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Geophysical Assessment of an Active Open Dump site in Basement Complex of Northwestern Nigeria

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ABSTRACT:A2D Electrical resistivity, Seismic refraction tomography and Azimuthal resistivity soundings have been undertaken of an active open dumpsite in Kaduna, Northwestern Nigeria which is characterized by shallow groundwater conditions. The aim is to study the potential for leachate intrusion into and consequent contamination of groundwater. Results of the resistivity imaging delineated the leachate plume as low resistivity zones (6 - 33 ohm - m) while both resistivity and seismic models delineated fractures beneath the weathered basement layer which may provide contaminant pathways for the leachate plume. Longitudinal conductance (S) of the upper 10 m of the resistivity models in the study area varies from 0.02 mhos to 0.1 mhos. These low values are suggestive of poor protective capacity of subsurface materials and is believed to play a major role in providing access to leachate plume to reach the shallow aquifer in the study area. The coefficients of anisotropy obtained from Azimuthal Schlumberger VES measurements at greater depth (45 m) are significant with λ ranging between 1.37 and 1.40. These λ values are indicative of homogeneously anisotropic ground. However, the ratios of the long to short axes are quite low which suggests absence of fracturing at these depths.

Keywords: *Nigeria, open dump, leachate plume, azimuth, anisotropy*

I. INTRODUCTION

The environmental and health hazards associated with open dumping of waste are well known (Porsani et al. 2004; Karlik et al. 2000; Benson et al. 1997; Mukhtar et al. 2000; Klinck et al. 1995). For instance, deposited wastes undergo changes through chemical reactions and shallow sediments above the water table can produce toxic concentrations of leachates thereby contaminating usable subsurface and surface water supplies. Generally, geophysical methods provide economic and nondestructive means to investigate contaminant plumes from landfills (Cahyna 1990; Carpenter et al. 1990; Ross et al. 1990). In particular, when the leachate which includes many anions causes an increase in dissolved salts in the ground, the consequent increase in its conductivity may be detected by electrical survey. Resistivity surveys are also used to map fracture zones in hard rock terrain (Barker et al. 1992; Carruthers and Smith 1992) because high resistivity contrasts usually occur between solid rocks and saturated fractures. Seismic refraction method has been commonly used in groundwater and contaminated site investigation because of its relative simplicity and adaptability for shallow zone investigation. Due to the dependence of seismic velocity on the elasticity and density of the material through which the energy is passing, seismic tomography data is used to detect and map fracture and fault zones which could provide pathways for the contaminant plumes.Azimuthal resistivity survey incorporating different electrode configuration and spacings have been used successfully to detect the presence of aligned vertical and subvertical fractures which causes anisotropic behavior with azimuth and determination of the fracture strikes (Taylor and Fleming 1988 ; Watson and Baker 1999 ; Busby 2000 ; Lane et al. 1995 ; Hagrey 1994 ; Boadu et al. 2005). The Nigerian landmass is underlain by various crystalline rocks of the Basement Complex of Precambrian to early Paleozoic. These crystalline basement rocks have been subjected to deformation of varying intensities throughout the geological period resulting in folding and fracturing of the rocks. Consequently, N-S, NE – SW, NW – SE and to lesser extent, E – W fractures have developed (Oluyide and Udoh 1989). Figure 1 shows the fracture system in Nigeria. There is no doubt that the fractures in Nigerian landmass provide the opening to the wealth of the nation. They provide pathways for mineralisation, oil traps and reservoir for groundwater. In hard rock areas, groundwater is found in the cracks and fractures of the local rock. According to Olayinka and Barker (1990), such a zone is known to be favourable to groundwater accumulation, since their hydrogeaological characteristics such as hydraulic conductivity and porosity must have been enhanced due to fracturing. Solid waste landfills constitute integral part of the soil hydrological system (Rosqvist et al. 2003);

consequently, the occurrence of fractures in and around landfills may enhance hydraulic contact between the leachate and groundwater. In such environment, the potential for ground water contamination is high.The present study applied Electrical resistivity imaging (ERI), Seismic refraction tomography (SRT) and Azimuthal resistivity surveys (ARS) techniques at an active municipal solid waste facility in Unguwan Dosa, Kaduna North, Nigeria with the objective of the potential for leachate intrusion and delineationof subsurface contaminant pathways that may be responsible for the transportation of the leachate plumes.

