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INTEGRATED GEOPHYSICAL METHODS IN THE CHARACTERIZATION OF SUBSURFACE CONDITIONS OF LAPITE DUMPSITE IN IBADAN, SOUTHWESTERN NIGERIA

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ABSTRACT

Groundwater contamination within the vicinity of dumpsites has elicited public health concern in recent time. Studies have shown that contaminants may infiltrate into the groundwater through permeable soils, weathered and fractured bedrocks. Lapite village, underlain by Basement Complex rocks, hosts one of the largest and most active dumpsites in Ibadan. The dumpsite came into existence without prior hydrogeophysical evaluation of its suitability as a landfill site, especially its likely impacts on the surrounding groundwater. This study was designed to assess the suitability of the dumpsite for waste disposal by evaluating hydrogeophysical properties of rocks in the area. Geological field mapping was carried out around Lapite dumpsite to determine various rock types. Very Low Frequency-Electromagnetic (VLF-EM) measurements consisting of four transverses and sixty-one Vertical Electrical Soundings (VES, using Schlumberger array) were carried out along the 200.0 and 400.0 m of the dumpsite. Banded and migmatite gneisses were the underlying rocks in the area. The VLF-EM pseudo-section showed high conductivity zones indicating the presence of fluid-filled fractures in the rocks. The VES geoelectric section revealed four layers namely, topsoil (33.6-973.7Ωm), lateritic sand (82.0-520.4Ωm), weathered layer (11.9-133.0Ωm) and fractured/fresh bedrock (387.0-3767.4Ωm) with thicknesses (m) of 0.1-2.8, 0.8-4.8, 1.2-49.2 and undeterminable respectively. The presence of fractured basement as indicated by VLF-EM pseudo-section and VES geoelectric section may act as a transmitting medium for leachate that may emanate from waste dump into the surrounding groundwater. Lapite dumpsite is located on weathered and fractured bedrocks and these may permits infiltration of contaminants into the surrounding groundwater. Thus, the present condition of waste dumpsite is not suitable for an ideal waste dumpsite.

Keywords: *Characterization, subsurface condition, dumpsite, Groundwater contamination*

INTRODUCTION

Location of a waste dumpsite within a basement complex terrain like Ibadan could be difficult due to presence of hidden nature of fractures in the rocks (Akintola, 2014). The existence of thick overburden, weathered and fractured bedrocks are known to act as conduit for leachate (Akintola, 2004). Also, highly compressible soils such as soft clay are known to exist within overburden layers and can potentially cause differential settlement of structure and buildings (Temowo and Yussuf, 1998). Open dumps found in Ibadan are land disposal sites at which solid wastes are disposed of in a manner that is harmful to the environment, susceptible to open burning and exposed to disease, vectors and scavengers. Ibadan has a total land coverage of 3,080km^2 (Areola,1994) and a population estimate of 3,847,500 people (NPC, 2006) which are responsible for the generation of waste often deposited in open spaces, river banks, road side etc. consequently degrading the quality of the environment. In an attempt to mitigate environmental pollution within the city, six waste disposal sites were located strategically at the outskirt of the city. However, the selection, design, construction and operational activities of these sites did not consider the geology of the area and impacts on the adjacent environment.Many of these dumpsites pose threats to human health through groundwater and soilpollution and their attendant effects on the entire ecosystem. Hence, need to employ the integrated use of geophysical methods in evaluating the subsurface condition of solid waste dumpsite.

Several researchers have established that geophysical methods can be successfully adopted for waste disposal operation in the evaluation of site characterization and in delineating diverse sub-surface geometry, such as movement of contaminant leachate plume and fracture zones in crystalline basement rocks. They include Urish, 1983; Saksa and Korkealakso ,1987 ; Barker, 1996; Carpenter *et al.,* 1990; Parker *et al.,* 1993; de Lima *et al.,* 1995; Onions et al., 1996; Ariyo,et.al.,2013; Cardarelli and Bernabini, 1997; Walraevens*et al*., 1997; Benson *et al.*, 1997; Bernstone and Dahlin, 1997; Kayabali*et al.*, 1998.

