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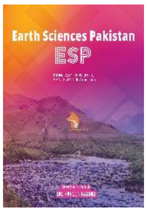

RESEARCH ARTICLE

IMPACT OF LANDFILLS ON GROUNDWATER QUALITY USING HYDROCHEMICAL AND ELECTRICAL RESISTIVITY METHODS AT APETE/AWOTAN AREA, IBADAN, SOUTHWESTERN NIGERIA

Adebo Babatunde[a], Ilugbo Stephen Olubusola[a]*, Ozegin Kesyton Oyamenda[b], Abiodun Caleb Oluwagbogo[a], Omotosho Oluwatoyin Abisoye[a], Oduah Adewumi Oluwaseun[c]

[a] *Department of Physics, Lead City University Ibadan, Oyo State, Nigeria*
[b] *Department of Physics, Ambrose Alli University Ekpoma, Edo State, Nigeria*
[c] *Deaprtment of Basic Science and general studies, Federal College of Forestry Ibadan*
**Corresponding Author Email: bussytex4peace44@gmail.com*

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ABSTRACT

Water is one of the determinants of the human-earth system. Diseases may spring up through water pollution, especially groundwater contamination, and rapidly spread beyond human expectations because of its flow mechanism. This study aims to assess the impact of landfills on groundwater quality in Apete/Awotan area, Ibadan, Oyo State, Southwestern Nigeria using The Electrical Resistivity and hydrochemical methods. The Electrical Resistivity method involves the use of 2D Electrical Resistivity Tomography (ERT) and Vertical Electrical Sounding (VES) techniques. The hydrochemical method involves the collection of seven water samples from boreholes and hand-dug wells, with sampling depths ranging from 9 to 75 m. Sixteen VES were carried out using Schlumberger array with current electrode spacing varying from 1 to 65 m, with 2-D ERT using Wenner array with an electrode spacing of 5 m interval and was used to determine the subsurface lithologies. The results from both methods indicate high levels of chemical contamination of the water from the boreholes and well water within and outside the dumpsite to a distance of 20 m away; health problems such as typhoid fever or worm infestation are imminent when such water is consumed. Good correlations exist between the Electrical Resistivity results and hydrochemical analysis for contamination in some strategically located notably S1, S2, and S3. 30 m away from the dumpsite are yet to be contaminated and can be relatively said to be of good water quality based on their locations and anions concentrations falling within the maximum permissible limit for water constituents by the World Health Organization.

KEYWORDS

Groundwater Quality, Landfill, 2D ERT, VES, Hydrochemical Analysis

1. INTRODUCTION

Water is the most surplus environmental resource on the planet earth but the way of reaching it depends on the quantity, quality, area, and time (Ilugbo et al., 2019; Olubusola et al., 2023). It can be made available in several quantities and forms, but its main purpose depends on the quality (Ilugbo et al., 2018a). The percentage of water in the human body and plants is within the range 60-70% (Smith and Edger, 2006). Water is one of the major factors of human existence, activities, and settlement on the planet earth. The amount and occurrence of water depend on the dynamic of formation storage and accumulation (Sharma, et al., 2017, Singh, et al., 2011, Bawallah et al., 2018, Adebo et al., 2021, Ozegin et al., 2023). Lack of good- quality water remains a major environmental challenge most developed and developing countries face (Alabi et al., 2019). Without treatment and remedy, groundwater remains polluted once it's contaminated (Afolayan et al., 2012).

Water is one of the factors that make human existence visible on the earth (Adesola et al., 2021). It is the major segment of animal and plant cells, it is the origin of life, and important factor in the development of an area (Bawallah et al., 2020a). Water is crucial in our daily activities and the major component of nature i.e. It occupies more than 70% of the planet's surface (Ilugbo and Adebiyi, 2017; Adebo et al., 2018; 2021). Since there is no existence without water, water remains a vital and most significant resource of any country (Adebiyi et al., 2018). It has a specific uniqueness in the midst of other natural resources because life or a nation can survive without the presence of other natural resources, except water (Garg, 2009, Singh et al., 2014; Purushothaman et al., 2012). In the planning and operation of a standard system, water priorities and allocation should be based on irrigation, agro-industries, drinking, hydropower, non-agricultural industries, and ecology with other uses (Adebo et al., 2022). Oceans, Streams, rivers, brooks, seas (surface water), ice, snow, and subsurface water form the main sources of water. However, their mode of existence determines their exploitation and exploration (Afolayan et al., 2012, Adebo et al., 2019, Bawallah et al., 2020b).

Solid waste is mostly the major occurrence in dumpsites/landfills (Alabi et al., 2019). Regarding groundwater analysis, its flows direction varies from higher to lower topography, thereby bringing about the investigation of the groundwater contaminant of the study area as a result of the leachate generated from the degradable material (Ilugbo et al., 2018b; 2020). Filling of depression land using disposal of solid waste is a major landfill practice. The depressions site where solid wastes are mostly dumped include abandoned sites such as excavation areas, quarries, or specific regions within the commercial and residential areas in the urban

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or rural communities with enough space to dispose off, collect, and process waste in a safe manner and cost-efficient is often limited. Landfill practices in most developing countries are not in accordance with recommended specifications (Eludoyin and Oyeku, 2010). However, a standard landfill practices is sited in a selected area, well-constructed and maintained ensuring proper investigation such as geophysical, engineering, and environmental studies, and also minimizing air, water, and soil pollution and risk to mankind and animals.

The leachate generated from the waste must be properly controlled to prevent infiltration of subsurface lithologies which could cause adverse effects on the groundwater (Longe and Balogun, 2010; Eludoyin and Oyeku 2010). A standard landfill is a major method of controlling solid waste on land without polluting surface and subsurface water (Longe and Balogun, 2010). The water supply quality scheme should be properly planned. In this situation, water quality management becomes an important component to ensure better water quality, durability, and sustainability. Attention must be shifted toward future generations. In this regard, there is a need to increase the delineation of water quality, which has led to the major motivation behind this research.

According to the 2014 atlas, Apete/Awotan landfill was one of the fifty biggest landfills in the world. Many of the people leaving around this landfill has lost hope, many had resigned to fate, and some that could not afford to abandon their houses did so to become a tenant in other parts of Ibadan due to odoriferous air generated and spreading in the area. The landfill became active in 1998 and received 36,000 tonnes of municipal solid waste per annum. The landfill had about five hundred thousand (500,000) people within 10 kilometers, with the distance of closeness of resident only 20 meters away from the landfill. But for years, their cries were met with no response from successive administrations; most of the inhabitants leaving around the disposal site (study area) depend largely on wells and boreholes for their domestic and daily survival. The situation has been of major concern as a result of the traces of contaminant in their wells and boreholes due to their closeness to the disposal site, which has affected aquifer formation, as a result of the migration of the contaminant through lithologies formations. The Objective of this research is to determine both the vertical and lateral extent of the contaminant and the impact of landfill on groundwater quality using Hydrochemical and Electrical Resistivity Methods.

