INTEGRATED VERY LOW FREQUENCY ELECTROMAGNETIC (VLF-EM) GEOPHYSICAL AND HYDROGEOCHEMICAL STUDY OF ABEKU DUMPSITE IN IBADAN, SOUTHWESTERN NIGERIA

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Abstract

Very Low Frequency Electromagnetic (VLF-EM) and hydrogeochemical studies have been integrated to measure ground conductivity and also determine the concentration of leachate derived contaminants in the groundwater around Abeku dumpsite in Ibadan, southwest Nigeria. Ten (10) VLF-EM profiles were occupied within and around the dumpsite fence. Water sample from wells were also analyzed to determine the concentration of pollutants in the study area. Qualitative interpretations of VLF-EM results indicate relatively high ground conductivity within the dumpsite, which decreases away from the actual waste dump phase of the dumpsite. Ground conductivity is relatively higher in the south and east of the dumpsite which are located downhill of the groundwater hydrostatic head when compared with the north and west of the study area situated uphill of hydraulic gradient. Hydrogeochemical analyses present NO_3^-, SO_4^{2-} and PO_4^{2-} ions concentration in the range of 9.24 – 13.64 mg/L, 3 – 12 mg/L and 0.33 – 1.07 mg/L respectively. The SO_4^{2-} and PO_4^{2-} ions concentrations are within permissible limits, while the NO_3^- ion concentration is slightly above the Federal Ministry of Environment's standard for potable water in Nigeria.

Keywords: Abeku Dumpsite; Very Low Frequency Electromagnetic; Leachate; Contaminants.

1 INTRODUCTION

The only known public waste disposal method in Ibadan, Southwestern Nigeria is the open dump system which is the practice of dumping wastes on several hectares of fenced open land, referred to as dumpsites or landfills. The wastes are left open to the atmosphere, and as it is common for these dumpsites to be in close proximities to human settlements, they regularly constitute environmental disturbance. The dumpsites serve as breeding grounds for germs, flies and rodents, which are pathogens and disease vectors. The decay and occasional burning of the wastes causes air pollution, due to the generation of offensive odours and smoke (Abua, 1996).

Groundwater pollution caused by decomposing wastes at dumpsites result from the formation and transportation of leachates in the ground. Leachates are formed when solid wastes are partially or completely dissolved by rain water and the type of leachate pollutants generated depend to a large extent on the type of wastes and disposal method. Landfills of any type usually contain both biological and chemical wastes (Schneider, 1970) which upon dissolution is able to generate leachates in substantial amounts and the leachate derived pollutants are able to concentrate to cause soil and groundwater pollution. In order to safeguard human's health, the quality of groundwater is required to be monitored on a regular basis, in order to ensure that the concentration of pollutants remain within permissible limits (FEPA, 1991).

This study therefore attempts to evaluate the degree of leachate derived contamination within the vicinity of the Abeku dumpsite, especially as the generated ions and cations from the leachates increase ground conductivity above the normal background level as well its implications on groundwater pollution.

2 LOCATION AND GEOLOGY OF THE STUDY AREA

The Abeku dumpsite is one of the four major operational dumpsites in Ibadan. The three other dumpsites are the Ajakanga, Akinyele and Awotan dumpsites. The Abeku dumpsite is located between longitude 003°59′ 03 – 003° 59′ 19″ E and latitude 07°19′22″ – 07° 19′ 30″N (Fig. 1). It is situated along the Akaran expressway in Ibadan, Southwestern Nigeria. The dumping ground is about 25 hectares in size; it is surrounded by a perimeter fence and has been in operation for over 25 years. Geologically, the dumpsite is underlain by schistose-quartzite rock (Fig. 2), which is part of the Migmatite Gneiss Complex of Southwestern Nigeria (Jones and Hockey, 1964). The average surface elevation of the study area ranges from 121 to 156 m above the sea level.

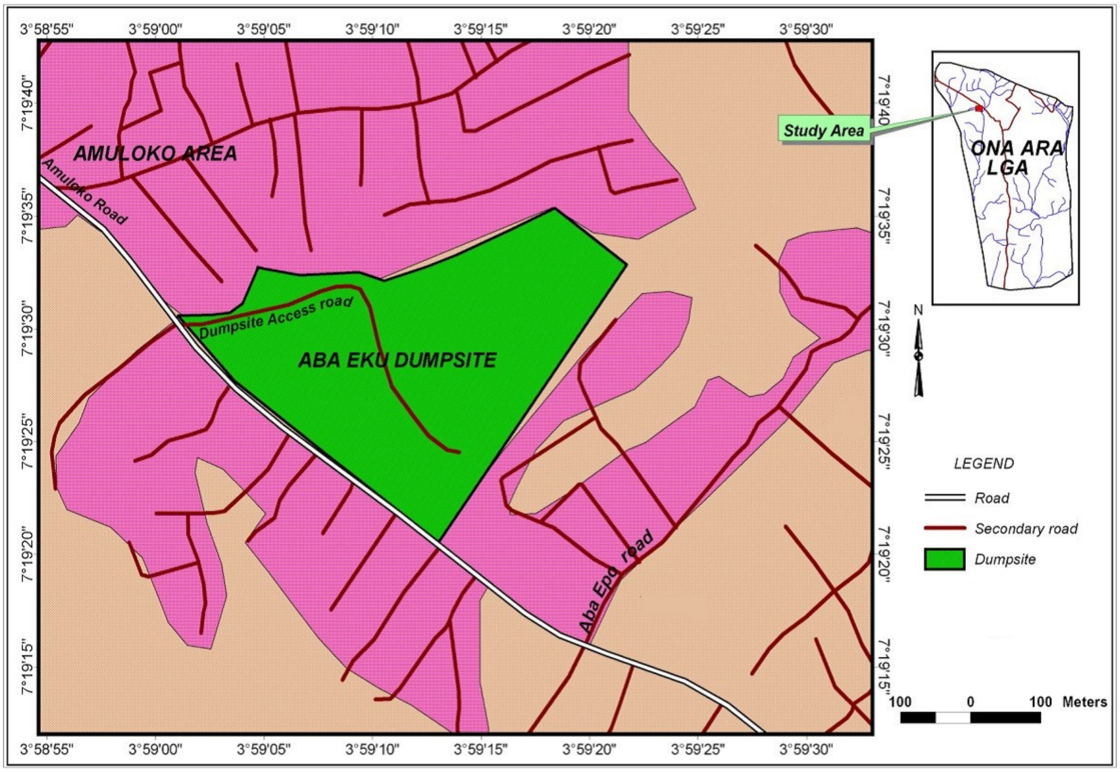

Figure 1: Map of Ona-Ara Local Government Area (inset) showing the study area (Modified after Oni and Hassan, 2013)