MATERIAL AND METHODS

Site Description and Geology of the Study Area

Ibadan city is located between longitude 7°2’ and 7°40’E and latitude 3°35’ and 4°10’N on the geographical map of Nigeria. The study area is located in Lapite village, within Akinyele Local Government area, Ibadan. It is between old Oyo road and newly constructed Ibadan- Oyo express road (Fig.1).

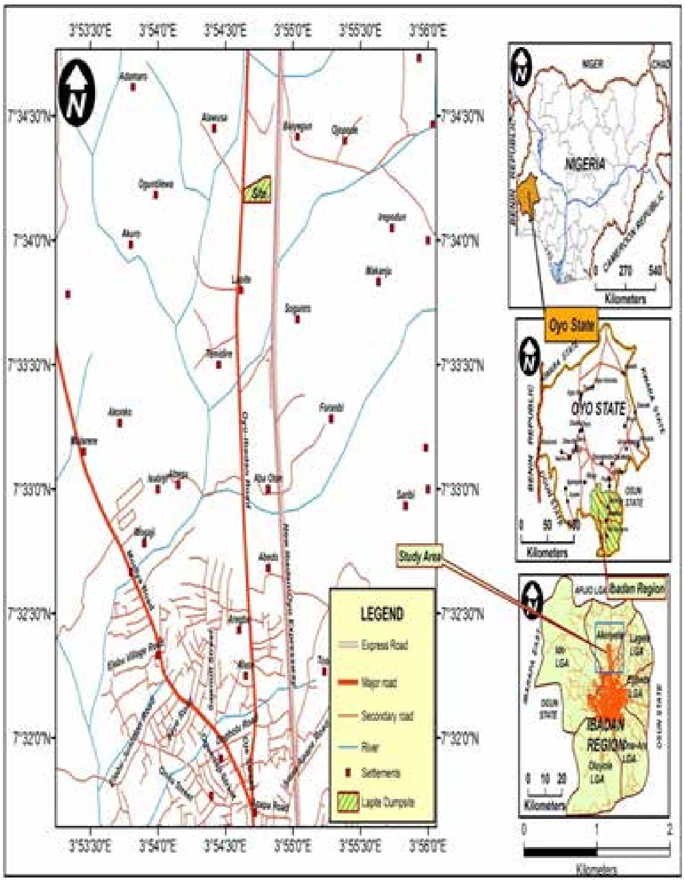

Figure 1: Map of the Study Area.

The dumpsite covers an area of 200 by 400 meters and sited on high elevation. Tones of wastes generated and collected from various locations in Ibadan and its environs are deposited on a daily basis onto the dumpsite, giving rise to large heap of waste of varying composition, up to 3.0m high relative to the groundsurface. The study area forms part of the areaunderlain by Basement Complex rocks of southwestern Nigeria. They comprise igneous and metamorphic units such as gneisses, migmatites including older granite ridges and pegmatite. The major rock types in study area and it’s environ are migmatite and banded gneisses (Fig. 2). The rocks are coarse grained in texture and light grey in colour. Alternations of light and dark coloured minerals defined a clear banding in the rocks. Compositional variations in the outcrops are indicated by closely spaced alternating bands of leucocratic minerals (quartz and feldspars) and melanocratic minerals indicated by the preponderance of biotite minerals. The banded gneisses with alternating parallel light and dark coloured bands are common in the study area. Fractures are noticed in most rocks of the study area.