2. SITE DESCRIPTION AND GEOLOGY OF THE INVESTIGATED AREA

Ibadan was founded in 1829 and was initially occupied by immigrants, who relocated into the city for security purposes due to intertribal wars. Ibadan metropolitan is the largest city in Nigeria and the second largest in the South Saharan of Africa after Cairo in Egypt. Ibadan is the capital city of Oyo State, it consists of eleven Local Government Areas. The commercial and administrative importance of Ibadan has been tailored to land being the key investment asset and a major factor in population. The Awotan/Apete landfill and its environs were used as a case study. It is located in Ibadan, Southwest Nigeria. Apete/Awotan dumpsite is located along Akufo road which is situated in Ido Local Government Area (Figure 1). The study area falls within latitudes 7°14’27.97’N to 7°14’50.64’’N and longitudes 5°10’5.03”E to 5°10’27.95”E. that is, (805100 to 805900 Northings and 740200 to 740600 Eastings) using the Universal Traverse Mercator (UTM). Major and minor road linkages characterize the study area.

The topography of the landfill is generally undulated as result of heaps of waste and the main road within the dumpsite is sloppy tending towards the main gate. The surface soil within the landfill consists of clay, sandy clay, sand, and laterite. The landfill location is majorly over 360 m above sea level. The hydrogeology of the study area consists of streams and geological structures such as faults, fractures, and joints. There is a problem of groundwater around the study location due to the crystallite nature of the subsurface rock which lacks primary porosity and permeability. But due to occurrences of tectonic activities which caused the subsurface rock to disintegrate and fractured resulting in the accumulation of groundwater within the geological structures. The basement complex rocks of Nigeria are made up of heterogeneous assemblages (Rahaman, 1988). The area of investigation falls in hard rock terrain and it is underlain by the Precambrian crystalline rocks typical of the Nigeria basement complex (Rahaman, 1976). The dominant rock type is migmatite (Figure 2).

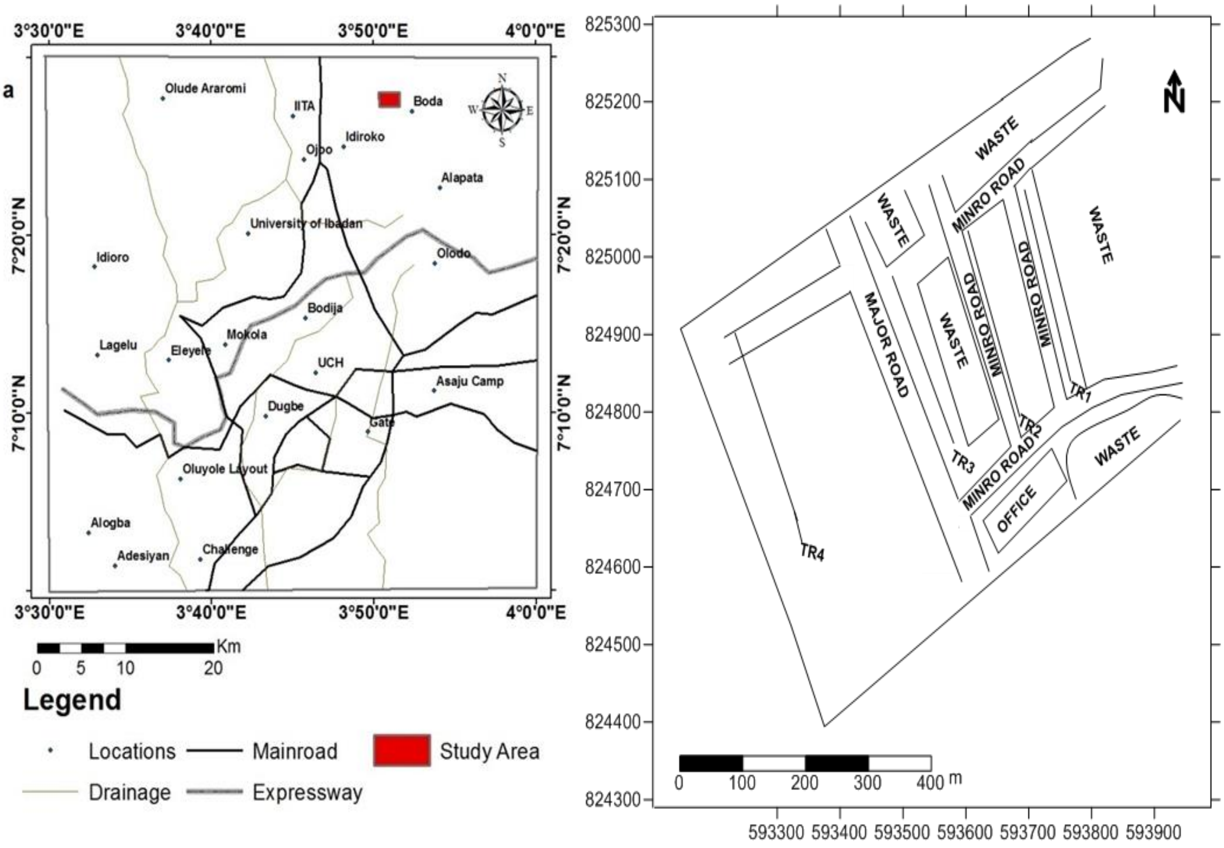

Figure 1: (a) Map of Ibadan indicating the study area (b) Sketch map of the study site

