A Geophysical and Hydro-Physiochemical Study of the Contaminant Impact of a Solid Waste Landfill (SWL) in Port Harcourt Municipality, Nigeria

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ABSTRACT

The contaminant impact of a municipal solid waste land fill on ground water in Port Harcourt municipality were investigated by integrating 2-D resistivity imaging and microbial with physiochemical analysis of water samples (BH1, BH2, and BH3), from three boreholes located 18.0 and 27.0m, respectively, parallel to the landfill in the south and 37.0m perpendicular to the landfill to the west. The results of the 2-D resistivity imaging of four profile lines isolated two distinctive pollutants mainly, anomalously low and high resistive structures, interpreted as rock material contaminated with leachate plume and land fill gases, respectively. The composition of these landfill gases are predominantly, likely to be methane (CH_4) gas, than ammonium (NH_3), hydrogen sulphide (H_2S), and carbon dioxide (CO_2). The microbial and physiochemical analysis also isolated two main contaminants. These are low pH values and excessive amount of micro-organisms (Bacteria, fungi, and coliform), in the samples. The low pH values of the borehole samples is an indication that the ground water is slightly acidic, with BH3 being the most acidic, while BH1 is the least. BH2 has the highest bacteria count, while BH3 has the least. BH1 has the highest coliform and fungal counts followed by BH2, and none in BH3. The low pH, with the corresponding low ionic constituents and heavy metals which are within the WHO reference standard for portable drinking water, suggests that the contamination of ground water is dominantly by land fill gases, while the excessive amount of micro-organisms is an indication of leachate contamination. These contaminants have migrated to depths exceeding 31.3m well below the aquifer, and over 40m offsite distance to the south from the landfill in the investigated site.

(Keywords: landfill, solid waste, leachate plume, landfill gases, resistivity)

INTRODUCTION

Portable and safe drinking water is a necessary requirement for the health and productive life of humans in any society. Ground water is a valuable source of portable drinking water in most of our urban and rural communities, and for industrial and agricultural applications. However, maintaining a portable ground water supply that is free from microbial and chemical contaminants is far from reality in most of our urban centers, and in particular Port Harcourt municipality, due to poor waste disposal and management practices.

Recent industrial development and increased urbanization in the municipality have resulted to enormous generation of all kinds of waste ranging from municipal to industrial. The municipality is faced with the problem of 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 the area. All these contribute significantly in the contamination of soil and ground water. Ground water is considered contaminated when it becomes unsafe and unfit for the intended use. Once contaminated, the ground water becomes unusable due to taste, odor, high microbial, ionic and volatile organic content, which has significant adverse impacts on groundwater quality and public health.

The major source of ground water contamination in the municipality is the solid waste landfill. Others are improperly functioning septic tank systems, hydrocarbons, and industrial chemicals. Solid waste landfills (SWL) have become a popular waste management system for the disposal of all manner of waste materials in the municipality. They are usually abandoned or disused exhumed pits used for road construction, and are therefore, not engineered for the containment of landfill emissions into the environment.

As a result of the imminent impact of solid waste landfills (SWL), it has become necessary to investigate the subsurface contaminant level of soil and ground water around a municipal solid waste landfill. The landfill site is located in Choba, along the East-West road, approximately 500m from the University of Port Harcourt main gate. It is delineated between Longitude $6^0$55.06 to $6^0$55.11E and Latitude $4^0$53.23 to $4^0$53.26 (Figure 1). The land fill receives a mixture of municipal, commercial, and mixed industrial wastes with hazardous and non hazardous constituents. These releases large amount of gases, particles, and leachate into the surrounding soil and ground water.

Landfill related studies have been carried out using the 2-D resistivity imaging method by various authors (Olayinka and Olayiwole, 2000, Samsudeen et al, 2006, and Esmail et al, 2008). This is because of its inherent ability to detect vertical as well as lateral resistivity changes related to variations in fluid content, chemical composition, and contaminant migration. Research on ground water contamination by landfills have also focused on the microbiology and chemistry of ground water (Hussein et al, 1989, Both and Vogt 1990, Asmuth and Stranberg, 1993), based on the laboratory analysis of groundwater samples.

