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Application of Very Low Frequency Eletromagnetic and Hydro-Physicochemical Methods in The Investigation of Groundwater Contamination at Aarada Waste Disposal Site, Ogbomoso, Southwestern Nigeria.

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Abstract: Groundwater contamination both in rural and urban area is growing alarming in Nigeria today. Some people ignorantly believe infiltration must take place before the refuse been dumped on topsoil reached the water table in the subsurface without taking into consideration depth to the aquifer and flow of underground water. This has necessitated this research about investigation of groundwater contamination around the waste disposal site at Aarada in Ogbomoso, Oyo State, Nigeria. The study was conducted using Very Low Frequency Electromagnetic (VLF-EM) and hydro-physicochemical methods. A total of twelve VLF-EM profiles were carried out with length ranging between 50 to 130m. The hydro-physicochemical analysis was conducted at the peak of the dry season on nine water samples taken from nine different hand-dug wells in the research area. The result obtained from the processed VLF-EM data revealed the presence of leachate (contaminant fluid) at the subsurface in the area. The water quality analysis report showed hazardously high values of Fe^{2+}, Pb^{2+}, Zn^{2+}, Cu^{2+} and NO_3- to confirm the findings from the VLF-EM survey. Conclusively, the study reveals that domestic usage of water from hand-dug well in the investigated area without undergoing water treatment is very hazardous. Oyo State Government should enforce law against dumping of refuse in that area, or if the place would continue to be used for dumpsite, Government should evacuate people living within the dumpsite in order not to be contacted with water borne diseases.

Key words: groundwater, leachate plume, contaminants, health hazard, electromagnetic).

INTRODUCTION

Groundwater is an essential source of water supply for domestic, industrial and agricultural purposes. Potable and safe drinking water represent a valuable requirement for the fundamental existence of humans in any society. However, maintaining a potable groundwater quality that is free from chemical and microbial contaminants is a major concern in most of the urban centers, due to poor waste disposal and management practices. Recent industrial development and uncontrolled growth of the urban population have resulted to the increase in production of different types of waste ranging from municipal to industrial. Most of the cities in the country are faced with waste management problems, for example, inadequate trained waste disposal personnel and equipment, poor waste collection, sorting and disposal methods, and indiscriminate sitting of disposal sites without regards to the local geology and hydrogeology of that particular area. All these factors contribute significantly to the contamination of the ground water. Ground water is said to be contaminated when it becomes unfit and unsafe for the intended use. This contamination makes the ground water unusable due to taste, odor, high microbial, ionic and volatile organic content, which has considerably adverse impacts on groundwater quality and public health.

The major source of groundwater contamination in the research area is a solid waste disposal site that has been in operation for more than two decades. The refuse contents consist of various kinds of materials like metallic, organic and non-biodegradable materials. Hand dug wells are sited within a distance of 3 to 25m away from the study area with shallow depths ranging from 4.1 to 6.5m. Among the available geophysical methods, electrical resistivity and electromagnetic methods have been found remarkably suitable for this kind of environmental studies, due to the conductive nature of most contaminants (Atekwana *et al*., 2000; Orlando and Marchesi, 2001). Electromagnetic surveys have been proved particularly useful as they can delineate waste, conductive fluids and buried metals. Degradation of organic material in field-saturated conditions produces a terrain conductance signature that is enhanced above background conditions. The elevated signature can be used to locate waste, delineate the waste boundaries and provide a rough estimate of depth of wastes. Fasunwon *et al.* (2010) investigated the impact of a dumpsite on the neighbourhood of a part of southwestern, Nigeria using

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geophysical methods. Odewande (1999) researched on hydro-chemical characterization of environmental impact of solid waste dump site using Orita-Aperin central refuse dump site in Ibadan, South-Western, Nigeria, as a case study. As a result of the hazardous impact of solid waste disposal site on local community, it has become necessary to investigate the contaminant level of the underground water around Aarada Refuse dumpsite, Ogbomoso, Oyo State, Nigeria. In this research work, the integration of hydro-physicochemical and very low frequency electromagnetic methods was employed to locate and determine the extent of contamination of the water table in the study site. Contamination results from the intrusion of leachate from the waste disposal site, thereby introducing ions and parasitic micro-organisms into the underground water.

Geology and Hydrogeology:

The study area is located in Ogbomoso, southwestern Nigeria between latitude 8°06′70″ and 8°06′98.7″ north and between longitude 4°14′28.2″E and 4°14′56.9″ east. The geology of this area consists of Precambrian rocks that are typical for the basement complex of Nigeria (Rahaman, 1976). The major rock associated with Ogbomoso area form part of the Proterozoic schist belts of Nigeria, which are predominantly, developed in the western half of the country. In terms of structural features, lithology and mineralization, the schist belts show considerable similarities to the Achaean Green Stone belts. However, the latter usually contain much larger proportions of mafic and ultra mafic bodies and assemblages of lower metamorphic grade (Jones and Hockey, 1964; Rahaman, 1976).