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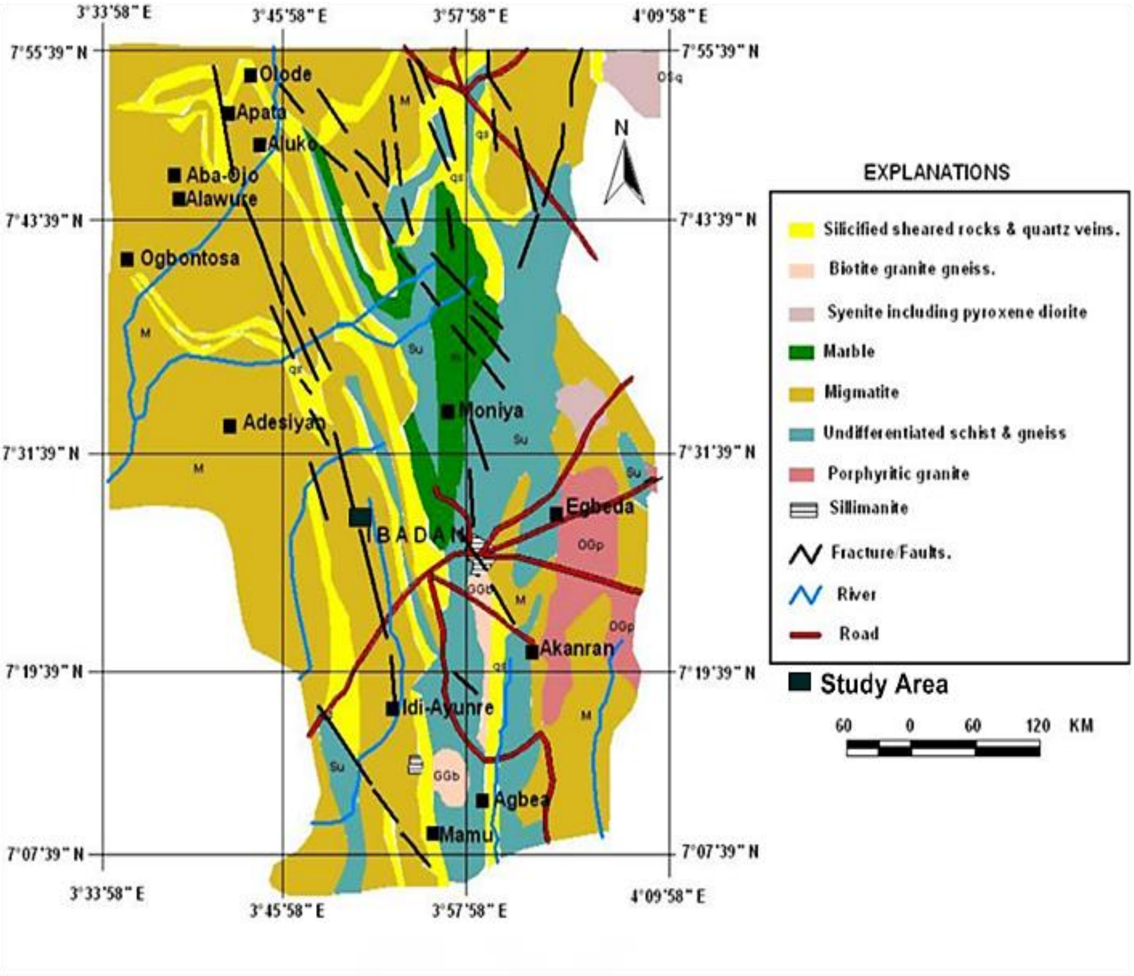


Figure 2: Geological map of Ibadan Metropolis showing the study site (Modified after Rahaman, 1988)

3. Materials and Methods

The data acquisition procedure involved two phases which involve hydrochemical and Electrical Resistivity methods.

3.1 Phase1

3.1.1 Hydrochemical Method

Seven (7) water samples were acquired from different wells and boreholes within and outside the disposal site at a distance of 0, 20 m, 40 m, 60 m, 80 m, 100 m, and GPS positioning of the sample points covering the area of interest. The first sample was taken at a leachate control point within the landfill (Figure 3a) and the remaining six samples were taken from wells and boreholes within and outside the disposal site (Figure 3b). The hydrochemical investigation was derived from a sampling network with four (4) wells, two (2) boreholes, and one from the leachate control point within the dump site. The sampling depth ranges from 9 to 75 m. Moreover, the Electrical conductivity (Ec), temperature, and pH were determined in situ using a field conductivity meter. The major elements (cations and anions) were analyzed in the Chemistry Department Laboratory, Lead City University Ibadan. The water samples were analyzed by using the protocol for standard methods for the examination of water and wastewater (APHA 1995). The cations; Na^+, Ca^{2+}, Mg^{2+}, and K^+ were measured by the spectrometry of atomic absorption. The anions were determined by many techniques. Chloride was dosed by Argentometric titration using standard AgNO3. Bicarbonate concentrations were determined by the potentiometric method. The gravimeter method using $BaCl_2$ was performed to measure the sulfate concentrations.

3.2 Phase 2

3.2.1 Electrical Resistivity Method

Four traverses were generated approximately W-E direction within and outside the landfill with the fourth traverse which serve as control (Figure 3b). The resistivity terrameter used was Pasi resistivity meter with the associated source of power (Battery) which allows for the readout of current (I) injected into the earth and the resultant voltage (V). The unit has in-built current transmitter (power source) and receiver (potential measuring devices). To ensure that sufficient current was passed to the ground, packs of external battery were always attached to it. The unit has sensitivity range of 0.1mA and 0.1mV for current and voltage respectively. The electrode used during this study were made of steel material of about 0.5m long with one pointed edge of about 10cm. the protruding edge serves as the driving point of the electrodes into the ground. Four of these types of electrodes were used during the field survey – 2 currents and 2 potentials electrodes. Four reel bearing cables with crocodile pins at their ends were used to connect the electrodes to the resistivity meter. Other field equipment used for the field data acquisition includes cutlass and hammers, compass clinometers, and handheld GPS.

3.2.2 Phase 2 Data Collection Involves Two Techniques

3.2.2.1 Vertical Electrical Sounding (VES)

Vertical Electrical Sounding (VES) using Schlumberger configuration. In Schlumbeger array, the separation between the current electrodes (AB) is successively expanded while the two potential electrodes (MN) have a short separation and remain partially stationary at the depth sounding position. The geoelectric survey is such that the minimum electrode spacing "AB/2" m and gradually increase to a maximum spread length "AB/2" of 65 m. Sixteen (16) VES points were occupied to cover the study area. The apparent resistivity data was processed and analysis. The VES iterated results was used to generate geoelectric sections and geoelectric maps

3.2.2.2 2D Electrical Resistivity Tomography

2D Electrical Resistivity Tomography gives significant information on the trends and properties of the subsurface structural which were taken at various intervals. Resis2D software was used to invert the data obtained using 2-D subsurface images.

The results from both methods were integrated to determine the lateral and vertical extent of the contaminant and groundwater quality of the study area.