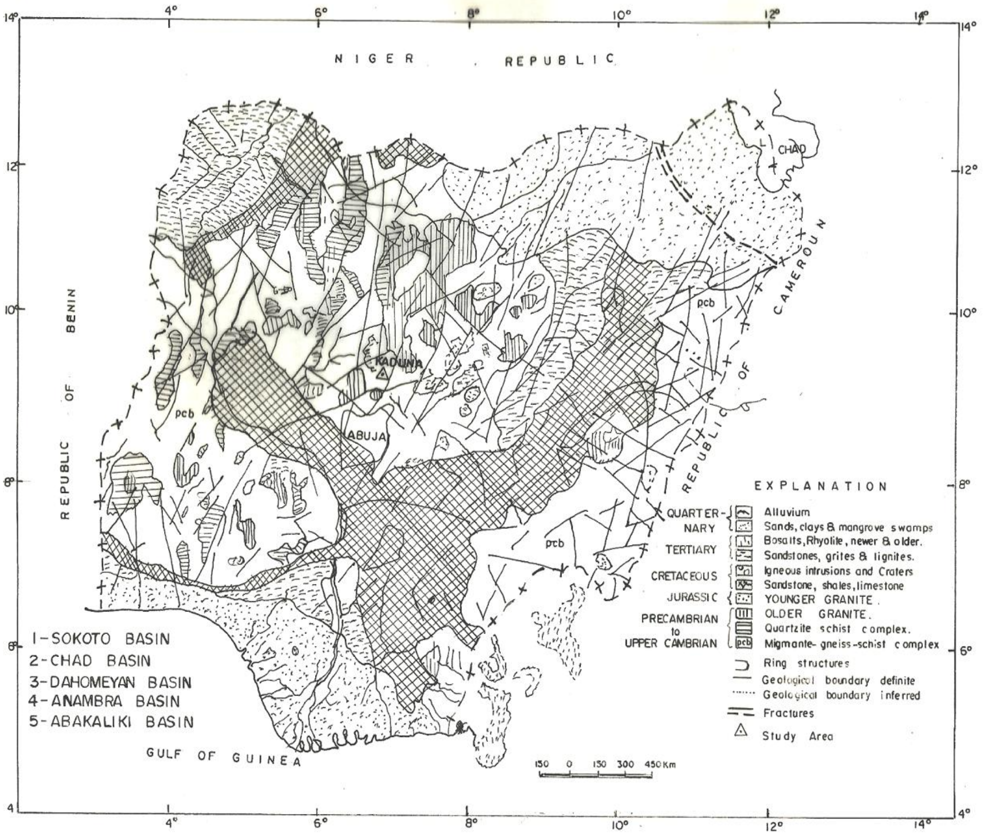

Figure1: Fracture pattern in Nigeria (Modified after Geological Survey of Nigeria, sheet 2515)

II. STUDY AREA DESCRIPTION

The survey area (Fig.2) is located at College Road with co-ordinates $10^0 30''$ N and $07^0 25''$E in Unguwan Dosa, Kaduna North Local Government Area, Kaduna State, North Western Nigeria. The landfill is a typical uncontrolled open solid waste facility that has been in operation for the past 30 years. The dumpsite consists of heterogeneous refuse with a maximum difference in elevation between the top of the solid waste and the surrounding area of 5 m. The study area (Fig.1) is underlain by a regional series of granites, gneisses, migmatite and a sequence of lateritic clay, clayey sand/sand and weathered/fractured bedrock. The top soil varies in composition, colour and texture and at most places are predominantly laterite and quartz grains (deep brown or reddish brown soil). The maximum depth of water table in the study area is 5.17 m while clayey sand/sand and weathered/fractured bedrock constitute the main aquifer (Osazuwa and Abdullahi 2008). Regional groundwater flow direction in Kaduna metropolis is towards the northeast (Dan-Hassan and Olorunfemi 1999).

