Geophysical and physicochemical characterization of organic waste contamination of hydrolithofacies in the coastal dumpsite of Akwa Ibom State, southern Nigeria

Johnson C. Ibuot, Francisca N. Okeke, Nyakno J. George and Daniel N. Obiora

ABSTRACT

Geophysical and physicochemical methods were carried out to examine the effect of leachate on groundwater in a dumpsite location in Akwa Ibom State, Nigeria. This was done to ascertain the level of organic contamination in the wells located in the study area. The analysis of water samples from boreholes close to the dumpsite was done to constrain the interpretation of electrical resistivity data on the reality of the effect imposed by dumpsite leachate on the hydrolithofacies. The resistivity values of the underlying layers were observed to be lower than the overlying layer, an effect which may be associated with the infiltration of leachate into the underlying layers. The geohydrolayer resistivities range from 78.4 to 1,669.8 Ωm. The contour maps generated display the variations of the parameters. The elevation contour map indicates the flow of groundwater in a southwest–northeast direction which also depicts the direction of leachate flow. The physicochemical water samples show differences in concentrations of the physicochemical parameters. The concentrations of the ions in the water samples measured are compared with the WHO standard for drinking water. The sodium absorption ratio and sodium percentage show that the groundwater within the dumpsite has no negative effect on the subsurface.

Key words | aquifer, groundwater, leachate, physicochemical, resistivity

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INTRODUCTION

The most common disposal practice in Nigeria involves the dumping of organic waste (municipal solid waste) in open receptacles placed in different locations on the roadside of the study area. The degradation of the organic waste produces stench and leachate when finally disposed to dumpsites. Leachate percolation into the groundwater repositories has been identified by researchers (earth scientists and scientists from other related fields of science) as the major groundwater contaminant (Al-Tarazi *et al.* 2008; Hossain *et al.* 2014; Ganiyu *et al.* 2015). The migration of leachate from the unsaturated zone to the saturated zone (aquifer units) is influenced by the gravitational pull of the earth. The unconsolidated or porous and permeable nature of the soil allows for easy percolation of leachate into the subsurface aquifer repositories. The retention time of rainwater on the land surface is increased due the relatively flat nature of the study area, which impedes runoff, thus increasing infiltration into the subsurface (Nwankwaola & Ngah 2015). Dumpsites, which are potential sources of leachate, are indiscriminately located and can be found close to residential settlements, thus contributing to environmental problems (Pastor &

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Hernandez 2012). Increase in population, urbanization and industrialization, which facilitate rapid growth in waste generation, leads to increase in dumpsite locations (Ayolabi *et al.* 2013; Andrade 2014). In Nigeria, areas close to the vicinity of dumpsites are exposed to contaminants emanating from the dumpsites and a greater possibility of groundwater contamination. The compositions of the dumpsites include biological, chemical and mechanical materials. The contamination of the aquifer depends on factors such as the depth of the water table, concentration of contaminants, permeability of subsurface layers, geological setting and the direction of groundwater flow (Lopes *et al.* 2012; Bayode & Adeniyi 2014). Groundwater in the dumpsite under study is not exposed to saltwater–freshwater interaction and as such the possibility of contamination by ingress of saltwater into freshwater in the dumpsite location is not decipherable (George *et al.* 2015b). In determining the quality of groundwater, the geochemical or biogeochemical mineral composition of aquifer rocks and groundwater flow are considered. The flow of these minerals helps in determining the direction of leachate flow in the groundwater. Although the mineralized water has agricultural benefits, environmental and human health conditions can be negatively affected.