The rocks of the Ogbomoso district may be broadly grouped into gneiss-migmatite complex, mafic-ultra mafic suite (or amphibolite complex), meta sedimentary assemblages and intrusive suite of granitic rocks. A variety of minor rock types are also related to these units. The gneiss-migmatite complex comprises migmatic and granitic, calcareous and granulitic rocks. The mafic-ultramafic suite is composed mainly of amphibolites, amphibole schist and minor meta ultramafites, made up of anthophillite-tremolite-chlorite and talc schist. The meta sedimentary assemblages, chiefly meta pelites and psammitic units are found as quartzites and quartz schist. The intrusive suite consists essentially of Pan African (c.600Ma) Granitic units. The minor rocks include garnet-quartz-chlorite bodies, biotites-garnet rock, syenitic bodies, and dolerites (Jones and Hockey, 1964; Rahaman, 1976).

The study area is bounded to the north by a river which flows downhill into the valleys. The drainage pattern is dendrites with irregular branching of the tributary streams. Ogbomoso area overlies the western upland region of the Nigeria highland plateaux with average altitude between 1000m and 1500m above mean sea level (Akinloye *et al*. 2002). The drainage type is intrinsically dendrites. Locally, Ogbomoso area experiences tropical rainfall which dominates most of southwestern part of Nigeria and the area has two distinct seasons, the wet season usually between March and October, and the dry season which falls between November and February every year. The annual rainfall for the study area is 1247mm, but the amount varies from 1016mm to 1524mm, and is almost entirely concentrated in the wet season. The study area falls within the guinea savannah belt of Nigeria but human activities such as exploitation are gradually changing the vegetation to that of Sudan savannah.

MATERIALS AND METHODS

VLF-EM Measurements:

Very Low Frequency electromagnetic (VLF-EM) geophysical prospecting method is a passive geophysical method which uses radiation from military navigation radio transmitters operating in the very low frequency band (15–30 kHz) as the primary EM field to generate signals for various applications (Babu *et al*., 2007). In this research work, VLF-EM method was employed to map the contaminant zones using the Abem Wadi VLF-EM equipment with an in-built digital display unit and powered by 12V battery type. For the VLF-EM measurements, radio signal station with frequency value of 22.4 kHz was employed to generate the primary electromagnetic field around the contamination plumes in order to induce the detected secondary field and measured as a fraction of the primary field by the VLF-meter. In total, twelve profiles were occupied with measurement station intervals of 10m with lengths ranging from 50m to 120m for convenience of space limitation. Each profile runs perpendicular to the general north–south geologic strike in the study area.

Subsequent to field survey measurements, VLF-EM data were subjected to data processing and evaluation as the basis for interpretation. These procedures transform the raw field data into a simplified form that is directly related to the physical property of the subsurface geological structure. Thus measured raw real and imaginary components were subjected to Karous-Hjelt (Karous and Hjelt, 1983) filtering operations to suppress noise and enhance signal.

Hydro-Physicochemical Analysis:

In order to assess the level of groundwater contamination by the solid waste leachate, water quality analysis was conducted on water samples from nine hand dug wells in the research area. Sampling was conducted in December, 2011 at the peak of dry season to avoid the effect of dilution that may result from precipitation during rainy season. The depth of the hand dug wells varied between 4.1 and 6.5m, and also their locations from the waste dumping site ranged from 3 to 25m. The water samples were analyzed for physical parameters {Temperature, pH, Conductivity, Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Total dissolved solids (TDS), SO_4^{2-} (sulphate), PO_4^{3-} (phosphate), and NO_3- (nitrate)} while the chemical analysis was conducted for four trace elements (Pb^{2+}, Zn^{2+}, Fe^{2+} and Cu^{2+}). Water samples collected were stored in well-drained clean polythene bottles already rinsed out with same water samples from each hand dug well. The water samples collected for chemical analysis were acidified with dilute nitric acid and stored in a refrigerator prior to analysis. Analysis of all the physical parameters were done using the various standard methods for water analysis (APHA, AWWA and WPC, 1985) while preserved water samples were analyzed for cations and anions using Atomic Absorption Spectrometer (AAS) method. The results of the hydro-physicochemical analysis are presented in table1.