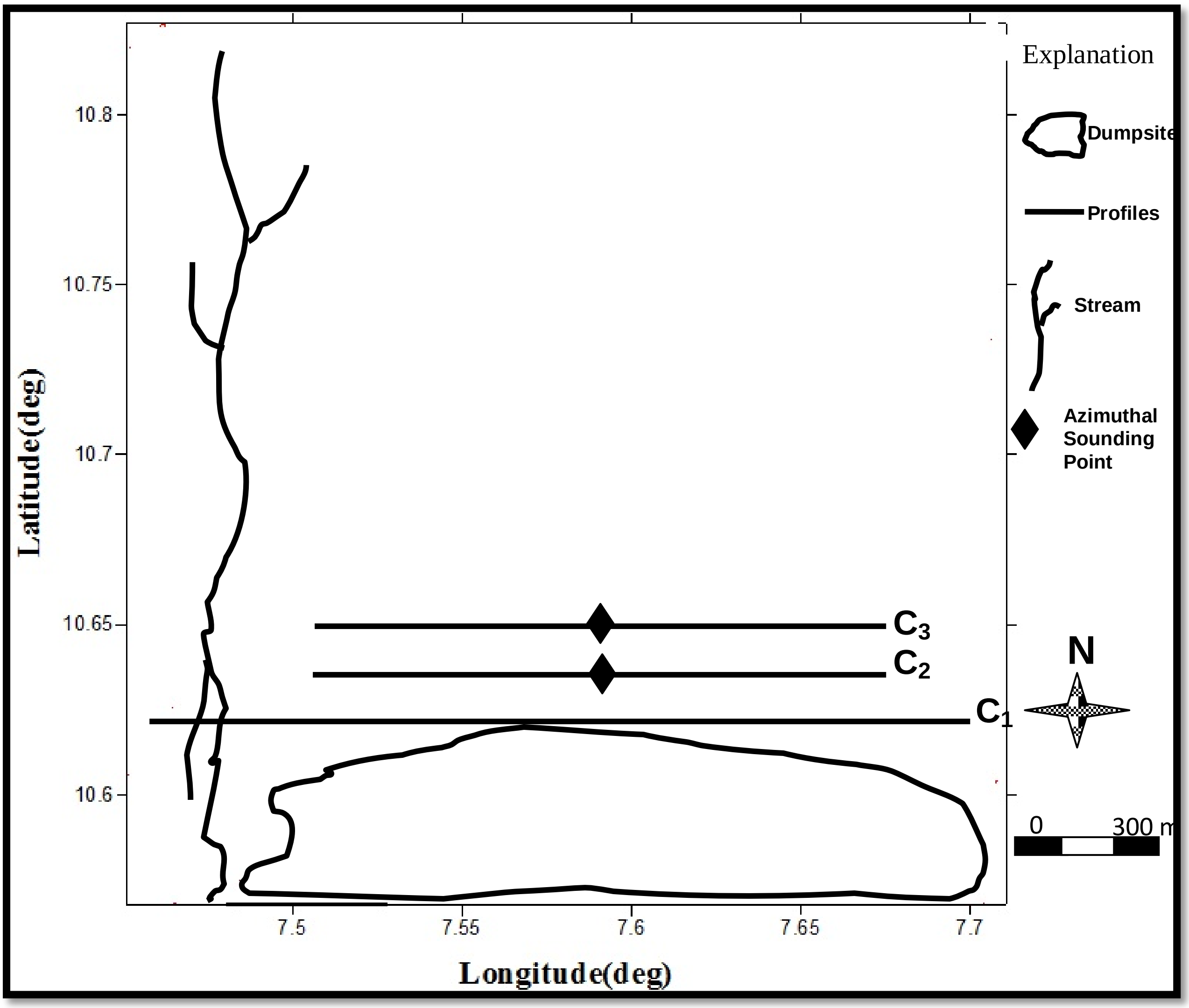

Figure2: Map of study area showing location of investigated profiles

III. FIELD METHODS

3.1 Electrical Resistivity Imaging

Two–dimensional (2D) electrical resistivity data were collected with ABEM Lund Imaging equipment to determine subsurface geo-electric layers, their thickness and to map fractures that may serve as contaminant pathways. Three profiles oriented east-west, separated by 5 m, were made. The geo-electric data was collected with the WEN 32 SX, which employs the Continuous Vertical Electrical Sounding technique using the Wenner alpha electrode configuration (Wenner CVES-α). CVES, combines profiling and sounding, so that 2D data coverage along a profile is obtained. This results in an image of the apparentresistivity structure along a profile. The collected geoelectrical data were processed by means of the RESD2INV (Loke 2004) modeling software. The inversion routine is based on the robust method.

3.2 Seismic Refraction Tomography (SRT)

Data were collected with Terralock MK6 on the same profiles the resistivity surveys were conducted. The aim is to compliment the 2D resistivity imaging in detection and delineation of subsurface structures that can act as contaminant pathways. The geophones were laid out at an interval of five metres and seismic energy was sent into the ground with the aid of 16 kg hammer blow on a base plate. Shot was taken at every geophone and in between geophones (2.5m) on the profile after adjusting the equipment for this mode in order to have dense data. The seismic refraction data collected from the field was subjected to different stages of processing using the REFLEXW package (version 4.5.5) to enhance the signal-to-noise ratio. The application of band pass frequency filtering process helped in improving the quality of the real signal, after the noise has been filtered out.

3.3. Azimuthal Resistivity Survey (ARS)

Azimuthal resistivity surveys incorporating 4 collinear Schlumberger arrays were conducted along observed anomalous zones recorded in the resistivity and the Seismic refraction models. The ARS data were collected specifically to verify and correlate qualitatively the observed anomalies from the two measurements (ERI and SRT) and also, understands fracture behaviour at depth along different directions. The instrument used was the ABEM 300C SAS Terrameter with stainless steel electrodes. Electrode spacing (AB/2) and potential electrode spacing (MN/2) were rotated about a center point (N-S) in three directions at an angle of 45^0 each to give NE-SW, E- W and SE- NW directions respectively. Eleven current electrode spacings were probed along each orientation. The current electrode spacing AB/2 was made to change from 1- 45 m with the potential electrode MN changing correspondingly from 0.3-5 m. Resistivity as a function of azimuth in radial coordinates were plotted to produce polygons of anisotropy. Apparent coeficent of anisotropy for the Schlumberger array was calculate using the relationsip (Mota et,al.2004),

$$\lambda_a = \sqrt{\frac{\rho_{max}}{\rho_{min}}} \quad (1)$$

Where $\rho_{\max}$ is the apparent resistivity measure along the ellipse major axis; $\rho_{\min}$ apparent resistivity measure along the ellipse minor axis direction.