The integrated use of geophysical and hydro physiochemical methods are often recommended in landfill studies (Bensoil et al, 1983, Mathias et al, 1994, kayabali et al, 1998). In this work, the Geoelectrical and hydro physiochemical methods were integrated to determine potential contaminant sources, their spatial distribution, and migration pathways around and within the landfill site.

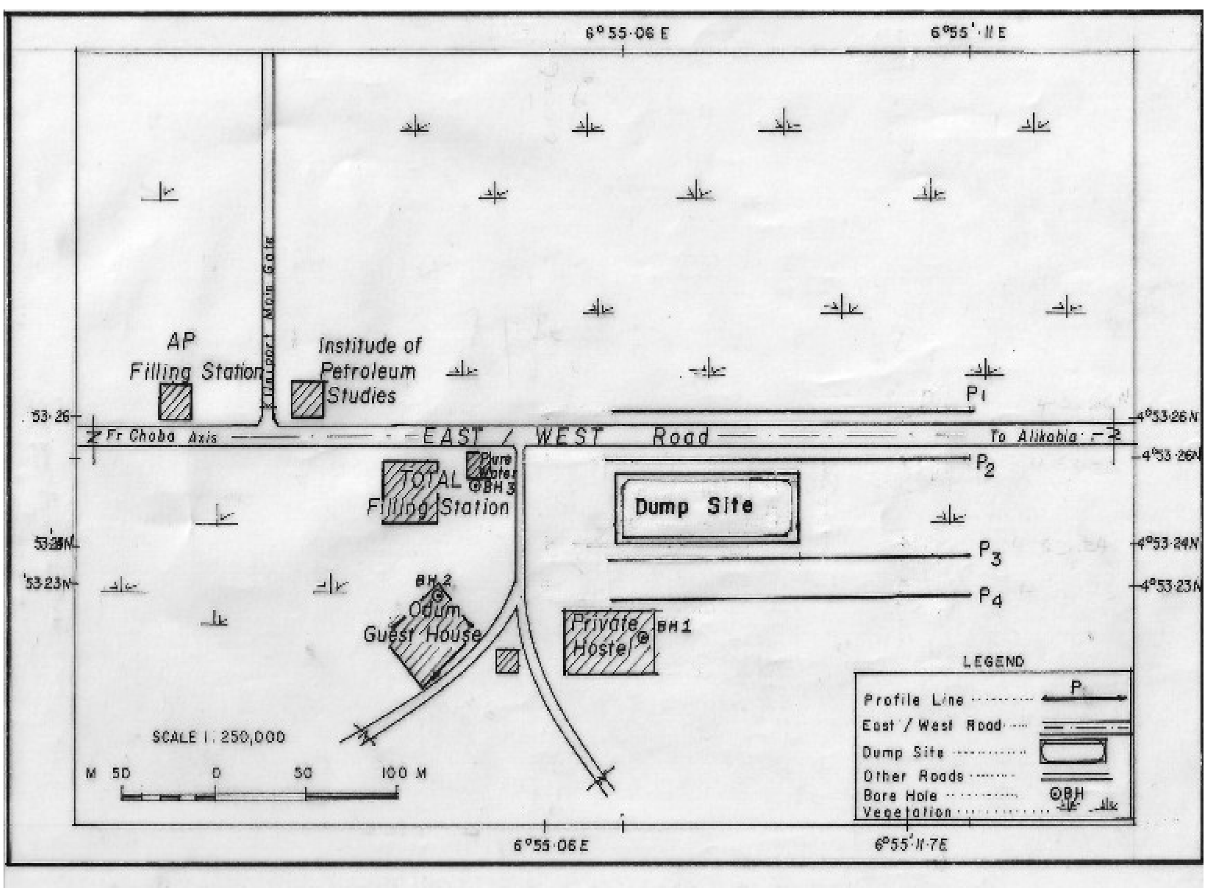


Figure 1: Location Map of the Study Area.