RESULT AND DISCUSSION

The Karous-Hjelt current density data plots were employed for the VLF-EM data interpretation to detect the leachate flow and to map its spatial distribution as shown from fig. 4 to fig. 11. The current density value on the Karous-Hjelt filter plot in fig. 4 is high at a distance of 13 to 19m, revealing the presence of dissolved salts from decayed organic matter from the waste body. The VLF-EM profile 4, also carried out at the northern side of the waste disposal site area revealed high conductivity value on the apparent current density cross-section of the 2-D Karous-Hjelt filter image at a distance of 44 to 50m as a result of the infiltration of leachate which is made up mainly dissolved salts from the refuse dumping site in the research area. Similar geologic trend was also observed in fig. 6 at a distance of 41 to 49m in which the Karous-Hjelt modeled plot depicted high conductivity value indicative of leachate contamination from the waste disposal site. The apparent current density cross section of the Karous-Hjelt filter model in fig. 7 detected high conductive zones at distance 6 to 7m due to the presence of contamination plume from the decomposition of organic matter in the study area, and also at distance 41 to 46m. From a distance of 19 to 25m in fig. 8, leachate contamination was observed revealing high current density zone on the Karous-Hjelt modeled section. High conductivity value was depicted on the apparent current density cross section of the Karous-Hjelt modeled filter plot on VLF-EM profile 9, reflecting the presence of contamination plumes between distance 52 and 65m, and from distance 88 to 112m in the research area. In the same vein, contaminated zone was detected at the subsurface in fig. 10, at distance 50 to 65m. Finally, intrusion of leachate plumes was also depicted at distance 38 to 42m and also between 65 and 71m distance on the apparent current density cross section of the Karous-Hjelt model plot in fig.11.

The depth of the hand dug wells from which the nine samples were collected and their locations from the waste body are shown in Table 1. The result of the concentration of cations and anions as well as the total bacteria and coliform counts are also presented in Table 1. The concentration of each ion is an indication of the potability of the water (Ehinola, 2002). The World Health Organization (WHO) standard for good quality drinking water serves as criteria for assessing the potability of the sampled hand dug wells in the research area. The analysis of the result obtained from the hydro-physicochemical method indicates that most of the hand dug wells (especially those nearest to the waste disposal site) in Aarada area are fairly acidic, shows elevated values in the concentration of TDS, NO_3^-, Cl^- and bacteria counts compared to the guidelines recommended by WHO. This reveals that the usage of these hand dug wells for domestic purposes without administering any form of treatment in advance poses a serious health hazard.

The concentration of various parameters tested in wells A, B, C, D and E falls within the WHO standard, which is an indication of good conditions of the wells. The poor conditions of wells F, G, H and I are attributed to anomalously high concentration of NO_3^- which is caused by anthropogenic pollution and high total coliform counts in the water samples. The increase in the concentrations of the trace metals are possible due to the effect of the leachate migrating from the waste body to the underground water. The high electrical conductivities are attributed to contaminant fluids rich in total dissolved solids. The increase in BOD concentration is an indication of high concentration of biodegradable organic substances from the waste disposal site while the increase in COD concentration indicates pollution from both oxidizable organic and inorganic pollutants. The elevated concentration of arsenic, copper, lead, nitrate, iron and zinc ions in the water samples is an indication of toxic substances in solid forms in the leachate (Meju, 2000). The high concentrations of these hazardous substances (lead, nitrate and iron) observed in wells F, G, H, and I call for urgent concern because their intake may have adverse effect on the intestinal tract, the central nervous system and the kidney/liver of the victims (Bashir , 2001). The high concentration of total dissolved solids in most of the samples may be a reflection of gradual weathering of the basement rocks.

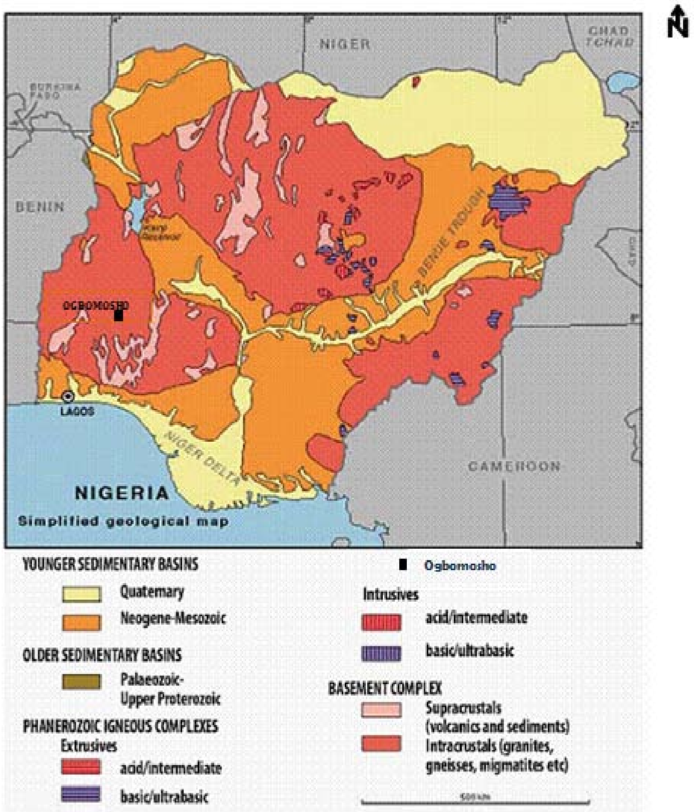

Fig. 1: Geological map of nigeria showing the location of ogbomoso.