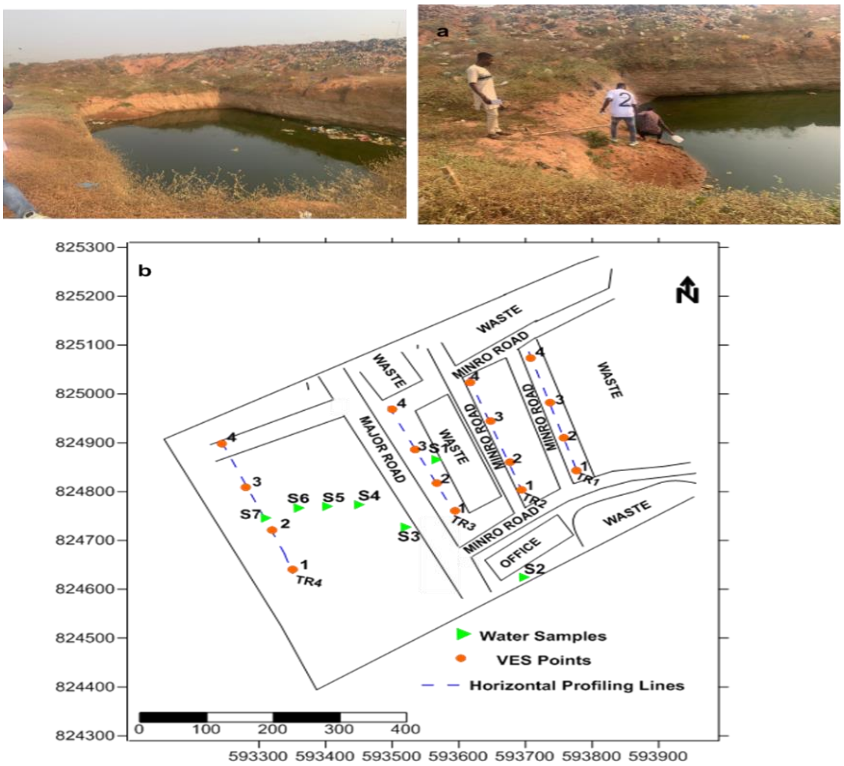
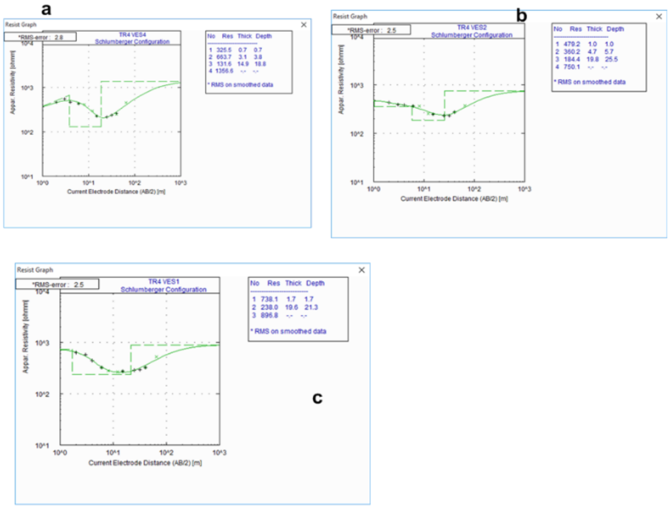


Figure 3: (a) Leachates control point (b) Data acquisition map of the study area

4. RESULTS AND DISCUSSION

4.1 Typical Sounding Curves

In the study area, three (3) curve types were identified, these are QH, H, and KH (Figure 4), and H curve type has the highest percentage (75%) of occurrence.



No	Res	Thick	Depth
1	325.5	0.7	0.7
2	663.7	3.1	3.8
3	131.6	14.9	18.8
4	1356.6	-.-	-.-

* RMS on smoothed data

No	Res	Thick	Depth
1	479.2	1.0	1.0
2	360.2	4.7	5.7
3	184.4	19.8	25.5
4	750.1	-.-	-.-

* RMS on smoothed data

No	Res	Thick	Depth
1	738.1	1.7	1.7
2	238.0	19.6	21.3
3	896.8	-.-	-.-

* RMS on smoothed data

Figure 4: Typical Iterated Curves Types (a) KH (b) QH (c) H

4.2 Geoelectric Sections along Traverse One to Four

Four (4) geoelectric sections were drawn from the layer resistivity and thicknesses obtained from the interpretation of the depth-sounding curves. The sections drawn along the four traverses within and outside the landfill in approximately west-east directions of the study area show a total of four subsurface layers namely: the topsoil, contaminated zone/weathered layer, fractured basement, and fresh basement. The first layer of the geoelectric section along traverse one constitutes the topsoil with layer resistivity ranging from 82 to 205 Ωm and its layer thickness varies from 1.1 to 3.5 m (Figure 5a). The varying topsoil resistivity suggests clay, clayey sand, sandy clay, sand, and laterite. The second layer with resistivity values ranging from 16 to 45 Ωm is the contaminated zone with layer thickness varying from 3.3 to 24.5 m. The lithologies of this layer show low resistivity as a result of infiltration of leachate from the landfill. The third layer is the fresh basement with resistivity values ranging from 368 to 571 Ωm. The depth to the top of the bedrock ranges from 16.8 to 29.0 m. The recognizable groundwater zone was observed beneath VES1 which could be a good aquifer, although the leachate generated from the landfill has infiltrated the aquiferous zone which has caused a great impact on the groundwater quality for drinking purposes.

Figure 5b shows the geoelectric section along traverse two with the topsoil layer resistivity ranging from 89 to 157 Ωm and its layer thickness varies from 1.8 to 3.2 m. The varying topsoil resistivity suggests clay, clayey sand, sandy clay, and sand. The contaminated zone has resistivity values ranging from 24 to 35 Ωm, with its layer thickness varying from 14.2 to24.5 m. The lithologies of this layer show low resistivity as a result of infiltration of leachate from the landfill. The third layer is the fresh basement with resistivity values ranging from 495 to 992 Ωm. The depth to the top of the bedrock ranges from 16 to 26 m. The leachate generated from the landfill has caused a great impact on the groundwater quality by the infiltration of the contaminant.

Figure 5c shows the geoelectric section along traverse three with the topsoil layer resistivity ranging from 39 to 99 Ωm and its layer thickness varies from 1.3 to 2.6 m. The varying topsoil resistivity suggests clay, clayey sand, and sandy clay. The contaminated zone has resistivity values ranging from 13 to 31 Ωm, with its layer thickness varying from 8.3 to 21.6 m. The lithologies of this layer show low resistivity as a result of infiltration of leachate from the landfill. The third layer is the fresh basement with resistivity values ranging from 403 to 522 Ωm. The depth to the top of the bedrock ranges from 9.9 to 23 m. The leachate generated from the landfill has infiltrated the aquiferous zone which has caused a great impact on the groundwater quality for drinking purposes.

Figure 5d shows the geoelectric section along traverse four with the topsoil layer resistivity ranging from 99 to 738 Ωm and its layer thickness varies from 0.7 to 2.7 m. The varying topsoil resistivity suggests clay, clayey sand, sandy clay, sand, and laterite. The weathered layer has a resistivity value ranging from 19 to 664 Ωm, with its layer thickness varying from 8.3 to 21.6 m. The varying weathered layer resistivity suggests clay, clayey sand, sandy clay, sand, and laterite, while the low resistivity at VES3 is indicating clay. The third layer is the fractured basement observed at VES2 and VES4 has resistivity values ranging from 132 to 184 Ωm with its thickness varying from 14.9 to 19.8 m, while the last layer is the fresh basement with resistivity values ranging from 750 to 1357 Ωm. The depth to the top of the bedrock ranges from 15.0 to 25.5 m. The recognizable structural feature in this section is the fracture observed beneath VES2 and VES4. Most especially, the fractured could be a good aquifer prospect for groundwater with appreciable thickness. There are no traces of leachate along this traverse; however, the landfill has no negative impact on the quality of the groundwater potential.