IV. RESULTS AND DISCUSSION

4.1. Electrical resistivity imaging and Seismic refraction tomography

Figure 3 is the 2D the resistivity model measured along profile C_1. This investigated profile was taken at northern margin of the dump (Fig.2). The electrode spacing used was 5 m which gives 25 m as depth proved. Due to the marshy nature of the ground surface in the eastern and western sections of this profile, the 1^{st} and last five electrodes were planted with difficulty. This prompted four electrode tests to be conducted in order to correct for poor electrode contact.Looking at the inverse resistivity model, it consists of three zones. The top soil layer shows lateral variations and is very conductive. This zone has resistivity ranging between 6.8 – 93.2 ohm-m. The lower end (6.8 ohm–m) from the ground surface down to the depth of 20 m between profile positions 125 – 140 m is the stream that cuts across the western section of the dump. With a resistivity value of $\leq$ 11 ohm-m, the stream is believed to be contaminated as a result of leachate accumulation. The zone with resistivity values ranging from 32 ohm-m to 98 ohm-m consists of fine medium coarse sand while deeply weathered crystalline rock which is marked by resistivity values > 271 ohm-m forms the third zone along this profile.

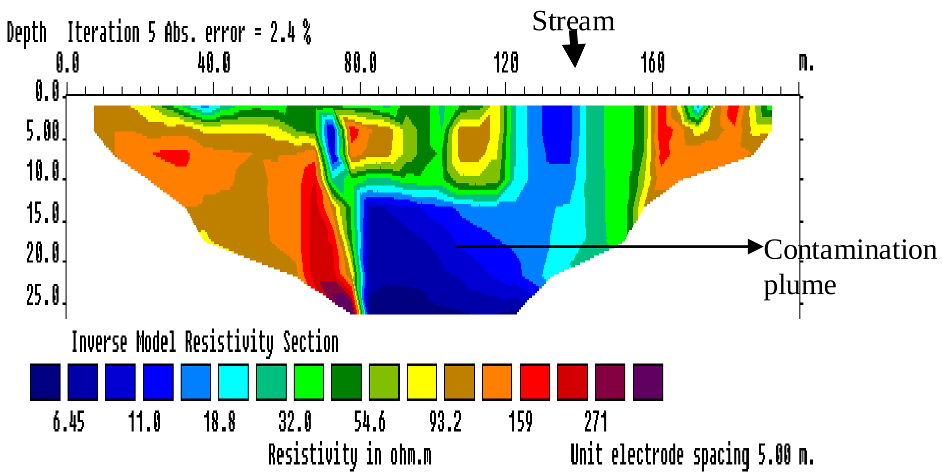

Figure3: Resistivity inverse model along profile C_1

Figure 4 shows the resistivity inverse model along profile C_2 measured 5 m from C_1. In this model, the inverted resistivity depth sections show two layers interpreted as overburden and bedrock (intensely weathered). Resistivity values < 250 ohm-m represent overburden while values > 250 ohm –m indicate intensely weathered bedrock. The substantial decrease in zones with resistivity values less than 30 ohm-m were interpreted as contaminated coarse sand due to accumulation of leachate. Weathered bed rock drops at profile position x = 30 m and resurfaces at a distance of ~ 50 m along the profile indicating the presence of a fractured zone.

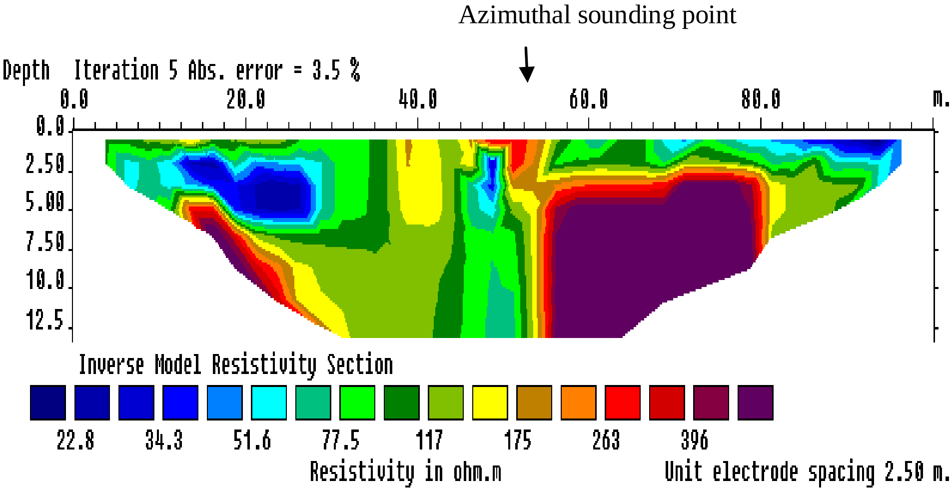

Figure4: Resistivity inverse model along profile C_2

Figure 5 is the corresponding seismic refraction inverse model along profile C_2. Examining the tomosection, there is evidence of significant differences in the physical properties of the basement rock (below 16 m depth). The low velocity zone (2700 m/s to 3800 m/s) flanked by high velocity zones (7200 m/s to 9200 m/s) is interpreted as a weak zone (Fracturing in the basement rock). The low p-wave velocity zone corresponds to the zone identified as fracture in the resistivity inverse model (Fig.4).