Groundwater compared with surface water has a lesser degree of contamination (George *et al.* 2014). The chemicals in the waste are dissolved by water (a process called leaching) resulting in leachate, which has the potential to pollute groundwater resources. The electrical properties of the groundwater change as a result of the contaminants percolating into the subsurface (Al-Tarazi *et al.* 2008). The physicochemical characteristics of the leachate depend primarily upon waste composition and water content (Mor *et al.* 2006). There is need for proper knowledge of the subsurface geology since groundwater is the major source of water supply. Wildcat drilling has exposed many groundwater repositories to contamination due to inadequate scientific knowledge of the location of water-bearing sediments (Ibuot *et al.* 2013; George *et al.* 2014; Ibanga & George 2016). Electrical resistivity methods enable the detection of contamination plumes due to the large contrast in the electrical conductivity of leachate generated to that of groundwater (Pomposiello *et al.* 2012). The integration of geophysical and physicochemical methods in assessing groundwater quality gives precise and valuable results, since the physicochemical method helps in confirming the resistivity characteristics of groundwater (Abbaspour *et al.* 2015).

Generally, the electrical resistivity method is preferred in a groundwater study due to its high resolving power, economic viability and its minimal to non-invasiveness. In a geophysical survey, the measured physical parameters are unique, as these parameters give anomalous signatures of which the interpretation is important. Researchers have employed the electrical resistivity method in characterizing groundwater problems related to contamination by delineating zones of leachate generation, migration and the extent of contamination (Lopes *et al.* 2012; Abdullahi *et al.* 2013; Syukri *et al.* 2013; Omolayo & Tope 2014; Bayowa *et al.* 2015; Obiora *et al.* 2015). The use of the electrical resistivity method is very important in environmental monitoring and assessment. This method is based on the response of the subsurface to the flow of current and the vertical electrical sounding (VES) employed measures the vertical variations of resistivity with depth.

The objective of this study is to employ the applicability of the electrical resistivity method and physicochemical analysis of water samples from boreholes close to the vicinity of the dumpsite to delineate leachate distribution and migration. Effort is also geared towards identifying the possible leachate plume, concentration of ions and the assessment of the risk of groundwater contamination.

LOCATION AND GEOLOGY OF THE STUDY AREA

The study area is located in Eket in the south western part of Akwa Ibom State. It lies between latitudes 4.33 °N to 4.45 °N and longitudes 7.52 °E to 8.02 °E. It is bordered in the north by Nsit Ubium Local Government Area, in the south by Ibeno Local Government Area, in the east by Esit Eket Local Government Area and by Onna Local Government Area in the west as shown in Figure 1. The dumpsite, which has been operated for more than two decades, has average areal coverage of 5 square kilometres. It is located in the coastal plain sands known as the Benin Formation, which is the uppermost and youngest unit of