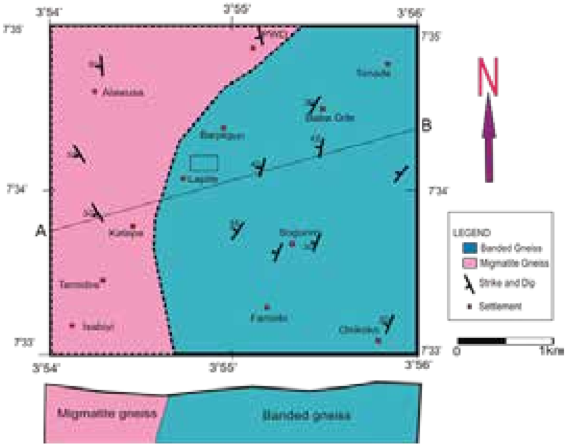

Figure 2. Geological Map of the Study Area

Integrated geophysical investigation involving both the Very Low Frequency Electromagnetic (VLF-EM) and Vertical Electrical Sounding (VES) methods was carried out along the traverses/profiles established around the dumpsite. According to Benson *et al.,* (1997) and Carpenter *et al,* (1990),Very Low Frequency Electromagnetic (VLF-EM) and Vertical Electrical Sounding (VES) methods are very important in obtaining subsurface information. Several researchers haveshown that a combination of VLF-EM and VES methods have provided useful results in mapping (Telford *et al.,*1990;Onions *et al.,* 1996; Cardarelli and Bernabini, 1997; Walraevens *et al.,* 1997; Benson *et al.,* 1997; Bernstone and Dahlin, 1997 and Kayabali *et al.,* 1998.) The two methods are both use to detect the water bearing basement fracture columns due to the relatively high bulk electrical conductivities (Ariyo, *et al.,* 2009). Both methods were therefore found useful and hence were integrated in this study.

VLF-EM method was used as a fast reconnaissance tool to map possible linear featuressuch as faults and fracture zones while the VES method was used to investigate prominent EM anomalies and provide a geoelectric pseudo- section of the subsurface sequence.The VLF-EM method of investigation was carried out with the aid of WADI instrument. Four Traverses of such measurement were taken around the Lapite dumpsite for detailed structural delineation. The ranges of each of the traverses were 200m and measurements were made at 10m intervals. The VLF-EM measurement was carried out to map the study area with the aim of isolating linear features which can be interpreted as fractured zones likely to serve as conductors pathways for groundwater contamination and conductive regions. Although both the real and imaginary components of VLF anomalies were recorded but only the filtered real component data were processed for qualitative interpretation because they are more diagnostic of linear features. The measured raw real and filtered real data were subjected to Fraser (Fraser, 1969) and Karous-Hjelt (Karous and Hjelt, 1983) filtering,in order to suppress the noise and the enhance signal.

Vertical electrical sounding method was employed with schlumberger electrode configuration, AB/2 spread up to 133m and 50m station spacing was adopted.A total Number of 61 VES stations were probed. In all, 11, profiles were designed in which 10 profiles were laid around the dumpsite and the 11th profile (control) was obtained at about 400m from the site.

For quantitative interpretation, a computer-assisted one-dimensional inversion algorithm of the Schlumberger sounding data (Zohdy, 1989) was carried out and subsequent production of geoelectric section of the area were done to enable an understanding of the subsurface condition.

RESULTS AND DISCUSSION

Very Low Frequency- Electromagnetic (VLF-EM)

In order to enable qualitative identification of linear features, plots of the filtered real anderaser filtering anomaly curves were made from the raw field data. According to Olorunfemi *et al.* (2005), these linear features suspected to be geological interfaces are usually delineated as points of coincidence crossovers and positive peaks of the filtered real and eraser filter anomaly curves.

The Karous-Hjelt filtered current density pseudo sections are presented in figure 3a to 3d for transverse 1 to 4.

