, showing a significant influence from the waste dump. The first layer 481 Ωm is slightly corrosive, with limited contamination. The third layer 2635.3 Ωm has extremely high resistivity, suggesting negligible contamination, as deeper layers are less affected by the waste activities.

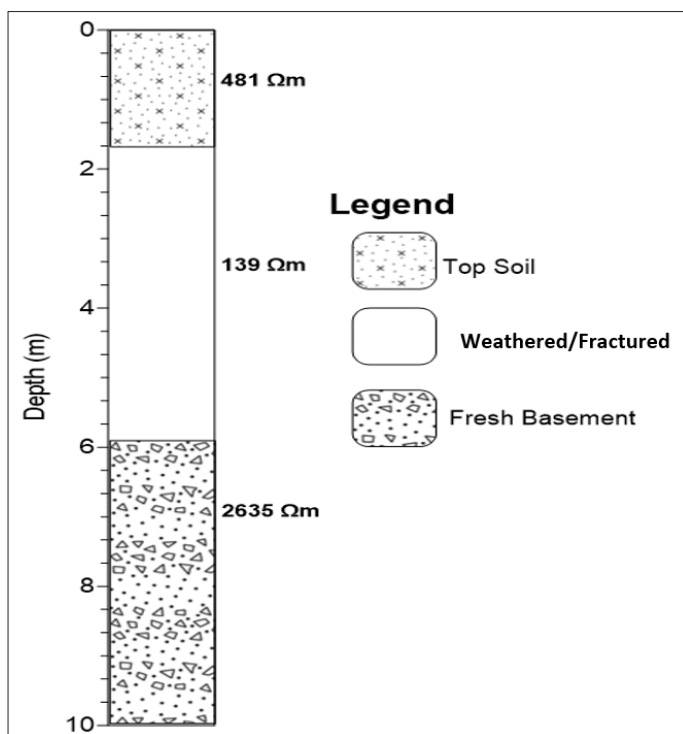


Figure 3.4: Resistivity log of Profile 2

Pseudo-sections and 2-D Resistivity Profile 2: The Field Data Pseudo-section displays resistivity measurements collected using an electrode array configuration at varying depths and distances along a survey line. The color scale indicates variations in resistivity values, with blue and green zones representing higher resistivity and yellow to red zones suggesting lower resistivity. Contour lines help visualize lateral and vertical changes in the subsurface.

Theoretical Data Pseudo-section is a predictive tool that simulates subsurface resistivity distribution from mathematical inversion of field data. It validates field measurements and refines the true resistivity structure model. A good match between field contours and theoretical pseudo-sections indicates accurate interpretation, while significant discrepancies may indicate further investigation or noise in the original data.

2-D Resistivity Structure: The upper layers (0 – 5 meters depth) show lower resistivity values (green to yellow), indicating shallow contamination likely due to leachate infiltration. The middle and deeper layers (10 – 20 meters) have higher resistivity (red to orange), suggesting compact, less permeable materials or non-contaminated zones. The resistivity values around 137 Ωm near the surface are relatively low, supporting the likelihood of pollution. Contamination level, the low-resistivity zones near the surface suggest leachate infiltration, which could pose a risk to groundwater quality. The higher resistivity at depth (>10 meters) suggests limited deep infiltration, meaning contamination may be concentrated in the upper aquifer layers. The horizontal spread of low resistivity indicates lateral migration of contaminants, increasing environmental risks, Batayneh [69].