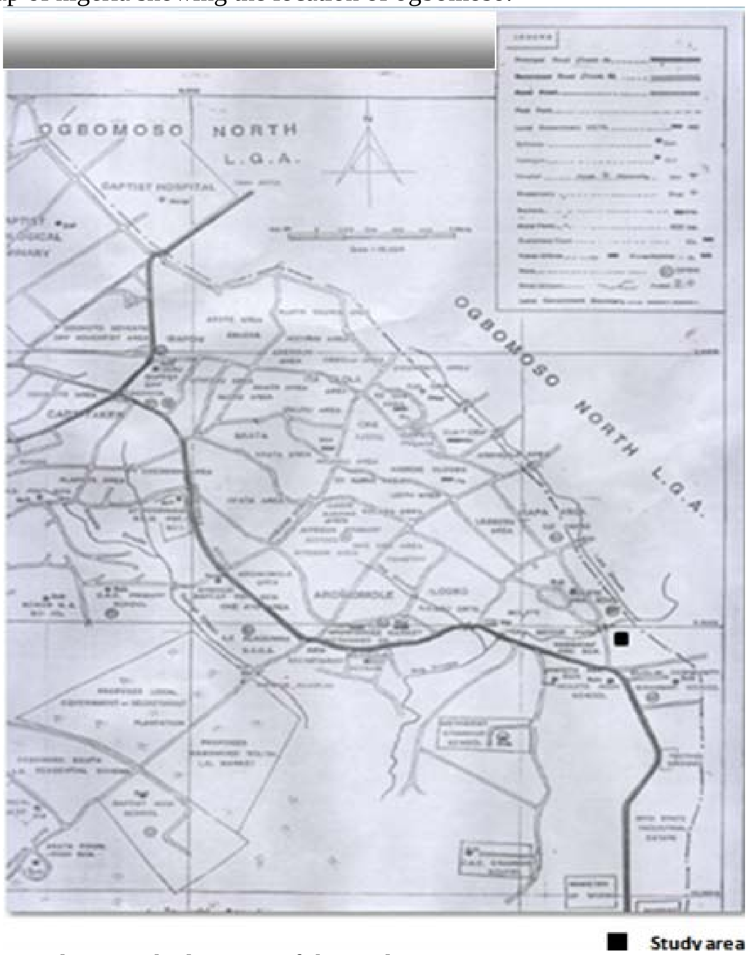

Fig. 2: map of ogbomoso showing the location of the study area.

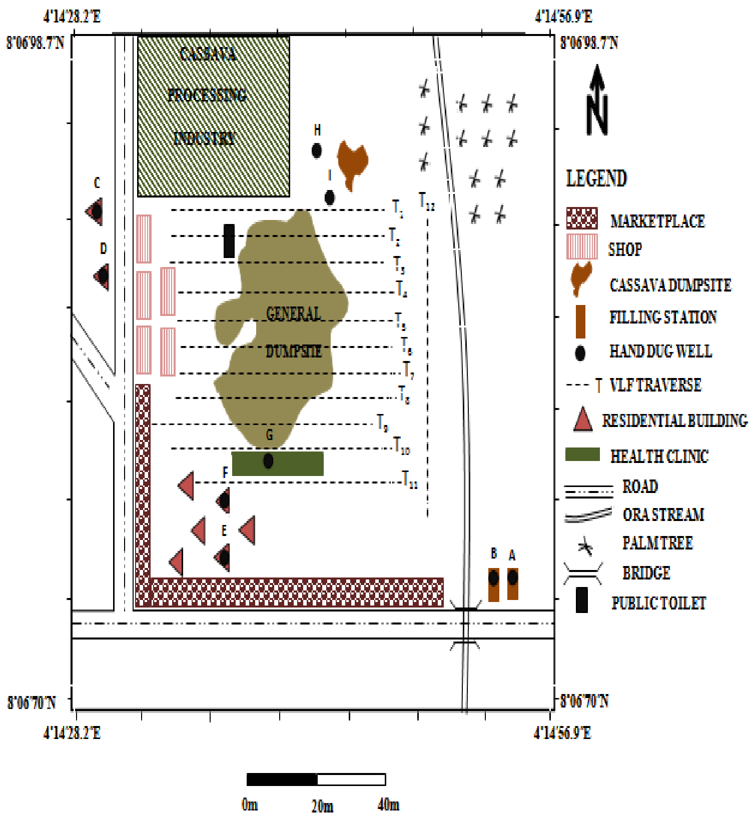

Fig. 3: Base Map Of The Study Area.