EM Traverse 1 and 2 have a maximum distance of 200m (Fig. 3a & 3b). Four regions of high conductivities zones were observed at 20 m, 50 m, and 100 m and at about 200 m respectively in Traverse 1 (Fig.3a). These zones possibly indicate presence of fluid-filled fractures in the rocks while in traverse 2, the EM shows maximum peak at about 100m. Other points on the profile showed low to very-low conductivity peak hence, constitute region of relatively high resistivity or conductivity (Fig.3b).
EM Traverse 3 and 4 are about 400 m in length (Fig.3c & 3d). Series of high conductivity zones were also observed at 50m, 110m, 170m, 230m, 300m and 380m in transverse 3. Also, the Karous filter indicated high conductivities at about 130 m, 240 m and 350 m respectively, along the profile in traverse 4 (Fig.3d).
The VLF- EM survey (traverse 1 and 3) showed zones of high conductivity along the downslope side of waste dump indicating presence of fluid filled fractures which are believed to be filled with conductive fluid like water. These may permit infiltration of contaminants from waste dumpsite into the groundwater.

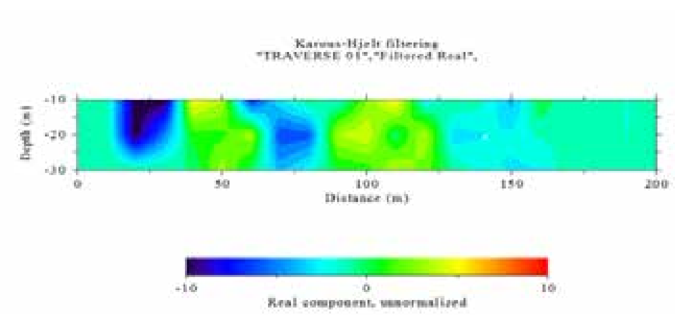

Figure 3a: Karous-Hjelt filtering of profile 1

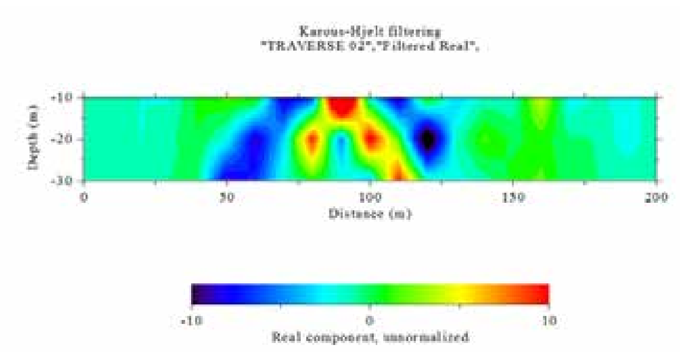

Figure 3b: Karous-Hjelt filtering of profile 2

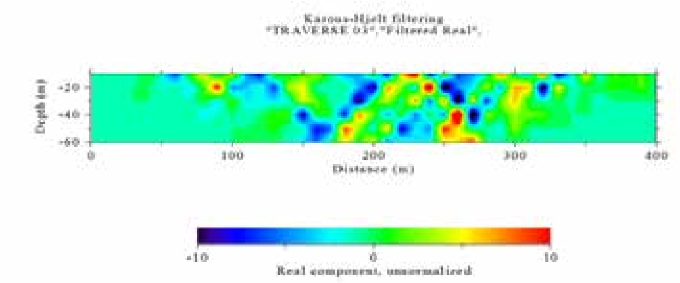

Figure 3c: Karous-Hjelt filtering of profile 3

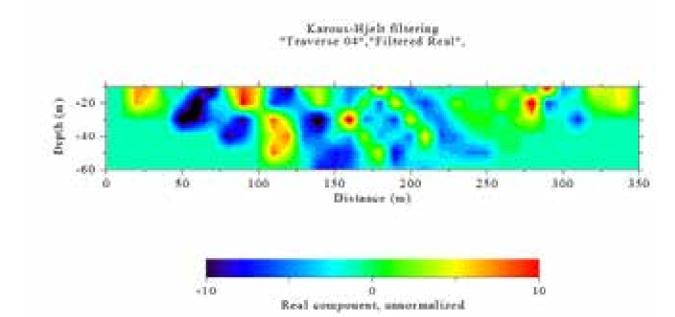

Figure 3d: Karous-Hjelt filtering of profile 4

Vertical Electrical Sounding (VES)

Electrical resistivity of weathered layer are controlled by the degree of water saturation (Odusanya and Amadi, 1990, Ariyo & Adeyemi, 2010). Resistivity of rocks is greatly dependent on the degree of fracturing and percentage of fracture filled with ground water.

