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Archives of Applied Science Research, 2013, 5 (6):29-40
(http://scholarsresearchlibrary.com/archive.html)

ISSN 0975-508X
CODEN (USA) AASRC9

Geophysical and hydro-physicochemical evaluation of hand-dug wells near a dumpsite in Oyo state, Nigeria

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ABSTRACT

Access to potable water has become a difficult task in many countries of the world including Nigeria. In Nigeria, the government is trying her best to make water supply available to the masses but till now this vision has never been accomplished. If those living in urban areas could not have access to water supply by government, what is the fate of the people living in rural areas? Therefore, exploitation of groundwater through the construction of hand-dug wells is a major source of drinking water for majority of the populace as many could not afford the high cost of drilling borehole. Many people construct these hand-dug wells without linings because they believe that groundwater is the safest water for consumption without considering the environment these wells will be sited and other factors regarding to its construction. The aim of this present study is to evaluate the groundwater resources at Aarada waste disposal site, Ogbomoso, Oyo State, Nigeria. An electromagnetic survey to locate leachate plumes migration pathways was conducted around Aarada refuse dumpsite, Ogbomosho, Oyo State, Nigeria using the VLF-EM method. A total of seven VLF-EM profiles were carried out with length ranging between 60 to 150m. Hydro-physicochemical analysis was also conducted at the peak of the raining season on six water samples taken from six 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.

Keywords: Contaminants, Hand-dug wells, Health Hazard, Hydro-physicochemical Analysis, Groundwater Quality, Leachate Plume, Very Low Frequency.

INTRODUCTION

Water borne diseases are caused by pathogenic microorganisms that most commonly are transmitted in contaminated water. Infection commonly results during bathing, washing, drinking, in the preparation of food, or the consumption of food thus infected. According to the World Health Organization, water borne diseases account for an estimated 4.1% of the total Daily Global Burden of Disease, and cause about 1.8million human death annually. The World Health Organization estimates that 88% of that Burden is attributable to unsafe water supply, sanitation and hygiene [1]. Groundwater contamination is one of the main concerns of earth scientists and researchers from other related fields of science worldwide. Urban waste materials, mainly domestic garbage, are usually disposed of without the appropriate measures imposing a high risk to the underground water resources. The quality required of groundwater supply depends on its purpose [2]. The basic purposes for which water is domestically required include drinking, bathing, cooking and general sanitation such as laundry, flushing of closets and other household chores, whereas for agricultural purposes it is essentially used for irrigation and livestock. Therefore an assured supply of water both qualitatively and quantitatively for these purposes greatly improves the social, economic and agricultural activities of the people.

This present study is borne-out of the need to evaluate the groundwater resources at Aarada waste disposal site, Ogbomoso, Oyo state, Nigeria. The hand-dug wells in this area are sunk within a distance of 3 to 25m away from the waste disposal site with depth ranging from 3.5 to 5m. This study particularly aims at determining the drinking and domestic usability of the water. The research site which was presumed to have existed for over fifteen years covers an area of about 300 to 500 square meters with the refuse content consisting of various kinds of materials like metallic, organic and non-biodegradable materials. Among the available geophysical methods, electrical resistivity and electromagnetic methods have been found remarkably suitable for such environmental studies, due to the conductive nature of most contaminants [3-6]. 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.

In this work, the combination of hydro-physicochemical and very low frequency electromagnetic methods was employed to determine the level and extent of contamination to the water table by the leachate from the waste disposal site. Similar methods were applied in the past for landfill characterization and delineation [7-12]. Groundwater pollution results from the elevation in the concentration of anions and cations, for example, Cu^{2+}, Fe^{2+}, Zn^{2+}, NO_3^-, present and also the introduction of bacterial, viral and parasitic micro-organisms. It must be noted that drinking from the polluted groundwater by the local community without the necessary treatment in advance causes serious health hazards. This integrated technique has been found remarkably suitable for delineating contaminated zones of groundwater. Therefore, the objective of this study is to assess the impact of solid waste on the groundwater quality at Aarada Refuse Dumpsite environs in Ogbomoso, Southwestern Nigeria.