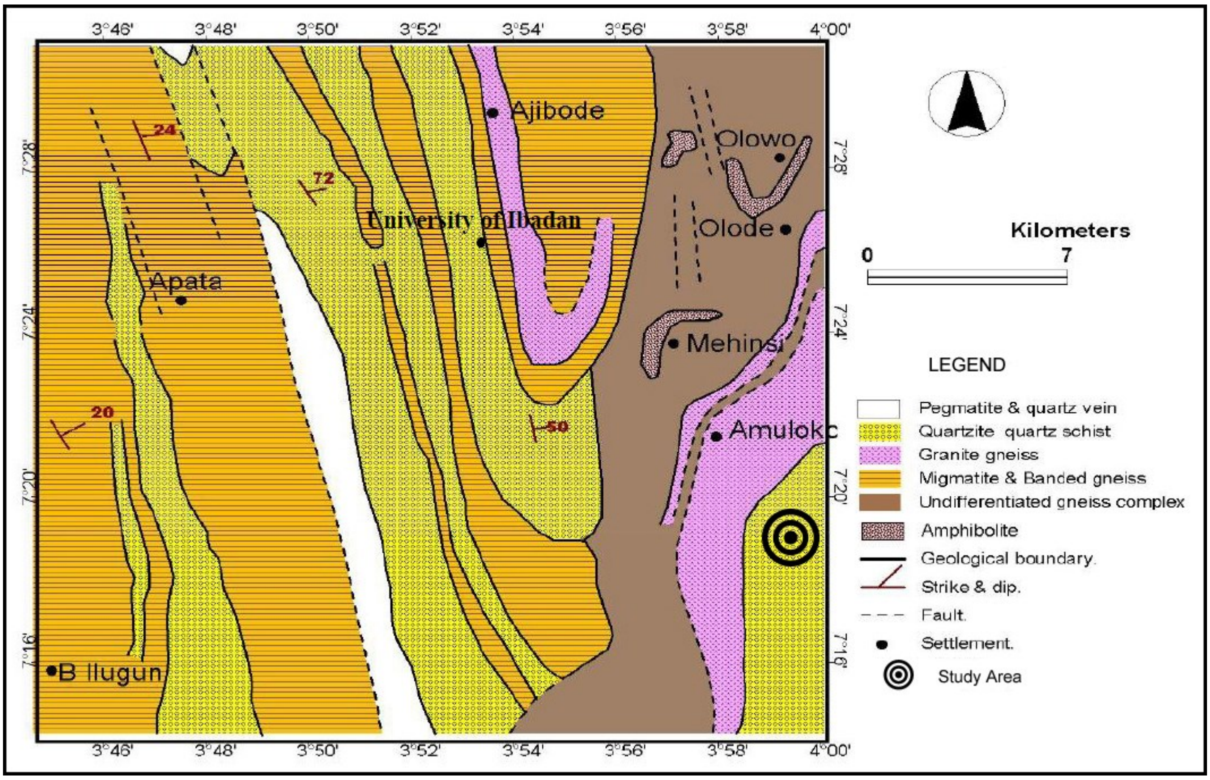

Figure 2: Geologic map of Ibadan showing the study area (Modified after Okunlola *et al.*, 2009)

3 MATERIALS AND METHODS

ABEM WADI VLF-EM meter was used to measure the ground conductivity in terms of the ratio of the real (Re) to the imaginary (Im) components of the propagating electromagnetic (EM) waves within the subsurface. The meter is a battery-powered digital display device that measures relative ground conductivity. It measures the response, that is, the secondary electromagnetic field (Hs) generated through the flow of eddy current within the subsurface conductor, when a time-varying very low electromagnetic field (primary field, Hp) propagates through the subsurface. The primary electromagnetic field is generated by powerful radio transmitters situated in different countries which transmit EM waves either continuously or with Morse code, for the purpose of military communication on frequencies in the band 15-25 KHz. The meter through the measurement of the difference in field intensity and phase lag between the primary (Hp) and the secondary (Hs) fields is able to detect the occurrence of conductors or conductive zones in the ground. For example, a phase lag of the secondary EM field relative to the primary EM field of about half a period (180^o) indicate a conducting ground, while a resistive ground (poor conductor) will cause the secondary EM field to lags the primary EM field by 90^o (Palacky*, et al.*, 1981). ABEM WADI VLF meter normally records two components; the in-phase and out-of-phase components and the ratio of the real component (Re) to the imaginary component (Im) determines the degree of conductivity.

For this study, ten (10) VLF-EM profiles were established and occupied within and around the Abeku dumpsite. The profiles were occupied to sample the most active part of the dumpsite and thus formed an enclosure around the dumped wastes (Fig. 3). Profiles T4, T5, T6, T7 and T9 were established outside the dumpsite, at about 5 m from the perimeter fence, while the rest of the profiles were established within the dumpsite. Profiles T1, T2, T3 and T8 were established along truck passage ways within the dumpsite, while profile T10 was established directly over dumped wastes and laid parallel to Profile T2. Each of the profiles was occupied twice using 6 m and 10 m station intervals in order to sample two different subsurface depths. For this study an operating frequency of 27.4 KHz and signal strength of 14 were adopted to ensure high integrity measurements. The ABEM-WADI instrument records values of Raw-real and Raw-imaginary on the field. The raw field data were then processed using Karous-Hjelt filter to obtain the filtered outputs of the in-phase and out-of-phase components of the secondary EM field as filtered-real and filtered-imaginary (Karous and Hjelt, 1983).

4 HYDROGEOCHEMICAL STUDY

Hydrogeochemical sampling and subsequent laboratory analyses involved sampling of four open dug-wells around the study area. Three of the wells (L1, L2 and L3) are situated close to the dumpsite, while the fourth well (L4) is located much farther away and it serves as control to ascertain that the observed water chemistry reflect contamination effect from the leachate derived contaminants. Two of the wells (L1 and L2) are situated uphill in the north of the dumpsite while L3 and L4 are located downhill of in the east and southeast of the dumpsite. Hydrological and hydrogeochemical study involved determination of the pH and Total Dissolved Solids (TDS) of the well water samples using a Milwaukee pH 600 pocket size pH meter and a Sprite Water Pro TDS Meter, respectively. The wet chemical analytical method was used for other geochemical analyses which include gravimetry, titrimetry, calorimetry and flame photometry. The techniques were employed to determine the concentration of cations such as $Ca^{2+}$and Mg^{2+}. A HACH 44600 portable data logging spectrophotometer was also used to identify anions such as bicarbonate (HCO_3^-), nitrate (NO_3^-), sulphate (SO_4^{2-}) and phosphate (PO^{3-}) ions.

The generated geophysical data raw real (in-phase) and imaginary (out-of-phase) components of EM field were quality checked (QC) and spurious measurements removed. The data were further processed with the Karous-Hjelt filter to obtain the filtered real and imaginary components of the EM field. The ratios of the vertical to horizontal magnetic components (Hv/Hh) were plotted against offset distances in meters. Six plots were generated for each profile; three plots for each station interval (6 and 10 m) measurements. Cross plots generated for each profile with a station interval include raw-real/filtered-real, filtered-real/filtered-imaginary and finally, raw-real/raw-imaginary against offset distances.