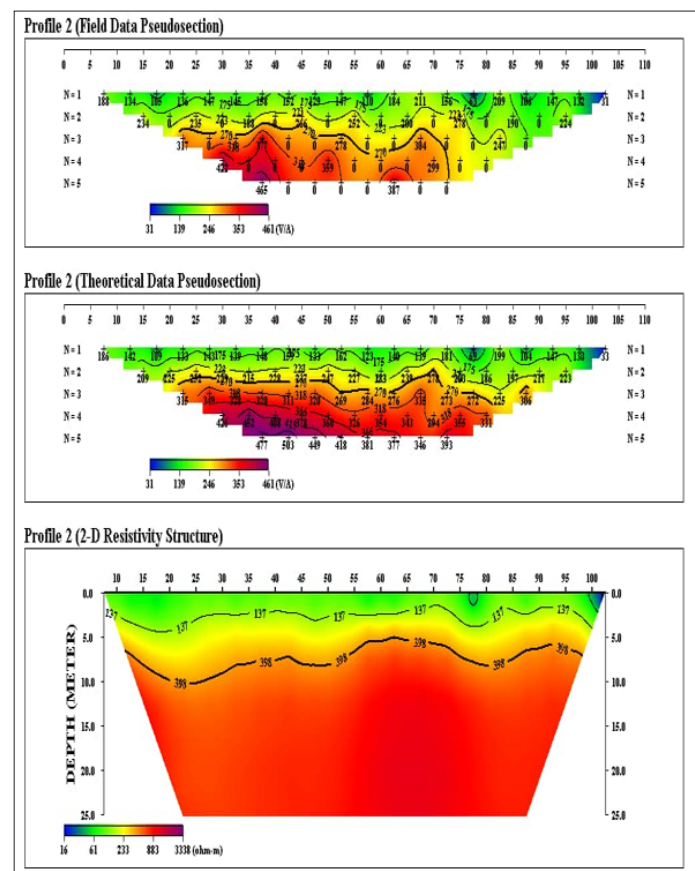


Figure 3.5: Pseudo-sections and 2-D Resistivity Profile 2

Geological cross-section of Profile 3

Top Soil (0 - 1.56 m) this layer exhibits a low resistivity value of 414 Ohm-meter, which typically signifies the presence of water-saturated materials, such as clay or silt.

Weathered/Fractured Layer (1.56 – 10.03 m) with a resistivity of 169 Ωm , slightly lower than that of the topsoil, this layer likely consists of partially decomposed bedrock or soil blended with weathered rock fragments.

Fresh Basement (10.03 – 14.0 m) this layer is characterized by a very high resistivity of 1297 Ωm , indicating a zone of fresh, unaltered bedrock with minimal water content.

The second layer 1629 Ωm shows moderate contamination from

the waste dump. The first layer 414 Ωm is slightly corrosive, suggesting limited contamination, while the third layer 12967 Ωm , with its high resistivity, suggests minimal contamination or natural attenuation at greater depths.

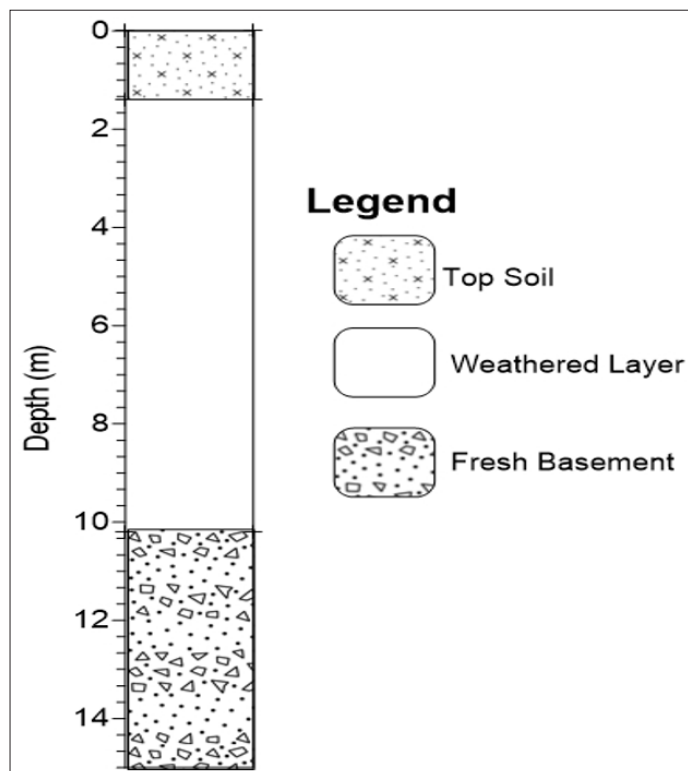


Figure 3.6: Resistivity log of Profile 3

Pseudo-sections and 2-D Resistivity of Profile 3: Field Data Pseudo-section representing raw resistivity data collected in the field. The color scale, ranging from blue to red, indicates varying levels of apparent resistivity, with blue (low values) representing areas of low resistivity and red (high values) indicating regions of higher resistivity.

The Theoretical Data Pseudo-section which represents a modeled or calculated version of the field data for comparison. The same color spectrum is used to differentiate resistivity levels.

2-D Resistivity Structure: The uppermost layers (0–5 meters depth) show a mix of moderate to high resistivity values (green to yellow), indicating less contamination near the surface. A large, high-resistivity zone red, ~607 Ωm at depths of 5–15 meters suggest a less permeable material, possibly compacted waste or bedrock. The blue-green zone ~10 Ωm at depths of 10–20 meters represent significant contamination due to leachate accumulation in lower layers. Contamination level, the low-resistivity zone in the deeper layers suggests the presence of leachate, which could have seeped from surface waste materials. Lateral movement of contaminants is evident, as seen in the spread of low resistivity towards the right side of the section. The presence of high resistivity near the surface suggests limited immediate contamination at shallow depths, but deeper groundwater resources may be at risk.