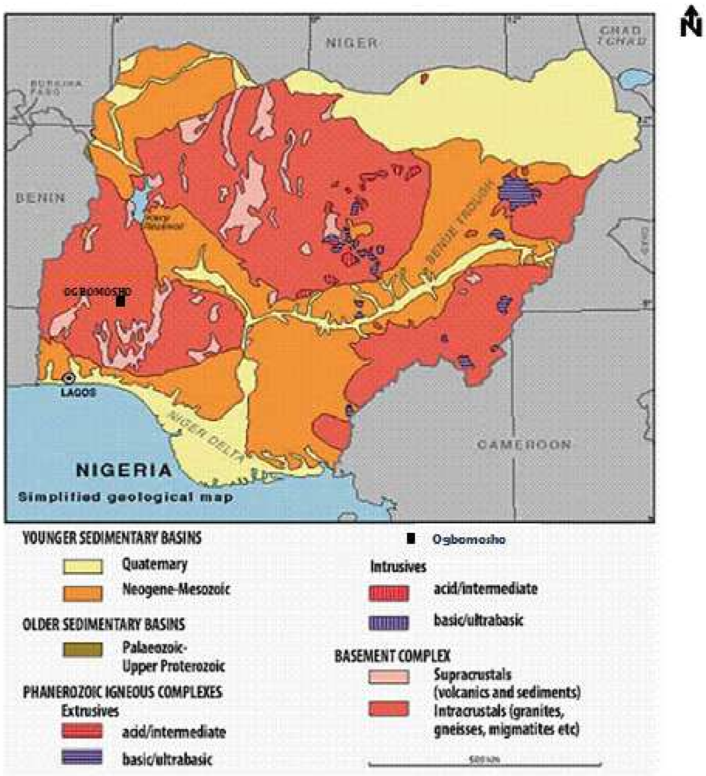

Figure 1: Geological Map of Nigeria Showing the Location of Ogbomoso

Geology and hydrogeology

The study area (fig. 1, 2 and 3) 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 [13]. 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 [13, 14].

The gneiss complex which underlies the northern and southern part of the Ogbomoso district comprises a considerable broader area of outcrops. Locally, the rock sequence composes of basically weathered quartzite and older granites. The minerals found in this area constitute mostly amphibolites, amphibole schist, meta ultra mafites and meta pelites. Extensive psammitic units with minor meta pelite can also be found. These consist of quartzites and quartz schist. All these assemblages are associated with migmatitic gneisses and are cut by a variety of granitic bodies [13, 15].