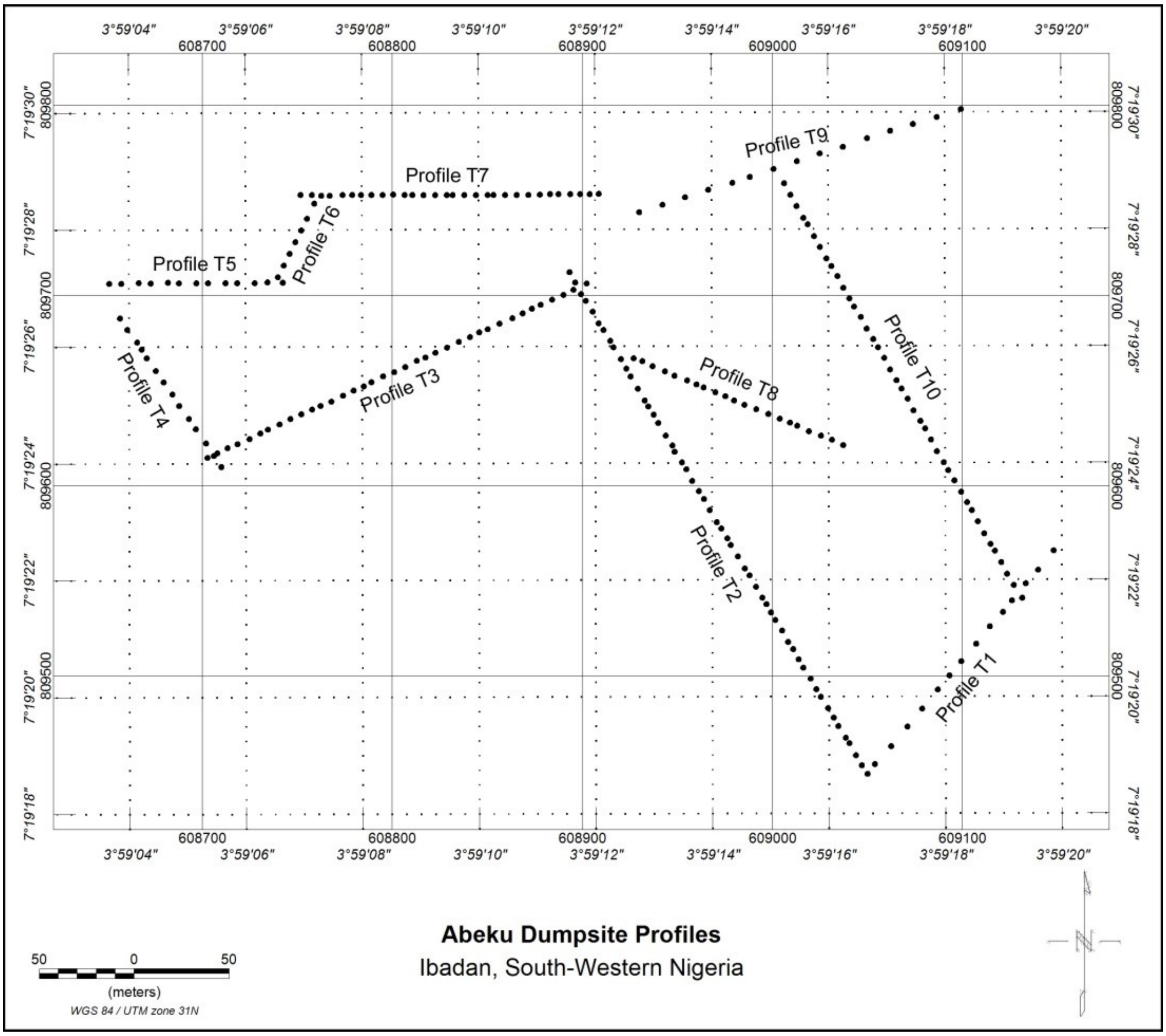

Figure 3: VLF-EM Profile Layout Across the Study Area.

5 RESULTS AND DISCUSSION

The VLF-EM results are presented as cross-plots, which are displayed in figures 4 to 13. The interpretations are mainly qualitative; conductive zones in the subsurface presents characteristic high positive peaks on the filtered-real and corresponding high negative peak on the filtered-imaginary plots (inflexion). Also, moderately high positive peak on the filtered-imaginary plot could indicate conductive zone (Olorunfemi *et al.*, 2005; McNeill and Labson, 1991; Osinowo and Olayinka, 2012). In addition, the occurrence of high (maximum) negative anomalies of the filtered-imaginary indicates shallow fractures or dyke intrusions. A plot of raw-real and raw-imaginary against station gave idea of overburden thickness, where the occurrence of negative anomaly in both the raw-real and raw imaginary plots indicate a shallow overburden thickness (Ariyo *et al.,* 2009).

Generally, the VLF-EM results generated at all occupied profile locations indicate moderate to high conductive ground. The measurements obtained from the profiles occupied in the northern part of the study area (T5, T6, T7 & T9) are the least conductive while the profiles established in the southern part of the dumpsite (T1, T2 & T3) present increased level of conductivity, which could be attributed to the concentration of leachate derived contaminants.

5.1 Profile T1

The cross plots of the real and imaginary components together with their filtered equivalents generated along profile T1 are presented in Figure 4. The data acquired using 6 m sampling interval (a = 6 m) indicates anomalies at 20, 50, 80 and 130 m marks of the profile. At these points, the plots of raw-real/filtered-real and filtered-real/filtered-imaginary indicate high conductive peaks. Likewise, low positive peaks on the filtered-real and the negative peak on the filtered-imaginary plots also indicate conductive zones. The data generated at 10 m sampling interval only indicate conductive readings between 60 – 90 m marks of the filtered-real plot and decreases to the left and right of the profile. This pattern indicate occurrence a conductive zone which could suggest occurrence of a leachate plumes or buried materials. The raw-real/raw-imaginary plots also indicate a fairly thick overburden.

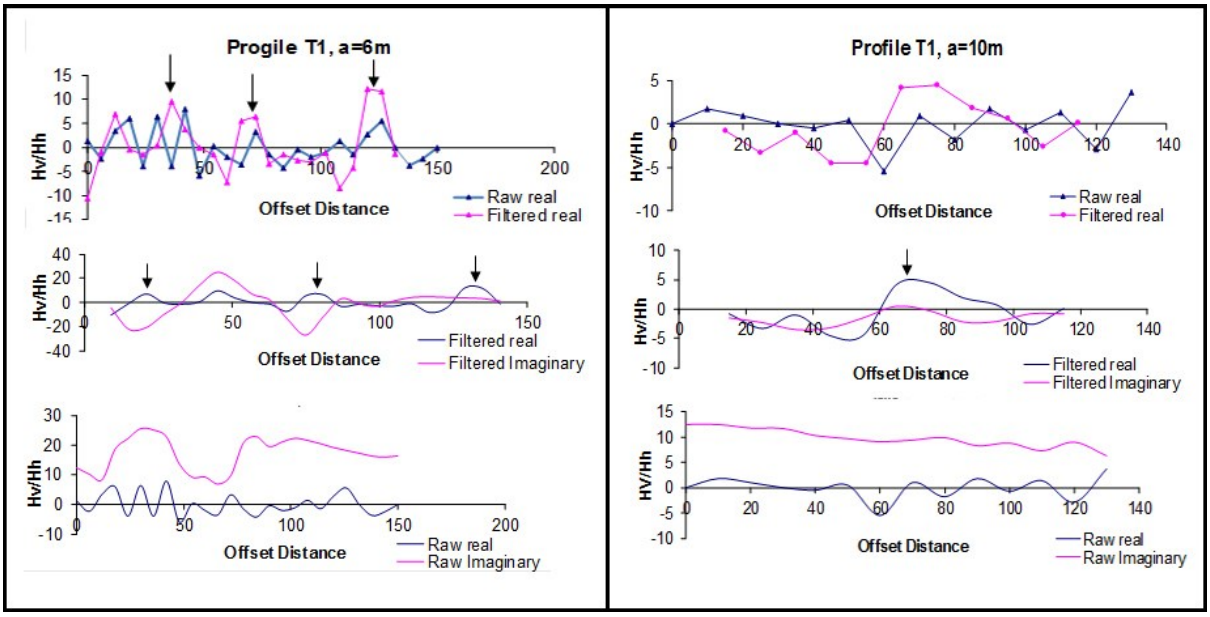

Figure 4: VLF-EM data plots along Profile T1

5.2 Profile T2

The cross plots of VLF-EM measurements along profile T2 are presented in Figure 5 and the plots indicate a generally high level of ground conductivity, which may likely be attributed to the occurrence of clayey unit as well as leachate contamination. The 10 m station interval plots display VLF anomalies around the 20 – 90 and 200 – 280 m marks of the profile. Although the profile indicates a generally conductive ground, a prominent conductivity anomaly delineated around 200 – 280 m mark of the profile suggests the occurrence of leachate plumes. The raw-real and raw-imaginary (a = 6 m) plots indicate a fairly thick but uneven overburden. In addition, positive real peaks and negative imaginary peaks are characteristic of shallow fractures and water-filled fracture zones (Monteiro *et al*., 2006; Sundararajan *et al*., 2006).