Results of VES survey were used to generate geo-electric sections and are presented in Figure 4a to 4e. Eleven VES profiles were generated: VES Profile 1 to 4 gives rise to LOOP 1, VES Profile 5 to 8 gives rise to LOOP 2; VES profile 9 and 10 while VES profile 11 which serve as control (Fig.4a – 4e).

LOOP I (VES Profile 1-5)

The geo-electric sections for VES 1-21 are presented in Fig.4a (i) & 4a (ii) as VES loop 1.

VES profile 1 (loop 1): The profile (VES 1- 5) is on higher elevation (upslope section) about 268m and has three layers as shown by geo-electric section [Fig. 4a (i)]. Resistivity values of the top soil range from 72-381Ωm. It has one of the thinnest top layers with the highest value of 1.4 m. The thickness of overburden layers range from 5.0 m to 9.0m while resistivity values are between 34 and 94 Ωm.

VES profile 2 (loop 1): The profile (VES 6-12) showed moderate uniform; thin top soil with thickness vary from 1.3m to 4.0m and has three to four resistivity layers [Fig.4a (ii)]. Relatively high resistivity value of 520Ωm was observed from VES 10 at shallow depth, indicating possible presence of hard pan lateritic clay/ large boulder. The overburden layer has resistivity values range from 15 Ωm to 80Ωm. The basement resistivity values are between 108Ωm and 3780Ωm. Low resistivity values of 108Ωm, 224Ωm and 409Ωm were observed on the down slope side of waste dumpsite from VES point 9, 11 and 12 respectively. The low resistivity may indicate presence of fluid filled fractures which may permit the infiltration of contaminants from waste dumpsite into the surrounding groundwater.

VES profile 3 (loop 1): The profile 3(VES 13-16) has three geo-electric layers [Fig. 4a (ii)]. The thin top soil layer has resistivity values ranging from 78-173Ωm The weathered layer has low resistivity values ranging from 12 Ωm to 48 Ωm on the downslope side of waste dump and this may be attributed to presence of conductive zones and pores containing water/highly saturated clay. The basement rocks underlying the thick weathered layer have resistivity values ranging from 376 Ωm to 993 Ωm and this indicates presence of fracture in few places and fresh bedrock in other places. Hence there may be super-imposition of the upper layer resistivity on the lower basement layer. Since low resistivity indicates high conductivity; high conductivity zones observed from VLF Pseudo-section (profile 1) confirms the low resistivity values recorded from the weathered/ fractured layer of VES profile 3 [Fig.4c & 4a (ii)].

VES profile 4 (loop 1): This profile has three layers; the top soil has resistivity values ranging from 34 Ωm to 440 Ωm with maximum thickness of about 1.5 m. The weathered layer is thicker at the centre with resistivity values varying from 19 Ωm to 133

Ωm. Most of the resistivity values fall within clay layer. The third layer which is the basement rock has resistivity values ranging from 703 Ωm to 1574 Ωm.