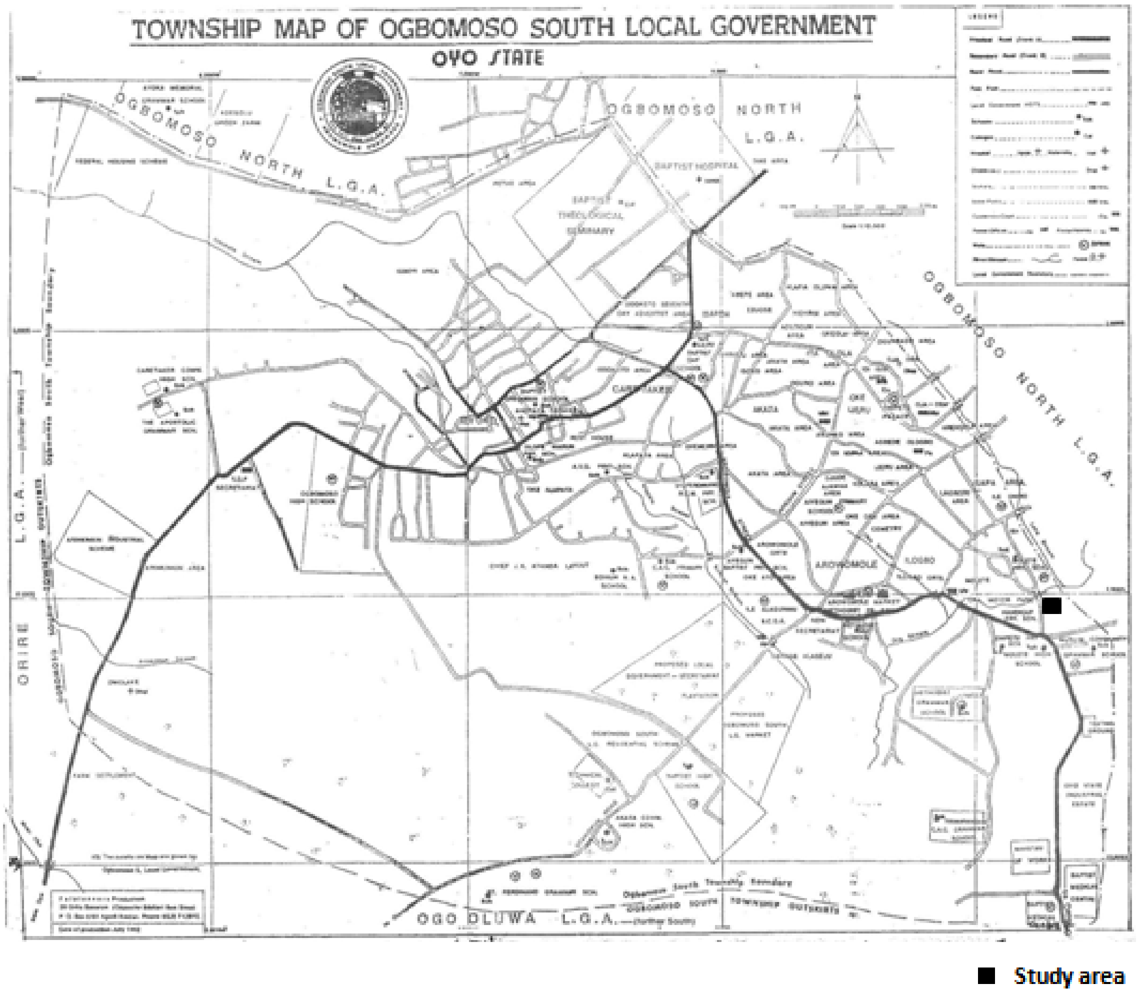

Figure 2: Map of Ogbomoso Showing the Location of the Study Area

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 [13, 16].

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. It overlies the western upland region of the Nigeria highland plateaux with average altitude between 1000m and 1500m above mean sea level [17]. 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 west 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.

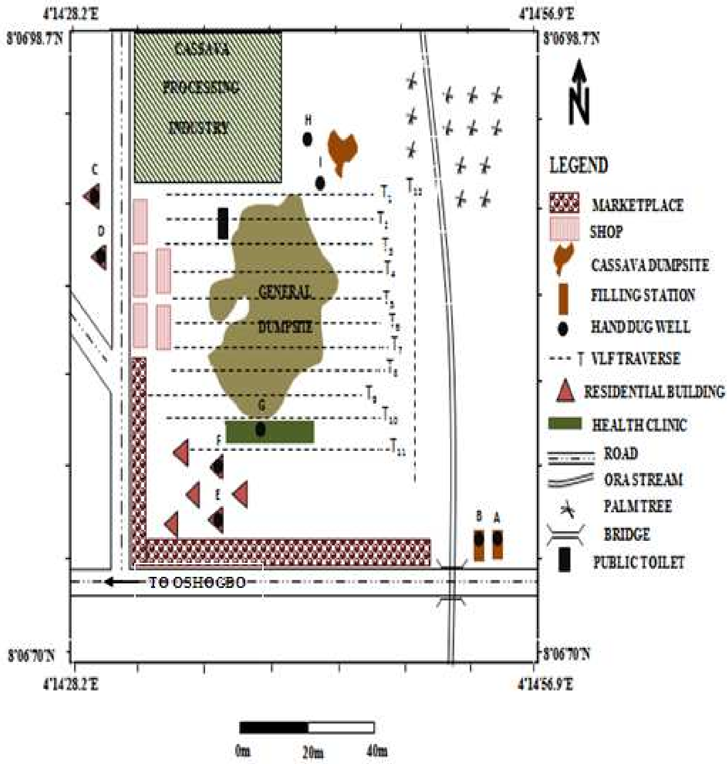

Figure 3: Base Map of the Study Area

MATERIALS AND METHODS

Very Low Frequency Electromagnetic Survey

Very low Frequency Electromagnetic Method was employed to investigate the level and extent of leachate contamination around Aarada Refuse Dumpsite, Ogbomoso, Southwestern Nigeria (fig. 3). The instrument used for the acquisition of data in this field exploration was the Abem Wadi VLF-EM equipment which employs the magnetic component of the electromagnetic field generated by military radio transmitter that uses very low frequency band 25-30KHz. This frequency band is applied majorly in long distance communication. The very low frequency electromagnetic method (VLF-EM) of the geophysical survey was applied in east-west direction on the research site to obtain information on the physical properties of the subsurface. The data collected consists of the real part and the imaginary part. Seven traverses were conducted in all with inter-traverse separation of 10m; traverses 1, 2, 3 and 4 have lengths 80m, 70m, 100m and 90m respectively, while traverses 5, 6 and 7 have a length of 140m each for convenience of space limitation. The filtered data (real and imaginary) were plotted against the station positions to obtain the VLF-EM curve types for the area reflective of the subsurface geology.