GEOLOGY OF THE SITE

The landfill site is underlain by the Benin Formation (Coastal plain sands) of the Niger Delta Basin. It is a continental deposit with over 90% sandstone with shale intercalations at depth, which may represent back swamps deposits (Figure 2). It is coarse grained, gravelly, locally fine grained, poorly sorted, sub angular to well round in texture with a thickness of about 2,100m (Reyment, 1965).

The formation is known for its high aquifer potential and aquifer conditions from nearby boreholes around the landfill exist at depths varying between 25 to 40m below the water table. The recharge of the aquifer system is principally by precipitation and the regional ground water flow is in the NW-SE direction, in line with the Niger Delta trend.

The site is characterized by the proximity of the aquifers to the surface, flat topography, high annual rainfall, and permeable soil media, which contributes to insignificant runoffs in the site, and implies that the total precipitation goes into storage. This enhances decomposition activities by bacteria and fungi and leaching of contaminants into the aquifer.

METHODOLOGY

Two-dimensional (2-D) resistivity surveys were carried out with a digital read out Abem Teremeter SAS 1000C, using the Werner - α linear array configuration. A total of four profile lines were occupied, two each on either side of the landfill, with a profile length of 200m, interspaced by 20m each, and oriented in the East – West direction.

Measurements were made at sequences of increasing offset distances (a – spacing) along the profile lines ranging from 10m to 60m using twenty stainless steel electrodes. The electrodes were moved from one end of the profile to the other in a lip frog manner to achieve continuous horizontal coverage of the subsurface. A total of two hundred and twenty eight (228) data points were occupied, which were subsequently processed into apparent resistivity values using the appropriate geometric factor (k).

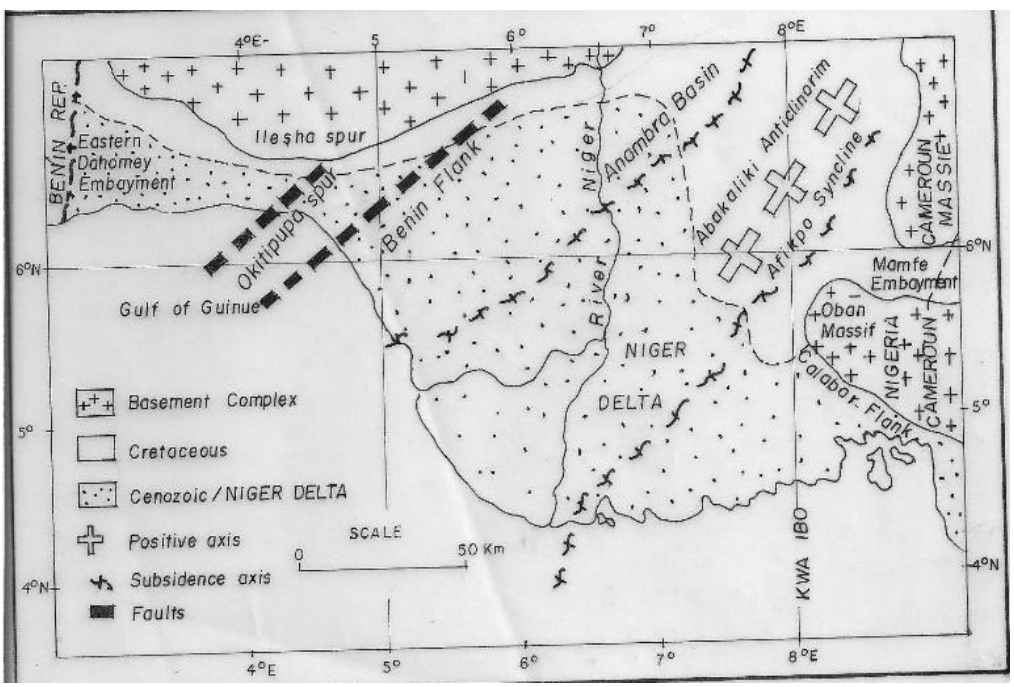


Figure 2: Geological Map of Niger Delta (Modified after Stanley, 1999)

PRESENTATION OF RESULTS

Geoelectrical Result: The measured 2 – D resistivity data were processed using RES2DINV inversion software (Loke, 1999). The program uses the least – squares inversion scheme to minimize the difference between the calculated and measured apparent resistivity values, by iterative process. The results are displayed as inverted sections of the true resistivity of the subsurface rocks (Figures 3 - 6). The sections were subsequently, visually inspected to delineate areas of anomalously high or low resistivities related to subsurface structures.