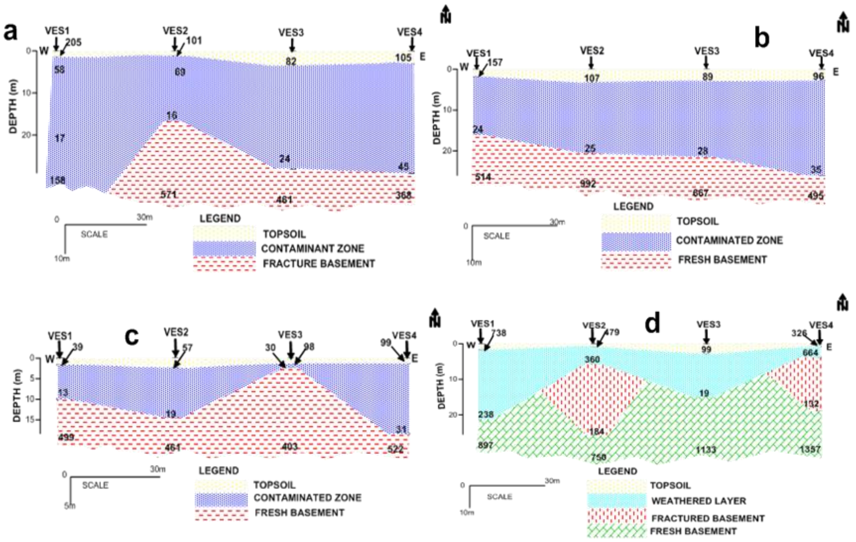


Figure 5: Geoelectric Section along Traverse (a) One (b) Two (c) Three (d) Four

4.3 Geoelectric Maps

The topsoil resistivity map (Figure 6a) generated shows that topsoil with relatively low resistivity (blue colour) was observed within and 20 m away from the landfill in the northeastern, eastern, southeastern, and central parts. The lithologies of topsoil layers show low resistivity as a result of infiltration of leachate generated from the landfill. The moderate topsoil resistivity (green colour) was observed in northwestern, southwestern, and traces in the southeastern and northeastern regions of the study area. The high topsoil resistivity (red colour) values are restricted to the edge of the study area in the northwestern, western, and southwestern regions. High thickness (red colour) units are found in the northeastern, eastern, southeastern, and a trace in the southwestern portion of the study area (Figure 6b). The moderate topsoil thickness (green colour) was observed in the northern, northwestern, western, southwestern, southeastern, and central regions of the study area. While low topsoil thickness (blue colour) was found in the southern, northwestern, and traces in the northeastern and southwestern parts of the investigated area.

The overburden thickness in the study area is assumed to include the topsoil, the contaminated zone/weathered layer, and the fractured basement. Hence, the established depths to the bedrock beneath all the VES stations were contoured to produce the overburden thickness map (Figure 6c). The overburden thickness varies from 9.9 to 29.0 m. The map shows a relatively high overburden thickness (red colour) in the eastern, southeastern, and northeastern parts which correspond to basement depression which is groundwater convergent zones. Hence, they are relatively good prospects for groundwater development. Moderate overburden thickness (green colour) was observed in the northeastern, southwestern, and central parts of the study area while the relatively low overburden thickness (less than 11m) corresponding to basement highs was found in the southern and a trace in the southwestern regions. The groundwater flow pattern is from the basement highs to the basement depression.

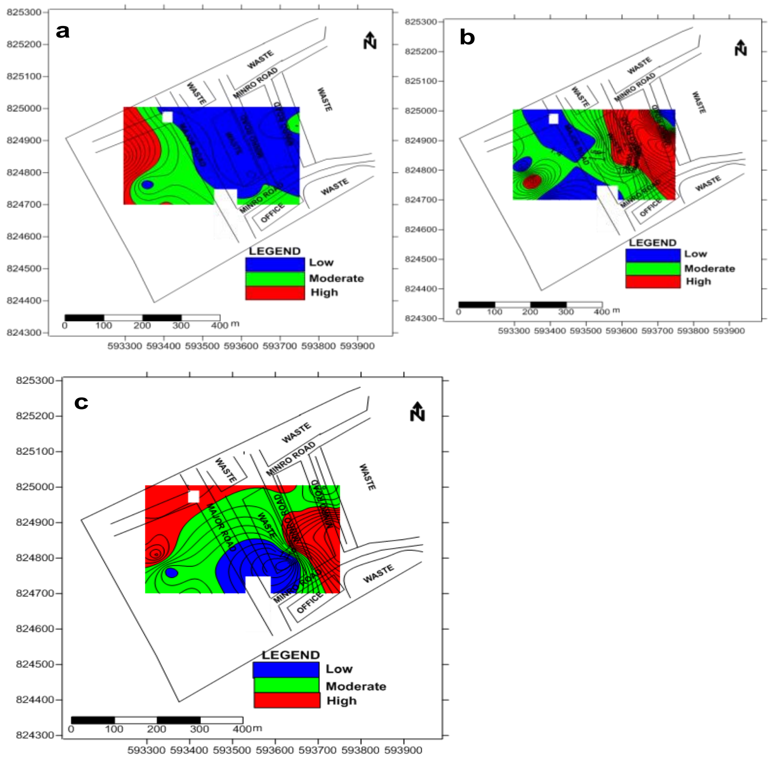


Figure 6: Geoelectric Maps within the Study Area (a) Topsoil Resistivity Map (b) Topsoil Thickness Map (c) Overburden Thickness Map

4.4 2D Electrical Resistivity Tomography (ERT) along Traverse One to Four

The 2D Electrical Resistivity Tomography (ERT) imaging of the subsurface which measures lateral and vertical variation with depth gave useful information on the subsurface geological strata. Traverse, one exhibits low resistivity as a result of leachate generated from the landfill which has infiltrated into the subsurface beyond 12.5 m depth between distances of 25 to 60 m (Figure 7a). However, between the distance of 7.5 to 20 m and 60 to 95 m, the contaminant has infiltrated to a of 10 m. From the 2D imaging, the upper surface has been contaminated which has imposed a

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threat on the groundwater quality of the area. 2D imaging along traverse two (Figure 7b) shows low resistivity as a result of leachate coming out from the waste dumped on the landfill which has infiltrated into the subsurface beyond 12.5 m depth between distances of 25 to 60 m. However, between the distance of 7.5 to 20 m and 60 to 95 m, the contaminant has infiltrated to a depth of 10 m. From the 2D imaging, the upper surface has been contaminated which has imposed a threat on the groundwater quality of the area.