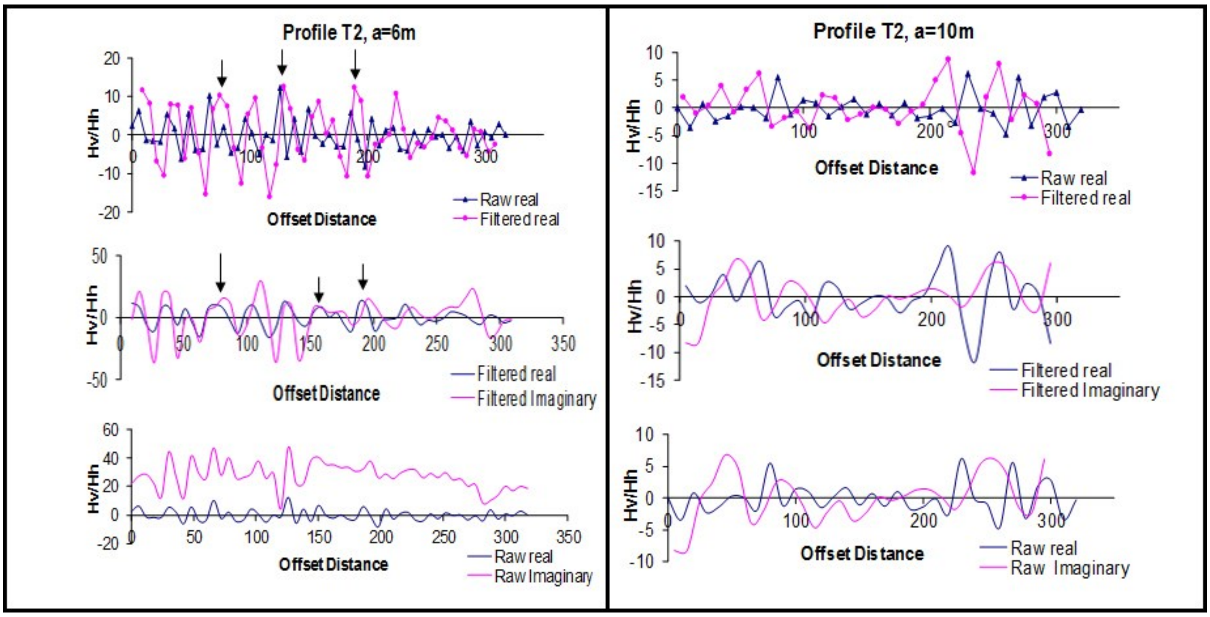

Figure 5: VLF-EM data plots along Profile T2

5.3 Profile T3

The plot of the VLF-EM data generated along profile T3, using 6 and 10 m station intervals indicate a generally conductive ground (Figure 6) which likely reflects the effect of ground contamination from leachate derived contaminants. The cross plots of the measurements taken using 6 m station interval indicate low ground conductivity between 40 – 120 m offset which suggest variation in the level of leachate contamination and could be attributed to either higher leachate concentration resulting from higher porosity of the formation underlying the section of the profile at 130 – 155 m. A leachate plume is suspected around 155 m mark of the profile with characteristic inflexion points on the raw-real and filtered-real data plots (Hazel *et al*., 1988; Osinowo *et al*., 2011). The raw-real/raw-imaginary plots indicate a fairly thick and even overburden thickness across the profile.

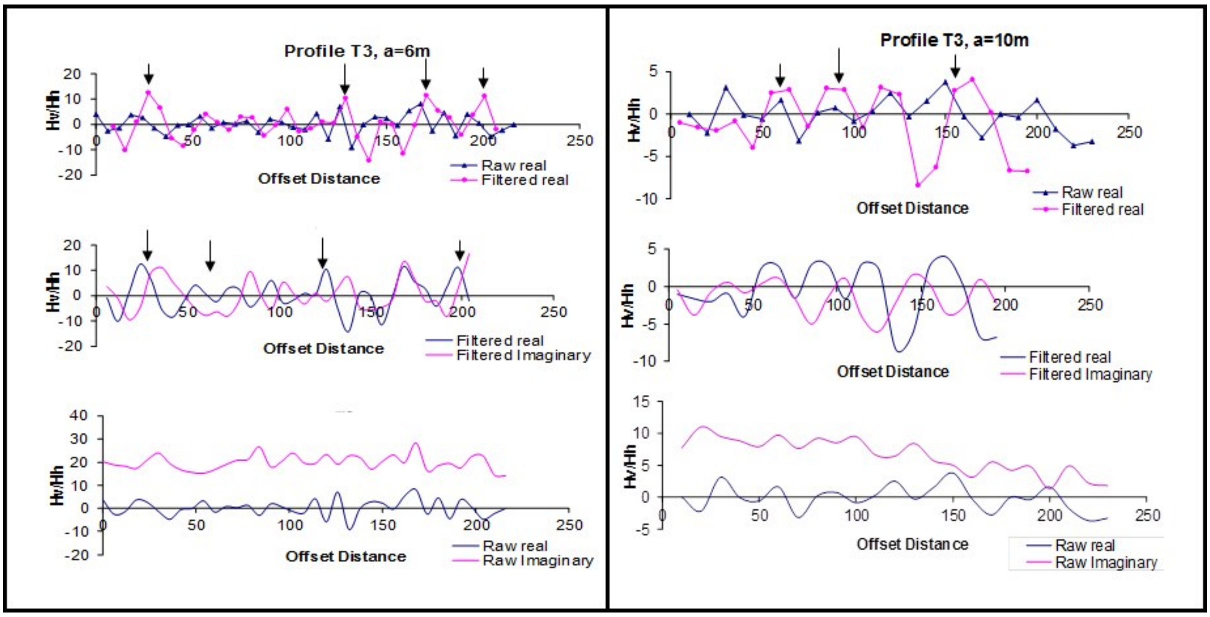

Figure 6: VLF-EM data plots along Profile T3

5.4 Profile T4

Figure 7 presents the VLF-EM cross plots of measured data obtained along profile T4. The profile was occupied outside the dumpsite; about 5 m from the perimeter fence and thus generally present relatively low subsurface conductivity level, especially when compared to the conductivity distribution across profiles occupied within the dumpsite. Waste dumping activity is low at this side of the dump and hence, ground conductivity is less affected by leachates and waste materials. The 6 m station interval plots have two conductive peaks, located around the 10 and 50 m marks, while the 10 m station interval plots have a single conductive peak, located around the 60 m mark. The raw-real/raw-imaginary plots indicate that the overburden is relatively shallow.