P - Profile 1

This profile lies 20m away from the edge of the landfill to the North west along the East – West road (Figure 3). The low resistivity zones (Deep blue) with resistivity <207Ωm are isolated mostly at the top section of the profile, with the most prominent structure situated at 40 – 50m surface points, and at the depth of 6.80m to the west of the profile. These are interpreted to be soil or sand saturated with leachate. The high resistivity zone is isolated as an oval shaped anomaly (Brown to purple) with resistivity > 1601Ωm at 55 – 115m surface points, and at the depth of 31m to the centre of the profile. This is interpreted as soil or sand saturated with landfill gas migrating southwards in the profile. Sandwiched between these zones of low and high resistivity anomaly is an intermediate resistivity zone (Light green to yellow) with resistivity < 779Ωm, interpreted as rock materials having varying moisture content and composition.

P- Profile 2

This profile lies at the edge of the landfill, 20.0m away from P – profile1 along the East – West road to the North west (Figure 4). The low resistivity zones (Deep blue) with resistivity < 96Ωm are well pronounced in the profile. The most dominant of these anomalies is isolated at 17.5 – 90.0m surface points, and at depth of 8.2m to the west of the profile. These are interpreted as soil or sand saturated with contaminant leachate.
Two high resistivity anomalies (Brown – purple) with resistivity > 709Ωm are isolated on the profile. The most prominent anomaly at 30.0 – 115.0m surface points, and at the depth of 31.0m to the west of the profile, is interpreted as landfill gas. The second high resistivity anomaly lies at 130.0 – 150.0m surface points, and at the depth of 4.0m to the East of the profile. This is interpreted as probably surfacing materials used for the road construction/or land fill gas. Lying between these anomalous structures is an intermediate resistivity zone (Light green – yellow) with resistivity < 350Ωm, interpreted as rock materials having varying moisture content and composition.

P – Profile 3

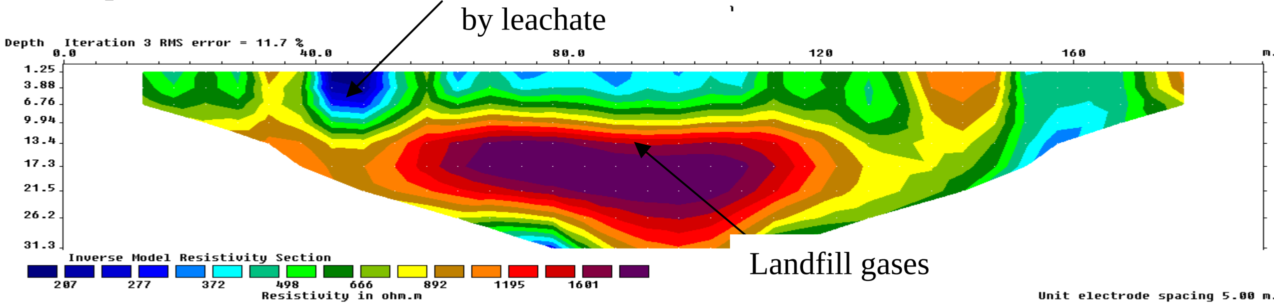
P – Profile 3 is situated at an elevated ground, and due to logistical reasons, it lies 8.0m away from the second edge of the landfill to the south and parallel to the East – West road to the South east (Figure 5).. Anomalously high resistive zones (Brown – Purple) are isolated at the top sections of the profile. The first and the most prominent anomaly with resistivity > 2239Ωm lies between 40.0 – 115.0m surface points, and at the depth of 17.5m to the west and centre of the profile. The second high resistive anomaly is isolated at 155.0 – 185.0m surface points and at the depth of 13.5m to the East of the profile. These high resistive anomalous features are interpreted as landfill gases migrating southwards in the profile.