Hydro-physicochemical Analysis Method
Nine water samples were collected from nine different hand-dug wells situated within the research area for chemical and bacteriological analysis. The depth of the hand-dug wells in the study area varied between 3 and 5m, and also their locations from the refuse dumpsite ranged from 5 to 20m.

RESULTS AND DISCUSSION

The results obtained from VLF-EM data interpretation are presented as profiles. The VLF-EM curves of the filtered real and filtered imaginary data against the station values are shown from fig. 4 to 17 as illustrated by McNeil and Parasnis [18, 19]. The positive minimum and maximum crossover points between the filtered real and the filtered imaginary plots represent leachate intrusion at the subsurface in the study area.

Assessing VLF-EM profile 3 in fig. 4, at distance 28m and 33m, the crossover signs indicate the presence of conductive contaminants which are dissolved salts from decayed organic matters at the subsurface.

PROFILE 3

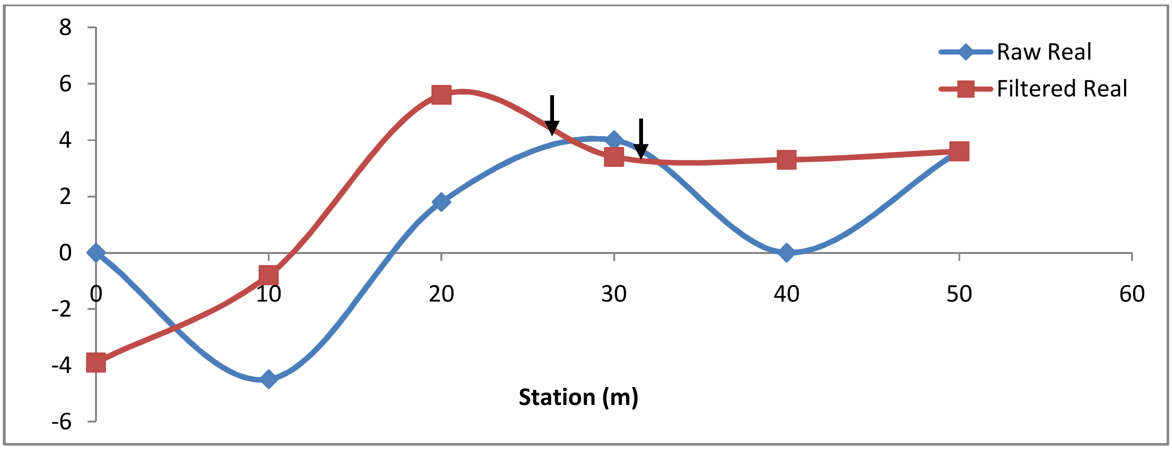

Figure 4: A Graph of Raw Real and Filtered Real Against Station Values on Profile 3

In fig. 5, moving along VLF-EM profile 4, at distance 20m and 30m, high conductivity zone indicative of leachate pollution from the waste body was detected.