The information from traverses one and two conformed to each other. 2D imaging along traverse three (Figure 7c) which was obtained at 20 m away from the landfill show low resistivity at the near surface but to a depth beyond 12.4 m at a distance between 7.5 to 35 m and 75 to 95 m, showcasing that the contaminant has migrated away from the landfill and infiltrated to a specific depth which has imposed threat on the groundwater quality. The 2D imaging along traverse four (Figure 7d) which serves as control at 100 m away from the landfill show low resistivity values at the near-surface. The low resistivity is indicative of the clayey nature of the area which causes the seasonal variation of their wells except those that drilled boreholes within the vicinity. It was observed that the contaminants are yet to migrate beyond 30 m from the landfill which indicates good quality groundwater potential.

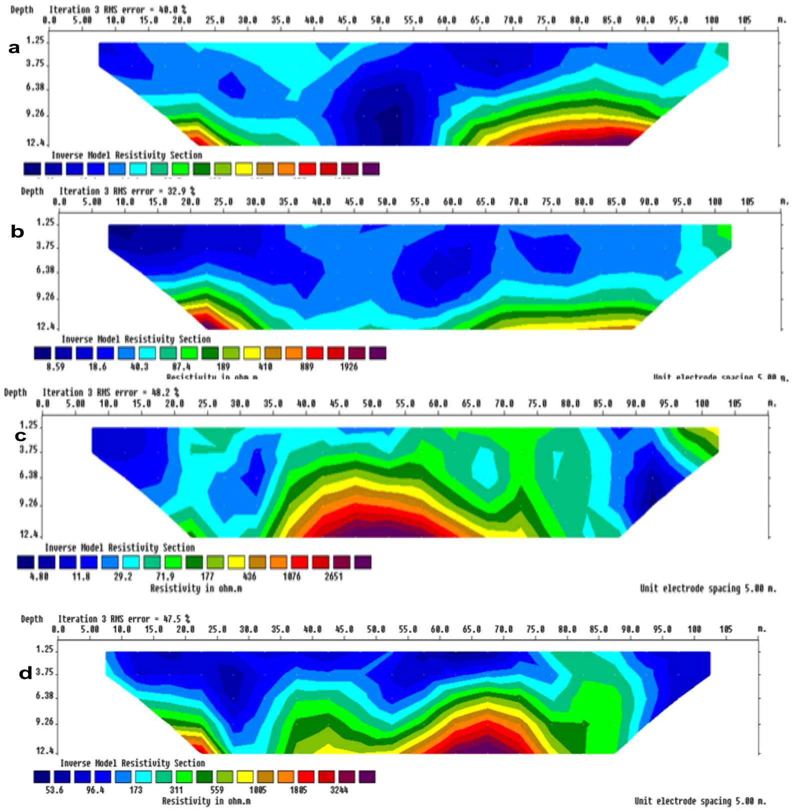

Figure 7: 2D Electrical Resistivity Tomography (ERT) along the Study Area (a) Traverse One (b) Traverse Two (c) Traverse Three (d) Traverse Four

4.5 Hydrochemical Analysis

Figure 8a shows the pH value ranges from 6.39 to 8.5 with an average of 8.47. pH value of 6.39 to 6.45 was obtained from S1, S2, and S3 revealing that the groundwater in the study area is acidic. The acidity is probably due to the presence of organic matter in the soil. However, free CO generated from the dumped waste and the atmosphere is suspected to enter the groundwater system as rainwater percolates the subsurface soil and groundwater and reduces the pH value of the water in the area. The pH values of 6.39 – 6.45 are lower than the WHO recommended safe value of 7.0 is indicative of groundwater pollution compared to S4, S5, S6, and S7 where the pH values fall within the recommended WHO standard value suggesting quality groundwater (WHO, 2004). When the pH of water becomes greater than 8.5, water taste can become bitter. This elevated pH can also lead to calcium and magnesium carbonate building up in your pipes. While this higher pH doesn't pose any health risks, it can cause the skin to become dry, itchy, and irritated.

Figure 8b displays conductivity values ranging from 200 - 605 μScm^{-1} with an average value of 382 μScm^{-1} usually indicates the concentration of dissolved ions in groundwater samples. However, the higher conductivity values within SI, S2, and S3 suggest groundwater pollution within the study area. The more ions that are present, the higher the conductivity of water. Likewise, the fewer ions that are in the water, the less conductive it is. Figure 8c displays TDS values ranging from 400 - 505 ppm with an average value of 461 ppm usually indicating the concentration of dissolved ions in groundwater samples. However, the lower TDS values within SI, S2, and S3 suggest groundwater pollution within the study area. The values within S4, S5, S6, and S7 fall within the WHO recommended safe values for drinking water. Even if the high amount is due to the presence of beneficial minerals, increased levels of TDS can give water a bitter, metallic, or salty taste, along with the discoloring of the water and creating an unpleasant odour.

Figure 8d exhibits the total hardness of groundwater samples in the study area which ranges from 198 – 380 ppm $CaCo_3$ with an average value of 265 ppm $CaCo_3$. The values obtained at S1, S2, and S3 are generally more than the WHO recommended safe values of 200 ppm $CaCo_3$ drinking water. Relatively higher total hardness is indicative of groundwater pollution when compared to S4, S5, S6, and S7 which fall within the recommended WHO standard value for drinking water. Water hardness relates to the amount of calcium and magnesium compounds present in water. That is, it has a high concentration of Ca2+ and Mg2+ ions, which react with soap to form scum. If bicarbonates and carbonates of calcium and magnesium are present, it is called temporary or carbonate hardness. This can be largely removed by boiling or the addition of lime. But if sulphates, chlorides, and nitrates of calcium and magnesium are present which cannot be removed by previous processes (liming and boiling), is known as permanent or non-carbonate hardness. Underground waters are generally harder than surface waters (Ayoade, 2003).

Figure 8e shows the Sulphate content of groundwater in the study area generally ranges from 89 to 201 ppm. The values obtained at S1, S2, and S3 are generally less than the WHO recommended safe values for drinking water. The values within S4, S5, S6, and S7 fall within the WHO recommended safe values for drinking water. The relatively low Sulphate concentration within S1, S2, and S3 suggests groundwater pollution within the investigated area. Figure 8f displays the NO_3- concentration values for groundwater ranging from 8.9 to 31 with average values of 21.36 ppm. The values obtained at S1, S2, and S3 relatively fall below the WHO recommended safe value for drinking water. The lower concentrations of nitrate are an indication of leachate saturation and hence confirm the leachate pollution within the locations. However, S4, S5, S6, and S7 fall within the recommended WHO safe value for drinking water. High nitrate levels in the bloodstream reduce the ability of the red blood cells to transport oxygen. Ingestion of nitrates in drinking water has been known to cause methemoglobinemia in infants less than six months. Alkalinity refers to the capability of water to neutralize acid and its importance is underscored by its ability to control pH changes. Figure 8g displays the alkalinity concentration values for groundwater ranging from 200 to 501 ppm with average values of 379.86 ppm. The values within S1, S2, and S3 generally fall below the WHO recommended safe value for drinking water. The lower concentrations of alkaline are indicative of leachate saturation and hence confirm the leachate pollution within the area. However, S4, S5, S6, and S7 fall within the recommended WHO safe value for drinking water. High alkalinity, while not detrimental to humans may cause drinking water to have a flat, unpleasant taste.