The low resistive anomaly (Deep blue) with resistivity < 247Ωm is isolated at 65.0 – 120.0m surface points, and at the depth of 31.3m to the centre of the profile. This is interpreted as a contaminant leachate plume in the soil material migrating south ward in the profile. Lying between these resistivity anomalies is an intermediate resistivity zone (Light green to yellow) with resistivity < 761Ωm, interpreted as rock materials having varying moisture content and composition.

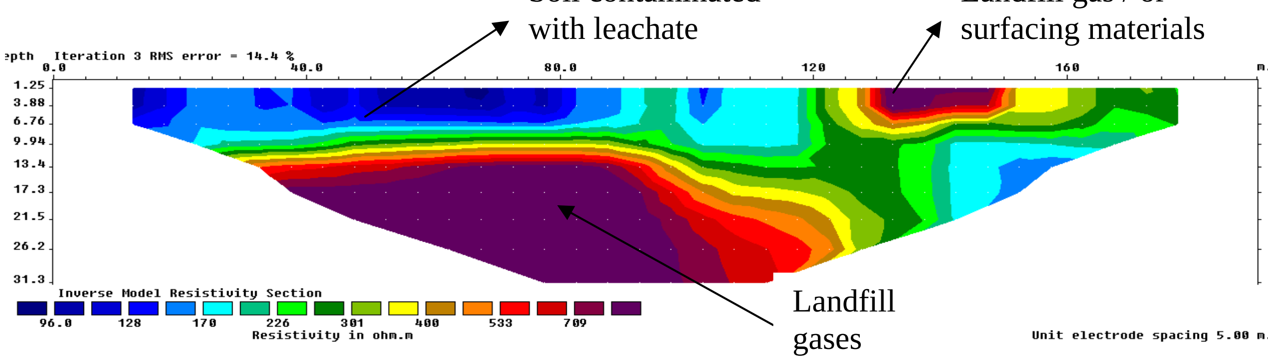
P – Profile 4

This profile lies 20m away form P – profile 3, and parallel to the East – West road to the South east (Figure 6). A high resistivity anomaly (Brown to Purple) with resistivity> 2702mΩ, is isolated at the top section of the profile at surface points 70.0 - 175.0m, and at the depth of 10.0m to the East of the profile. This is interpreted as landfill gases. The low resistivity oval shaped anomaly (Deep blue) with resistivity <395mΩ is isolated at 75.0 to 155.0m surface points, and at the depth of 28.0m to the centre and East of the profile. This is interpreted as contaminant leachate plume in the soil material migrating southwards in the profile. Lying between these resistivity anomalies is an intermediate resistivity zone (Light green to yellow) with resistivity < 1053Ωm, interpreted as rock materials having varying moisture content and composition.