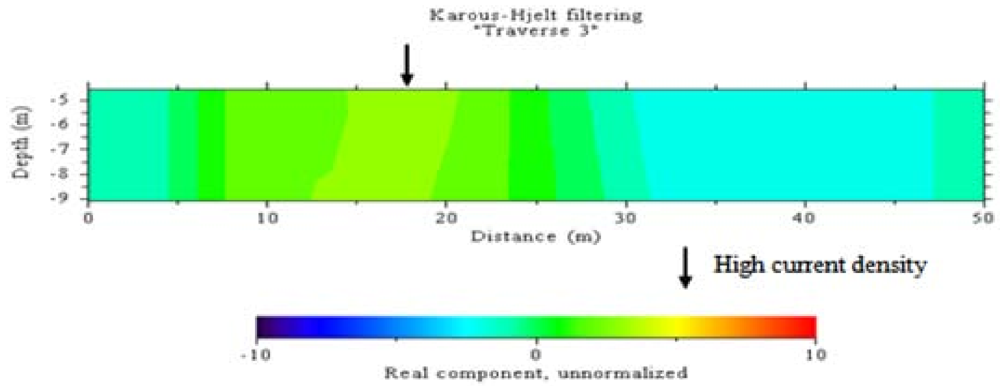

Fig. 4: Karous-Hjelt Current Density Plots For Vlf-Em Profile 3.

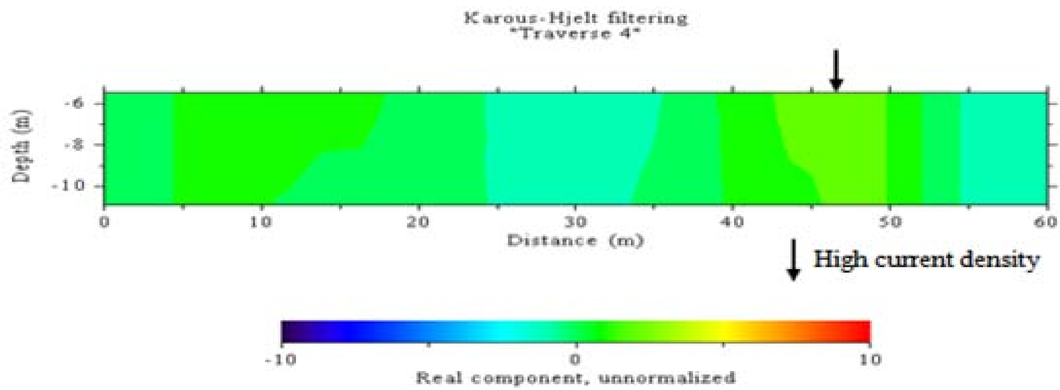

Fig. 5: Karous-Hjelt Current Density Plots For Vlf-Em Profile 4.

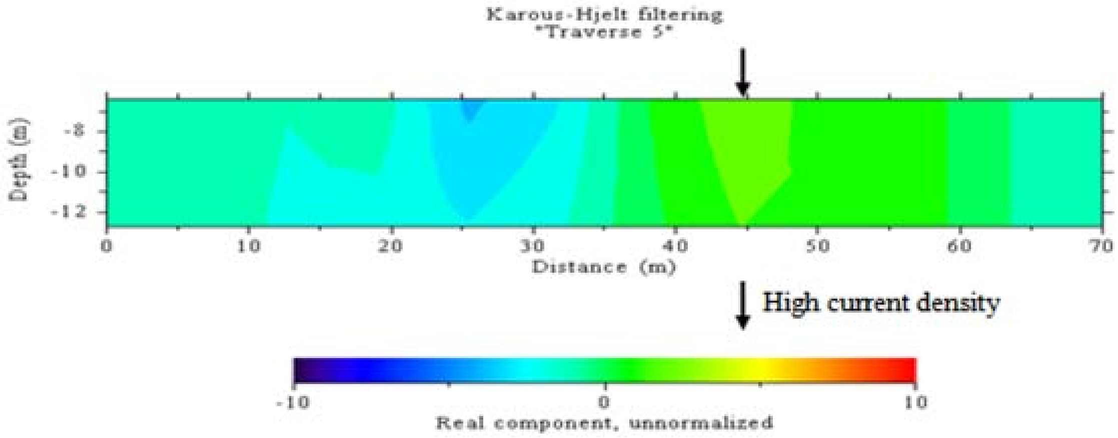

Fig. 6: karous-hjelt current density plots for vlf-em profile 5.

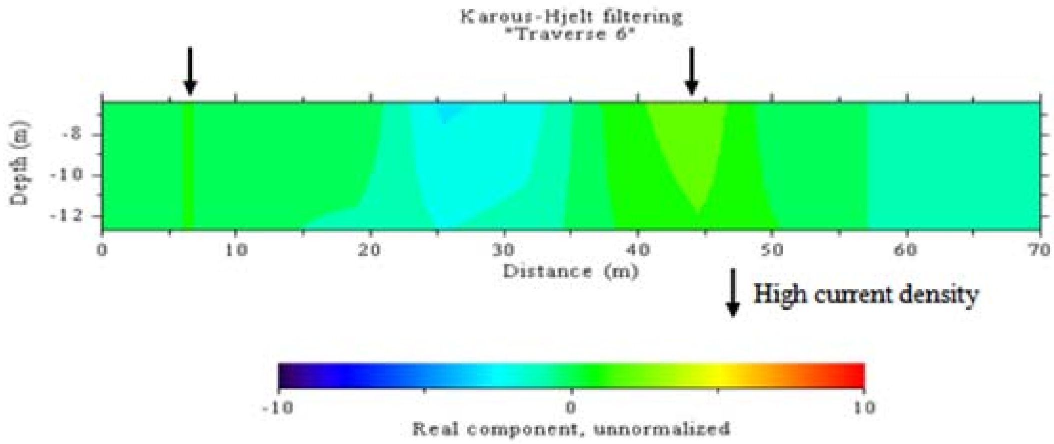

Fig. 7: Karous-Hjelt Current Density Plots For Vlf-Em Profile 6.

