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Integrated Geophysical Assessment of the Level of Contamination at the Closed Dumpsite in Mpape, Abuja, Federal Capital Territory, Nigeria

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Abstract:
Background*: The United States Environmental Protection Agency (EPA) provided grant to the Centre for People and the Environment (CPE) to carry out a study titled "Landfill Recovery and Use in Nigeria". The closed dumpsite in Mpape was one of the landfills investigated. One of the recommendations in the report published by CPE in June, 2010 was the need to carry out detailed investigation to estimate the waste limits, depth, volume, and subsurface condition in order to fully determine the viability of the gas utilization system. To date, no study has been carried out on the closed dumpsite in Mpape in response to the recommendations. Therefore, we undertook this research to evaluate the extent of leachate contamination in Mpape, using integrated geophysical method.*
Materials and Methods*: Integrated geophysical technique involving very low frequency electromagnetic (VLF-EM) and electrical resistivity (ER) methods were deployed in this research. VLF-EM and ER data collected along 5 profiles which were common to the two methods were processed using different software and modeling techniques. Two water samples representing surface water and groundwater were analyzed to determine the concentration of selected contaminants. The interpretations obtained from the geophysical and physicochemical methods were compared to determine the extent of contamination at the dumpsite.*
Results*: Conductive leachate plumes which indicated contamination were delineated in the 2-D current density cross sections and 2-D pseudo cross-sections generated with VLF-EM and ER data respectively. The results obtained showed that up to depth of between 15 and 40 m of the dumpsite had been contaminated. The results obtained from the analysis of 18 parameters in each of the two water samples showed high concentration of some contaminants which cut across physical parameters, ions and heavy metals.*
Conclusion: *The results obtained with the geophysical and physicochemical methods correlated well, thus confirming the approach as a cost effective, environmentally friendly, and non-invasive method for contamination evaluation and related geophysical studies.*
Key Words*:Dumpsite; Leachate; Electrical Resistivity; Contamination; Geophysical; Water; Contaminants.*

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I. Introduction

Over the years, poor management and indiscriminate disposal of wastes (solid, liquid, and gaseous) have remained one of the recurring decimals, among the myriad of environmental issues confronting industrialized and developing countries (Ayolabi et al. 2013). Due to the unavailability of standard dumpsites and coupled with a substandard waste management system in these countries, wastes are dumped indiscriminately at un-engineered dumpsites, open lands, and water bodies. These unethical practices of indiscriminate disposal of unsorted waste pose a threat and endanger groundwater and other subsurface resources. Globally, consumption of polluted drinking water is responsible for the loss of ~ 2 million lives annually (Okonkwo et al. 2005).

Among other environmental challenges associated with improper disposal of wastes are air pollution and the outbreak of epidemic. Leachates are complex and highly concentrated effluent that are generated when liquid, particularly rainwater percolates through substandard dumpsites. They flow downward due to gravity and may pollute the groundwater, shallow wells and water boreholes which are estimated to meet ~85% of the domestic andagricultural needs in Nigeria (Bayode andAdeniyi 2014). Once leachate makes contact with the groundwater, the potability of the groundwater is impaired.

The closed dumpsite in Mpape was originally a quarry site before it was converted to an unengineereddumpsite which was operated between 1989 and 2005. Upon commissioning in 1989, the dumpsite was remote to settlements. But due to high pace of urban expansion in Abuja over the years, the Mpape closed dumpsite is currently at the centre, bordering numerous residential, commercial and industrial facilities.There is no record to show that geophysical investigation was conducted before selecting the site. Typical of substandard dumpsites that usually lack bottom liner, it is expected that the subsurface including groundwater underlying the dumpsite have been heavily contaminated over the years following downward percolation of leachate emanating from the decomposed wastes. (CPE 2010) undertook a study entitled "Dumpsite Recovery and Use in Nigeria". The closed dumpsite in Mpape was one of the dumpsites that were investigated. One of the key recommendations of the study which was funded by the US Environmental Protection Agency (USEPA) was the need to carry out a detailed investigation in order to determine the subsurface conditions of the sites. Groundwater is the only source of water for domestic, agricultural and industrial purposes at Mpape. It is most likely that the closed dumpsite has affected the quality of groundwater in the study area. Presently, there is no data or technical information to guide the development of water boreholes within the vicinity of the dumpsite as well as the neighbouring community.Therefore, the main objectives of this study which seeks to address the issues raised above are: assessment of the degree of contamination of the subsurface in the study area; evaluation of the impact of the closed dumpsite on the surrounding environment using results of the laboratory analysis of liquid samples; and characterization of selected contaminants evolving from the closed dumpsite.

(Ibuot et al. 2017) used geophysical and physicochemical methods to characterize organic waste contamination of hydrolithofaciesin the coastal dumpsite of Akwa Ibom State, Nigeria. The results obtained showed that the resistivity values of the underlying layers were lower than the overlying layer, possibly due to the infiltration of leachate into the underlying layers. Results of the physicochemical analysis of water samples from boreholes near the dumpsite were used to corroborate the interpreted resistivity data. (Olafisoye et al. 2012) employed VLF-EM and hydro-physicochemical methods in the investigation of groundwater contamination at Aarada Waste Disposal Site, Ogbomoso, and Southwestern Nigeria. The results obtained from the processed VLF-EM data revealed that the surface of the study area was heavily contaminated by leachate. The water quality report showed hazardously high values of heavy metals, which confirmed the findings of the VLF-EM survey. (Popoola andAdenuga 2019) used integrated geophysical methods to determine leachate curtailment capacity of selected dumpsites in Ogun State, Southwestern Nigeria. The study concluded that the area was underlain by laterite and sand which both lacked the capacity to curtail the infiltration of pollutants into the aquifer. From the results obtained in these prior studies among others, it is certain that the output of this research will help stakeholders to successfully plan and implement subsequent groundwater projects within the vicinity of the closed dumpsite to ensure sustainable utilization of the resource.

II. Description of the Study Area

Mpape is a popular settlement in the Abuja Municipal Area Council (AMAC) in the Federal Capital Territory (FCT), Abuja Nigeria. It forms part of the region commonly referred to as the Middle Belt of the country. The geographical coordinates of Mpape are latitude 9 08$^{/}$ 45$^{//}$ and longitude 7 29$^{/}$ 44$^{//}$. Accordingly, the FCT is located between latitudes $8^{0}25^{/}$ and $9^{0}25^{/}$N of the Equator and longitudes $6^{0}47^{/}$ and $7^{0}40^{/}$E of the Greenwich Meridian. The heat experienced in the area is attributed to high temperatures and relative humidity that characterize the Niger-Benue trough. The average annual temperature in the area is 27.3 ^{0}C (FCT 2003). Typical of tropical zones, precipitation in Mpape is dominated by rainfall. The weather conditions of Mpape is also influenced by the peculiar terrain of the area with prominent rock outcrops and inselbergs occasionally causing mountain-induced precipitation in the area (Abam andNgah 2013).

III. Geology and Hydrogeology of Mpape

Mpape is underlain by two major rock formations i.e. the basement complex and the sedimentary rock formations. The basement complex consists essentially of undifferentiated Precambrian rocks. This rock type underlies about 90% of the FCT. The rocks are distinguished in broad terms into migmatites, Older Granites, and meta-sediments. The meta-sediments are generally restricted to the southeastern part of the Territory and occur as isolated strip patches within the granite massifs (Longpia et al. 2013). Apart from these two rock groups, coarse conglomerates, clay-sand-pebble admixtures, and cross-stratified sandstones underlie the area. This sediment is referred to as the basal sediment that is alluvial in origin. Due to persistent exposure to different climate and seasonal conditions such as rainfall, the heating effect from the sun, wind, etc rocks in Mpape often experience weathering that changes them into Earth materials with different characteristics. Some of the Earth materials include reddish micaceous sandy clay, clay minerals, and laterite.

Among the favorable geologic signatures for prolific aquifer systems in the basement complex formation are thick and unconsolidated overburden (Bala and Ike 2001). Two types of aquifer are common in the basement complex terrain i.e. overburden and fractured zone aquifers. Depths to the water table in Mpape are discrete such that there is seasonal fluctuation in the volume of groundwater in the area, particularly in the overburden aquifer. The climatic and geologic factors that promote the occurrence and accumulation of groundwater in Mpape are favorable temperature, high rainfall, thick overburden, weathered basement, and interconnected fractured zones (Abam andNgah 2013). The geological map of Mpape is presented in Figure 1.

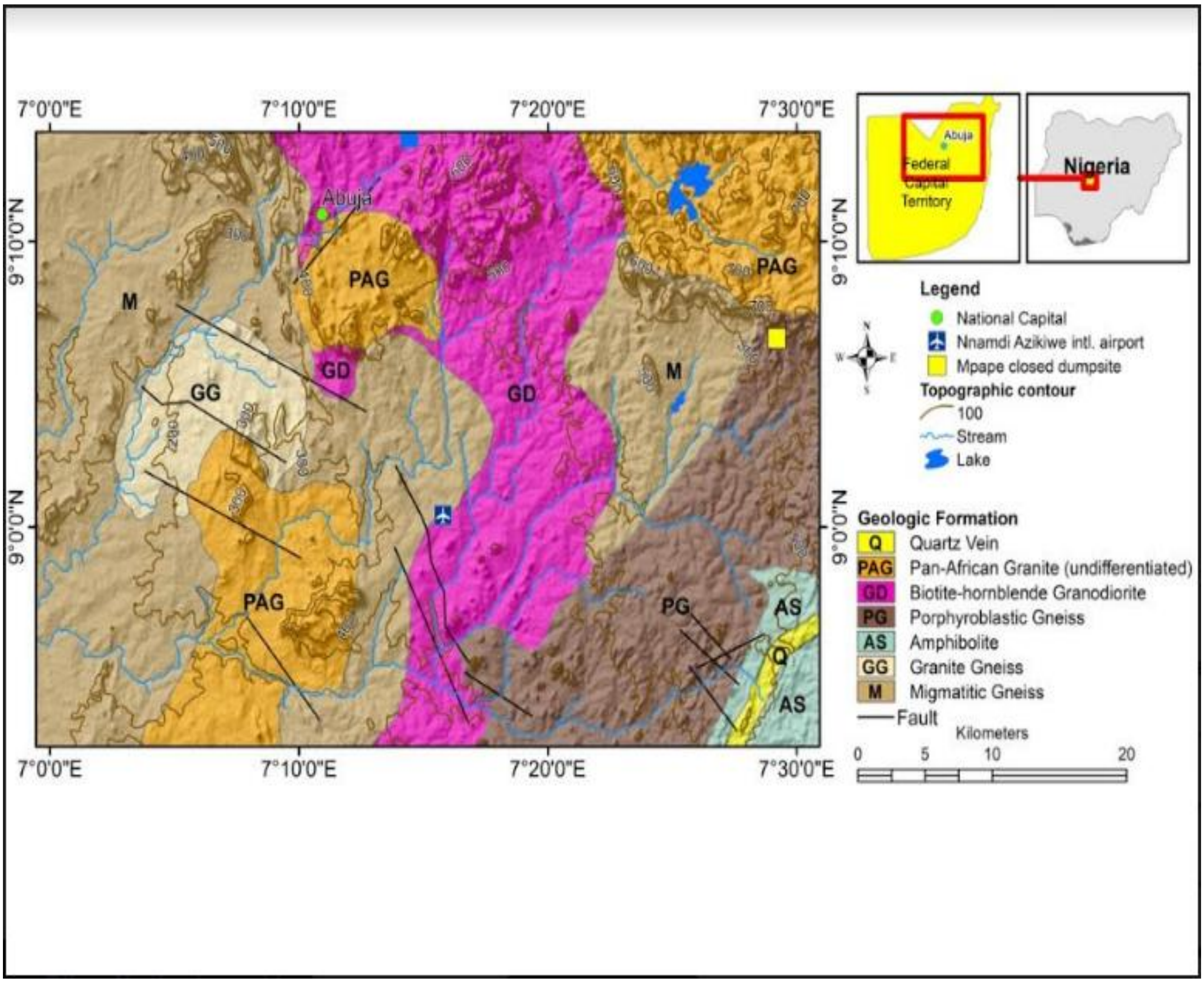


Figure 1: Geological map of Mpape showing the location of the closed dumpsite (NGSA 2006)