PROFILE 4

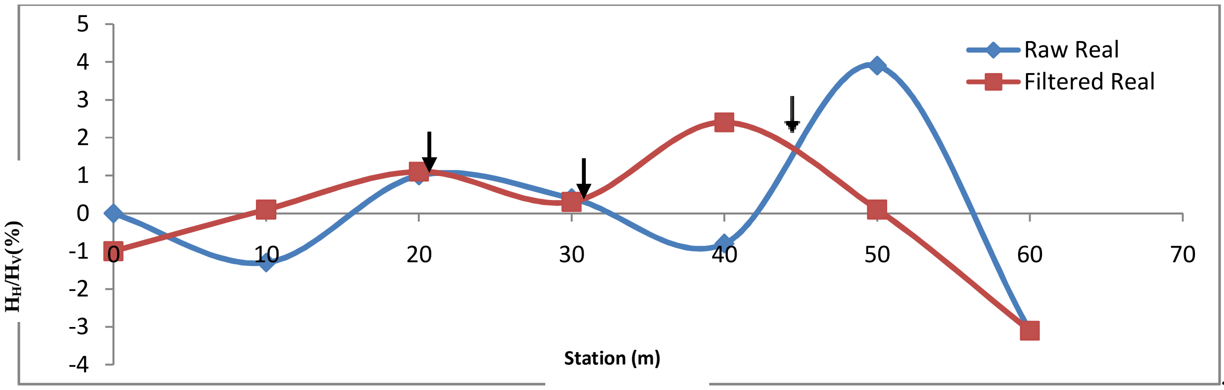

Figure 5: A Graph of Raw Real and Filtered Real Against Station Values on Profile 4

Similar geologic structural trend was depicted in fig. 6, at a distance of 16 and 48m (where contamination plumes were observed).

PROFILE 6

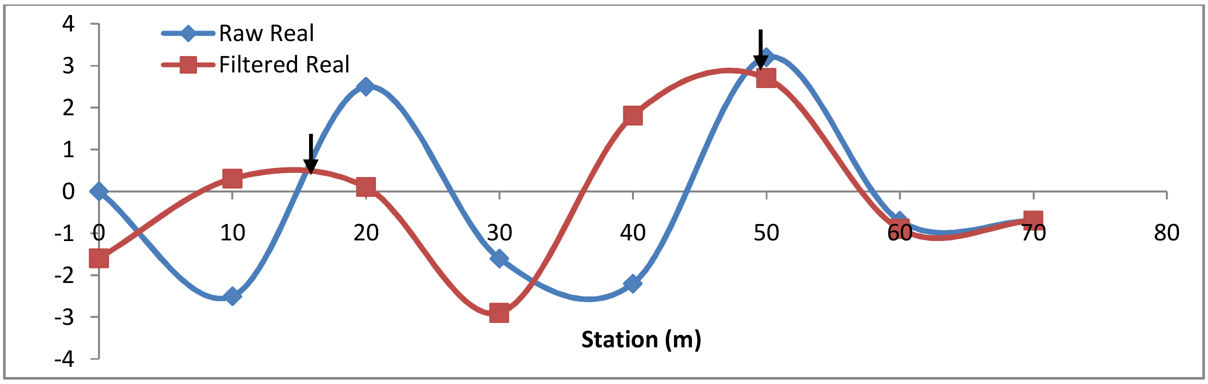

Figure 6: A Graph of Raw Real and Filtered Real Against Station Values on Profile 6

Furthermore, high conductivity value depicting leachate intrusion was also detected at distance 10m in fig. 7.

PROFILE 7

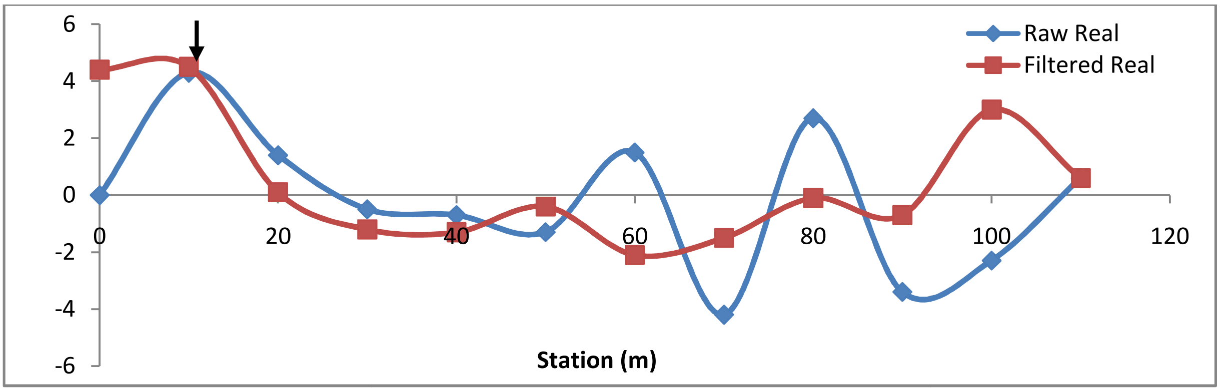

Figure 7: A Graph of Raw Real and Filtered Real Against Station Values on Profile 7

The crossover points at distance 50m and 110m indicate the detection of contamination patches within the research area in fig. 8.