Figure 8h shows the Chloride content of groundwater in the study area with values ranging from 247 to 290 ppm with an average value of 261.86 ppm. The values obtained at S1, S2, and S3 are generally higher than the WHO recommended safe values for drinking water, which is a result of leachate saturation in the groundwater. The values within S4, S5, S6, and S7 fall within the WHO recommended safe values for drinking water. A high level of chloride can cause plumbing corrosion problems, and the wearing of pipes, pumps, water heaters, and fixtures. High chloride may also mean possible pollution of well water from sewage sources.

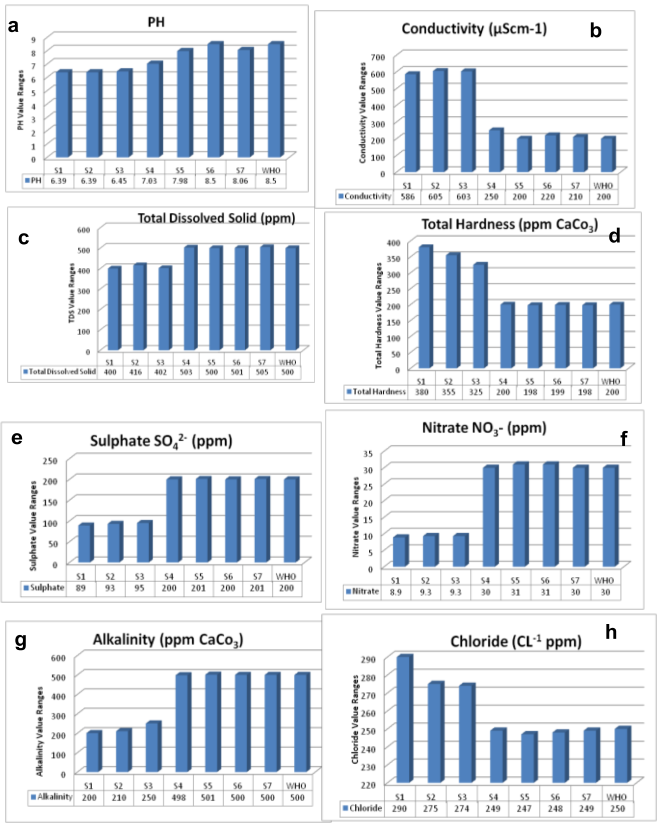

Figure 8: Histogram showing (a) ph (b) Conductivity (c) Total Dissolve Solid (d) Total Hardness (e) Sulphate (f) Nitrate (g) Alkalinity (h) Chloride of the Study Area

Figure 8i displays the copper concentration of groundwater with values ranging from 0.051 to 1.49 ppm with average values of 0.87 ppm. The values within S1, S2, and S3 generally fall below the WHO recommended safe value for drinking water. The lower concentrations of copper are an indication of leachate saturation within the area. However, S4, S5, S6, and S7 fall within the recommended WHO safe value for drinking water. A high intake of Copper can cause liver and kidney damage which may eventually lead to death. It also causes stomach aches, dizziness, vomiting, and diarrhea. Figure 8j shows the Iron content of groundwater in the study area with values ranging from 0.11 to 0.32 ppm with an average value of 0.24 ppm. The values obtained at S1, S2, and S3 are generally lower than the WHO recommended safe values for drinking water. The values within S4, S5, S6, and S7 fall within the WHO recommended safe values for drinking water.

Iron concentrations however do not pose a potential health risk as they fall well within the recommended safe value (S4, S5, S6, and S7). Water with high iron concentrations may be discoloured and stain-washed clothing. Figure 8k displays the Manganese concentration values for groundwater ranging from 0.01 to 0.5 ppm with an average value of 0.29 ppm. The values obtained at S1, S2, and S3 fall below the WHO recommended safe value for drinking water. The lower concentrations of Manganese are an indication of leachate saturation and hence confirm the leachate pollution within the area. However, S4, S5, S6, and S7 fall within the recommended WHO safe value for drinking water. At a concentration greater than the WHO recommended standard, manganese may cause a noticeable colour, odour, or taste in water. However, potential health effects from manganese are not a concern until concentrations are approximately six (6) times higher.

Figure 8l exhibits the phosphate concentration of groundwater with values ranging from 0.01 – 1.99 ppm with an average value of 0.78 ppm. The values obtained at S1, S2, and S3 are generally more than the WHO recommended safe values of 0.03 ppm of drinking water. Relatively higher phosphate concentration obtained from S1, S2, and S3 is an indication of groundwater pollution when compared to S4, S5, S6, and S7 which fall within the recommended WHO standard value for drinking water. Too much phosphorus can cause increased growth of algae and large aquatic plants which can result in decreased levels of dissolved oxygen a process called eutrophication. A high level of phosphorus can also lead to an algae bloom that produces algal toxins which can be harmful to humans and animals.

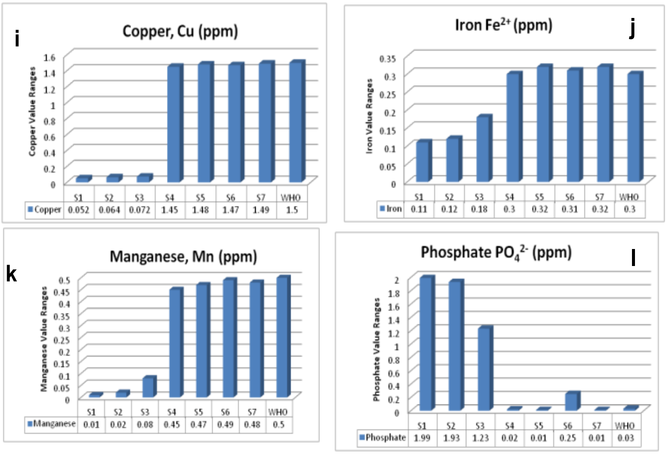

Figure 8: Histogram showing (i) Copper (j) Iron (k) Manganese (l) Phosphate the Phosphate of the Study Area

4.6 Contaminant Map

Figure 9 shows the contaminant map which was computed using the VES resistivity values across the investigated area. The contaminant map was classified into two; the contaminated zone and the uncontaminated zone. The contaminated zone (blue colour) was observed in the northern, northwestern, northeastern, eastern, and southeastern regions of the study area. These indicate that the leachate generated from the waste dumped on the landfill has affected the lithological properties within and to a distance of 20 m away from the landfill which posed threat to the impact of groundwater quality in the region. The uncontaminated zone (blue colour) indicates the region of good groundwater quality which was observed in the northwestern, western, southwestern, and southern parts of the investigated area.