IV. Materials and Method

The ABEM Wadi VLF receiver that utilizes only a magnetic field component was used to collect very low frequency electromagnetic(VLF-EM) data in this research. It measures raw real (RR) and raw imaginary (RI) data sets. With the help of an inbuilt filtering program, the device automatically filters the noise from the signals (raw real and raw imaginary) to produce filtered real (FR) and filtered imaginary (FI) components. In other words, it measures the ratio of the vertical component of the magnetic field (H_z) which depends on the subsurface conductor and the horizontal component (H_x) of the primary magnetic field which depends mostly on the transmitter (Mittal et al. 2014). Generally, the depth of investigation for the VLF-EM method depends on the skin depth which is a measure of how closely electric current flows along the surface of a material. If the geological strike is along the Y-axis from the point of observation, then the tilt angle α, which is the inclination of the major axis of the polarization ellipse, and the ellipticity e, which is the ratio of the minor to the major axis are calculated by the formula:

$$\text{Tan } 2\propto = \pm \frac{2(H_z/H_x)\cos\Delta\emptyset}{1-(H_z/H_x)^2}$$

$$e = \frac{H_z H_x \sin\Delta\emptyset}{{H_1}^2} \qquad (1)$$

where the phase difference $\Delta\emptyset = \emptyset_z - \emptyset_x$, in which $\emptyset_z$is the phase of H_z, $\emptyset_x$ is the phase H_x, and $H_1 = \left|H_z e^{i\Delta\emptyset} \sin\propto + H_x \cos\propto\right|$(Smith & Ward 1974).

VLF-EM measurements were conducted along four parallel profiles which were perpendicular to the general N-S geologic strike in the study area. The length of each profile established at the closed dumpsite, which was separated by a distance of 3 m, was 160 m. VLF-EM measurements were taken at 5 m intervals on each profile such that the number of stations per profile at the closed dumpsite was 33. Accordingly, the profiles were oriented at high angles to the direction of the VLF transmitter. All the profiles were common to the two geophysical methods used in this research. For control purposes, VLF-EM data were collected on three profiles along the outer northern expressway, Abuja. Since the results obtained from the three profiles were similar, one profile (P1) was selected to serve as control. The length of the profile was 135 with 28 stations, while the distance between the dumpsite and the control site was 1.24 m.

ABEM SAS 4000 Terrameter, which has the capacity to directly measure apparent resistivity, was used to collect resistivity data in this research. For Wenner electrode geometry:

$$K = 2\pi a$$

$$\text{Therefore, } \rho_a = 2\pi a R \quad (2)$$

where K is the geometrical factor; a is the distance between electrodes;ρ_a is the apparent resistivity; and R is the resistance in Ohms. From this equation, the corresponding resistance for each data set can be calculated using equation 3:

$$R = \frac{\rho a}{2\pi a} \quad (3)$$

Wenner electrode configuration was used in collecting resistivity data at the closed dumpsite and control site respectively. Nigeria is characterized by two main geological formations i.e. basement complex and sedimentary formations. While sedimentary formations require wide current electrode separation for deep exploration because of its thick overburden, the basement complex formation where this research was conducted is characterized by relatively shorter overburden such that wide current electrode separation is not required for deeper penetration.As per survey design, the same geometry, parameters and dimensions used in the collection of VLF-EM data were maintained. All the profiles were established within the periphery of the closed dumpsite and the location chosen for control purposes. The data and sample acquisition map is shown in Figure 2.

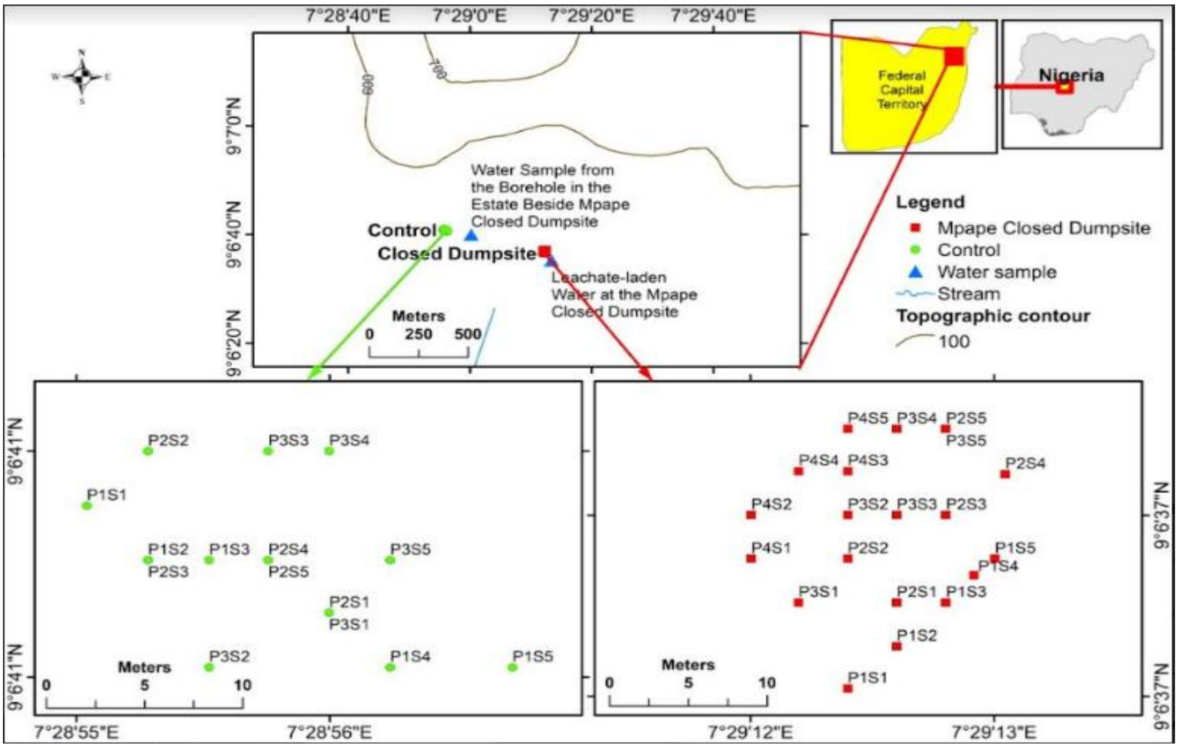


Figure 2: Data and sample acquisition map

V. Surface and Groundwater Sampling

Two water samples, representing surface water and groundwater were analyzed. The samples were collected using simple random sampling technique. While the surface water was the highly polluted leachate-laden water found within the vicinity of the dumpsite, a sample representing groundwater was collected from the borehole in the residential estate beside the dumpsite. The GPS coordinates of the point where the leachate-laden water sample was collected and the borehole in the residential estate were $9^0 6^/ 35.2^{//}$N,$7^0 29^/ 13.4^{//}$E and $9^0 6.666^/$N,$7^0 29.186^/$E respectively. Threefactors informed the choice of contaminants characterized in the water samples. These included the types of contaminants anticipated from dumpsites from FCT following the types of domestic, commercial, agricultural, and industrial activities that are common in the area. A good example is lead which is a common input for the production of alloys and lead-acid batteries in many sectors (WHO 2008). One of the sectors that generate lead-based solid waste is the automobile industry, which was one of the most viable sectors in the study area. Another factor was the impacts of the contaminants on human health and the environment. For example, there is evidence that cadmium is a carcinogenic element that destroys delicate body organs such as the kidney (WHO 2008). The last consideration was the availability of equipment, analytical systems, and the requisite expertise to measure and characterize the contaminants, particularly the suite of critical heavy metals selected for analysis in this research. The water samples were analyzed at the National Laboratory called the Sheda Science and Technology Complex (SHESTCO), Abuja, Nigeria. The contaminants characterized cut across physical parameters, ions, and heavy metals. The physical parameters that were characterized included pH, electrical conductivity, total dissolved solids (TDS), and turbidity, while the ions included chloride, phosphate, and nitrate. Accordingly, the heavy metals that were characterized included Iron (Fe), Lead (Pb), Cadmium (Cd), Chromium (Cr), Nickel (Ni), Copper (Cu), Zinc (Zn), Manganese (Mn), Potassium (K), Sodium (Na), and Cobalt (Co). While the concentrations of all the contaminants in the water samples were compared with WHO thresholds to determine their potability or otherwise, the identified contaminants were used to corroborate the results obtained from the VLF-EM and ER methods.

VI. Data Processing

Typical of contamination or pollution studies, the data sets used in this research were filtered real (FR) and filtered imaginary (FI) components. Very low frequency electromagnetic (VLF-EM) profiles were presented as composite plots of FR and FI components against distance using Microsoft Excel. The double plots of FR and FI components enabled the qualitative identification of linear features (Oluwafemi 2012). To aid easy identification of the two quantities (FR and FI) in the composite plots, color codes of red (for FR) and green (for FI) were assigned and maintained in all the plots. The Karous-Hjelt (K-H) and Fraser Filtering (KHFFILT) software was used to model the FR component of the VLF-EM data to produce the 2-D current density cross-sections. ER data (a andρ_a) were subjected to computer iteration and interpretation using the IPI2WIN software. The plots generated were used to determine the various geo-electric and formation signatures necessary to realize the objectives of this research. With the help of Golden Surfer Software, the interpreted results from resistivity data were used to produce 2-D pseudo cross-sections for each profile.