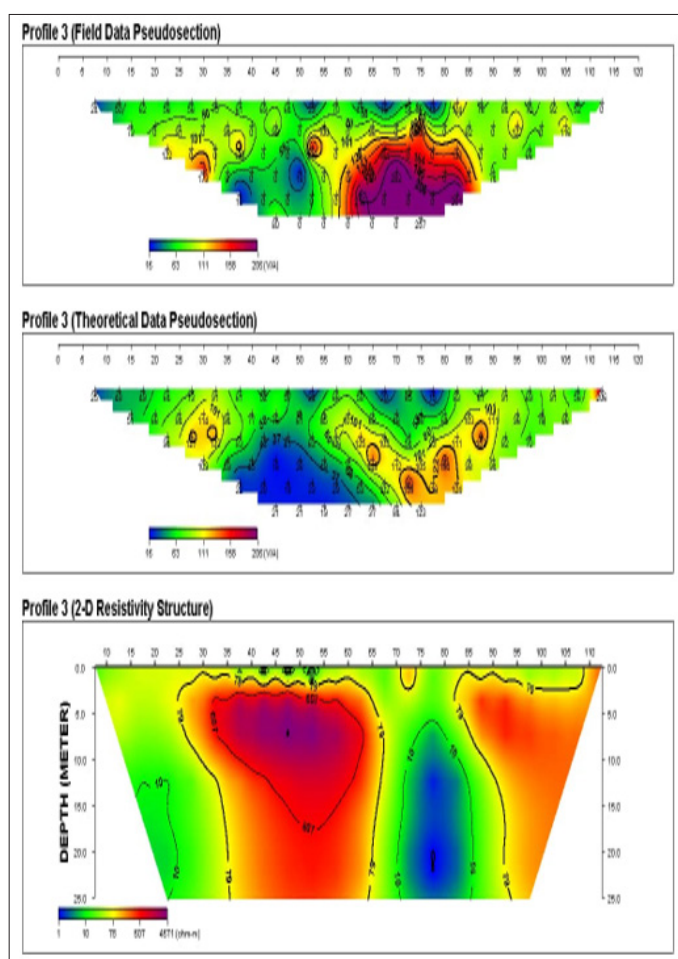


Figure 3.7: Pseudo-sections and 2-D Resistivity of Profile 3

Geological Cross-section of Profile 4

Top Soil (0 – 0.3 m) this layer displays a low resistivity of 306 Ohm-meter, typically indicating water-saturated materials such as clay or silt.

Weathered Layer (0.3 – 3.27 m) with a resistivity of 89 Ohm-meter, lower than that of the topsoil, this layer likely consists of partially decomposed bedrock or soil combined with weathered rock fragments.

Fractured Basement (3.27 – 10.92 m) this layer exhibits a resistivity of 342 Ohm-meter, reflecting reduced water content and a higher proportion of solid rock material.

Fresh Basement (10.92 – 14.0 m) the final layer features a very high resistivity of 1531 Ohm-meter, indicating fresh, unaltered bedrock with minimal water saturation.

The second layer 89 Ωm is highly corrosive, indicating severe contamination likely due to leachate infiltration. The first layer 305 Ωm is slightly corrosive, showing moderate contamination. The third layer 342 Ωm is moderately corrosive, reflecting the spread of pollutants with reduced severity. The fourth layer 1531 Ωm has high resistivity, indicating minimal contamination in the deeper strata.

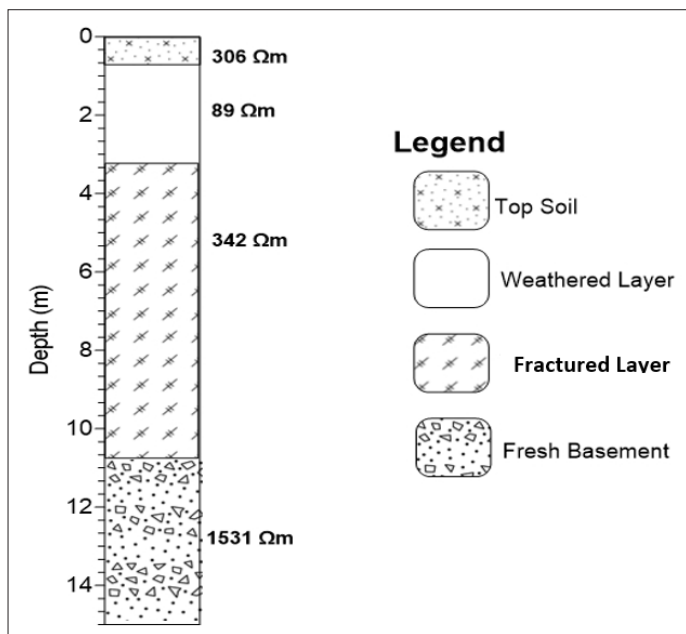


Figure 3.8: Resistivity log of Profile 4

Pseudo-sections and 2-D Resistivity Profile 4: Field Data Pseudo-section and Theoretical Data Pseudo-section show apparent resistivity values measured at different depths along a survey line. The colors represent resistivity values, with red typically indicating low resistivity (high conductivity) and blue indicating high resistivity (low conductivity).

The 2-D Resistivity Structure provides a visual interpretation of the subsurface resistivity distribution. The presence of low resistivity zones can indicate the presence of water-saturated materials, such as clay or sand, while high resistivity zones represent drier materials like bedrock or gravel.