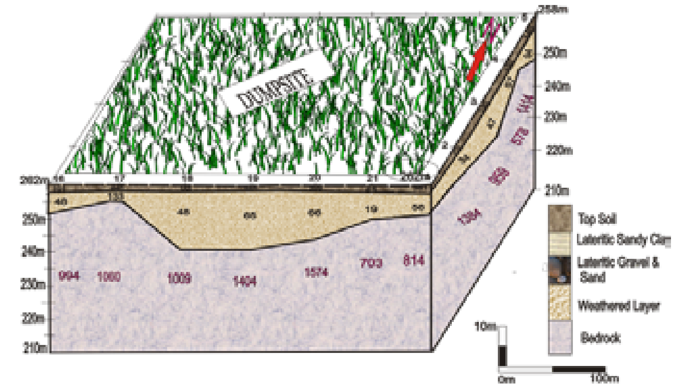

Figure 4ai: Geo-electric section for VES LOOP 1

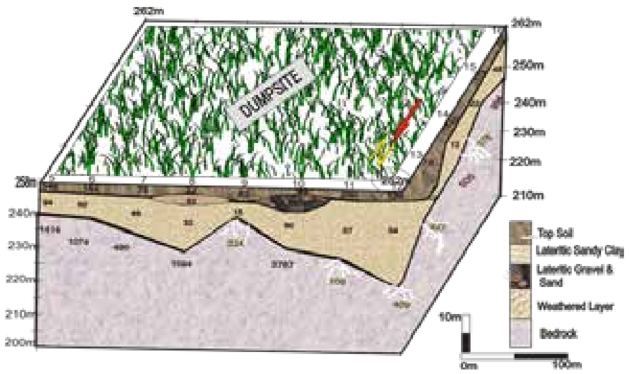

Figure 4aii: Geo-electric section for VES LOOP 1

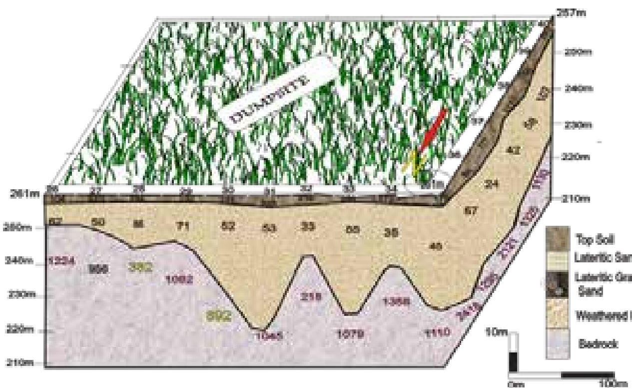

Figure 4bi: Geo-electric section for VES LOOP 1

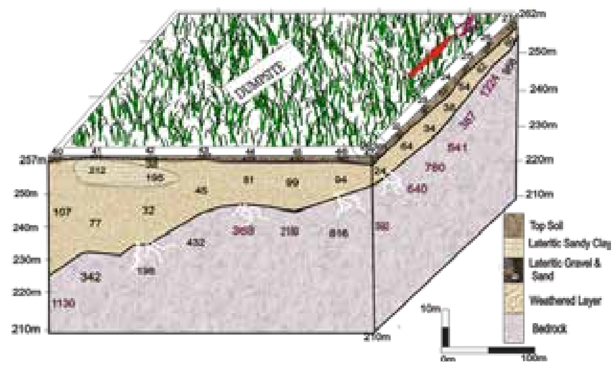

Figure 4bii: Geo-electric section for VES LOOP 2

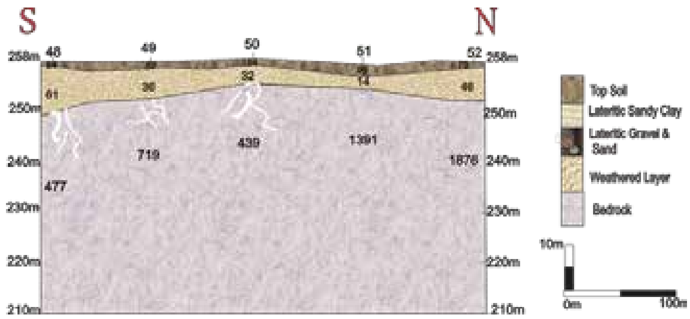

Figure 4c: Geo-electric section of VES profile 9

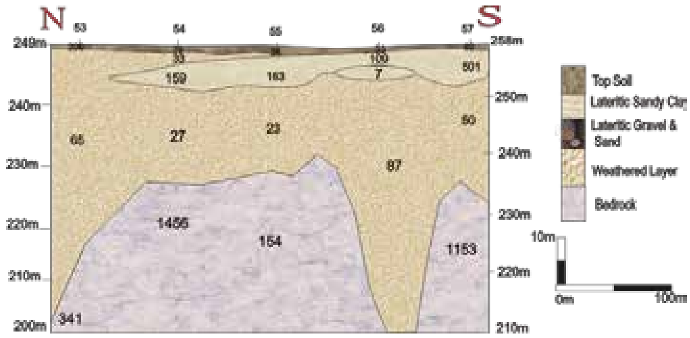

Figure 4d: Geo-electric section of VES profile 10

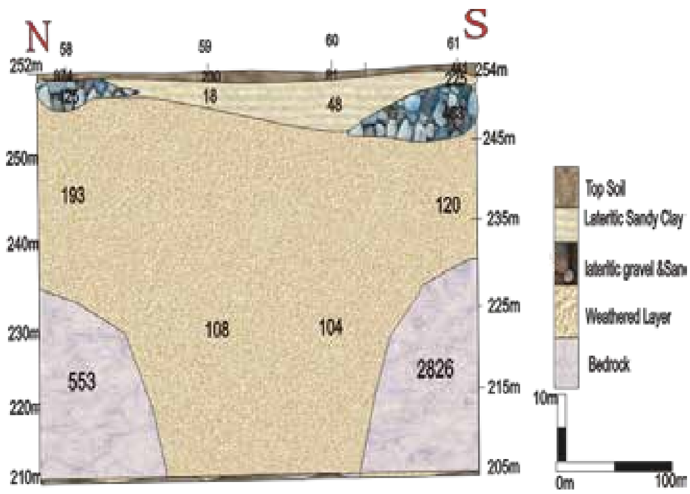

Figure 4e: Geo-electric section of VES profile 11(Control)

The thickness of above 10m and the resistivity signatures between 12 Ωm and 94Ωm may indicate storage zone for water. This agrees with similar work conducted by Enikaselu (2008) where he stated that resistivity values obtained for saturated zone is < 100 Ωm.

LOOP 2 (VES Profile 5-8)

This is about 40m away from waste dump and represents geo-electric sections obtained from VES 22-47 (Fig. 4b).

VES profile 5 (loop 2):- The (VES 22–26) has 3 geo-electric layers. The top soil has a thin layer with thickness ranging from 0.5m – 1.9m and resistivity values between 47 Ωm and 167 Ωm. The second layer has a relatively thin layer compared with other profile with the values ranging from 2.5 m to about 12.0 m and resistivity