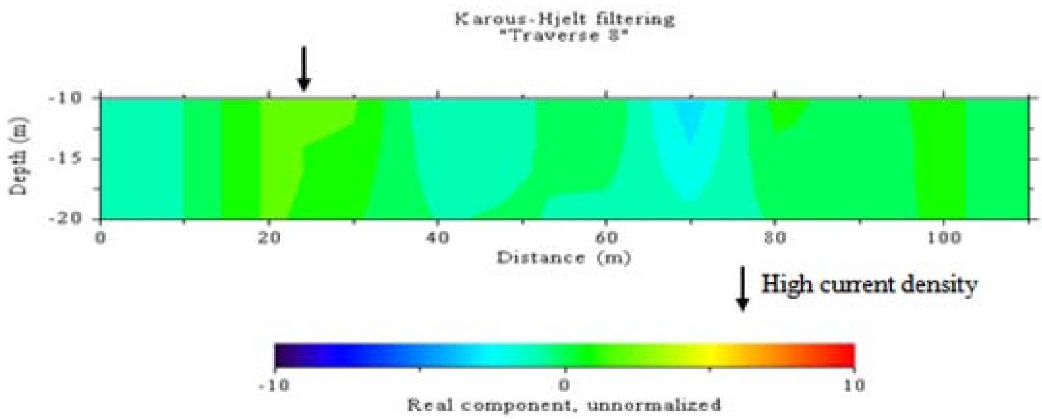

Fig. 8: Karous-Hjelt Current Density Plots For Vlf-Em Profile 8.

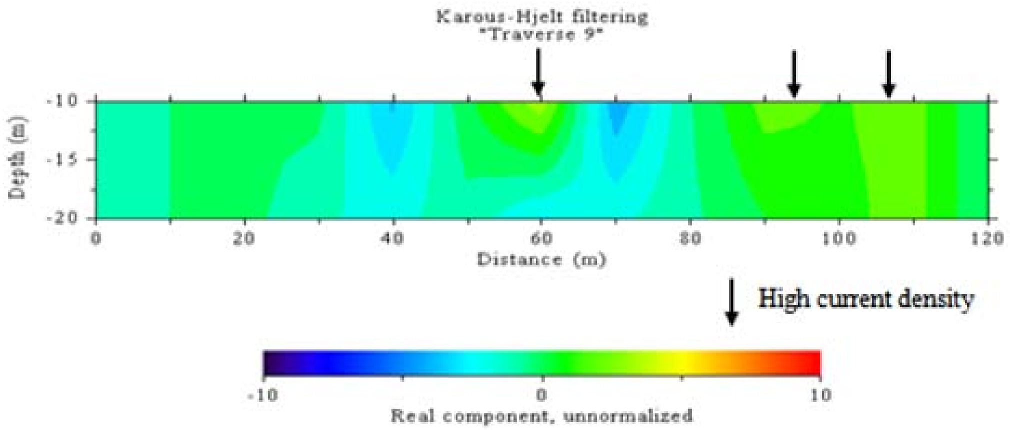

Fig. 9: Karous-Hjelt Current Density Plots For Vlf-Em Profile 9.

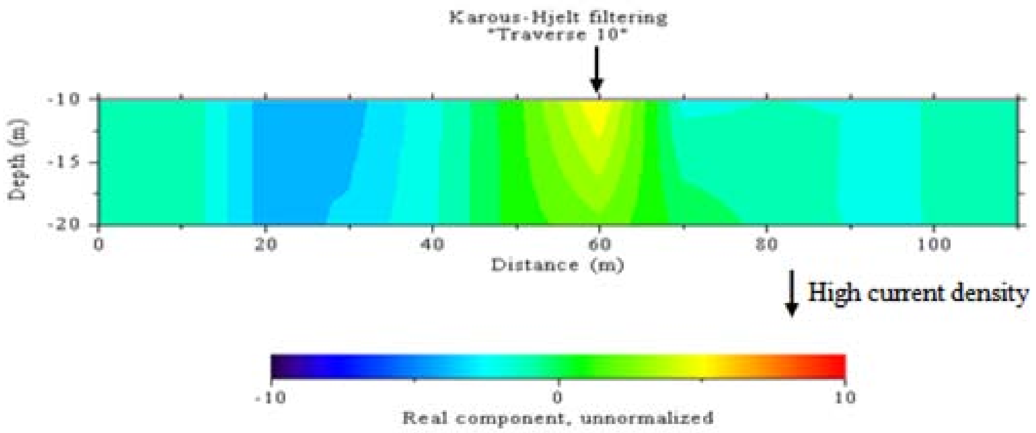

Fig. 10: Karous-Hjelt Current Density Plots For Vlf-Em Profile 10.