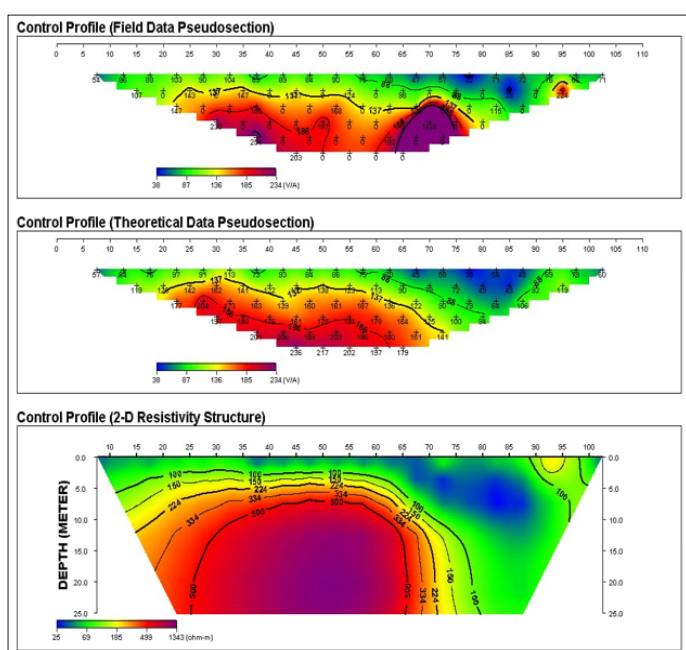


Figure 3.9: Pseudo-sections and 2-D Resistivity of Profile 4

3.4: Table of contamination risk

VES Station	Contamination Risk	Key Indicators
VES 1	High Risk	Low resistivity (96.1 Ωm), shallow contamination (0.7 m - 3 m depth).
VES 2	Moderate Risk	Increased resistivity (130.3 Ωm), deeper contamination (5.9 m).
VES 3	High Risk	Thick contaminated layer (162.7 Ωm , extending to 10.2 m).
VES 4	High Risk	Lowest resistivity (88.9 Ωm), deep contamination reaching 10.8 m.

The VES data indicates varying levels of contamination risk across the study area, with VES 1, 3, and 4 classified as high risk due to low resistivity values (88.9 Ωm - 162.7 Ωm), suggesting the possibility of significant leachate infiltration. VES 1 has shown an indication of shallow contamination (0.7 m - 3 m depth), making groundwater sources highly vulnerable. VES 3 and 4 show deep contamination extending beyond 10 m, indicating leachate migration into deeper subsurface layers, increasing groundwater pollution risks. VES 2, with moderate risk, has higher resistivity (130.3 Ωm) and contamination at 5.9 m depth, implying slower pollutant movement. Overall, the data highlights serious groundwater contamination concerns, necessitating hydro-chemical testing and remediation strategies to prevent further environmental degradation. This study further supports the use of geoelectrical methods (VES, Wenner array) as reliable tools for mapping subsurface contamination in waste dumpsites. However, integrating hydro-chemical analysis, as done in some of the referenced studies, could strengthen contamination assessments [70,71].

Conclusion and Recommendations

Conclusion

The findings from the geo-electrical and resistivity surveys conducted at the study area highlight the significant impact of solid waste disposal on groundwater quality. The vertical electrical sounding (VES) and 2D resistivity imaging techniques effectively delineated the subsurface resistivity variations, revealing layers of topsoil, weathered/fracture layers and fresh basement rock.

The resistivity value of the distinct three to four layers which includes the top layer, weathered layer, fractured basement and fresh basement ranges from 251.2 to 481.0 Ωm , its depth and thickness ranges from 0.7 to 1.7 m and 0.7 to 1.7 m respectively which corresponds to the geoelectrical parameters of fadama loam, weathered laterite and fresh laterite. The second subsurface layer has resistivity value of 88.9 to 162.7 Ωm , its depth and thickness ranges from 3.0 to 10.8 m and 2.5 to 9.8 m.

The low resistivity values detected in specific zones indicate the presence and migration of leachate plumes, confirming contamination pathways from the waste dumpsite into the surrounding groundwater system. These results validate previous

research showing the vulnerability of groundwater to pollution from improper waste management. The study underscores the critical need for sustainable waste management to protect groundwater resources in densely populated urban regions like Minna, Nigeria.

Recommendations

1. Authorities should adopt modern, engineered landfill systems with proper leachate containment and treatment mechanisms to minimize groundwater contamination risks.
2. Continuous monitoring programs using geophysical and hydro-chemical analyses should be established to track the extent of contamination and effectiveness of remediation efforts.
3. Encourage investment in deeper, protected boreholes or alternative water systems to ensure safe drinking water access while mitigating health hazards.

Contribution to Knowledge

The identification of low resistivity zones for 88.9 Ωm , 96.1 Ωm as indicators of contamination contributes to the geophysical modeling of polluted groundwater systems. The study also highlights the moderate to high contamination risk in the investigated area, emphasizing the need for proper waste disposal and groundwater protection strategies.