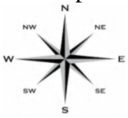
VII. Discussion of the Results of the Processed VLF-EM Data

The results of the processed VLF-EM data were presented as plots ofFR andFI against station distance and 2-D current density cross-section of FR data for each profile. To guarantee a fair comparison between the two processing techniques employed, the two models were stacked such that the 2-D current density cross-sections were placed directly under the plots of FR and FI against station distance. The 2D current density cross-section images the subsurface (Adagunodo et al. 2014). Interpretation was carried out by taking into consideration the high amplitude signals on the VLF-EM profiles that were diagnostic of contaminated zones. They could also be reflective of weathered or fractured zones. The double plots of FR and FI components of the VLF-EM data enabled qualitative identification of the top linear features i.e. points of coincidence of crossovers and positive peaks of the real and filtered anomaly (Oluwafemi 2012). The positive and negative peaks mapped on the FR and FI curves are zones of interest in groundwater contamination, which often show the contaminant plume as zones of low resistivity surrounded on both sides by materials of higher resistivity (Oluwafemi 2012). The asymmetry of conductive anomalies suggests that the conductive structures are dipping. One of the merits of using this interpretation technique is that FR plots are used to delineate real anomalies while RR plots are used to segregate discontinuities along the profiles. Often, the anomaly pattern exhibit varying amplitudes that are controlled by the depth of targets (conductive or resistive bodies) to the surface, geometry, and attitude. From a typical current density pseudo section, the attitude of the conductive body, the length of the contaminant plume(s), depth to top and bottom of the contaminant plumes, etc can be estimated. Generally, the occurrence of the conductive targets (contaminant plumes) on the current density pseudo sections often coincide with the zones of high current density delineated in the VLF-EM profiles using Microsoft Excel (Adagunodo et al. 2014). In current density cross-sections, conductivity is shown as color codes with conductivity increasing from left to right i.e. from negative to positive (Oluwafemi 2012).

The interpretation for profile 1 (figure 3a) revealed the presence of positive and negative amplitudes which represent conductive zones or resistive formations. High positive values indicate the presence of conductive subsurface structures while low or negative values are indicative of resistive formations (Ikhifa and Umego, 2016). Geologic signatures diagnostic of conductive zones were exposed at the horizontal distance between 40 and 130m. There was low conductivity response with amplitudes of about -9 between 10 and 20m. Low conductivity signatures were also recorded between 140 and 160m along the profile. These low conductivity responses with negative amplitudes are indicative of the existence of a resistive material (Oluwafemi, 2012). The corresponding 2-D current density cross-section for profile 1 (figure 3b) delineated conductive zones interpreted as contaminant plumes at four points i.e. between approximate distances of 20 and

35m; 40 and 45m; 60 and 80m; and 85 and 90m. In terms of size, the approximate width of the four contaminant plumes on this profile range between 10 and 25m. While contamination at distance between 20 and 45m terminated at approximate depth of 25m, contaminations at the distance between 60 and 90m extended beyond 30m of the subsurface. Aside contamination, conductive zones could be as a result of clayey materials, linear geologic features (such as faults, joints, fractures), and contact between two rock types. Zones with relatively higher resistivity as exposed between approximate distances of 8 and 15m as well as 110 and 145m are indicative of either of the following: extrusion of highly resistive rock, sparsely decayed solid wastes, high resistivity mineralization, etc. In Profile 2, low conductivity responses were observed at the horizontal distance between 5 and 25m and 125 and 150m (figure 4a) with amplitude ranging between -25 and -5. Also, positive amplitudes which depicted conductive bodies were revealed at several points along the FR and FI curves between 30 and 120m. In the associated current density cross-section (figure 4b), large dipping conductive materials suspected to be leachate plumes were exposed between 20 and 90m. While the leachate plume exposed at the horizontal distance between 20 and 50m extended from the surface to depth of about 25m, the plumes at the distance between 52 and 90m started from the Earth surface and stretched beyond 25m.

In profile 3, high and low positive and negative amplitudes were revealed along the FR and FI curves (figure 5a) between approximate distance of 15 and 55m. The plot was characterized by interchanging and seemingly regular positive and negative amplitudes between 60 and 145m. In the corresponding current density cross-section (figure 5b), large conductive materials interpreted as leachate plumes were revealed between 40 and 70m as well as between 75 and 110m respectively. The two plumes extended beyond depth of 25m. A large dipping resistive material trending between the surface and the depth and width of about 20 and 15m respectively was observed at the horizontal distance between 20 and 35m. Along profile 4 (figure 6a), points which were representative of conductive zones manifested laterally between station positions of about 25 and 145m. Noteworthy were the spikes in amplitude on the FR curve at station distances of 10 and 120m respectively. Accordingly, negative amplitudes of about -25 and -10 were revealed on the FI and FR curves at the two ends of the plot. In the corresponding current density model (figure 6b), a dipping contaminant plume (sandwiched by resistive materials) estimated to be 10m wide and extending from the Earth surface to a depth of about 20m was revealed. Also, a v-shaped, highly contaminated zone(sandwiched by resistive materials) within the horizontal distance between 50 and 105m and extending to depth of 25m was revealed in the pseudo cross-section.At the control profile in Mpape (figure 7a), negative amplitudes were exposed between 20 and 40m, 45 and 60m, and 80 and 90m. Also, positive amplitudes were revealed between 25 and 45m, 50 and 60m, and 100 and 130m. If the Earth were homogeneous, more negative amplitudes are expected at the control sites. However, due to the heterogeneous nature of the Earth in terms of the range of values of conductivity/resistivity of Earth materials, different features of varying degree of conductivity are anticipated (Oluwafemi, 2012). At the control sites, it was assumed that contaminants/leachate plumes were not responsible for the conductive zones revealed in the current density cross-sections across the profiles. The current density pseudosection for this profile (figure 7b) presented a mixed bag of resistive and conductive zones almost at 50-50 equity. While the resistive material between 8 and 25m along the profile trended from the Earth surface and terminated at a depth of about 15m, the resistive body observed between about 105 and 125m spanned from the Earth surface to a depth of about 20m. Accordingly, a v-shaped resistive zone that extended from the Earth surface dipped beyond 20m depth. The high resistivity zones were interpreted as extrusions of granite which dominated the rock outcrops in the area. Another informed geological possibility for the zone was marble deposits which has high resistivity (low conductivity) rating. Granite and marble are the solid minerals in the FCT with high resistivity signatures of different ranges (Obaje, 2009). The low resistivity zones (characterized by high conductivity) were interpreted as regolith aquifer, weathered basement, or fractured basement. It was also interpreted as possible deposits of solid minerals in the FCT with high conductivity (low resistivity) attributes. These included zinc, iron ore, gold, lead, and feldspar (Obaje, 2009). Further, conductive zones could also be as a result of clay mineralization in the study area.The composite plots of FR and FI against distance as well as the 2-D current density cross-section for all the profiles are presented in figures 3a through 7b.



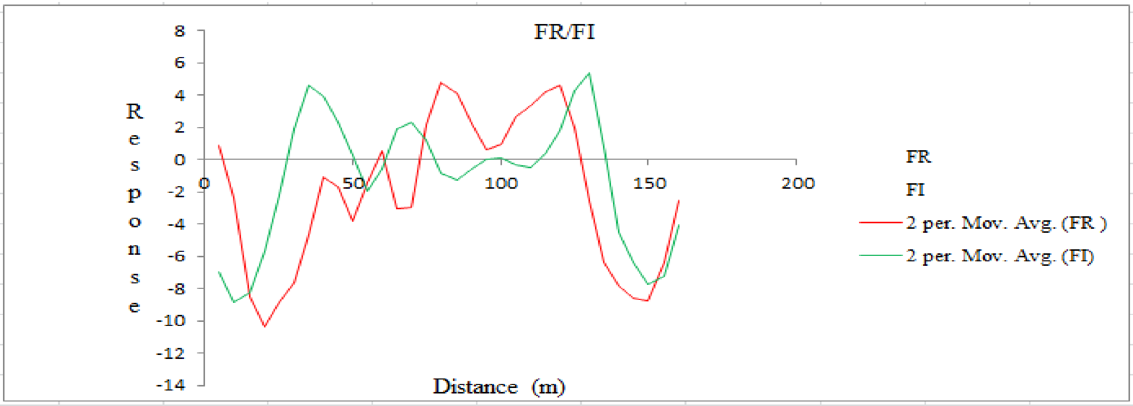


Figure 3a: Plot of FR and FI against distance for profile 1 at the Mpape closed dumpsite

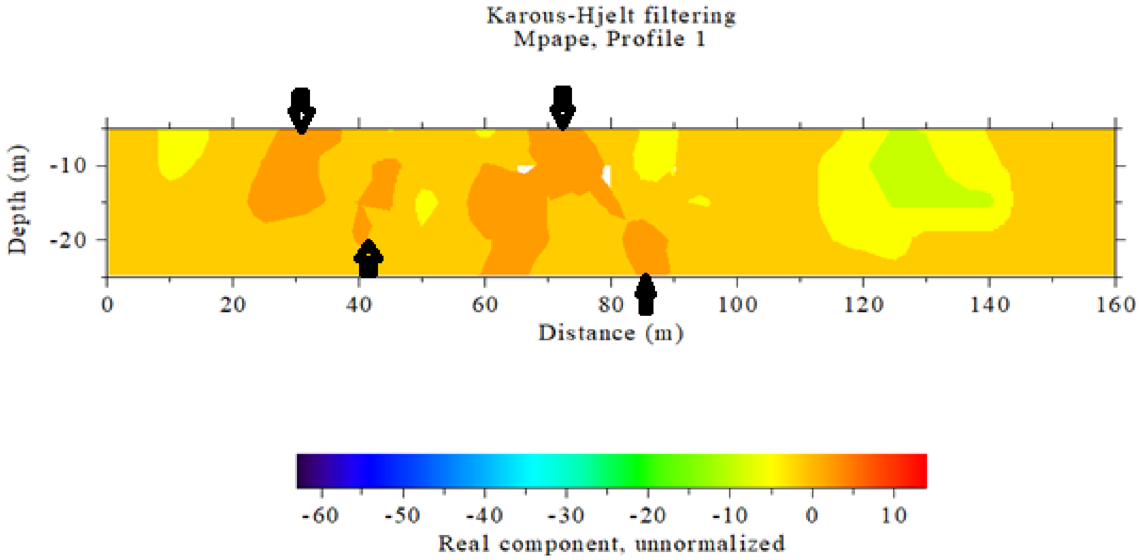


Figure 3b: 2-D Current density cross-section plot of FR data for profile 1 at the Mpape closed dumpsite