PROFILE 8

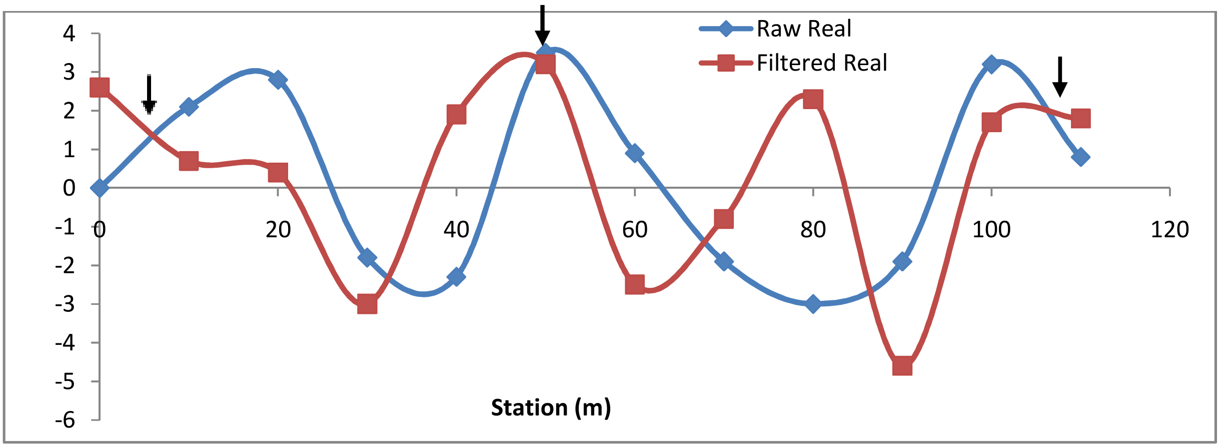

Figure 8: A Graph of Raw Real and Filtered Real Against Station Values on Profile 8

Moving along VLF-EM profile 9 in fig. 9, at crossover points 41m and 69m, infiltration of leachate within the subsurface was also depicted.

PROFILE 9

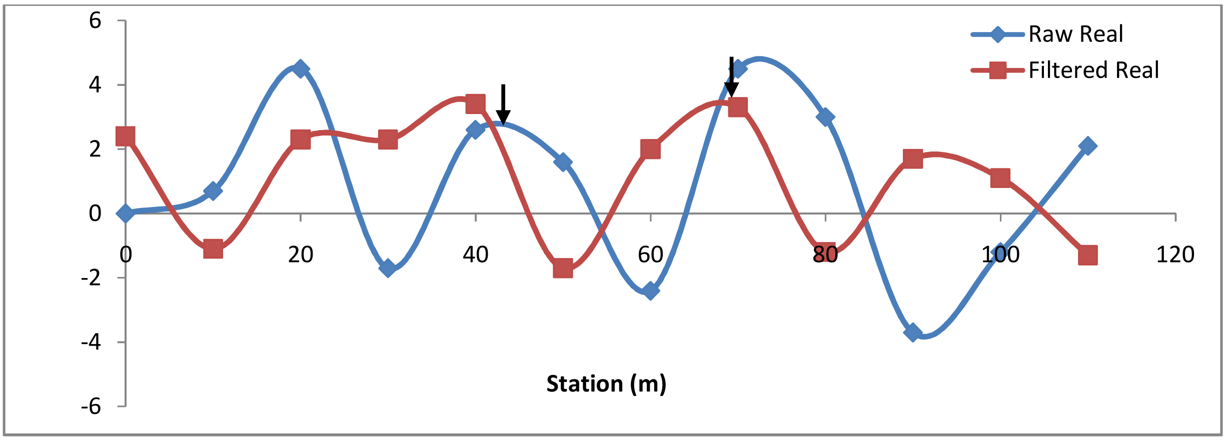

Figure 9: A Graph of Raw Real and Filtered Real Against Station Values on Profile 9

In fig. 10, high conductivity value reflective of leachate intrusion was observed at distance 20m, 45m and 80m.