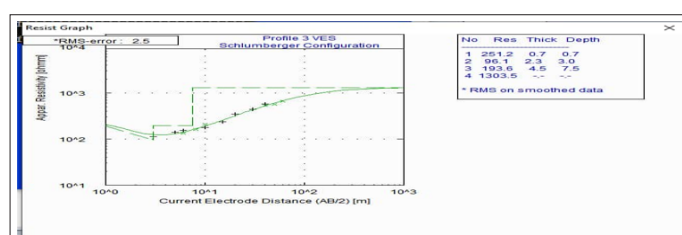
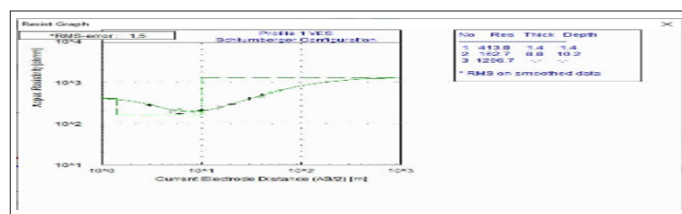
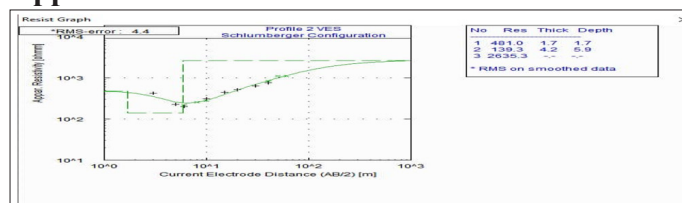
References

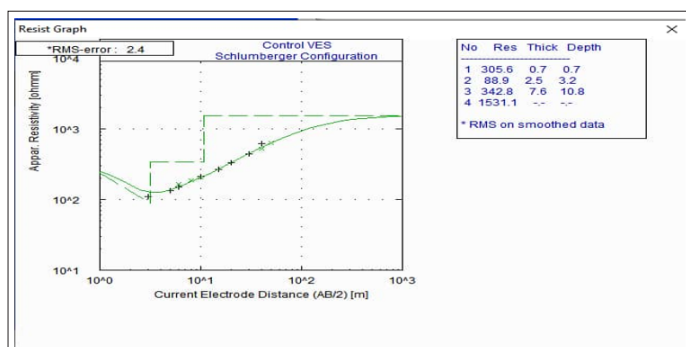
1. Momoh SO, Mgbemena CO, Agbadua SA, Mathew DO (2013) The physicochemical effect of leachates on ground water within Okpuno-Egbu Unu Dim Dumpsite Nnewi, Anambra State Nigeria. *DaffoDil Int. Uni. J. Sci. Tech* 8: 25–32.
2. Adekunle IM, Adetunji MT, Gbadebo AM, Banjoko OB (2007) Assessment of Groundwater Quality in a Typical Rural Settlement in Southwest Nigeria. *International Journal of Environmental Research and Public Health* 4: 307–318
3. International Solid Waste Association (ISWA) (2016) A Roadmap for closing Waste Dumpsites. The World's most Polluted Places: a report prepared as a part of ISWA's Scientific and Technical Committee Work-Program, ISWA 19–20.
4. Ige OO (2013) Geological and Geotechnical Evaluation of an Open Landfill for Sanitary Landfill Construction in Ilorin, Southwestern Nigeria. *Journal of Environment and Earth Science* 3: 9–17
5. Sunmonu LA, Olafisoye ER, Adagunodo TA, Ojoawo IA, Oladejo OP, et al. (2012) Integrated geophysical survey in a refused dumpsite of Aarada, Ogbomoso, Southwestern Nigeria. *Journal of Applied Physics* 2: 11–20.
6. Adesogan SO, Omonigho BO (2021) Assessment of leachate contamination potential of landfills in Ibadan, Nigeria. *African Journal of Environmental Science and Technology* 15: 170–187.
7. Amadi AN (2009) Evaluation of Surface and Groundwater Quality in Owerri Metropolis, Southeastern Nigeria. *International Journal of Chemical Sciences* 2: 212–219.
8. Aderemi AO, Oriaku AV, Adewumi GA, Otitolaju AA (2011) Assessment of Groundwater Contamination by Leachate near a Municipal Solid Waste Landfill. *African Journal of Environmental Science and Technology* 5: 933–940.
9. Udofia Udeme U, Udiba Udiba U, Lydia E Udofia, Ezike Nkechi N, Udiba Samuel U et al. (2016) Assessment of The Impact of Solid Waste Dumps on Ground Water Quality, Calabar Municipality, Nigeria. *Journal of Advance Research in Pharmacy and Biological Science* 2.
10. Aweto KE (2011) Aquifer vulnerability assessment at Oke-Ila area, Southwestern Nigeria. *International Journal of Physical Sciences* 6: 7574–7583.