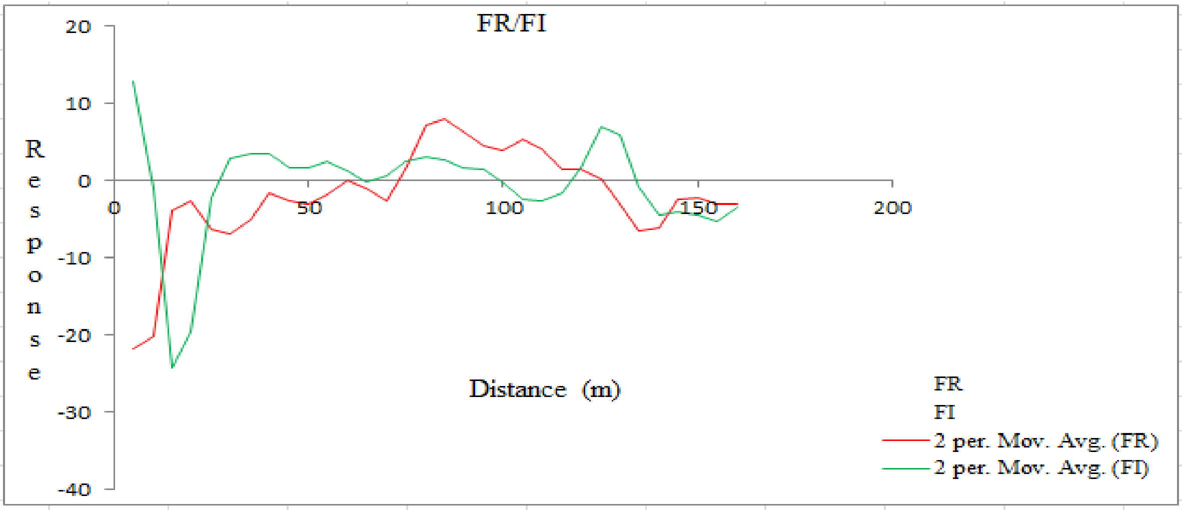


Figure 4a: Plot of FR and FI against distance for profile 2 at the Mpape closed dumpsite

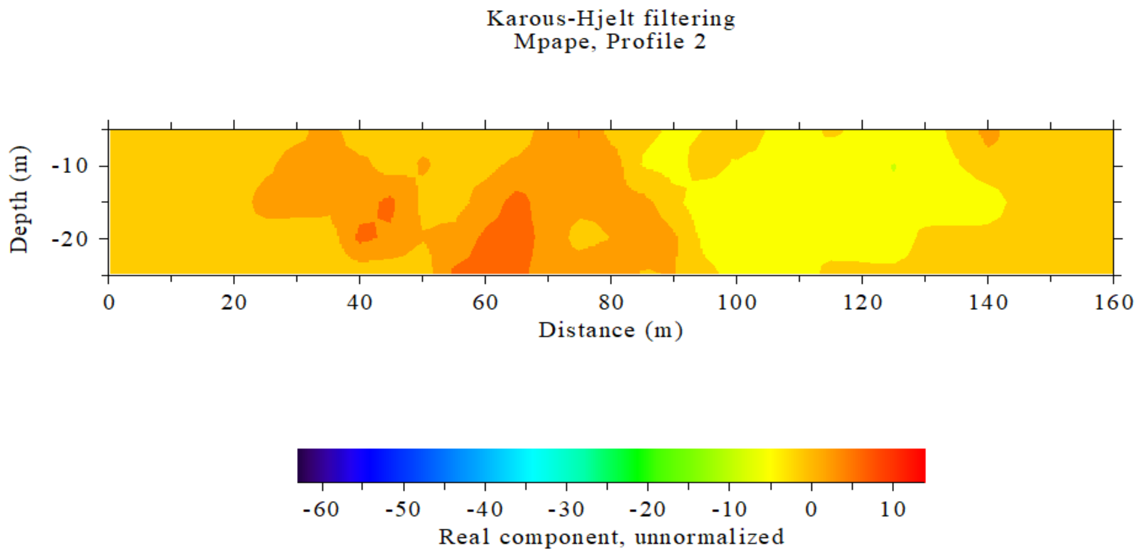


Figure 4b: 2-D Current density cross-section Plot of FR data for profile 2 at the Mpape closed dumpsite

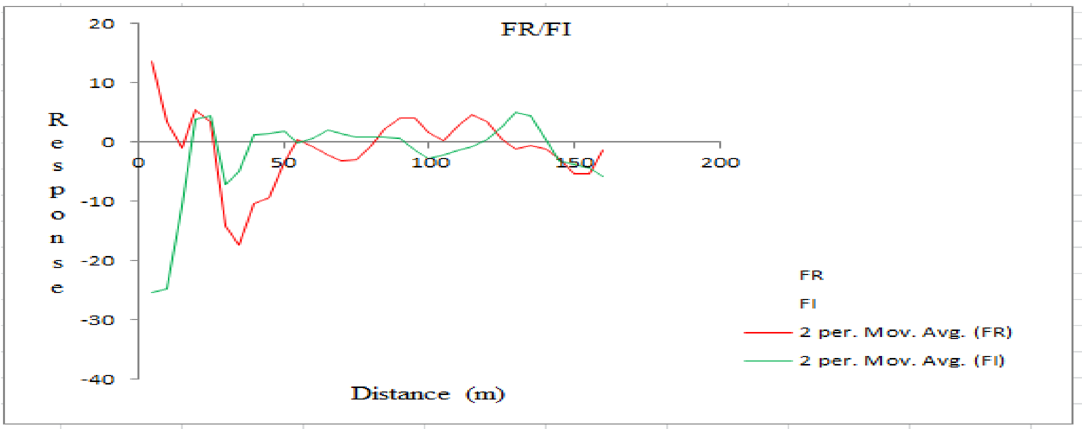


Figure 5a: Plot of FR and FI against distance for profile 3 at the Mpape closed dumpsite

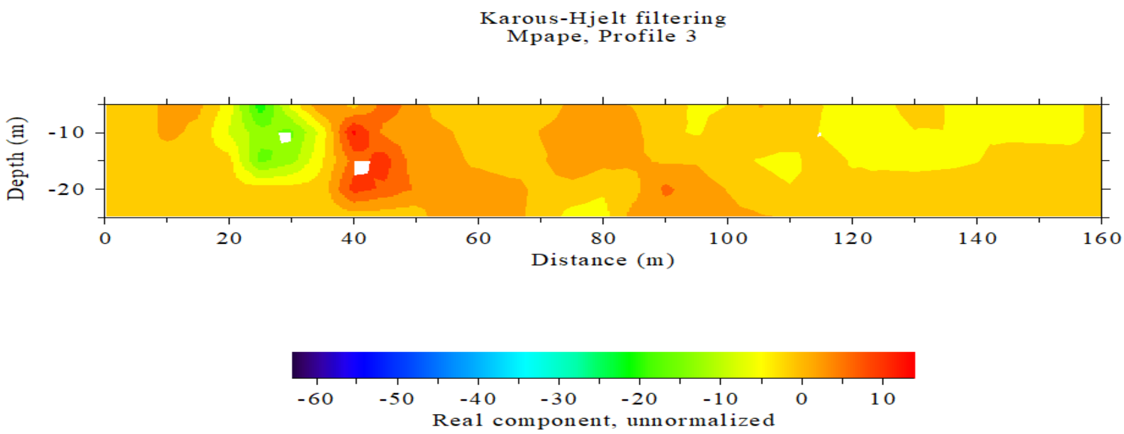


Figure 5b: 2-D Current density cross-section Plot of FR data for profile 3 at the Mpape closed dumpsite

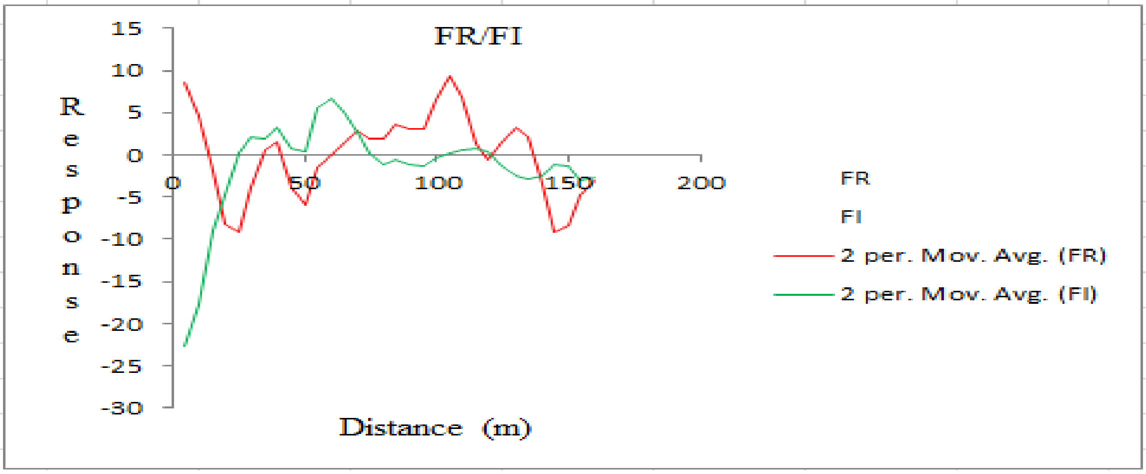


Figure 6a: Plot of FR and FI against distance for profile 4 at the Mpape closed dumpsite

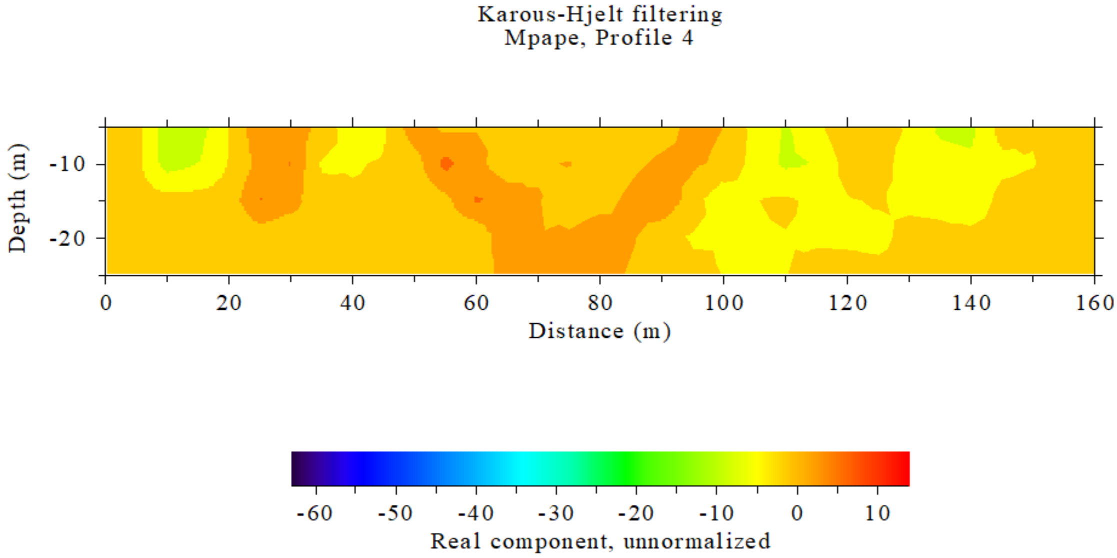


Figure 6b: 2-D Current density cross-section plot of FR data for profile 4 at the Mpape closed dumpsite