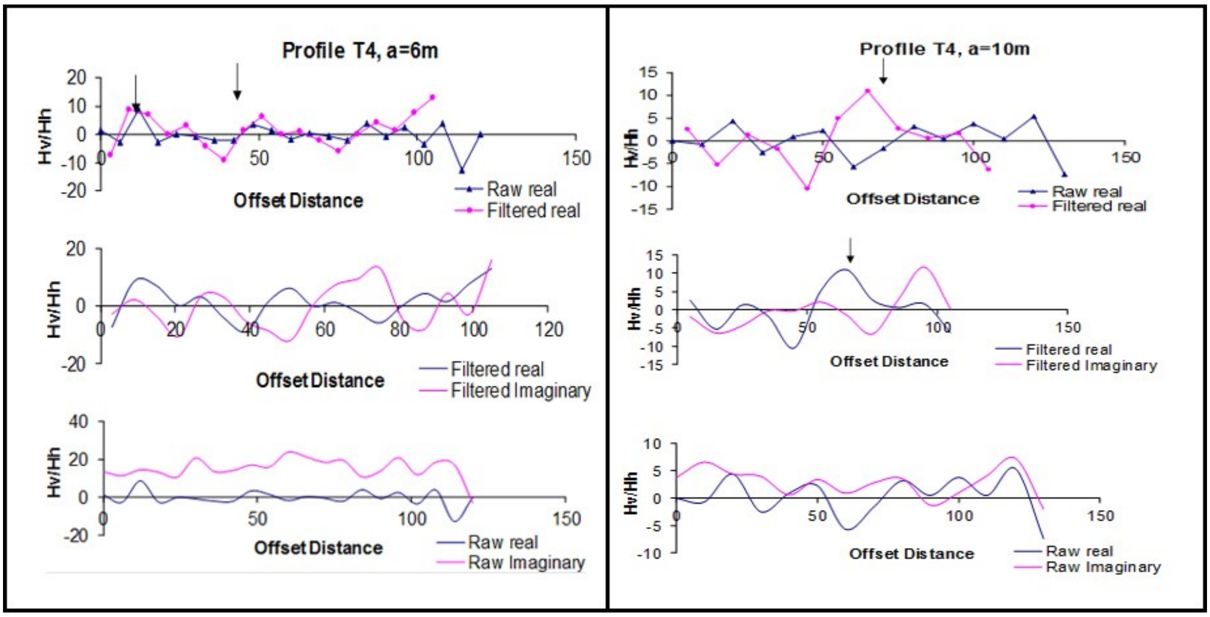

Figure 7: VLF-EM data plots along Profile T4

5.5 Profile T5

The plots of VLF-EM data obtained along profile T8 is presented in figure 8. The profile (T5), like Profile T4, was established outside the dumpsite, away from the dumped wastes and also displayed a generally low ground conductivity level. The low ground conductivity could be attributed to distance away from the leachate generating source, especially where the underlying geology is fairly constant throughout the study area. In addition, profile T5 sampled is the uphill of the dumpsite and thus less susceptible to underground contaminant migration. The 6 m station interval plots delineate two conductive peaks, located around the 70 and 130 m marks, while the 10 m station interval plots display only one conductive peak around the 60 m mark. The overburden thickness along this profile is relatively shallow and uneven.

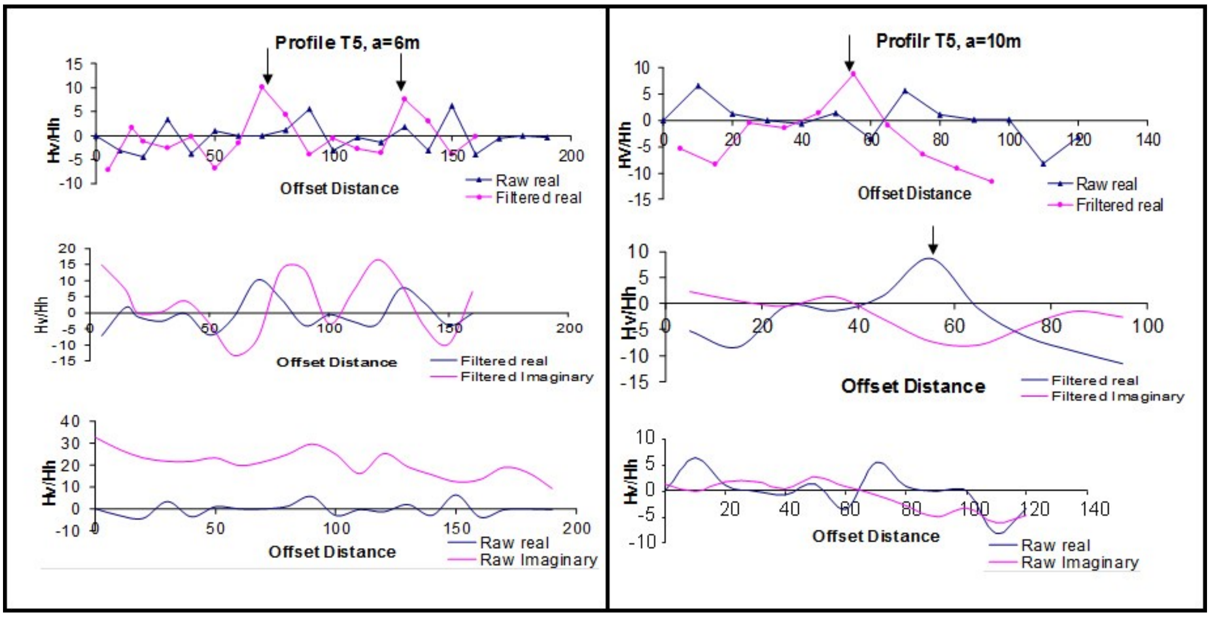

Figure 8: VLF-EM data plots along Profile T5

5.6 Profile T6

Profile T6 was occupied outside the waste dump, by the perimeter fence and the obtained measurements indicate low ground conductivity (Figure 9) which suggests least contamination effect from the leachates generated from the wastes deposited on the dumpsite. Since the profile was also established uphill of the dumpsite, topographic gradient will make northward migration of leachates formed downslope less feasible, if at all. The only recorded anomalous peak occurred around the 30 m mark on of the 6 m station interval raw-real/filtered-real plot. This anomalous peak may be associated with structures within the subsurface or isolated buried conductive object. The overburden thickness is also relatively shallow and uneven.