11. Ige OO, Ogunsanwo O, Iyang HI (2011) Characterization of Terrain and Biotite Gneiss Derived Lateritic Soil of the Ilorin, Nigeria, for Use in Landfill Barriers. *Global Journal of Geological Sciences* 9: 1–9.
12. Akinbile CO (2012) Environmental impact of landfill on ground water quality and agricultural soils in Nigeria. *Journal of soil and Water Resources* 7: 18–26.
13. World Health Organization (1979) Promoting Environmental Health in the Years 1978 - 1983. *WHO Chronicle* 33: 169–173.
14. Brennan RB, Healy MG, Morrison L, Hynes S, Norton D, et al. (2016) Management of landfill leachate. The legacy of European Union Directives. *Waste Management* 55: 355–363.
15. Egbai JC, Efeya P, Iserhien - Emekeme RE (2015) 2D Geoelectric Evaluation and Imaging of Aquifer Vulnerability of Dumpsite at Ozoro Isoko South LGA of Delta State. *Journal of Natural Sciences and Resources* 5: 1–11.
16. Jegede SI, Iserhien-Emekem RE, Iyoha A, Amadasun CVO (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 Technology* 6: 537–543.
17. Abdullahi KA, Isaac BO, Abraham O (2010) Detecting Municipal Solid Waste Leachate Plumes through Electrical Resistivity Survey and Physicochemical Analysis of Groundwater Samples. *Journal of American Science* 6: 18–35.
18. Rowe RK (2011) Systems Engineering, The Design and Operation of Municipal Solid Waste Landfills to Minimize Contamination of Groundwater. *Geosynthetics International* 18: 391–404.
19. Abdullahi AP, Olatunde FA (2017) Application of Sustainable Environmental design requirements in Filling Stations in Niger State Nigeria. *Confluence Journal of Environmental Studies* 11: 104–116
20. National Bureau of Statistics (2011) Annual Abstract of Statistics. http://istmat.info/files/uploads/53129/annual_abstract_of_statistics_2011.pdf.
21. Nouban F, Yunusa N (2020) Engr. Abdulkadir Abdullahi Kure Ultra-Modern Market Fire Safety Assessment. *International Journal of Innovative Science and Research Technology* 5: 192–199.
22. Favreau (2009) Estimating specific yield and transmissivity with magnetic resonance sounding in an unconfined sandstone aquifer (Niger). *Hydrogeology Journal* 17: 1805–1815.
23. Amadi AN, Ibe GC, Odigie MA (2012) Geoelectrical investigation of groundwater potential in southern Paiko