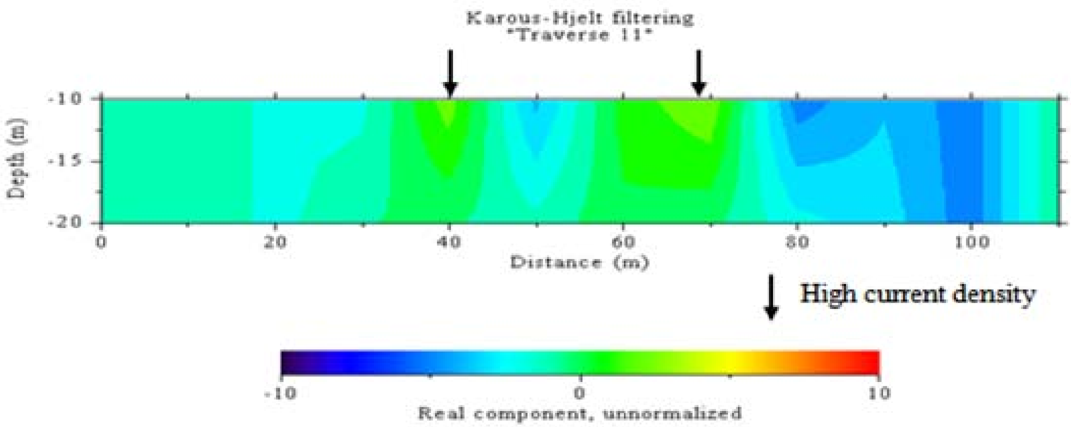

Fig. 11: Karous-Hjelt Current Density Plots For Vlf-Em Profile 11.

Table 1: result of the hydro-physicochemical analysis of hand dug well samples carried out at the peak of the dry season.

Parameters	Well A	Well B	Well C	Well D	Well E	Well F	Well G	Well H	Well I
Depth of wells (m)	5	4.5	4.0	5	4.5	3.5	4	4.3	4.1
Distance of wells from the dumpsite (m)	25	19	15	13	11	7	6	5	3
Colour	Clear, colourless	Clear, colourless	Clear, colourless	Clear, colourless	Light brown	Clear, colourless	Light brown	Light brown	Clear, colourless
Taste	Tasteless	Tasteless	Tasteless	Tasteless	Salty taste	Salty taste	Salty taste	Salty taste	Salty taste
Odour	Odourless	Odourless	Odourless	Odourless	Odourless	Undesirable odour	Undesirable odour	Odourless	Odourless
Ph	6.9	6.9	7.1	7.2	7.3	7.4	7.8	7.6	7.9
Temperature (°C)	26.1	26.1	26.4	27.2	26.9	27.9	28.2	27.5	28.9
Fe^{2+} (mg/L)	0.5	0.5	0.75	0.5	1.5	2.5	4.7	2.4	4.2
Pb^{2+} (mg/L)	0.0	0.001	0.002	0.004	0.005	0.007	0.7	0.009	0.75
Cu^{2+} (mg/L)	0.55	0.52	0.57	0.67	0.5	0.75	0.87	0.8	0.90
Zn^{2+} (mg/L)	1.45	1.3	1.4	1.61	2.20	2.1	2.5	2.0	2.5
K^{+} (mg/L)	10.5	14.5	20.0	16.0	27.5	27.0	70.5	30.5	75.3
Na^{+} (mg/L)	9.45	12.0	15.5	21.85	27.76	20.2	39.5	25.8	45.87
Mg^{2+} (mg/L)	11.54	5.9	12.4	6.6	10.8	17.5	23.0	19.87	24.0
Cl^{-} (mg/L)	5.34	12.5	15.0	25.5	25.67	33.7	60.65	35.85	55.75
SO_4^{2-} (mg/L)	1.75	1.5	1.88	0.75	3.97	4.5	9.75	4.05	10.5
NO_3^{-} (mg/L)	3.56	8.66	12.63	17.75	20.97	51.54	69.95	65.85	70.98
HCO_3^{-} (mg/L)	5.7	5.7	6.0	7.2	9.5	14.8	56.95	14.25	55.97
CN^{-} (mg/L)	0.31	0.25	0.3	0.2	0.35	0.42	0.26	2.45	2.36
Total Solids (mg/L)	1490	1440	1490	1470	1560	1680	1780	1690	1790
Total Dissolved Solids (mg/L)	500	700	840	700	845	740	815	805	900
Suspended Solids (mg/L)	1253	1180	1170	1290	1300	1395	1275	1355	1450
DO (mg/L)	77.19	41.65	50.89	66.56	47.87	89.65	101.51	93.73	55.6
BOD (mg/L)	0.01	2.5	2.0	3.5	3.89	4.21	4.20	4.5	5.75
COD (mg/L)	0.22	2.0	2.5	2.25	3.75	3.70	4.0	4.77	5.14
TotalHardness (mg/L)	51.12	48.75	22.11	55.76	67.76	51.7	69.54	71.89	71.65
Turbidity (mg/L)	0.0	0.0	0.0	0.0	0.0	0.15	0.25	0.37	0.39
Conductivity (µS)	600	607	607	785	876	1110	1254	1236	1333
THBC (cfu/ml)	4	43	57	69	77	87	570	99	700
THFC (cfu/ml)	Nil	Nil	Nil	Nil	Nil	Nil	3.42	Nil	4.23
Total coliform (cfu/ml)	Nil	Nil	Nil	Nil	Nil	Nil	1.24	0.04	3.1
Feacal coliform (cfu/ml)	Nil	Nil	Nil	Nil	Nil	Nil	1.12	Nil	2.56