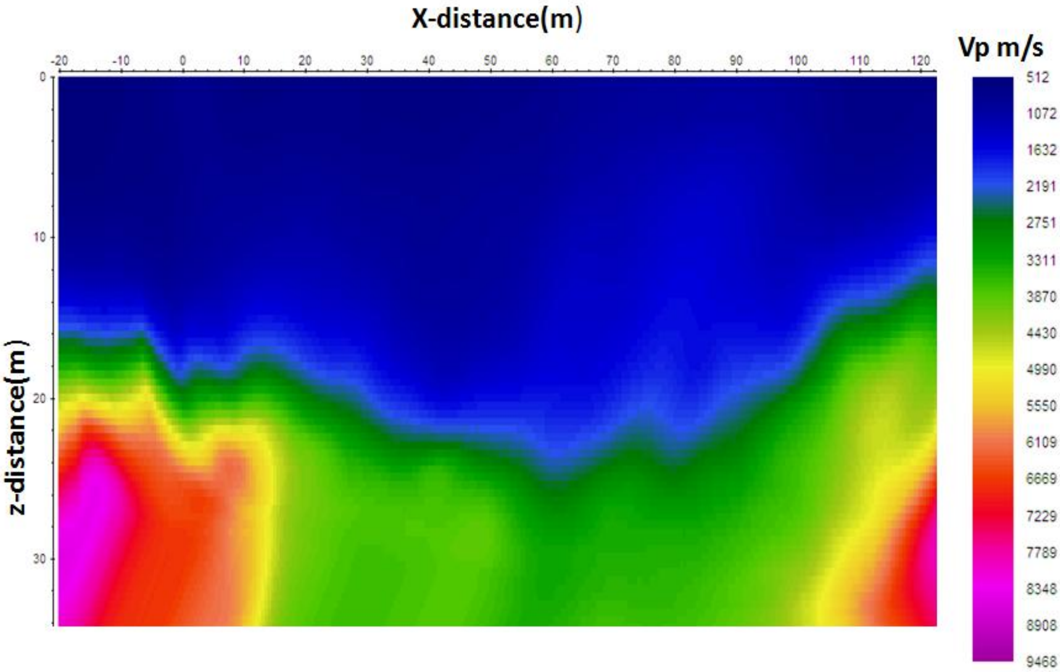

Figure5: Seismic refraction tomography section along profile C_2

Fig 6 shows the resistivity inverse model along profile C_3. In this model, a broad low resistivity anomaly is identified at depths below 5 m between profile position x= 0 m to x = 45 m. The resistivity of this zone varies between 55 ohm-m to 171 ohm-m and is clearly reproducing the structure seen in Figure 4. Weathered bedrock with resistivity values > 300 ohm-m is apparent between 50 m and 85 m at a depth of ~ 5 m. The corresponding seismic refraction tomography inverse model (Fig.7) correlates quite well with the resistivity inverse model. Areas with low p-wave velocity (≥ 2400 m/s) correspond to the low resistivity anomalous zone (Fig. 6). The weathered bedrock corresponds to zone with p-wave velocity > 5600 m/s.

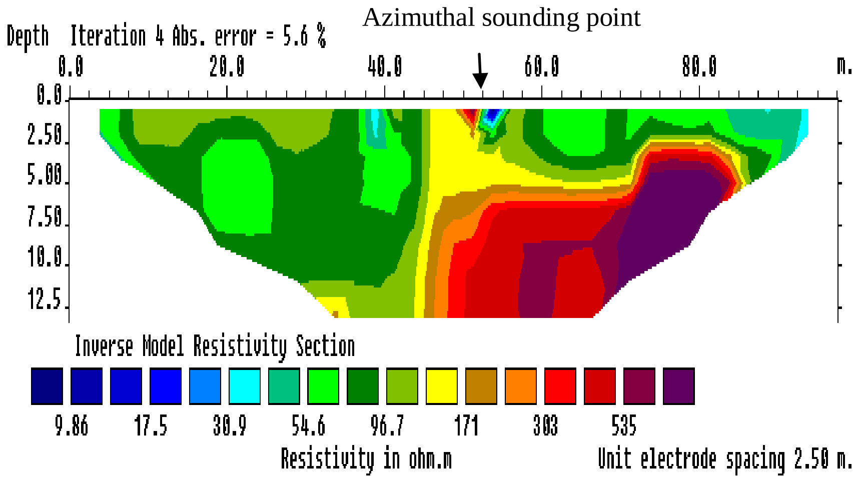

Figure6: Resistivity inverse model along profile C_3.