- area, northcentral Nigeria, using seismic refraction method. *Journal of Applied Geophysics* 67: 182-191.
24. Obaje NG (2009) *Geology and Mineral Resources of Nigeria*. Lecture Notes Earth Science. Berlin, Springer 120-221.
 25. Amadi AN, Okunlola IA, Eze CJ, Jimoh MO, Unueho CI, et al. (2015) Geotechnical Assessment of Clay Deposits in Minna, North-Central Nigeria for Use as liners in Sanitary Landfill Design and Construction. *American Journal of Environmental Protection* 3: 67-75.
 26. Okonkwo CM, Onyeneke FO, Akosu IA (2014) Petrological and geochemical characteristics of migmatites and associated rocks in the basement complex around Minna, North-central Nigeria. *Journal of African Earth Sciences* 97: 223-235.
 27. Dada OS (2021) The Schist Belt (Metasedimentary and Metavolcanic rocks). *Lapai Journal of Science and Technology* 7: 1-10.
 28. Martins O (2001) Water Resource Management and Development in Nigeria – Issues and Challenges in a New Millennium 11-20.
 29. Musa JJ, Bala JD, Mustapha HI, Musa ET, Akos MP, et al. (2020) Organic matter and heavy metals leachate effect on soils of selected dumpsites in Selected North Central States of Nigeria. *Arid Zone Journal of Engineering, Technology & Environment* 16: 193-210
 30. Gomez-Ortiz D, Martín-Velazquez S, Martín-Crespo T, Marquez A, Lillo J, et al. (2007) Joint application of ground penetrating radar and electrical resistivity imaging to investigate volcanic materials and structures in Tenerife (Canary Islands, Spain). *Journal of applied geophysics* 62: 287-300.
 31. Rosqvist H, Dahlin T, Founé A, Rohrs L, Bengtsson A, et al. (2013) Mapping of Leachate Plumes in Two Landfill Sites in South Africa Using Geoelectric Imaging Techniques. *Proceedings Ninth International Waste Management & landfill symposium*. Calgary, Italy, Sardina.
 32. McNeill JD (1980) *Electrical conductivity of soils and rocks*. Geonics Publish Limited.
 33. Oyediran IA, Iroegbuchi CD (2013) Geotechnical Characteristic of Some Southwestern Nigerian Clays as Barrier Soils. *Ife Journal of Science* 15: 17-30.
 34. Ezema FL (2005) Optical characterization of chemical bath deposited bismuth oxyiodide BiOD thin films. *Turkish Journal of Physics* 292: 103-114.
 35. Akamkpo AO, Igboekwe MU (2011) Monitoring Groundwater Control Using Surface Electrical Resistivity and Geochemical Methods. *Journal of Water Resources and Protection* 3: 318 – 324.
 36. Bayode OJA, Adewunmi EA, Odunwale S (2011) Environmental Implications of Oil Exploration and Exploitation in the Coastal Region of Ondo State, Nigeria: A Regional Planning Appraisal. *Journal of Geography and Regional Planning* 4: 113-116.
 37. Ibitola MP, Ehinola AO, Akinnigbagbe AE (2011) Electrical Resistivity Method in Delineating Vadose and Saturated Zone in Some Selected Dumpsites in Ibadan Part of Southwestern Nigeria. *International Journal of Geomatics and Geosciences* 2: 164–178.
 38. Raman N, Sathiyarayanan D (2011) Quality Assessment of Ground Water in Pallavapuram Municipal Solid Waste Dumpsite Area Nearer to Pallavaram in Chennai, Tamilnadu. *Rasanya Journal of Chemistry* 4: 481- 487.
 39. Olafisoye ER, Sunmonu LA, Adagunodo TA, Oladejo OP (2014) Groundwater Contaminant Investigation at Aarada Waste Disposal Site Using Geophysical and Hydro-Physicochemical Approach. *IOSR Journal of Environmental Science, Toxicology and Food Technology* 2: 243-256.
 40. Rafiu AA, Mallam A (2014) The impact of a waste disposal site on soil and groundwater in Dutse Kura Gwari, Minna, Niger State, Nigeria. *Nigerian Journal of Physics* 6: 01-05.
 41. George NJ, Ibuot JC, Obiora DN (2015) Geoelectro-hydraulic parameters of shallow sandy aquifer in Itu, Akwa Ibom State (Nigeria) using geoelectric and hydrogeological measurements. *Journal Africa Earth Science* 110: 52–63
 42. Rafiu AA, Mallam A (2016a) Investigation of solid waste disposal site and its relationships with groundwater in Angwan Jukpa, Minna, Niger state, Nigeria. *Nigerian Journal of Physics* 27: 102-108.
 43. Rafiu AA, Mallam A (2016b) Vertical Electrical Resistivity Evaluation at Solid Waste Disposal Site, Dusten kura, Minna, Niger State. *Nigerian Journal of Physics* 27.
 44. Rafiu AA, Mallam A (2016c) Investigation of Contamination Plumes at Mechanic Road, Bosso Waste Disposal Site Using Geophysical and Geochemical Approach. *Journal of Science, Technology, Mathematics and Education* 11: 47–56.
 45. World Health Organization (2011) *Guidelines for drinking water quality*, 4th ed. Geneva, World health organization incorporating first addendum). World Health Organization Press, Switzerland.
 46. Rafiu AA, Mallam A (2016d) Detection of Leachate Plumes Migration Using Vertical Electrical Sounding Method and Physicochemical Analysis at Kpangungun, Minna, Niger State, Nigeria. *Journal of Science, Technology, Mathematics and Education* 11.
 47. Omale M, Udensi EE, Okosun EA, Daniyan MA (2016) Assessment of Leachate Contamination of Groundwater at Some Waste Disposal Sites in Minna, North-Central Nigeria. Unpublished PhD Thesis, Federal University of Technology, Minna.
 48. Ganiyu SA, Badmus BS, Oladunjoye MA, Aizebeokhai AP, Ozebo VC, et al. (2016) Assessment of groundwater contamination around active dumpsite in Ibadan southwestern Nigeria using integrated electrical resistivity and hydro-chemical methods. *Environmental Earth Science* 75: 643.
 49. Agbalagba EO, Osimobi JC (2017) Geophysical Investigation of Groundwater Contamination levels in Obiaruku Waste Dumpsite Using Vertical Electrical Sounding Method. *FUPRE Journal of Scientific and Industrial Research* 1: 2017.
 50. Shehu J, Alhassan UD, Salako KA, Rafiu AA, Adetona AA, et al. (2018) Geoelectrical Investigation for Groundwater Potential and Aquifer Protective Capacity of Overburden Units at Unions Site, Gidan kwano Campus, Federal University of Technology, Minna, North Central, Nigeria. *Lapai journal of Applied and Natural Science* 3: 43-52.