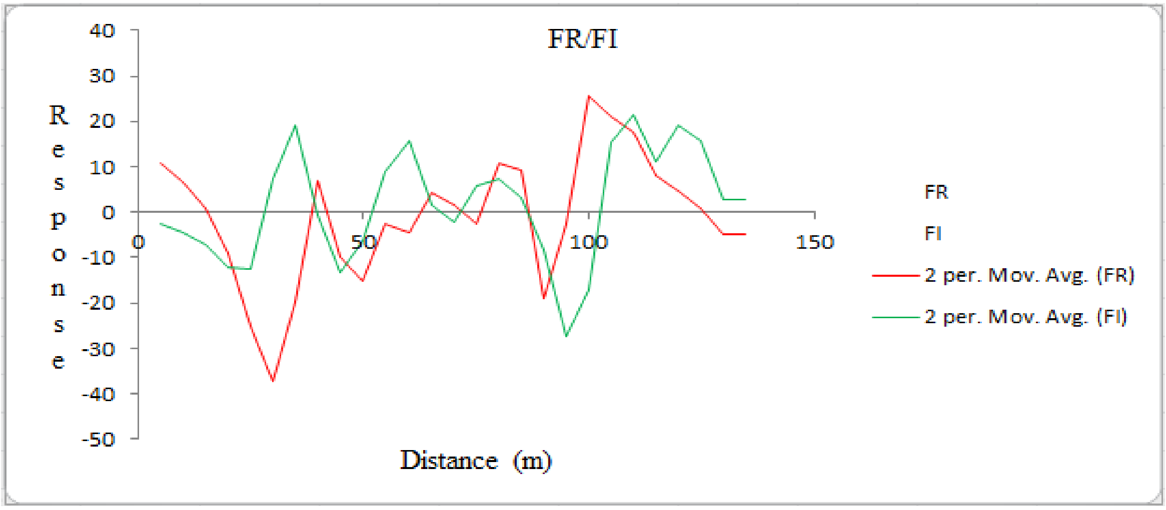


Figure 7a: Plot of FR and FI against distance for thecontrol site

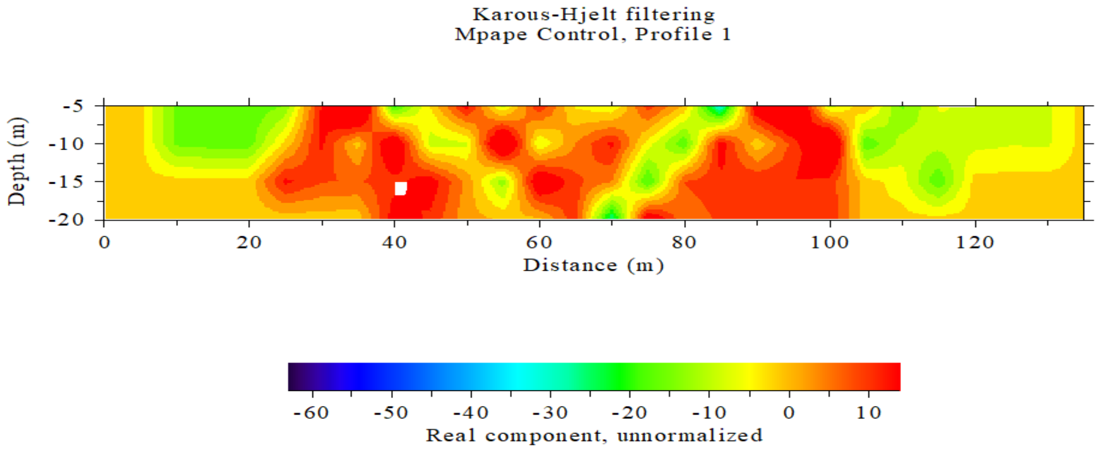


Figure 7b: 2-D current density cross-section plot of filtered real data for the control site

VIII. Discussion of the Results for the Resistivity Data

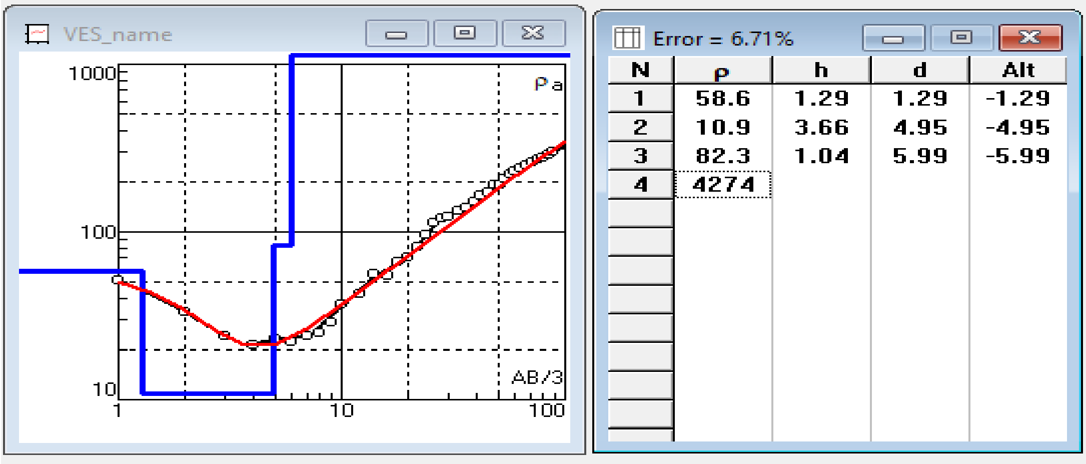
The results of the processed electrical resistivity data were presented in two modes i.e. as apparent resistivity (ρ_a) as a function of distance (AB/3) and as 2-D pseudo cross-sections. The observed low resistivity zones were attributed to the accumulation of leachate plumes. In the 2-D pseudo cross-sections, the resistivity is displayed as legends of colour codes. The light blue portions show zones of low resistivity contaminated leachate plume (or low resistivity subsurface structures), the blue to deep blue portions indicate zones of water bearing sands or gravel, while the green to red segment show zones of very high resistivity.

As seen in figure 8a, all the sounding points for profile 1 revealed 4-layer lithological sequence, all of HA curve type, with the first layer characterized by low resistivity values of between 51.5 and 91.3Ωm. The low resistivity values in the topsoil were attributed to leachate contamination. Layer thickness delineated for layer 1 across the five stations ranged between 0.965 and 1.29m. The layer thickness delineated across layers 2 and 3 across the five stations ranged between 0.651 and 4.17m, and 1.04 and 38.3m respectively. Relatively lower resistivity values of between 8.9 and 12.1Ωm for the second layer and 40.7 and 1502Ωm for the third layer were observed across the profile. From the depth of the third layer which ranged between 5.99 and 40m, it was concluded that up to about 40m depth of the profile was contaminated. A depth of 40m falls within the aquiferous or water bearing zone in a typical basement environment where confined aquifers are hosted within zones of weathering and fracturing which are often not continuous in vertical and lateral extent. The corresponding 2-D pseudo cross-section for profile 1 (figure 9) was characterized by low resistivity values between the surface and depth of between 5 and 20m. The relatively higher resistivity value exposed at some portions of the top layer of the section was attributed to the fact that upon closure, the surface of the dumpsite was covered by Earth materials of different electrical properties (Centre for People and the Environment, 2010). Pockets of isolated, highly contaminated leachate plume were delineated at depth of about 33 and 40m between S1 and S2, and S4 and S5 respectively. The section revealed that down to depth of about 40m was contaminated with the resistivity of the contaminated zone ranging from 50 to 100 Ωm. Based on the model, there was certainty of downward progression of leachate plumes over time. The model also demonstrated that the leaching pattern was both vertical and lateral, though occasionally discrete in terms of degree of contamination as seen in the leachate plumes (light blue colour) between depths of about 30 and 40m. As a guide, conductive and low resistivity zones are indicated by arrows in the current density and pseudo cross-sections for profile 1 respectively. The maximum depth penetrated across the profile was 40m in layer 3 of P1S4 with corresponding resistivity value and thickness of 47.4Ωm and 38.3m respectively. Accordingly, the lithology inferred across the profiles at the Mpape closed dumpsite comprised of lateritic topsoil, sandy clay, clayey sand, weathered basement, fractured basement, and fresh basement..The interpretation for profile 2delineated 4-layer lithological units of HA curve type across the profile. The resistivity values for the first, second, and third layers ranged between 54 and 76.3Ωm, 4.74 and 8.92Ωm, and 40.7 and 1823Ωm. While the thickness of the three layers ranged between 0.686 and 1.57m, 0.396 and 3.16m, and 1.26 and 20.5m, the corresponding estimated depths for the three layers ranged between 5.78 and 21.8m. The results obtained at P2S5 showed that down to depth of about 20.5m of the profile was contaminated. The corresponding 2-D pseudo cross-section (figure 10) detected a seemingly diagonal leachate plume which emanated from the western end of the section and terminated at the eastern end of the profile. Vertically, the plume started from the surface and terminated at depth of about 20m, thus suggesting leachate plume thickness of about 20m within the profile. The seemingly diagonal leachate plume was underlain by blue portions with resistivity values ranging between 300 and 500Ωm at estimated depths of 7.0 and 27 m respectively. The first blue portion at the depth of about 7 m was interpreted as regolith (overburden) aquifer while the second blue portion at the depth of about 27 m was inferred as confined aquifer within the geologic formation. They both represented the first and second aquifer systems of the area. A maximum depth of 21.8m was delineated in layer 3 of station 5 (P2S5) with corresponding resistivity value and thickness of 73.1Ωm and 20.5m respectively.The results of the interpretation for profile 3 followed the pattern of the results obtained for profiles 1 and 2. The curve types demonstrated by the layers were QH and HKH. Low resistivity values were delineated between layers 2 and 3 across the profile. The results obtained from station 3 (P3S3) was most representative of the degree of contamination along this profile. Hence for apparent resistivity value of 41.3Ωm (which connote contamination in the context of the resistivity values that characterized the study area) for layer 3, the corresponding depth of about 15m was assumed to have been contaminated along the profile. The 2-D pseudo-section for this profile (figure 11) delineated a highly contaminated leachate plume with some portions showing low resistivity value of about 40Ωm (light blue colour). The plume occupied between the surface and about 15m depth across the profile, implying that down to depth of about 15m of the profile was polluted by leachate.

Profile 4 revealed 3-4 geoelectric layers. The layers belonged to the H and HA curve type families. Low resistivity values ranging from 11.5 to 93.4Ωm occurred in the third layer at the 3 stations where four geoelectric layers were delineated (P4S2, P4S4, and P4S5) with thickness and depth ranging between 2.73 and 18m, and 4.63 and 24m respectively. Of the three layers demarcated at stations 1 and 3 (P4S1 and P4S3), the lowest resistivity value of 6.06Ωm which indicated a contaminated zone was recorded beneath P4S3 at depth of 3.05m. The 2-D pseudo cross-section (figure 12) showed that between the surface and depth of about 25m of the profile was contaminated with the highest concentration of leachate plume revealed between S1 and S2 (P4S1 and P4S2) and between S4 and S5 (P4S5). The colour scaling changing from light blue to blue reflects the changes in the concentration of leachate as it seeps down due to filtration by sediments. Based on the model, down to the depth of 25m of the profile was contaminated.