Table 2: summary of the results of the method employed and who standards of potable drinking water.

Parameters	Method Employed	WHO Standard
Colour	-	Clear, colourless
Taste	-	Unobjectionable to consumers
Odour	-	Unobjectionable to consumers
Ph	pH meter (APHA 4500 – H)	6.8 – 8.5
Temperature (°C)	Thermometer	24.5 – 39.7
Fe^{2+} (mg/L)	Atomic absorption spectrophotometry (APHA 3120 - B)	1.0
Pb^{2+} (mg/L)	Atomic absorption spectrophotometry (APHA 3120 - B)	1.05
Cu^{2+} (mg/L)	Atomic absorption spectrophotometry (APHA 3120 - B)	1.5
Zn^{2+} (mg/L)	Atomic absorption spectrophotometry (APHA 3120 - B)	4.0
K^{+} (mg/L)	Atomic absorption spectrophotometry (APHA 3500 - KB)	15
Na^{+} (mg/L)	Atomic absorption spectrophotometry (APHA 3500 - NaB)	200
Mg^{2+} (mg/L)	Atomic absorption spectrophotometry (APHA 3500 - MgB)	150
Cl^{-} (mg/L)	Titrimetry (APHA 4500 - B)	600
SO_4^{2-} (mg/L)	Spectrophotometry (APHA 4500 SO_4B)	400
PO_4^{3-} (mg/L)	Spectrophotometry (APHA 4500 P)	250
NO_3^{-} (mg/L)	Spectrophotometry (APHA 4500 NO_3B)	50
CN^{-} (mg/L)	Titrimetry (APHA 4500 - B)	0.5
Total Dissolved Solids (mg/L)	Gravimetry (APHA 2540 - B)	1000
Suspended Solids (mg/L)	Spectrophotometry (APHA 2540 - D)	30
DO (mg/L)	Titrimetry (APHA - O)	-
BOD (mg/L)	Titrimetry (APHA 5210 - B)	10
COD (mg/L)	Titrimetry (APHA 5220 - B)	40
Total Hardness (mg/L)	Titrimetry (APHA 2340 - B)	500
Turbidity (mg/L)	Turbidimeter (APHA 2130 - B)	5.0
Conductivity (µS)	Conducting meter (APHA 2510 - B)	1500

Conclusion and Recommendation:

The analysis and interpretation of the results of the VLF-EM survey conducted on the research site detected the leachate flow and mapped its spatial distribution at the subsurface. The VLF-EM images depict the leachate plumes inside the waste disposal site as conductive (dissolved salts from decayed organic matters) anomalies. The hydro-physicochemical report of the sampled wells F, G, H and I which are situated in the northern and southwestern part of the dumpsite facility with depth of penetration less than 5.5m, showed concentrations of organic and inorganic parameters tested exceeding World Health Organization's permissible limits. This observation revealed that the leachate plumes have extended to a depth of 5.4m at the subsurface in the study area. The results obtained for the hand dug wells A, B, C, D and E showed no sign of contamination. The good condition of these sampled wells is due to their various depth of penetration which is greater than 5.4m and their distance from the waste disposal area (more than 10m away). In addition, the anomalously high concentration of CN^- in wells H and I was due to their close proximity to the cassava waste dumpsite.

The intrusion of contamination plumes into the hand-dug wells in the research area can only be averted by drilling wells with greater depths of penetration, and also periodic geophysical assessment of the research area and analysis of water in the various hand dug wells sited in the area to determine the concentration level of the ions, that is, both anions and cations present should be conducted. The health clinic situated less than 5m away from the refuse disposal site should be evacuated by the Government due to its nearness to the waste dumping site. The result of the water quality analysis conducted on the hand-dug well sited within the hospital revealed that the well water has high total coliform counts, NO_3- and Pb^{2+} concentration. This shows that both drinking and domestic usage of this water without any form of treatment in advance is very hazardous.

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