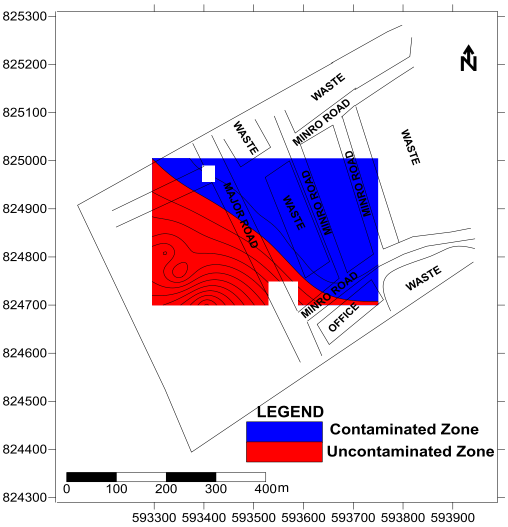

Figure 9: Contaminant Map of the Study Area

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4.7 Lateral and Vertical Extent of the Contaminant

Figure 10a exhibits the 3D view of the lateral extent of the contaminant. It was observed from the map that the contaminant has migrated to a lateral extent of 20 m away from the landfill. The migration of the contaminant has affected the groundwater quality of the area which has caused most of the people that built their houses 2 to 20 m to the landfill to seek another means of getting quality water. Figure 10b shows the 3D view of the vertical extent of the contaminant. It was observed from the map that the contaminant have migrated to a vertical extent of 29 m within and outside the landfill to a lateral extent of 20 m. The vertical infiltration of the contaminant has affected the groundwater quality of the area in which a proper intervention must be put in place for the people living close to the landfill.

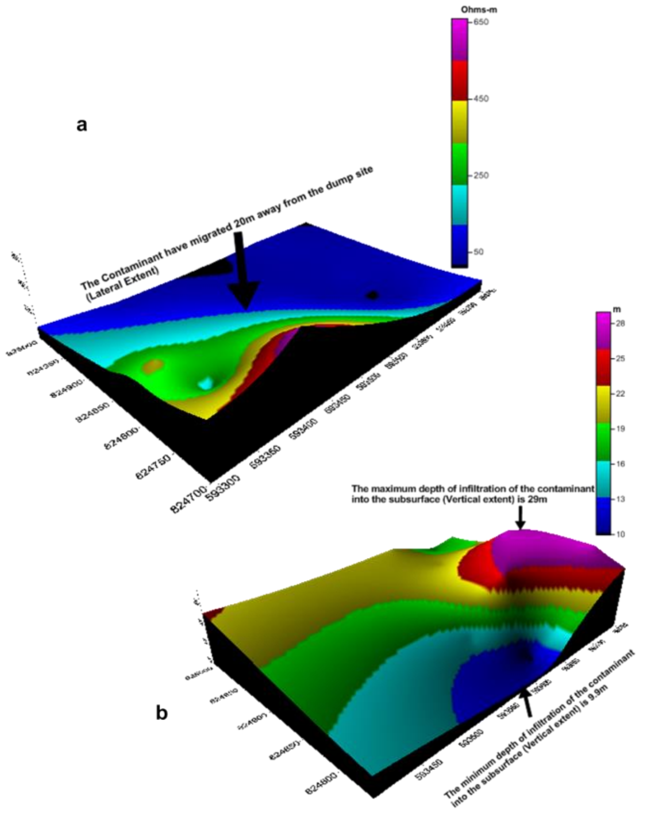

Figure 10: 3D View of the Contaminant Showing (a) Lateral Extent (b) Vertical Extent

4.8 Borehole Data Within and Outside The Landfill

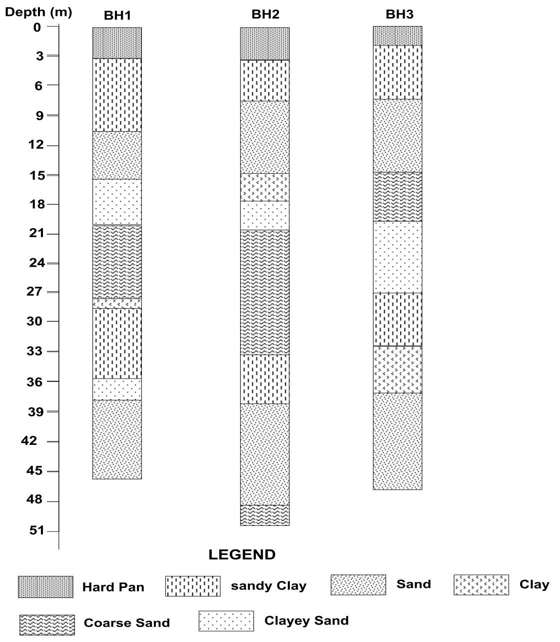

Figure 11: Borehole Data within and outside the landfill

The three-borehole data were analyzed based on the lithological properties to be able to ascertain the causes of migration of the contaminant (Figure 11). The upper 3 m was lateritic which has been contaminated due to the low resistivity observed at the topsoil followed by the sandy clay and sand formations. The sandy formation allows easy migration of the contaminant as a result of high porosity and permeability.

4.9 General Observation on the Leachate Control

The leachate control points were not properly maintained. From the borehole data within and at 20 m away from the landfill; it was observed that subsurface lithological properties have high porosity and permeability (Figure 12). The upper 3 m are lateritic and between 3 to 10 m are sandy clay and sand formation, which allow the easy migration of the contaminant laterally and vertically. A proper measure should be taken to prevent further movement or migration of the contaminant since the near-surface lithologies parameters are sandy in nature with high permeability.

Figure 12: Pictorial View of Leachate Control Points

5. CONCLUSION

The current study demonstrates how electrical resistivity and hydrochemcial analysis can be used together to assess the impact of landfills on groundwater quality. The groundwater in the study area is suspected to have been contaminated by the dumpsite and suspected impacted zones are characterized by relatively high conductivity responses in some strategically located notably S1, S2, and S3. The study revealed that the concentration of waste materials in the landfill site had systematically polluted the groundwater over time to the lateral extent of 20 m away from the dump site. The effect of such pollution as determined by the study declined away from the polluting source. This implied that the contamination of the groundwater was more dependent on the proximity to the dump sites.

Based on the results obtained and the limitations of this research, I hereby recommended that; necessary treatment should be applied to make it suitable or an alternative source of water may be sought in an area where the quality of the groundwater does not conform to the WHO standard. Governmental policies on waste disposal and management should be enacted and strictly enforced, citing dumpsites far away from the residential areas to minimize the pollution of nearby well waters, streams, and rivers, and waste sorting and treatment before disposal are encouraged. Re-designing of sanitary landfill with clay or plastic liners to prevent leachate from getting to the water table, adoption of clean technology for recycling greenhouse gases emanating from the landfill, and a sustainable land management program for reclamation are recommended.

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