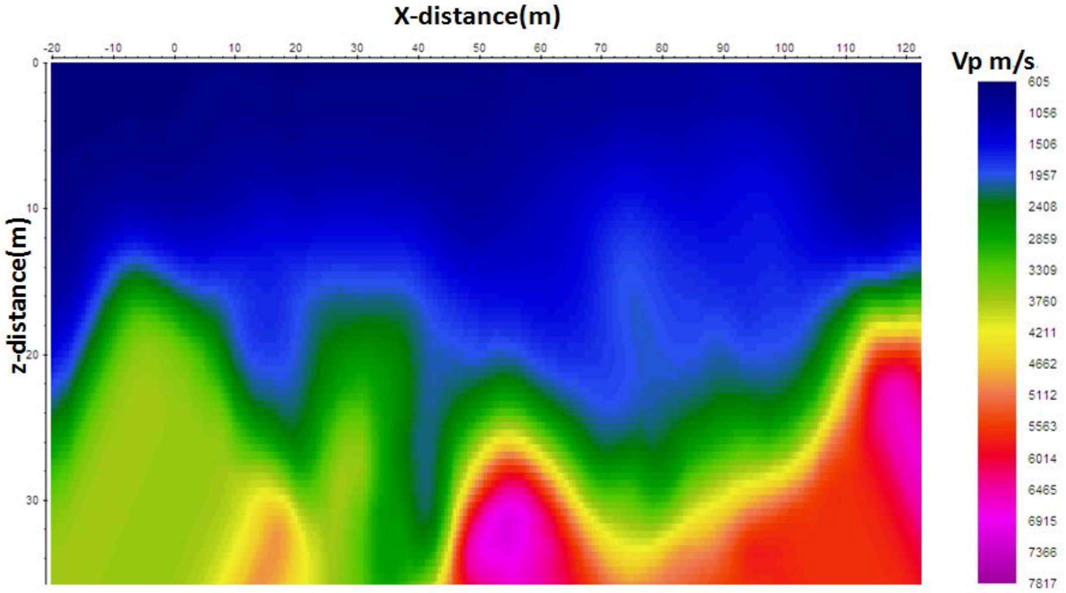

Figure 7: Seismic refraction tomography section along profile C_3

4.2. Azimuthal Resistivity Sounding

Figure 8 is a radial plot of the current electrode spacings (20 – 45 m) against their representative apparent resistivity values for all the directions adopted (0^0, 45^0 , 90^0 and 135^0) along profile C_2, denoted as S_1.The resistivity anisotropy polygons show characteristics elliptical shape. The plot is double peaked (NE-SW and N-S directions) at these depths. The apparent coefficient of anisotropy (λ) recorded at these spacings is significant, with λ equal to 1.27, 1.48 and 1.40, respectively. Figure 9 shows the anisotropy polygon plot along profile $C_{3,}$ denoted as S_2.The plot is similar to S_1 with multiple structural trends observed trending in the N-S and NE-SW directions as a result of intersections of joint. The apparent coefficient of anisotropy calculated for the depths considered were 1.08, 1.17 and 1.37 respectively. The anisotropy plots in both S_1 and S_2 are found to correlate with those deduced in the works of Oluyide and Udoh (1989), Ibe and Njoku, (1999) and Olaseinde and Raji (2007) who found the general directions of faulting in the basement areas to be along NE-SE, NW-SE, and N-S. Though both figures (8) and (9) depicts elliptical shapes indicative of homogeneously anisotropic medium, the ratio of the long to short axes are quite low which suggests absence of fracturing at these depths (Skjernaa and Jorgensen, 1993). The absence of fracture anisotropy from the Schlumberger azimuthal results may possibly be as a consequence of the low sensitivity to anisotropy of the electrode array (Schlumberger) at these spacings or the volume of rock investigated was insufficient because the electrode-array spacing was too small for the rock to behave homogeneously anisotropically.