PROFILE 10

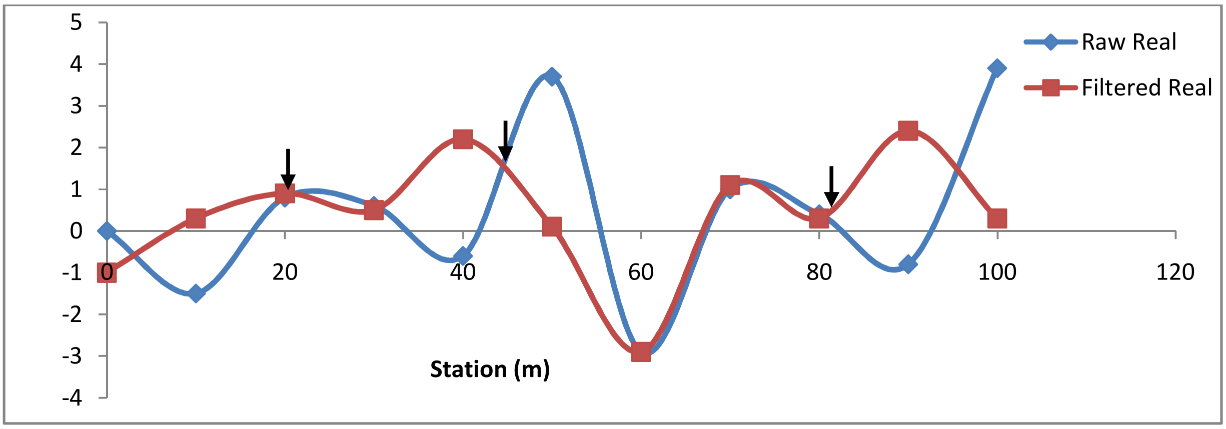

Figure 10: A Graph of Raw Real and Filtered Real Against Station Values on Profile 10

The geologic structural trend depicted in fig. 11, at a distance 11m, 42m, 47m and 97m revealed the presence of contamination plume.

PROFILE 11

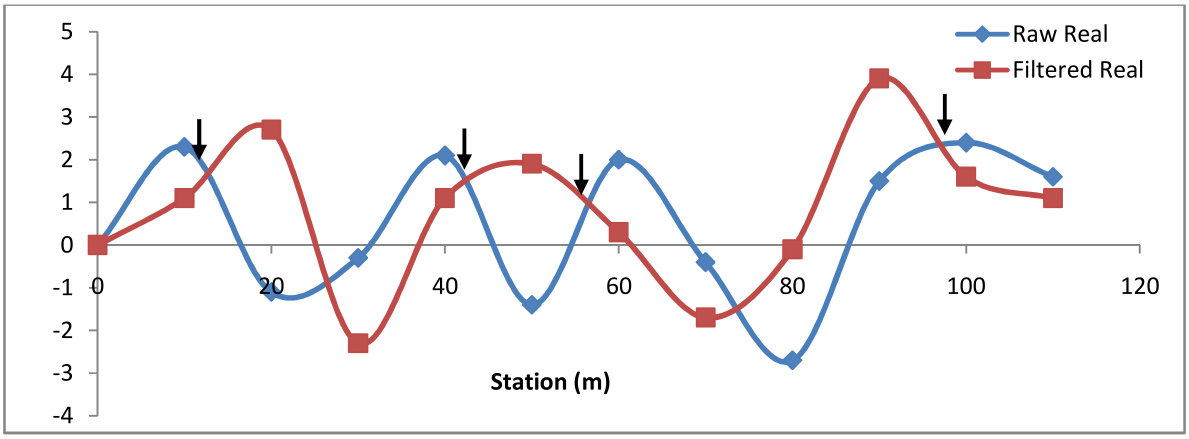

Figure 11: A Graph of Raw Real and Filtered Real Against Station Values on Profile 11

Also, at distance 28m, 60m and 84m on the VLF-EM profile 12 in fig. 12, the crossover signs indicate the presence of conductive contaminants as a result infiltration of dissolved salts from decayed organic matters from the surface.