51. Yusuf TU, Udensi EE, Rafiu AA, Eze PC, Salako KA, et al. (2018a) Assessing the Spatial Patterns in Soil Properties Which Strongly Influences High Crop Yields, Through Electrical Resistivity Method, in Mokwa, Niger State, Nigeria. *Lapai Journal of Applied and Natural Sciences* 3: 9-19.
52. Temitope T, Adetoro R, Taiwo O, Odunaike R, Oladunjoye H, et al. (2018) Geophysical Investigation of Groundwater Pollution Resulting from Leachate Flow at Ikoto and Oru Dumpsites in Ogun State of Nigeria. *African Journal of Science & Nature* 6: 1-13.
53. Alkali A, Shehu J, Alhassan UD, Salako KA, Rafiu AA, et al. (2019) Geoelectrical Investigation of Groundwater Potential, at Bosso Campus, Minna, Niger State, Nigeria. *Journal of Water Resources and Ocean Science* 8: 37-43.
54. Nwankwo RC, Udo AA (2021) Investigation of Groundwater Aquifer Contamination due to Leachate Intrusion Using a High-Resolution Real-Time Resistivity Technique at a Dumpsite around the University of Port Harcourt Environs, Choba, Rivers State, South-South, Nigeria. *International Journal of Innovative Environmental Studies Research* 9: 53-63.
55. Coker JO, Rafiu AA, Abdulsalamc NN, Ogungbed AS, Olajidea AA, et al. (2021) Investigation of Groundwater Contamination from Akanran Open Waste Dumpsite, Ibadan, South-Western Nigeria, using Geoelectrical and Geochemical Techniques. *Journal of the Nigerian Society of Physical Sciences* 3: 89-95.
56. Alao JO, Lawal HA, Nur MS (2023) Investigation of groundwater vulnerability to open dumpsites and its potential risk using electrical resistivity and water analysis. *Heliyon* 9: 3265.
57. Mubarak AF, Samuel OO (2015) Geophysical and Geotechnical characterization of newly constructed Abadina- Ajibode Road University of Ibadan, Ibadan. *Journal of Applied Sciences* 4: 2140-2150.
58. Oyelami AC Aladajana JA, Agbede OO (2013) Assessment of the impact of on waste dumpsites on groundwater quality, A case study of the Onibu-Eja dumpsite, Southern Nigeria. *Procedia Earth and Planetary Science* 7: 648-651.
59. Cristina P, Cristina D, Alicia F, Pamela B (2012) Application of Geophysical Methods to Waste Disposal Studies. Institute of Geochronology and Isotopic Geology (INGEIS, CONICET-UBA) Argentina 10.5772/29615.
60. Andy A Bery, Rosli Saad, Edy Tonnizam Mohamad, Mark Jinmin, Azwin IN, et al. (2011) Electrical Resistivity and Induced Polarization Data Correlation with Conductivity for Iron Ore Exploration. *EJGE* 17.
61. Oyedele KF (2009) Total Dissolved Solids (TDS) mapping in groundwater using geophysical methods. *New York Science Journal* 2.
62. Abiola O, Enikanselu PA, Oladapo MI (2009) Groundwater potential and aquifer protective capacity of overburden units in Ado Ekiti, southwestern Nigeria International. *Journal of Physical Sciences* 4: 120-132.
63. Ahmed T, Dar IA (2021) Impact of soil corrosivity on buried infrastructure: A geophysical approach using electrical resistivity methods. *Journal of Environmental Geophysics* 18: 233-245.
64. Rajasekaran G, Manoharan N (2020) Assessment of soil corrosivity using geoelectrical resistivity method and its implications on buried structures. *Journal of Applied Geophysics* 178: 104017.
65. Henriet JP (1976) Direct applications of the Dar Zarrouk parameters in groundwater surveys. *Geophysical Prospecting* 24: 344-353.
66. Odewumi SC, Ayuba MS, Zang CU, Misal AE (2022) Evaluation of Groundwater Resources and Geoelectric Properties using Electrical Resistivity Method at Barakin Rafin Gora Area, Jos-Plateau, Northcentral Nigeria. *Science World Journal* 17: 45-51.
67. Olufunmilayo IN, Alexander OO (2019) Effect of Selected Electronic Waste Dump Sites on Quality of Surrounding Water Bodies in Abuja, Nigeria. *FUOYE Journal of Engineering and Technology* 4.
68. Ekeu-wei IT, Azuma KI, Ogunmuyiwa FBB (2018) worked on assessment of environmental impact of solid waste Dumpsites Using Remote Sensing at Benin. *Nigeria Journal of Technology* 37: 275.
69. Batayneh AT (2010) Mapping Quaternary Deposits in the El-Jufr Playa (Southwestern Jordan Plateau) Using Geoelectrical Techniques: Implications for Geology and Hydrogeology. *Science Research Essays* 5: 3183-3192
70. Kogbe (Ed.), *Geology of Nigeria*. Lagos, Elizabethan Publishers 41-58.
71. Yusuf TU, Udensi EE, Salako KA, Rafiu AA, Eze PC, et al. (2018b) Investigating Groundwater Quality and Soil Cultivation Viability Using Geophysical and Geochemical Approach at A Dumpsite in Mokwa, Niger State, Nigeria. *Lapai Journal of Applied and Natural Sciences*. LAJANS 3: 9-19.

Appendix





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