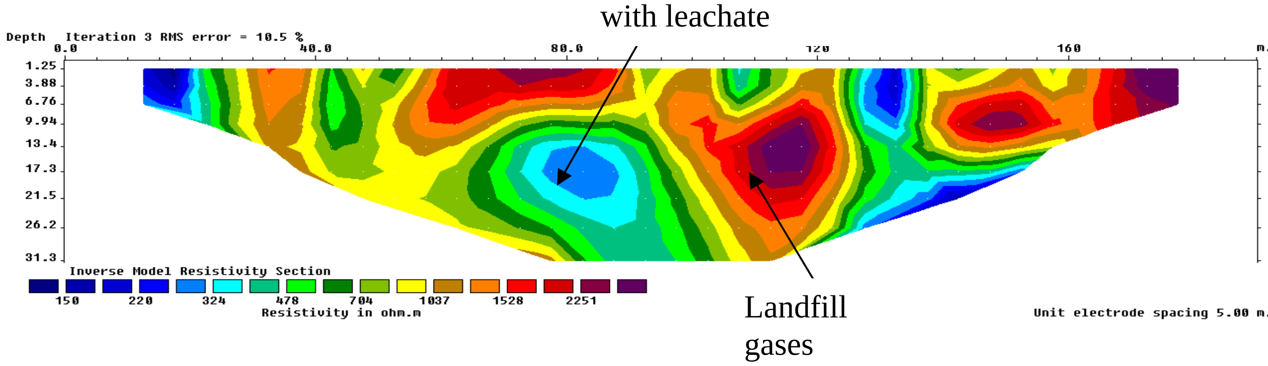
P profile 1



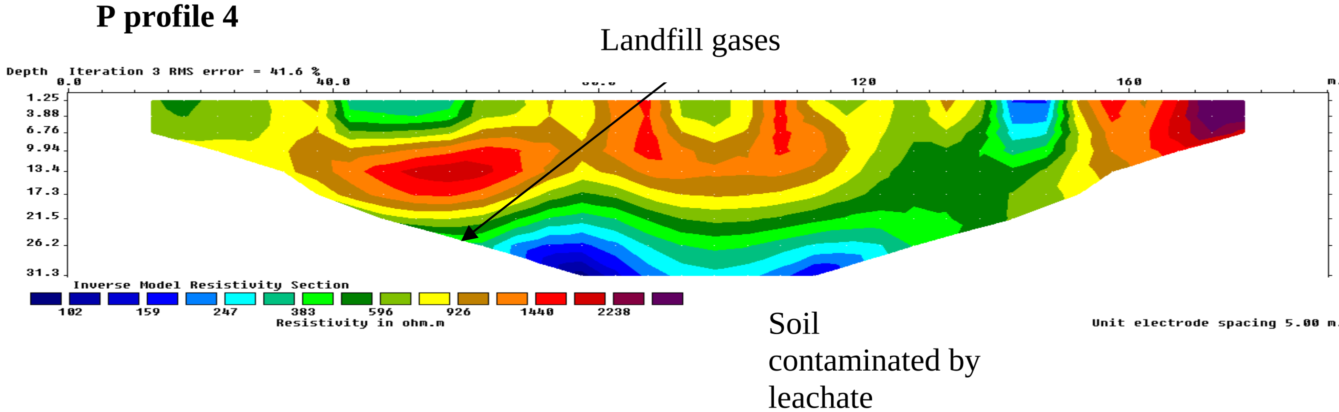
P profile 2



P profile 3



P profile 4



Figures 3-6: Inverted Resistivity Sections of the Profiles.

Hydro Physiochemical Analysis

Groundwater samples from three boreholes (BH_1 and BH_2) located south wards and BH_3 located west ward at 18m, 27m, and 35m, respectively, from the landfill were analyzed in the laboratory for in–situ parameters. Standard laboratory methods for biological and chemical analysis were employed for the determination of the parameters. A total of twenty six (26) chemical parameters (Table 1), and four (4) biological parameters (Table 2) were analyzed.

The result of the physiochemical analysis show that all the analyzed parameter values fall within the WHO reference standard for portable drinking water, with the exception of the pH parameter values in the three boreholes. The pH values of the three borehole samples BH_1, BH_2 and BH_3 are 4.67, 4.90 and 4.46, respectively, which is slightly acidic as against the WHO standard of 6.5 to 8.5 pH value (Table 1).

The bacteriological and fungi analysis of the samples show anomalous presence of bacteria level in the three borehole samples. The total heterotrophic bacteria count (THBC) is high in the three boreholes, with BH_2 having the highest count, while the total heterotrophic fungi count (THFC) is highest in BH_1 than BH_2, while this is totally absent in BH_3. Also, the total coliform count and feacal coliform are high in BH_1 than BH_2 and absent in BH_3 (Table 2). However, the presence of these microbes in the samples is an indication of ground water contamination by leachate.

Table 1: Summary Results for Hydro Physiochemical Analysis of Borehole Samples and WHO Standards for Portable Drinking Water.