PROFILE 12

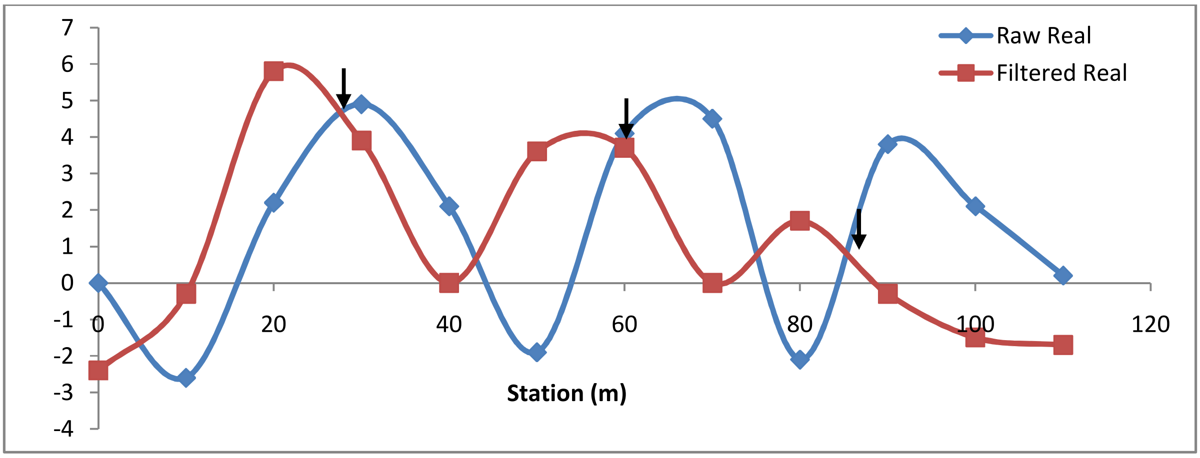

Figure 12: A Graph of Raw Real and Filtered Real Against Station Values on Profile 12

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 [20]. The World Health Organization [21] 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 are caused by anthropogenic pollution and high total coliform counts in the water samples. The high concentration of total dissolved solids in most of the samples may be a reflection of gradual weathering of the basement rocks.

Health hazard implications

The disease type predominant in the research area is waterborne diseases like cholera which forms about 25%, typhoid about 55% and gastroenteritis 20%. This analysis was made after personal communication with the medical doctors from the health clinic situated within the refuse dumpsite facility. The pathogens of most of these waterborne diseases are the coliforms group of bacteria which are the most abundant microorganisms occurring in polluted water. The coliform counts in some of the samples (well G and I) (Table 1) show that they are highly polluted with faecal waste, hence, residents of this area are exposed to high risk of infection due to contaminated water used for domestic purposes. On the contrary, wells A, B, C, D and E located more than 10m away from the waste disposal area show non-detectable coliform count suggesting a more hygienic environment. However, even in a clean environment, it is not unusual to detect high coliform count in wells, as there might be ingress of effluents from improperly constructed or damaged sewage tanks. Davis and Dewiest [22] observed that cementation of inner wall of wells provide a barrier against bacteriological contamination. Dournadeali and Tayback [23] stated that the use of pipe to pump well water reduces microbial contamination risk (rather than using plastic draws which can easily introduce contaminants into the groundwater).

Table 1: Result of the hydro-physicochemical analysis of hand dug well samples carried out during 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
Total Hardness (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

The integration of electromagnetic (Very Low Frequency Electromagnetic) and hydro-physicochemical analysis methods was used to detect the various locations of the leachate plumes and to assess the groundwater quality in the study area. The analysis of the VLF-EM data plots revealed the presence of leachate plumes in the southeastern and southwestern region of the research area. The hydro-physicochemical report of the sampled wells F and G which are situated in the southwestern part of the dumpsite facility with depth of penetration less than 4.1m, 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 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 4m and their distance from the waste disposal area (more than 10m away). In the same vein, assessing the outcome of the water quality analysis conducted on wells H and I, anomalously high concentration of CN^{-} was detected which was due to their close proximity to the cassava waste dumpsite.

It is however, recommended that wells to be dug in the area must have greater depth of penetration and must be constructed with linings to impede the infiltration of contaminant fluids, and also continuous assessment of the research site and periodic analysis of water samples from hand dug wells in the area to determine the amount and type of anions and cations present should be carried out. In addition, the result of the hydro-physicochemical analysis conducted on the hand-dug well located within the hospital situated less than 4m away from the waste disposal site shows high total coliform counts. It is therefore suggested that the hospital should be evacuated so that patients seeking health care delivery system in the clinic will not have their health problems compounded.

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