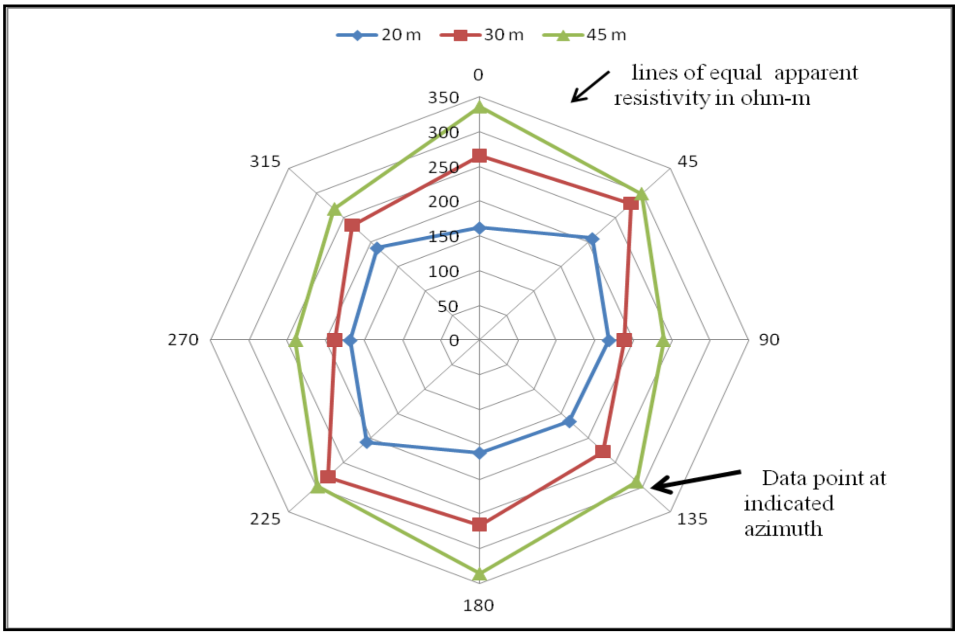

Figure8: Anisotropy polygon at sounding point S_1

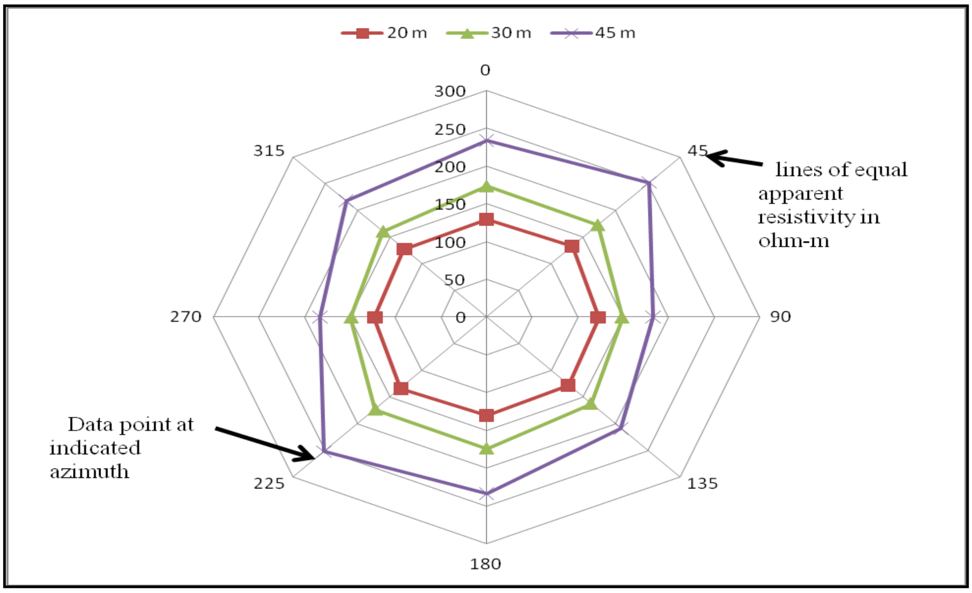

Figure9: Anisotropy polygon at sounding point S_2

4.3. Evaluation of longitudinal conductance as protective medium

The earth medium acts as natural filter to percolating fluid (e.g., leachate). Its ability to retard and filter percolating fluid is a measure of its protective capacity. The materials of the upper 10 m are evaluated using the layer parameters to obtain longitudinal conductance (S) which can be considered as being proportional to the protective capacity (Omoyoloye, et al., 2008). The higher the longitudinal conductance, the higher the protective capacity. The protective capacity ratings (table 1) adopted for this work are based on the works of Henriet (1976) which was modified by Oladipo(et al(2004). Figure 10 shows the stacked map of the longitudinal conductance of the materials of the upper 10 m along profiles C_2 and C_3 .The longitudinal conductance varies from 0.02 mhos to 0.1 mhos; thus the S values are generally low suggesting that the aquifer is poorly protected in the study area. This result implies that the topmost part of the resistivity models (0–0 -.10 m) is characterized by unconsolidated materials (coarse and medium sand) and suggests the absence of clay material which may impede the free movement of the contaminants in this region. Considering that the maximum depth to water table in the study area is 5.17 m (Osazuwa and Abdullahi, 2008), it appears that contamination of the groundwater by leachate is in progress.