S/N	Parameters	Method Employed	BH1	BH2	BH3	Stand WHO
1	pH	pH meter (APHA 4500 – H	4.67	4.90	4.46	6.8 – 8.5
2	Conductivity (xs/cm	Conducting meter (APHA 2510 – B)	20	20	20	
3	Turbidity (NTU)	Turbidimeter (APHA 2130 – B)	0.2	0.2	0.1	5.0
4	TDS (mg/1)	Gravimetry (APHA 2540 – C)	10	10	10	1000
5	Hardness (mg/1)	Titrimetry (APHA 2340 – B)	2.0	3.0	5.0	500
6	Chloride (mg/1)	Titrimetry (APHA 4500 – B)	4.0	8.0	5.0	600
7	Salinity (mg/1)	Titrimetry (APHA 4500 – B)	6.6	13.1	8.3	600
8	Total alkalinity (mg/l)	Titrimetry (APHA 2320 – B)	5.0	6.0	4.0	500
9	Sulphate (mg/l)	Spectrophotometry (APHA 4500 SO_4B)	1.0	0.8	1.1	400
10	Phosphate (mg/l)	Spectrophotometry (APHA 4500 – P)	<0.1	<0.1	<0.1	
11	Total suspension solid	Spectrophotometry (APHA 2540 – D	0.1	0.1	0.8	30
12	Nitrate (mg/l)	Spectrophotometry(APHA 4500 – NO_3B)	<0.1	<0.1	<0.1	
13	Redox potential (mV)	ORP Meter	101	103	100	
14	Dissolved oxygen (mg/l)	Titrimetry (APHA – 0)	4.8	4.9	4.6	
15	Biochemical oxygen demand	Titrimetry (APHA 5210 – B)	<0.1	<0.1	<0.1	10
16	Chemical oxygen demand (mg/l)	Titrimetry (APHA 5220 – B)	1.0	1.5	1.0	40
17	Mg (mg/l)	Atomic absorption spectrophotometry (APHA 3500 – MgB)	0.083	0.084	0.080	150
18	K (mg/l)	Atomic absorption spectrophotometry (APHA 3500 – KB)	2.79	2.85	2.81	
19	Ca (mg/l)	Atomic absorption spectrophotometry (APHA 3500 – CaB)	0.32	0.27	025	200
20	Na (mg/l)	Atomic absorption spectrometry (APHA 3500 – NaB)	1.19	1.15	1.12	200
21	Fe (mg/l)	Atomic absorption sepctrophotmetry (APHA 3120 – B)	0.083	0.068	0.061	1.0
22	Zn (mg/l)	Atomic absorption spectrophotometry (APHA 3120 – B)	0.140	0.140	0.138	4.0
23	Cr (mg.l)	Atomic absorption spectrophotometry (APHA 3120 – B)	<0.001	<0.001	<0.001	0.03
24	Cu (mg/l)	Atomic absorption spectrophotometry (APHA 3120 – B)	<0.001	<0.001	<0.001	1.5
25	Pb (mg/l)	Atomic absortion spectrophotometry (APHA 3120 – B)	<0.001	<0.001	<0.001	1.05
26	Mn (mg/l)	Atomic absorption spectrophotometry (APHA 3120 – B	<0.001	<0.001	<0.001	1.05

Table 2: Summary Results of the Microbial Analysis of the Borehole Samples.

S/N	Parameters	BH1(cfu/ml)	BH2	BH3	WHO Standard
1	THBC (cfu/ml)	2.3×10^2	4.6×10^2	1.8×10^2	100cfu/ml
2	THFC (cfu/ml)	5.0 x 10	3.0 x 10	Nil	
3	Total coliform (cfu/ml)	15/100ml	9/100ml	Nil	0/100ml.
4	Faecal coliform (cfu/ml)	Nil	Nil	Nil	0/100ml

DISCUSSION OF RESULTS

The impacts of municipal solid waste landfill on groundwater quality were investigated by integrating 2-D resistivity imaging and hydro physiochemical methods. Their is a strong correlation between the results of the 2–D resistivity imaging and hydro physiochemical analysis of water samples (BH_1, $BH_{2,}$ and BH_3) from three boreholes located at 18m, 27m, and 35m, respectively, in the neighborhood of the landfill. The results show the presence of contaminants in the ground water samples of the boreholes and the resistivity sections due to the landfill.