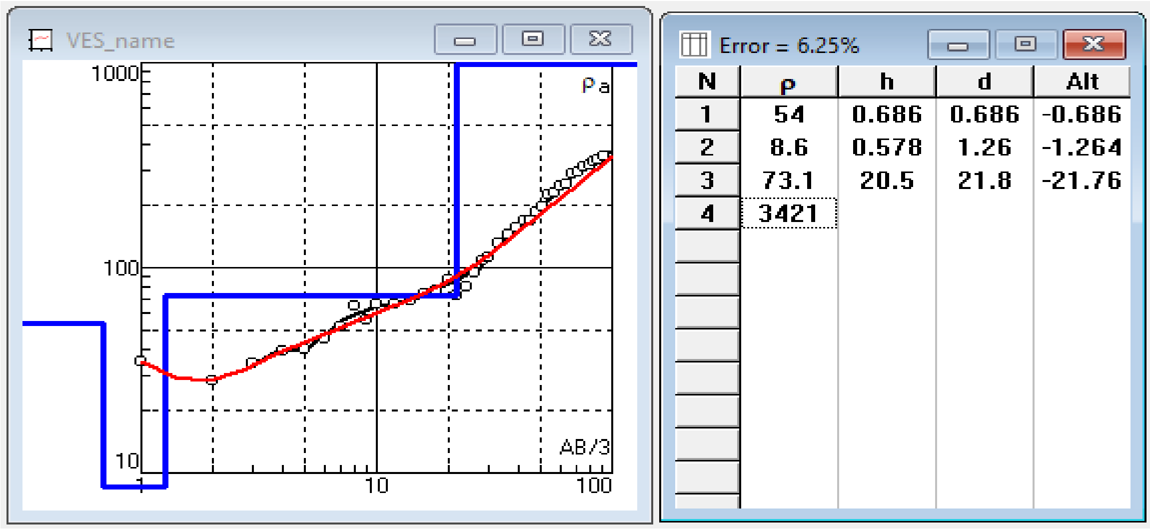
The sounding curves obtained for the five stations along profile 1 selected to serve as control were characterized by relatively higher resistivity values (figure 8e) compared to the values obtained at the dumpsite. The curve types derived for these stations were H and HA. The first three layers were crucial in evaluating the level of contamination at the closed dumpsite in Mpape, considering the fact that low resistivity values reminiscent of contaminant plumes dominated the second layer (in 3-layer case) or third layer (in 4-layer case) across all the profiles at the dumpsite. The first three layers in the five sounding stations along this profile exhibited high resistivity values ranging between 384 and 421Ωm, 192 and 266Ωm, and 433 and 18961Ωm. Layer thickness delineated across the profile ranged between 1.62 and 3.14m for the first layer, 17.5 and 62.4m for the second layer, and 35.5 and 43.3m for the third layer. Also, a maximum depth range of between 28.3 and 64 m was recorded across the profile. In the 2-D pseudo cross-section for the profile (figure 13), the resistivity of the upper layer i.e. between the surface and depth of between 15 and 30m ranged between 500 and 2000Ωm. This was relatively higher than the values obtained for equivalent layers at the dumpsite. With this result, there was possibility that the subsurface at the closed dumpsite at Mpape was highly contaminated following years of dumping of various categories of solid wastes. The low resistivity portion beneath S1 and S2 between depth of about 32 and 58m was interpreted as theaquifer formation beneath the profile. It was also assumed to represent possible deposits of any of the solid materials with low resistivity signatures associated with FCT. These included zinc, iron ore, feldspar, gold, and lead (Obaje, 2009). The green to red segment at the base of the section between S3 and S5 was interpreted to be highly resistive fresh basement underlying the profile. The inferred lithologies across the control site in Mpape were lateritic topsoil, sandy clay, weathered basement, and fresh basement. Samples of simplified 1-D sounding plots obtained across the study area are presented in figures 8a through 8e. Also, 2-D pseudo cross-sections for all the profiles investigated across the study are presented in figures 9 - 13.The inferred lithology was based on the apparent resistivity values associated with the layers and the borehole log of Mpape (figure 14).

P1S1: GPS coordinates: - $9^0 6^{/} 36.7^{//}$N,$7^0 29^{/} 12.3^{//}$E



N	ρ	h	d	Alt
1	58.6	1.29	1.29	-1.29
2	10.9	3.66	4.95	-4.95
3	82.3	1.04	5.99	-5.99
4	4274			

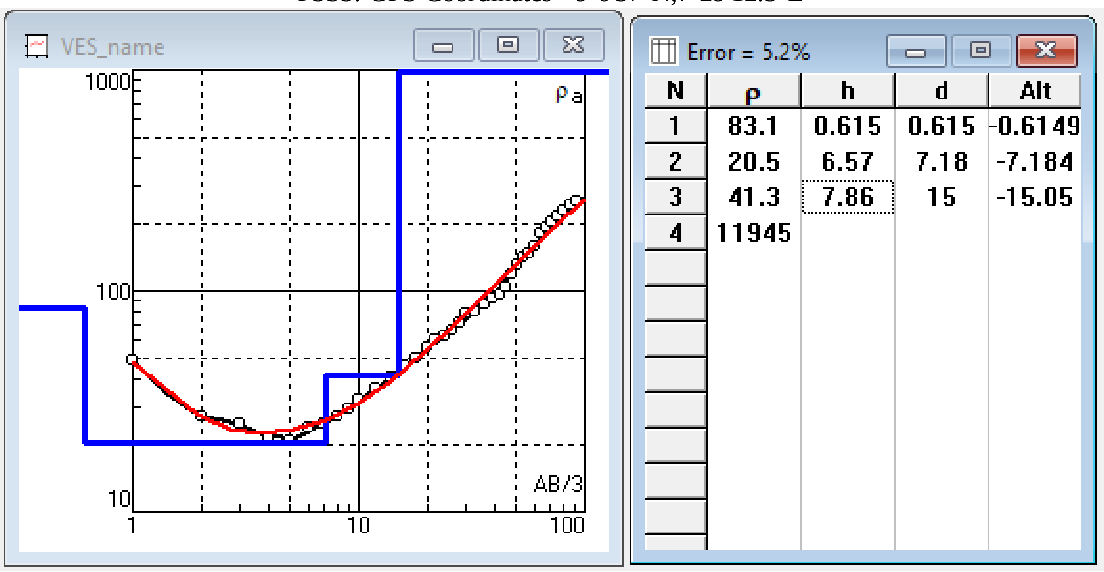
Figure 8a
P2S5: GPS coordinates - $9^0 6^/ 37.2^{//}$N,$7^0 29^/ 12.4^{//}$E



N	ρ	h	d	Alt
1	54	0.686	0.686	-0.686
2	8.6	0.578	1.26	-1.264
3	73.1	20.5	21.8	-21.76
4	3421			

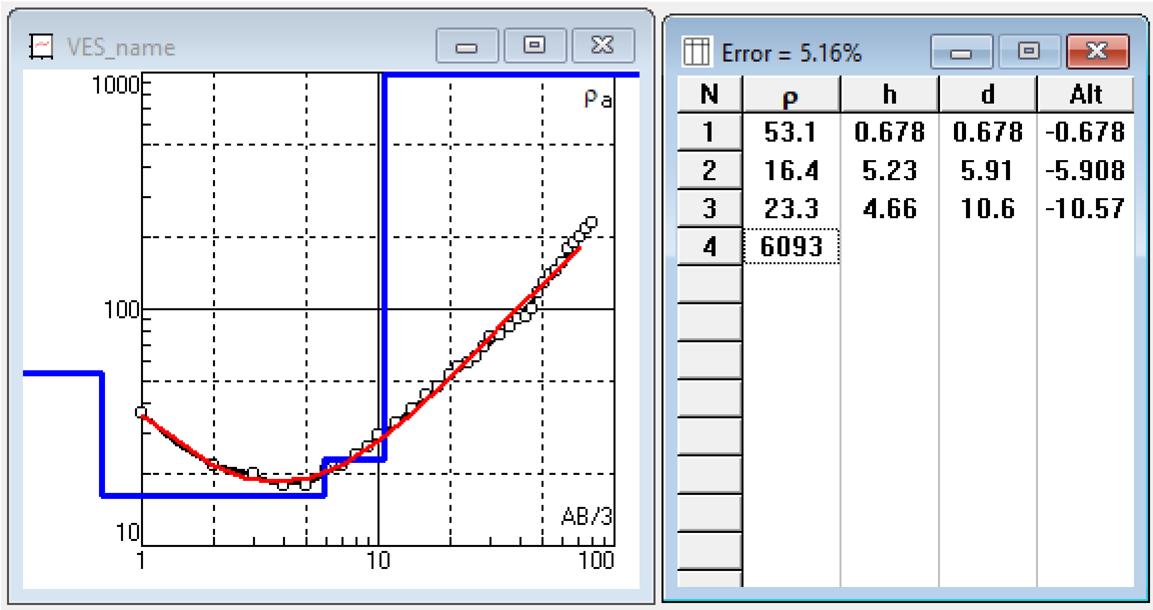
Figure 8b

P3S3: GPS Coordinates - $9^0 6^/ 37^{//}$N,$7^0 29^/ 12.3^{//}$E



N	ρ	h	d	Alt
1	83.1	0.615	0.615	-0.6149
2	20.5	6.57	7.18	-7.184
3	41.3	7.86	15	-15.05
4	11945			

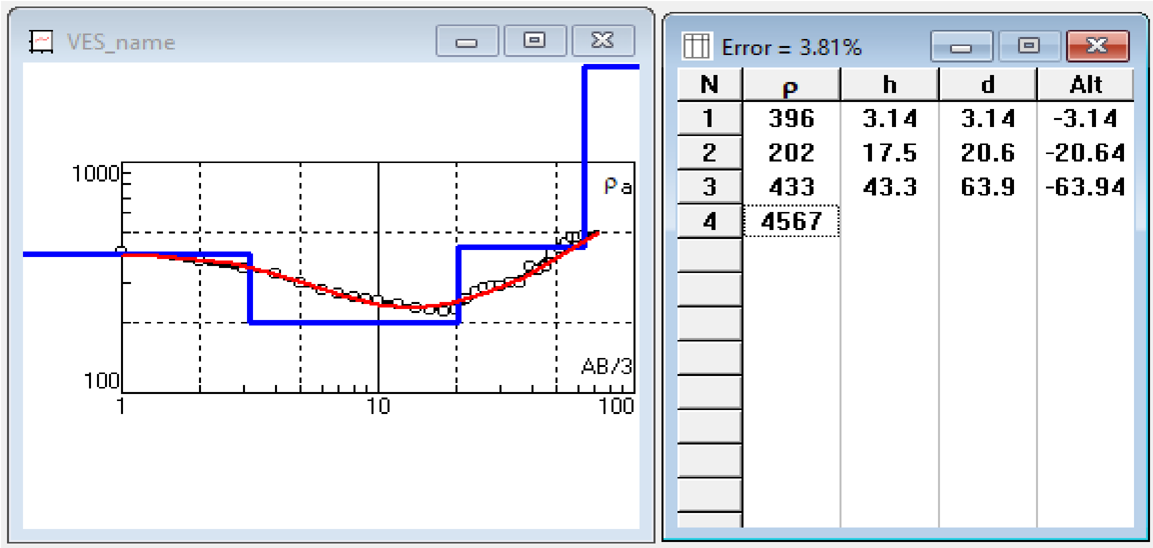
Figure 8c
P4S5: GPS oordinates - $9^0 6^/ 37.2^{//}$N,$7^0 29^/ 12.2^{//}$E