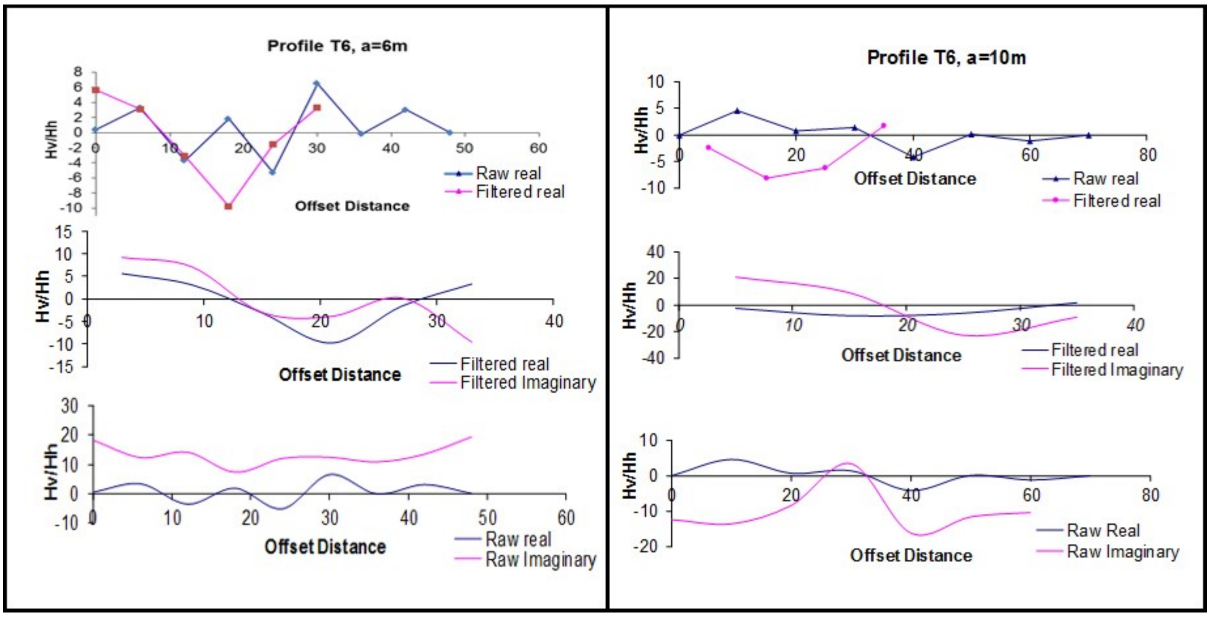

Figure 9: VLF-EM data plots along Profile T6

5.7 Profile T7

Figure 10 presents the VLF-EM ground response along profile T7. This profile indicates a moderately low level of ground conductivity, but relatively higher than the level observed on profile 6. The profile was established outside the waste dumpsite close to the perimeter fence, and thus reflects minimal contamination effect from leachate derived contaminants. The raw-real data plots on both 6 and 10 m station interval plots indicate a fairly uniform level of ground conductivity. The overburden thickness is observed to be relatively shallow and the thickness is fairly even throughout the profile.

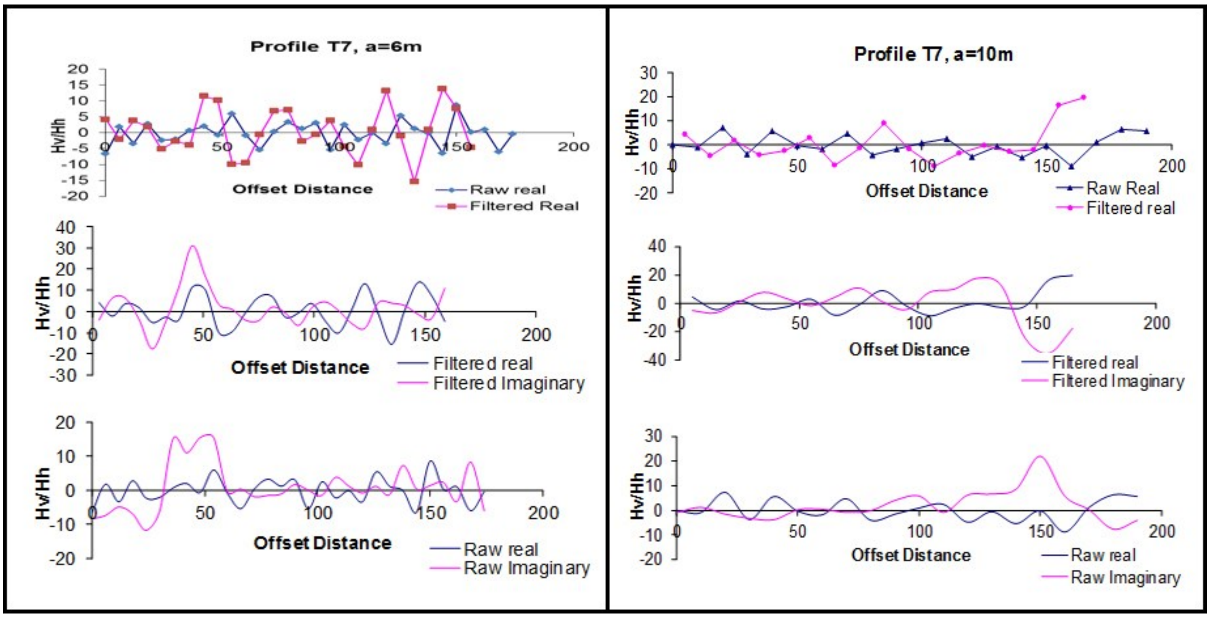

Figure 10: VLF-EM data plots along Profile T7

5.8 Profile T8

The generated plots obtained from VLF-EM data acquired over profile T8 are presented in Figure 11. The plots also present a generally low to moderate level of subsurface conductivity with conductive ground identified at 50 m and 40 m marks on the 6 and 10 m sampling intervals respectively, through the crossover (inflexion) of both the raw real and the filtered real.

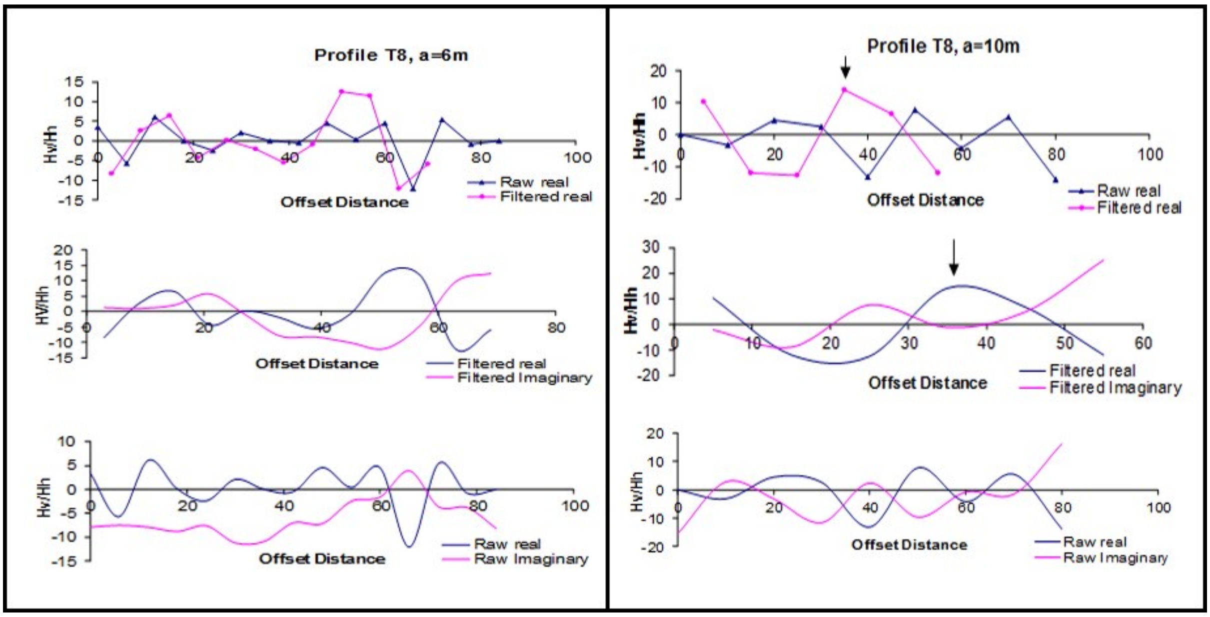

Figure 11: VLF-EM data plots along Profile T8

5.9 Profile T9

Figure 12 presents the VLF-EM data plots along profile T9 which was occupied 5 m away from the perimeter fence in the northern part of the dumpsite. The profile indicates a generally low to moderate level of ground conductivity, which is very similar to what is recorded on Profile T7. The generally low level of ground conductivity is also similar to that recorded along all the other profiles situated outside north of the dumpsite. The location of the profile at the uphill side of the dumpsite suggests that the ground conductivity is likely to be less influenced by contaminants derived from leachate generated from the wastes.