The 2-D resistivity imaging mapped two distinctive pollutants in each of the four profiles in the survey area. These are zones of anomalously low and high resistivity. The anomalously low resistivity zones (Deep blue) in the profiles are contaminant leachate plumes, which varies in resistivity between 170Ωm to 395Ωm, and depths exceeding 31.0m in the entire profiles. The high resistivity anomalies (Brown to purple) are landfill gases, with resistivity varying between 709Ωm to 395Ωm, and depths exceeding 31.3m near the edge of the landfill (profile line 2), and displaced to varying depths in the other profiles. The composition of these landfill gases are predominantly, likely to be methane (CH_4) gas than ammonium (NH_3), hydrogen sulphide (H_2S), and carbon dioxide (CO_2).

The isolation of these structures at depths in excess of 31.3m in the profiles, suggests that the subsoil and ground water may have been contaminated by leachate and gases, especially along profile 2, 3, and 4 in the south. Their concentrations are higher near the dumpsite than further away. This is evidenced by the low resistivity of these structures along profile lines 2 and 3 situated at the edges of the landfill. They spatial distributions increase further away from the landfill shown in profile 3 and 4.

Though the lithology of this study area may have aided contaminant leachate migration and gas diffusion, the ground water flow predominantly controls contaminant transport within the saturated zones in the south ward in line with the Niger Delta trend and explains the migration of the leachate to the south of the landfill. The gases however, do not strictly follow this trend, as they can migrate and contaminate subsoil in the up – and cross – gradient from the landfill.

Two main contaminants were also identified in the water sample analysis. These are low pH and excessive amount of microbes (Bacteria, fungi and coliform), while the other parameters are well within the WHO reference standard. BH_3 has the lowest pH value of 4.46 and lowest bacteria count of 1.8×10^2, while BH_2 has the highest pH value of 4.90 and highest bacteria count of 4.6×10^2. BH_1 has an intermediate pH value of 4.67 and bacteria count of 2.3×10^2, with the highest fungal and coliform count of 5.0×10^2 and 15.0/100ml, respectively, followed by BH_2 and none in BH_3.

It is however, evidently clear that the water samples are slightly acidic, with BH_3 being the most acidic. The bacteria counts in the samples decreases with low pH (acidic), while the fungal and coliform counts increases in excess amount with increasing pH (less acidic) in the borehole samples. The low pH values, with the corresponding low ionic constituents and heavy metals which are well within the WHO reference standard, by inference, implies that the contamination of ground water and soil is dominantly by landfill gases, while the excessive amount of microbes isolated in samples is an indication of leachate contamination of ground water in the study area.

These contaminants have migrated to depths exceeding 31.3m which is well within the aquifer system in the area and have also migrated over 40m offsite distance to the south from the landfill in the investigated site.

CONCLUSION

The results of the 2-D resistivity imaging and hydro physiochemical studies show the presence of contaminants in the ground water due to the landfill. The 2-D resistivity imaging isolated two distinctive pollutants in each of the four profiles namely, anomalously low and high resistivity structures interpreted as contaminant leachate and landfill gases, respectively.

Two main contaminants were also isolated in the hydro physiochemical analysis. These are low pH values and excessive amount of micro-organisms (Bacteria, fungi and coliform). The low pH values at the three borehole samples is an indication that the ground water is slightly acidic, with BH_3 being the most acidic and BH1 being the least. BH_2 has the highest bacteria count, while BH_3 has the least. BH_1 has the highest coliform and fungal counts, followed by BH_2 and none is BH_3.

The low pH, with the corresponding low ionic constituents and heavy metals which are well within the WHO reference standard, suggests that the contamination of ground water and soil is dominantly by landfill gases, while the excessive amount of micro-organisms is an indication of leachate contamination. These contaminants have migrated to depths exceeding 31.3m well below the aquifer and over 40m offsite distance to the south from the landfill in the investigated site.

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