values of 32-62 Ωm. The basement rock occurs at shallow depth with resistivity values ranging between 392 and 2267 Ωm (Fig. 4b). Those with resistivity values less than 1000 Ωm possibly indicate presence of fractures in the rocks.

VES profile 6 (loop 2): The profile (VES 26-35) has three geo-electric layers. The Top soil layer has thickness and resistivity values ranging from 0.5-3.3 m and 104-338 Ωm respectively. The overburden layer has thickness values varying from 6.5 m to 40 m. The thickness of overburden layer was high at the downslope side of waste dumpsite. The resistivity values (33-86 Ωm) of overburden layer indicates presence of lateritic clay and this can serve as a major storage for water and fluid activities. Exceptionally low basement resistivity occurs at VES point 32 (218 Ωm) which correspond to that of VES point 9 in profile 2 (loop 1).

VES profile 7 (loop 2): This profile (VES 35-40) has 3 layers which is a typical characteristic of basement complex terrain. The top soil has thickness ranging from 1.4 - 4.3 m with resistivity values varying between 57 and 172 Ωm. The overburden layer has thickness of about 45 m with resistivity signature ranging from 24 Ωm to 107 Ωm indicating presence of fluid saturated clay. The basement rock occurs at depth greater than 30 m and most of the resistivity values are greater than 1100 Ωm (Fig. 4b).