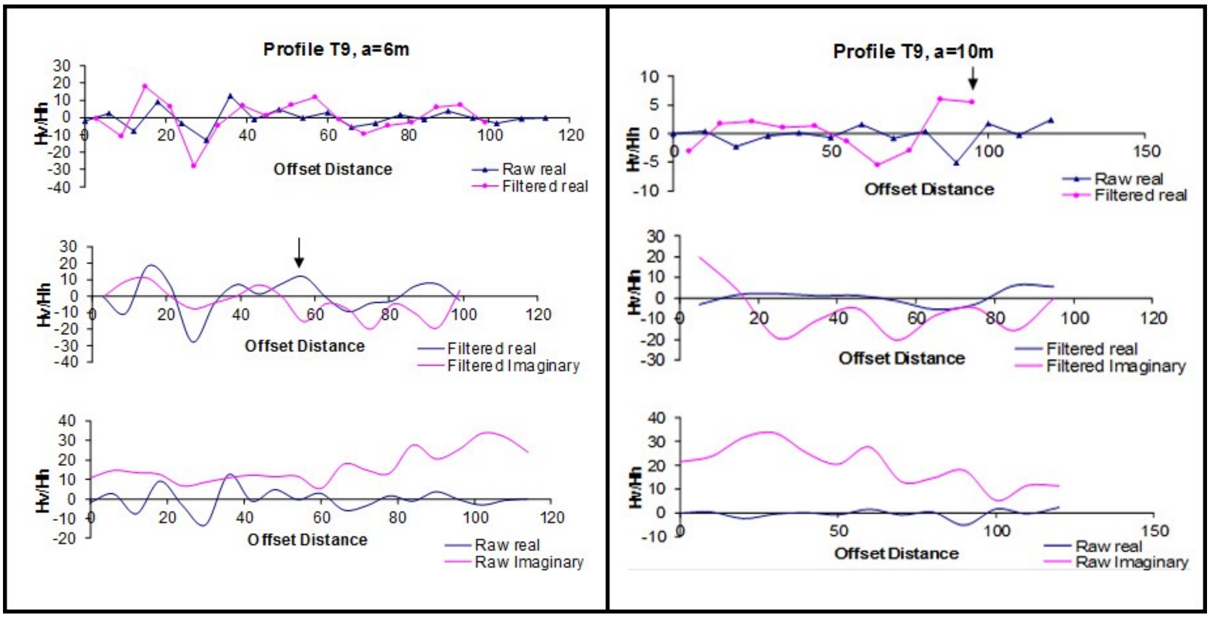

Figure 12: VLF-EM data plots along Profile T9

5.10 Profile T10

Figure 13 is the VLF-EM data plots along profile T10. This profile presents a generally high level of ground conductivity as indicated by several inflexion points (crossover of the filtered real and the imaginary real components of the secondary EM wave) on both the 6 m and 10 m station interval plots. This profile runs over dumped wastes and as such, the high level of ground conductivity can attributed to the contamination effect of the generated leachates. The overburden thickness is fairly thick and even.

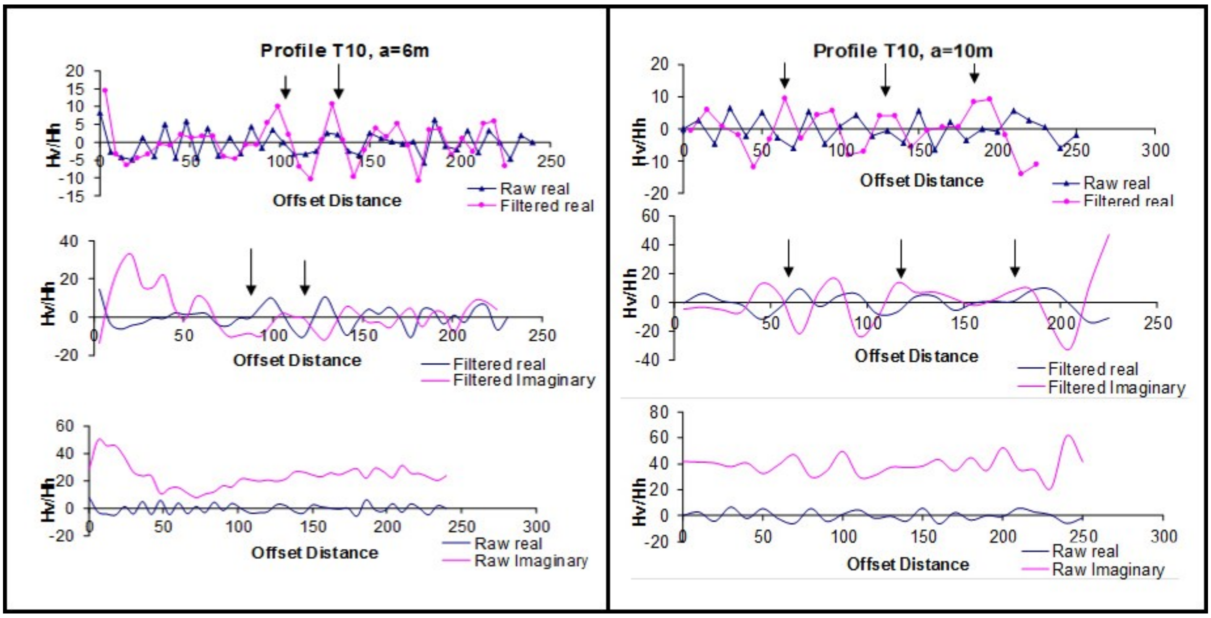

Figure 13: VLF-EM data plots along Profile T_{10}

5.11 Hydrological Result

The hydraulic/hydrostatic head map generated from well head measurements around the study area is presented in figure 14. The hydraulic head values range from 143 to 165 m with the highest value recorded in the northwestern region of the study area and gradually decreases eastward. The hydraulic gradient approximately trends in NW-SE direction, which indicates the general direction of groundwater flow in the subsurface (arrow). In essence, the direction of hydraulic gradient explains the reason why profiles established uphill, around the north and northwest of the waste dump has relatively low level of ground conductivity, which suggests absence of ground contamination by waste materials. This is because, apart from the non-existence of waste dumped in these areas, generated leachates are unable to migrate uphill to cause ground contamination which may likely result in raised ground conductivity. However, higher conductivity signatures characterize measurements recorded south and southeast of the dumpsite where down-hill migration of leachate derived contaminants is supported by gravity.