N	ρ	h	d	Alt
1	53.1	0.678	0.678	-0.678
2	16.4	5.23	5.91	-5.908
3	23.3	4.66	10.6	-10.57
4	6093			

Figure 8d

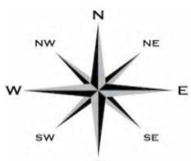
P1S2: GPS Coordinates - $9^0 6^{/} 40.8^{//}$N,$7^0 28^{/} 55.7^{//}$E



N	ρ	h	d	Alt
1	396	3.14	3.14	-3.14
2	202	17.5	20.6	-20.64
3	433	43.3	63.9	-63.94
4	4567			

Figure 8e (Control)

Figures 8a-e: Samples of simplified 1-D sounding plots obtained across the study area



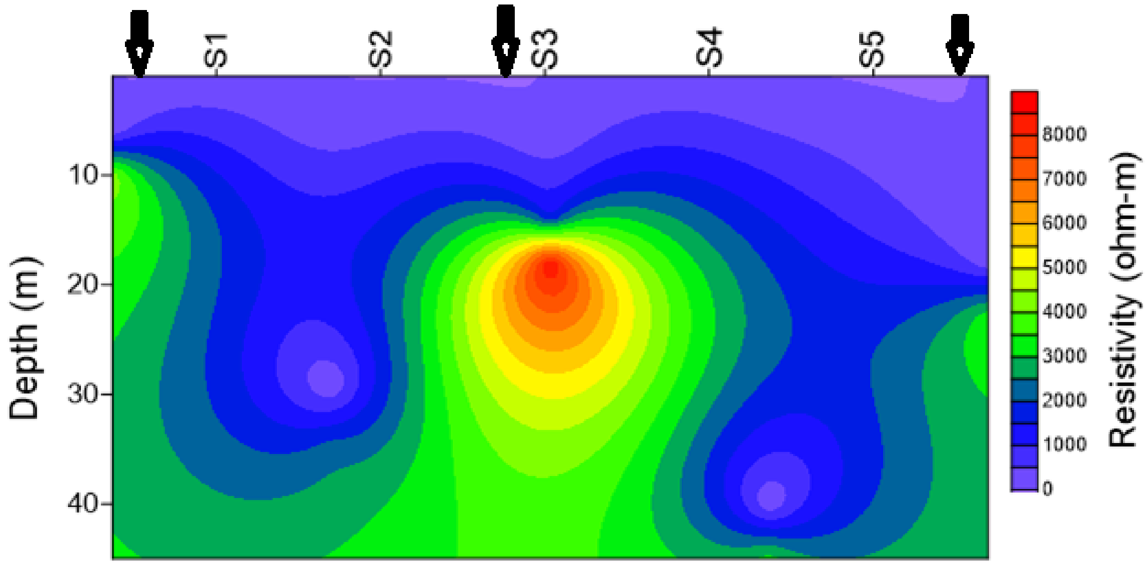


Figure 9: 2-D Pseudo Cross-section for Profile 1 at the Closed Dumpsite in Mpape

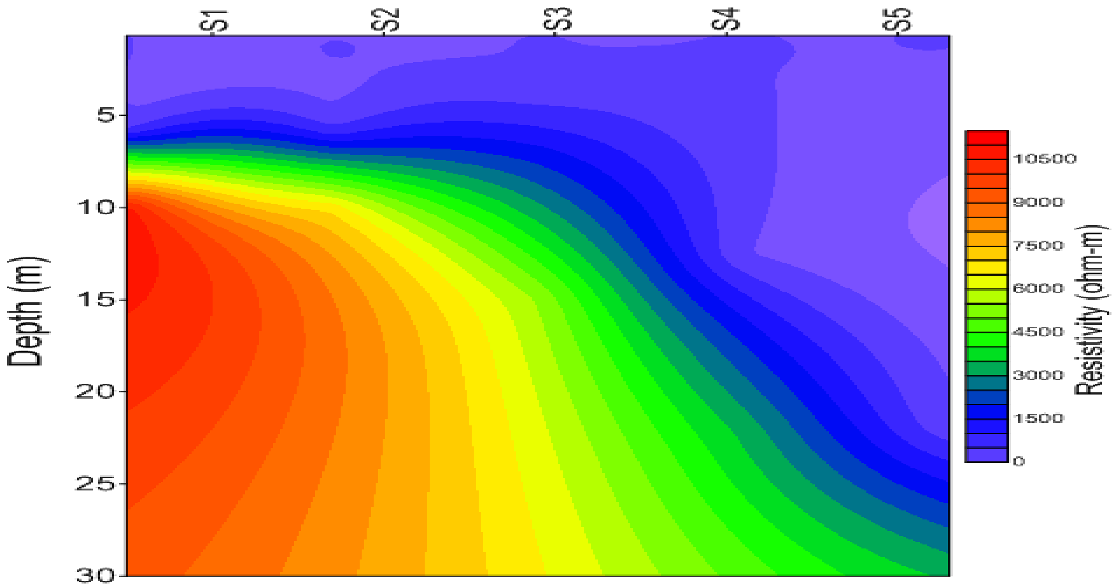


Figure 10: 2-D Pseudo Cross-section for Profile 2 at the Closed Dumpsite in Mpape

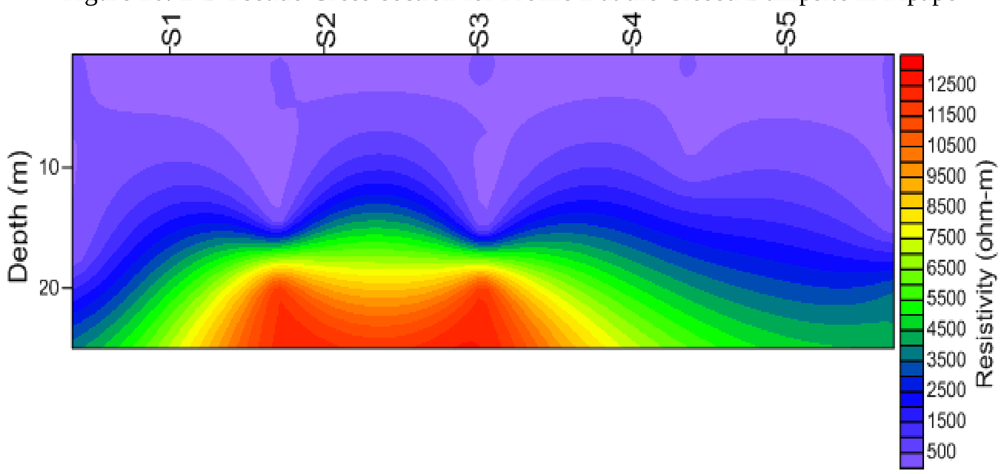


Figure 11:2-DPseudo Cross-section for Profile 3 at the Closed Dumpsite in Mpape

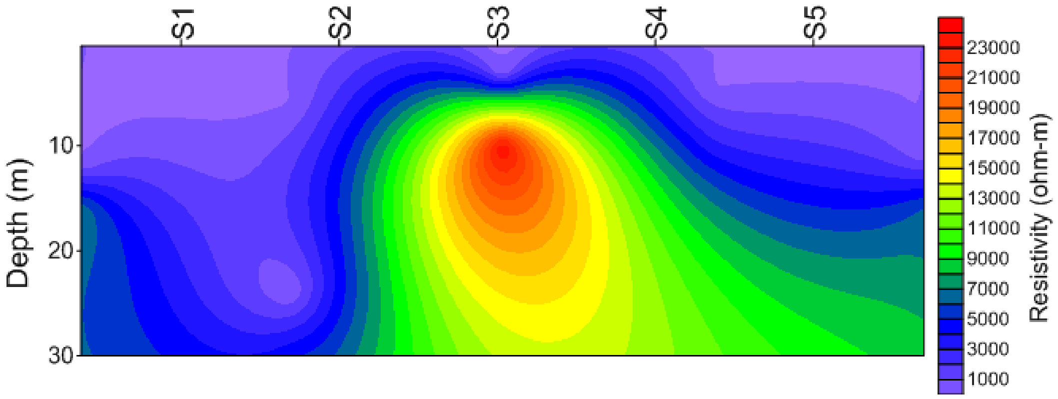


Figure 12: 2-D Pseudo Cross-section for Profile 4 at the Closed Dumpsite in Mpape