PROFILE 8 (LOOP 2):- This consists of VES point 40–47 and has three to five layers. It has a thin top soil layer at 0.75–1.3 m. The overburden layer is thinner at the upstream side of the dumpsite. The resistivity of overburden (weathered/fractured) layer varies from 32 Ωm to 107 Ωm and basement resistivity ranges from 198 Ωm to 1230 Ωm (Fig. 4b).

VES profile 9: The profile (VES 48 – 52) has three layers and is 60m away from the dumpsite. The top soil has thin layer with varying thickness of 0.25–2.3 m and resistivity values ranging from 75-154 Ωm indicating, the presence of lateritic sandy clay. The overburden layer has most of its thickness less than 10m and resistivity value occurring between 14 Ωm and 61 Ωm. The low resistivity in the overburden layer may indicate presence of fluid- filled fracture. The basement resistivity is found between 439 Ωm and 1876 Ωm (Fig. 4c).

PROFILE 10: The profile (VES 52 –57) has four to five geo-electric layers and is 60m away. The top Soil has thin layer with varying thickness ranging from 0.3–1.6 m and resistivity values ranging from 33 Ωm to 309 Ωm. The second layer indicates presence of clayey sand with resistivity values ranging from 109-501 Ωm. The overburden layer is very thick having minimum thickness of about 16m and resistivity values range from 23 to 87 Ωm. The basement resistivity occurs within the range of 154 to 1456 Ωm (Fig. 4d).

PROFILE 11: This is a control profile; consists of VES 58 – 61 and is 150m away from the site. The top soil has resistivity ranges between 81 Ωm and 974 Ωm and relatively thin layer between 0.3–1.3 m. Relatively high resistivity (425 and 463Ωm) occurred close to the top soil at VES 58 and VES 61. (Fig.4e). Overburden layer thickness occurs between 1.3 m and 24.6 m. This layer extends deeper at VES 59 and VES 60 respectively (Fig. 4e). Lower resistivity value (VES 58), at about 24m depth may indicate presence of fracture in the rock and fresh basement rock occurs at VES 61 due to its attendant high resistivity value.

Generally, VES geo-electric section revealed four layers namely, topsoil, lateritic sand/weathered layer, fractured zone and fresh bedrock. Also, low resistivity value of 12 to 100Ωm is an indicative of pollution in overburden layer (saturated i.e weathered/fractured zone). This may be attributed to the facts that leachate from the open dumps usually contain biological and chemical constituents and organic matter decomposing under aerobic conditions produces carbon dioxide which may reacts with the leaching water to form carbonic acid.

$$CO_2 + H_2O \longrightarrow H_2CO_3.$$

This may in turn react with metals in the refuse and other material in the soils and rocks resulting in increasing hardness and conductivity of contaminated water (Schneider, 1978)

CONCLUSION

Very Low Frequency- Electromagnetic (VLF-EM) pseudo-section showed high conductivity zones indicating the presence of fluid-filled fractures in the rocks. Also, vertical electrical sounding results indicated three to five layer namely, topsoil, lateritic sandy clay, weather layer, fractured and fresh bedrock. Low resistivity values observed in overburden layermay indicate pollution in groundwater among other things.The presence of fractured basement as indicated by VLF-EM pseudo-section and VES geoelectric section may act as a transmitting medium for leachate that may emanate from waste dump into the surrounding groundwater. Lapite dumpsite is located on weathered and fractured bedrocks and these may permits infiltration of contaminants into the surrounding groundwater. Thus, the present condition of waste dumpsite is not suitable for an ideal waste dumpsite.Geotechnical and hydrogeological investigations must be carried out to know the properties of soil and the impact of the waste dumpsite if any, on the surrounding ground water.

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