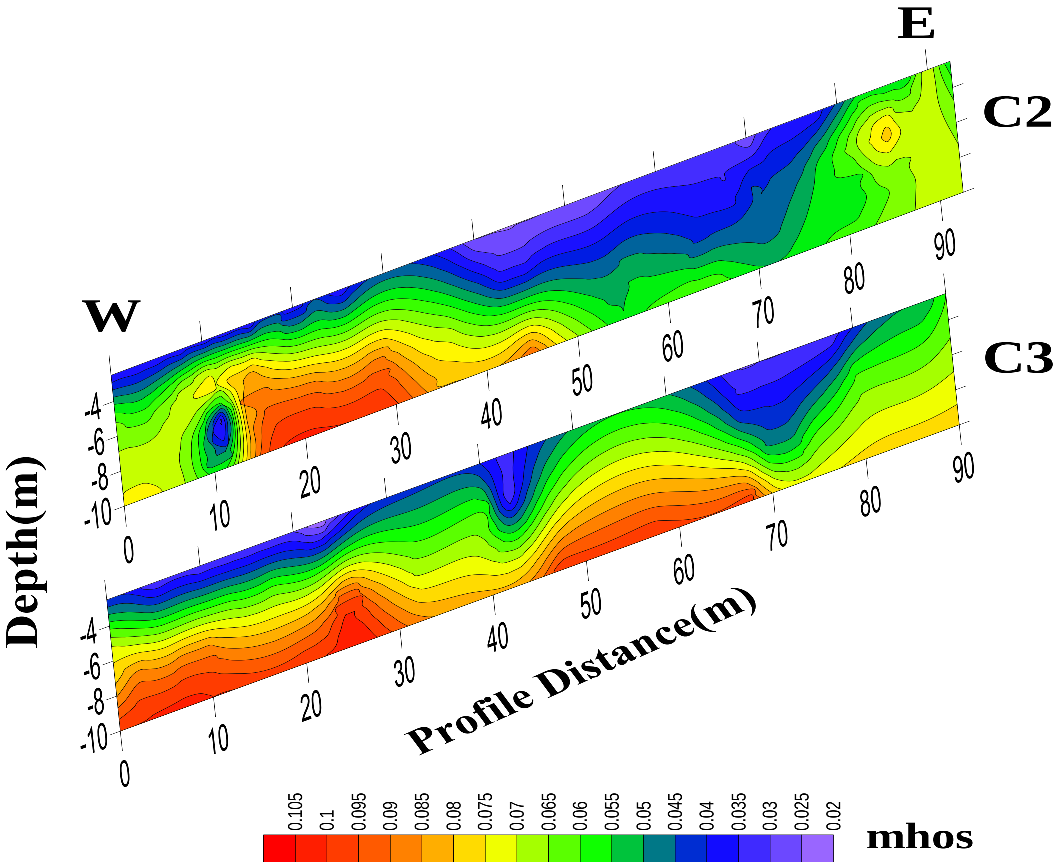

Figure10: stacked maps of longitudinal conductance along Profile C_2 and C_3.

Table.1: Soil protective capacity rating (After Henriet, 1976; Oladipo et al, 2004)

Longitudinal conductance (mhos)	Soil protective classification
<0.1	Poor
0.1 – 0.19	Weak
0.2 – 0.69	Moderate
0.7 - 4.90	Good
5.0 - 10.0	Very good
>10	Excellent

V. CONCLUSION

Three surface-geophysical methods were used as part of a hydrogeologic assessment of contamination of ground water in the premises of active open dumpsite located in the hard-rock area of Northwestern Nigeria. Three parallel traverses located around the perimeter of the dumpsite were surveyed using electrical resistivity imaging, Seismic refraction tomography and azimuthal resistivity sounding to help characterize geologic features around the dumpsite and to assess the potential of groundwater contamination associated with solid waste leachate. The resulting resistivity images obtained through inversion process clearly show the existence of contamination zones found within the aquifer units for the study area. The contaminated plume occurs as a low resistivity zone. Results from the ERI and SRT methods showed conductive features beneath the investigated profiles. These conductive anomalies were interpreted to be fractured zones which probably act as conduits for conveying contaminated plume into the surrounding groundwater. The upper subsurface materials which consist of loose permeable sediments also play a major role in providing access to the contaminant plume to reach the shallow aquifer in the study area. The figures produced from the Schlumberger Azimuthal resistivity survey are generally elliptical, which are departures from the circular pattern characteristics of a homogeneously isotopic subsurface. The coefficients of anisotropy obtained at electrode spacing of AB/2 =45 m are significant with λ equal to 1.40 at sounding point S_1 and 1.37 at sounding point S_2. These values are diagnostic of anisotropic medium given that for homogeneously isotropic medium, $\lambda = 1$. However, the ratios of the long to short axes are quite low which suggests absence of fracturing at these depths. This could possibly be as a result of the array's (Schlumberger) low sensitivity to anisotropy or the volume of rock investigated was insufficient (because the electrode-array spacing was too small for the rock to behave homogeneously anisotropically). The result of the study showed that the pollutants in the leachate can reach and contaminate the groundwater. This is a major threat to human population, especially those within the area. Therefore, urgency for leachate treatment at this site is recommended to prevent contamination of groundwater

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