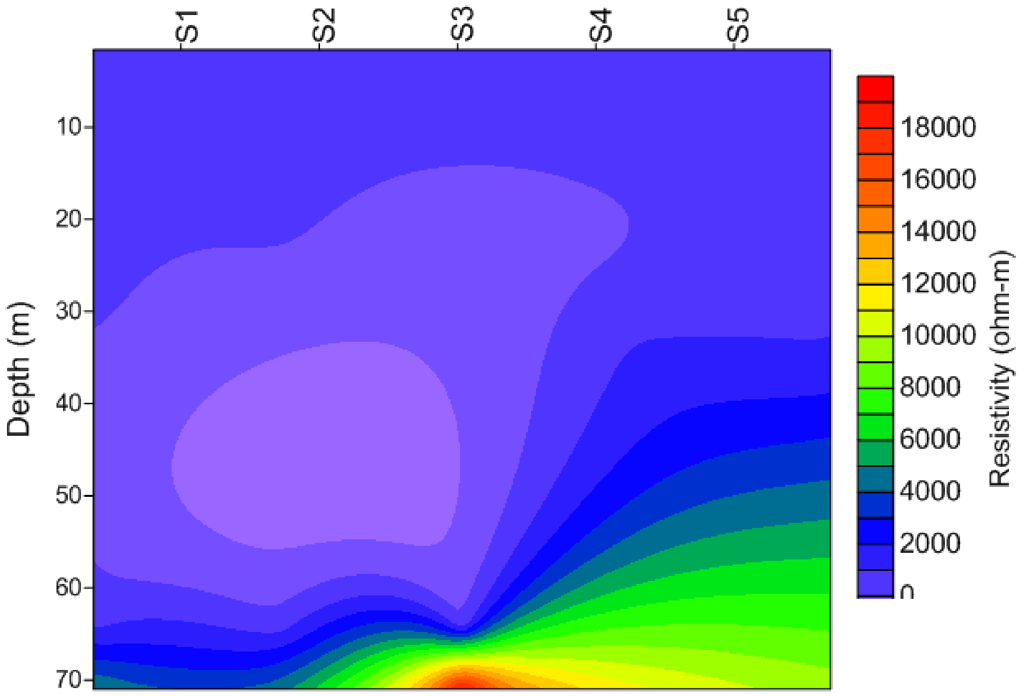


Figure 13: 2-DPseudo Cross-section for the Mpape Control Site

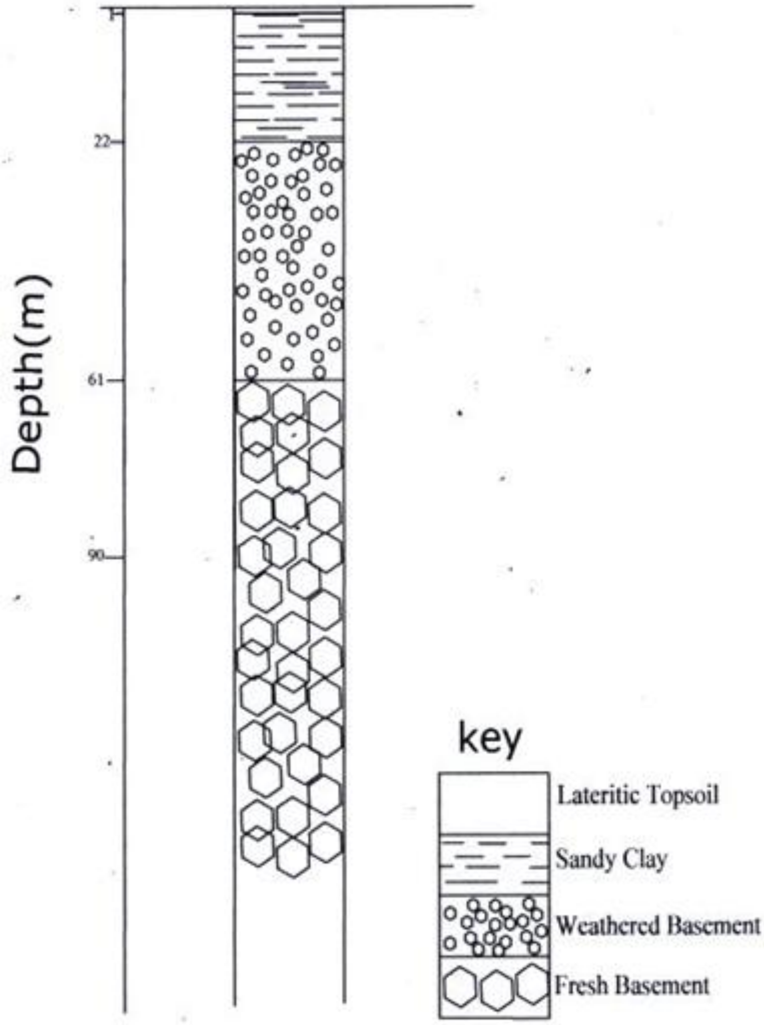


Figure 14: Typical borehole log of Mpape (Modified by Emerson Water & Co 2012)

IX. Analysis of Water Samples

(a) Water from the Mpape Closed Dumpsite

The pH of the water sample at Mpape closed dumpsite was 8.09, slightly above the WHO threshold of 6.5-8.0. This indicated that the leachate-laden water was alkaline in nature. Electrical conductivity which represents the concentration of dissolved ions in a liquid is one of the simplest indications for groundwater contamination (Dorota 2014). The sample presented an electrical conductivity value of 431.2 µS/cm which was above the WHO threshold of 100 µS/cm. Other parameters that showed deviation from WHO benchmarks were chloride and nitrate with concentrations of 351.99 and 187.16 mg/l respectively. The high level of chloride in the sample suggested that leachate in the aquifer system in the Mpape closed dumpsite had attained an advanced stage. While excess chloride in water increases blood pressure and causes kidney disease, excess nitrate in drinking water causes cyanosis (blue baby diseases) and asphyxia. The concentration of phosphate was safe i.e. 4.88 mg/l against WHO's prescription of 5 mg/l. High phosphate levels in drinking water may cause digestive problems in humans and animals (Ifeoma2014). Physical parameters which concentrations were within WHO benchmarks were total dissolved solids (TDS) (2.12 mg/l against WHO's benchmark of 600 mg/l) and turbidity (2.70 NTU against WHO's benchmark of 3.0 NTU). Presently, TDS is still being classified as a non-primary pollutant without verified health implications. The turbidity level was 2.70 NTU against WHO's 3 NTU. The higher the level of turbidity in drinking water, the higher the risk of gastrointestinal diseases. The concentration of some of the heavy metals evaluated demonstrated significant deviations from WHO benchmarks. They included iron, lead, cadmium, nickel, and manganese. While chromium was below detectable level (BDL), and copper, zinc, and sodium were within the WHO threshold, potassium, and cobalt with concentrations of 166.83 and 2.95 mg/l could not be assessed because WHO did not set a limit for them as at the time of conducting this research (WHO 2008). The concentration of iron was 0.53 mg/l against WHO's 0.3 mg/l. Accordingly, the levels of lead and cadmium exceeded the maximum contaminant level (MCL) set by the WHO. While the concentration of lead was 1.18 mg/l against WHO's 0.01mg/l, the level of cadmium was 1.21mg/l against WHO's threshold of 0.003mg/l. In terms of health risks, lead and cadmium are carcinogenic (WHO 2008). Nickel and manganese recorded concentration levels of 1.76 mg/l and 1.36 mg/l which were above the WHO thresholds of 0.07 and 0.4mg/l respectively. Inhaled nickel compounds are carcinogenic to humans. However, there is no evidence of carcinogenic risk from oral exposure to nickel (WHO 2008).

The concentration of copper, zinc, and sodium were 0.64 mg/l, 0.39 mg/l, and 72.23 mg/l against WHO's benchmarks of 2 mg/l, 3 mg/l and 200 mg/l respectively. The major health risk of copper is gastrointestinal disorder. While zinc does not pose serious health concerns at levels found in drinking water, a threshold of 3 mg/l was pegged for the purposes of the acceptability of drinking water (WHO 2008). Whereas no firm conclusion was drawn at the level of WHO regarding the possible association between sodium in drinking water and the occurrence of hypertension, a benchmark of 200 mg/l was prescribed to guard against the unacceptable taste of drinking water (WHO 2008). Presently, there is no scientific proof that the level of potassium detected in typical municipally processed water poses health risks (WHO 2008). The concentration of cobalt in the sample was 2.95 mg/l. Presently, WHO has not set threshold for cobalt.

(b). Water Sample from the Borehole in the Estate beside Mpape Closed Dumpsite

In this sample, pH, electrical conductivity, and TDS, with values of 7.07, 99.55 µS/cm, and 76.55 mg/l were within the permissible limits set by WHO. Turbidity (1.10 NTU), chloride (75.99 mg/l), and nitrate (5.71 mg/l) were also within the WHO threshold. Phosphate with a concentration of 6.01 mg/l surpassed WHO's threshold of 5 mg/l. Among the heavy metals, only zinc and sodium with concentrations of 0.55 mg/l and of 4.61 mg/l recorded levels that were safe byWHO standards. Iron, lead, cadmium, nickel, and manganese showed values of 0.47, 3.09, 0.87, 1.42, and 1.18 mg/l which were above WHO's prescriptions for the respective elements. While the concentration of chromium, copper, and potassium was BDL, the concentration of cobalt in the sample was 1.93 mg/l. From the results obtained for heavy metals in the leachate-laden surface water that emanated from the subsurface within the closed dumpsite, it was clear that the aquifer systems in the area were already contaminated by heavy metals and other pollutants as a result of years of percolation and infiltration of the underlying formations by leachate. It was assumed that the most vulnerable portion of the formation to contamination at the Mpape closed dumpsite was the perched and unconfined aquifer systems. The results of the physicochemical analysis of the two water samples are presented in Tables 1 and 2.

Table 1: Results of theanalysis of water sample collected at the closed dumpsite in Mpape.

GPS Coordinates: $9^{0}6^{/}35.2^{//}$N,$7^{0}29^{/}13.4^{//}$E			
Physical Parameters			
Parameter	Unit	Concentration	WHO Threshold
Ph	N/A	8.09	6.5-8.0
Electrical Conductivity	µS/cm	431.2	100
Total Dissolved Solids (TDS)	mg/l	2.12	600
Turbidity	NTU	2.70	3
Ions			
Chloride	mg/l	351.99	250
Phosphate	mg/l	4.88	5
Nitrate	mg/l	187.16	50
Elements/Heavy Metals			
Iron (Fe)	mg/l	0.53	0.3
Lead (Pb)	mg/l	1.18	0.01
Cadmium (Cd)	mg/l	1.21	0.003
Chromium (Cr)	mg/l	BDL	0.05
Nickel (Ni)	mg/l	1.76	0.07
Copper (Cu)	mg/l	0.64	2
Zinc (Zn)	mg/l	0.39	3
Manganese (Mn)	mg/l	1.36	0.4
Potassium (K)	mg/l	166.83	No limit listed
Sodium (Na)	mg/l	72.23	200
Cobalt (Co)	mg/l	2.95	No limit listed

Table 2: Results of the analysis of water sample collected from the borehole in the estate beside Mpape closed dumpsite

GPS Coordinates: $9^{0}6.666^{/}$N,$7^{0}29.186^{/}$E			
Physical Parameters			
Ph	N/A	7.07	6.5-8.0
Electrical Conductivity	µS/cm	99.55	100
Total Dissolved Solids	mg/l	76.55	600
Turbidity	NTU	1.10	3
Ions			
Chloride	mg/l	75.99	250

Phosphate	mg/l	6.01	5
Nitrate	mg/l	5.71	50
Elements/Heavy Metals			
Iron (Fe)	mg/l	0.47	0.3
Lead (Pb)	mg/l	3.09	0.01
Cadmium (Cd)	mg/l	0.87	0.003
Chromium (Cr)	mg/l	BDL	0.05
Nickel (Ni)	mg/l	1.42	0.07
Copper (Cu)	mg/l	BDL	2
Zinc (Zn)	mg/l	0.55	3
Manganese (Mn)	mg/l	1.18	0.4
Potassium (K)	mg/l	BDL	No limit listed
Sodium (Na)	mg/l	4.61	200
Cobalt (Co)	mg/l	1.93	No limit listed

X. Conclusion

The results obtained from the two geophysical methods showed that up to depth of between 15 and 40 m of the Mpape closed dumpsite has been contaminated. The borehole log of Mpape showed that this depth range is within the aquiferous/water bearing zone in the study area. Clayey sand and weathered basement which constitute the second and third layers at the dumpsite are characterized by poor aquifer protective capacity, thus making the groundwater to be highly vulnerable to contamination following the percolation of leachate from decomposed wastes at the site. High amplitudes of the FR component in the composite plots of FR and FI obtained at the closed dumpsite suggested fracture zones which can allow the infiltration of contaminants to the groundwater aquifer (Popoola andAdenuga 2009). High levels of electrical conductivity, chloride, nitrate, Fe, Pb, Cd, Ni, and Mn in the water sample collected at the closed dumpsite and phosphate, Fe, Pb, Cd, Ni, and Mn in the water sample collected from the borehole in the estate beside the dumpsite are chemical indications that the groundwater at the dumpsite and its surrounding environment have been contaminated.

It is recommended that the data and information generated in this study should be taken into consideration in designing future dumpsites and related subsurface projects in Mpape as well as the entire basement complex formation of northcentral Nigeria. Further, there is urgent need to sensitize policy makers on the implications of substandard dumpsites on the general wellbeing of the people who reside near the facilities. To this end, a multidisciplinary research programme on the health and environmental impacts of unengineereddumpsites on the quality of groundwater in the host communities in Nigeria should be initiated.

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