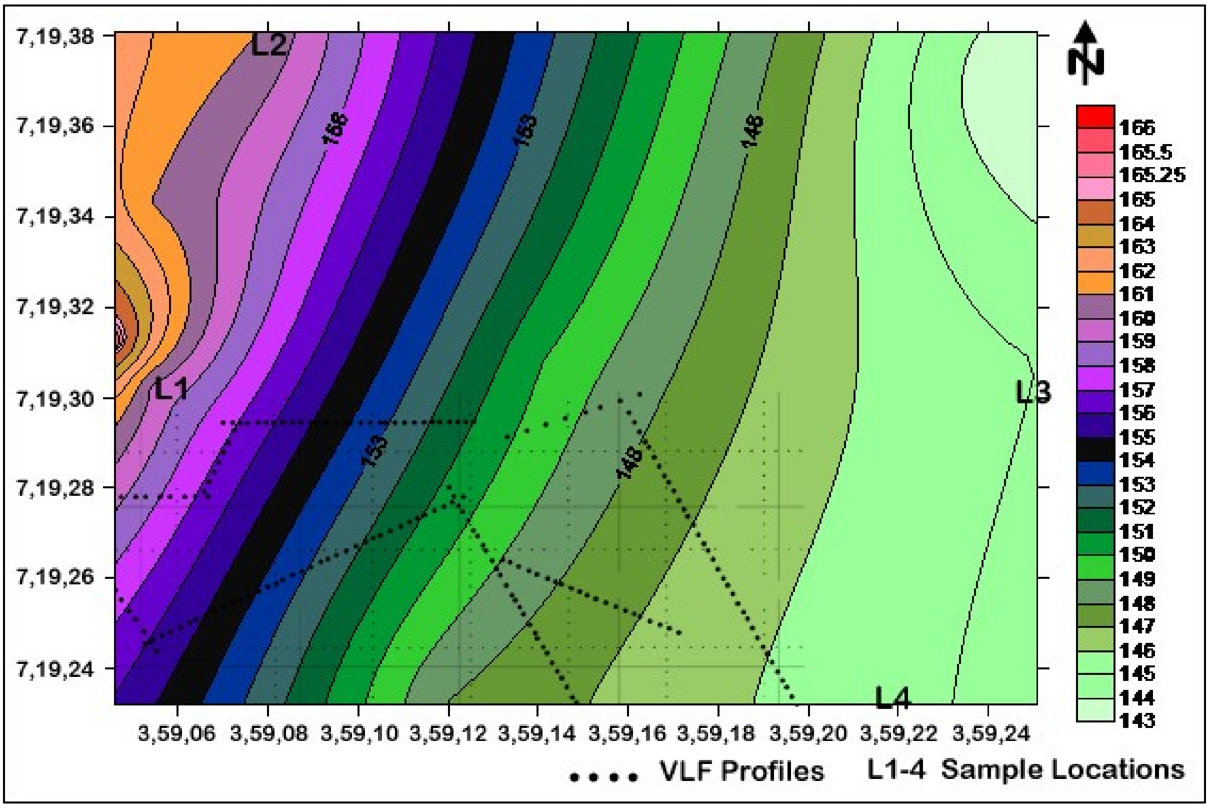

Figure 14: Hydraulic Head Map of the Study Area

5.12 Hydrochemical Result

The summary of hydrochemical analyses is presented in Table1, and the pH result indicates that all the samples are alkaline, and thus suggests higher concentration of metallic ions dissolved in the groundwater. Sample L3 has the highest Total Dissolved Solid (TDS) value and followed by sample L4, then L1 and L2 in that order with measured TDS values of 378, 135, 120 and 84 PPM, respectively. The two samples (L3 & L4) having highest TDS values were obtained from hand dug wells located downhill of the groundwater hydraulic gradient in the east and southeast of the dumpsite. However, samples L1 and L2 were obtained from wells located uphill in the north and west of the dumpsite. This suggests contribution from leachate derived contaminants as likely source of the high TDS values. Sample L3 also has relatively high bicarbonate (HCO_3^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions concentrations with values of 72, 805, 49.2 and 13.2 mg/L respectively. The relatively high concentration levels of cations (Ca^{2+} and Mg^{2+}) in sampled groundwater indicate high level of alkalinity, which agrees with the pH value of 8.8 measured from the well water. The samples also present slightly high nitrate (NO_3^{2-}) sulphate (SO_4^{2+}), and phosphate (PO_4^{3-}) ions concentration with values of 13.64, 7.0 and 1.07 mg/L respectively. The sample (L3) was taken from a hand dug well situated about 30 m east of the dumpsite perimeter fence, which is downhill based on the hydraulic head map (Figure 14) and thus indicate influence of groundwater contamination from leachate-derived contaminants. Sample L4, obtained from a hand dug well located 30 m southeast from the dumpsite also present relatively high concentration of both cations and anions, especially ions of NO_3^{2-}, HCO_3^-, Ca^{2+} and Mg^{2+}, which are higher compared to that obtained in wells located uphill of the hydraulic distribution head. The slightly higher nitrate ion concentration of sample L1 relative to samples collected downhill of the hydraulic head could be attributed to input from uncased peat latrines in the densely populated north of the dumpsite (Fervolden and Hughes, 1976). Generally, all the measured physical and chemical parameters compared favourably with FEPA (1991) standard. The TDS, pH, Ca^{2+}, $NO_3^-$and PO_3^- present values lesser value than FEPA (1991) standard. All the wells samples except L3 record lower measured value of SO_4^- than FEPA (1991) standard while both HCO_3^- and Mg^{2+} present higher measured values than the standard (FEPA, 1991) for all well samples.

Table 1: The Result of the hydrochemical analysis of the well water samples in the study area

Sample Number	TDS (ppm)	pH	NO_3^- (mg/L)	SO_4^{2-} (mg/L)	PO_4^{3-} (mg/L)	HCO_3^- (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)
L1	120	8.0	13.64	7.0	1.07	470	2.0	0.69
L2	64	8.2	12.76	3.0	0.61	915	36.0	0.83
L3	378	8.8	9.24	72.0	0.33	805	49.2	13.2
L4	135	8.6	12.76	4.0	0.4	640	30.0	1.25

6 CONCLUSION

The analyses of the various plots generated from the VLF-EM measurements recorded along occupied profiles indicate relatively high subsurface conductivity signatures within the dumpsite which generally decreases away from the dumpsite. Profiles occupied in the north and northwestern part of the dumpsite presented relatively low conductivity signatures while those established in the east and southeast displayed characteristically higher ground conductivity. The generally low ground conductivities recorded outside the dumpsite, especially in the north and northwest of the dumpsite can be attributed to less influence of leachate derived contaminants outside the dumpsite perimeter. The ground conductivity pattern is corroborated by hydrogeochemical study which revealed relatively higher concentration of anthropogenic groundwater contaminants downhill of the groundwater hydrostatic gradient. The generally low level of soil and groundwater pollution outside the dumpsite as indicated by the VLF-EM plots and hydrogeochemical study, may be attributed to management of the Abeku dumpsite which has a leachate containment system into which leachates from the dumpsite is drained through a network of pipes (Oni and Hassan, 2013). The recorded slightly raised soil and groundwater contamination in the east and southeast of the dumpsite is likely due to uncontained leachates which migrate down groundwater hydrostatic head.

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