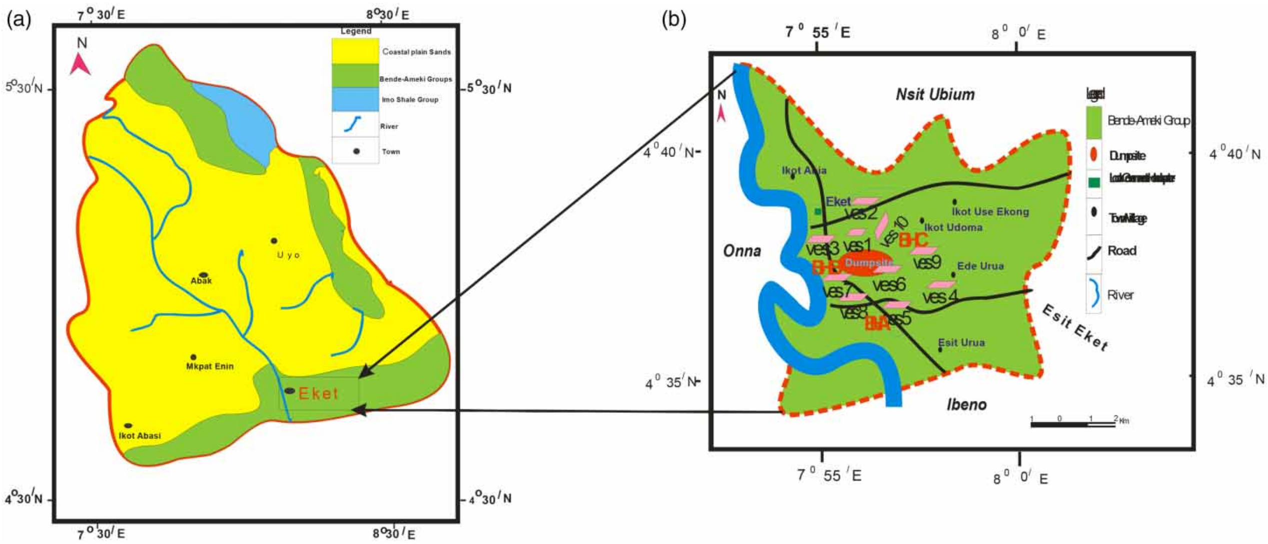

Figure 1 | (a) Geologic map of Akwa Ibom State showing the location of Eket Local Government Area. (b) Map of Eket Local Government Area showing the location of the dumpsite.

the Niger Delta Formation overlying the Agbada Formation (George *et al.* 2013, 2017). The Niger Delta is the most prolific basin in the world (Bilotti & Shaw 2005). The study area has an annual precipitation of about 2,200 mm. The study area is made up of sands, sandstone and gravels with clay and sandy clay intercalation in some places. The region is flat and low-lying, but three major physiographic units can be identified from the terrain: the alluvial plains (mangrove and flood plains), the beach ridge sands and the rolling sandy plains.

METHODS

Geophysical method

The electrical resistivity survey was carried out using an SAS 4000 ABEM Terrameter to determine the subsurface resistivity distribution from measurements made on the ground surface. The transmitting and receiving electrodes are the current and potential electrodes respectively. The Schlumberger electrode configuration was employed for the study and ten VESs were carried out covering the dumpsite. This was done within the half current electrode spacing ($AB/2$) ranging from 1.0 to 400.0 m and half potential electrode spacing ($MN/2$) of 0.25 to 20.0 m. From the current (I) and voltage (V) values, the apparent resistivity (ρ_a) was computed:

$$\rho_a = K\frac{V}{I} = K \cdot R_a \tag{1}$$

where K is the geometric factor and depends on the electrode arrangement and R_a is the apparent resistance that is measured on the field from the equipment. Equation (1) can also be written as

$$\rho_a = \pi \cdot \left[\frac{(AB/2)^2 - (MN/2)^2}{MN}\right] \cdot R_a \tag{2}$$

where AB is the distance between the two current electrodes, MN is the distance between the potential electrodes, and where

$$K = \pi \cdot \left[\frac{(AB/2)^2 - (MN/2)^2}{MN}\right]$$

The global positioning system was used in measuring the coordinates of the sounding points. The apparent resistivity obtained was plotted using a bi-logarithm graph and the curves were smoothed to remove the effects of lateral inhomogeneities and quantitatively interpreted in terms of true resistivity and thickness by conventional manual curves and auxiliary charts (Orellana & Mooney 1966). The manually interpreted data were improved on WinResist software to generate geological model curves. The interpretation of the resistivity curves was based on a number of layers depicted on the observed curves and models that are geologically reasonable and produce acceptable fit. The geoelectric parameters (resistivity, thickness and depth) of different layers are obtained after a number of iterations with minimal RMS error (Tables 1 and 2). The geoelectric parameters of the aquiferous layers (resistivity and thickness) obtained from the model curves were used in computing the parameters shown in Table 3. The parameters are the longitudinal conductance, which is the ratio of layer thickness to resistivity, and transverse resistance which is the product of layer resistivity and thickness.

The distribution of the Dar-Zarrouk parameters (longitudinal conductance and transverse resistance) were calculated from the interpreted layer parameters, resistivity and thickness (Maillet 1974; Niwas & Singhal 1981) using the expressions in Equations (3) and (4):

$$S = \frac{h}{\rho} \quad (3)$$

$$T = \rho h \quad (4)$$

where ρ is the resistivity of the layer, h is the layer thickness, S is longitudinal conductance and T is transverse resistance. Equations (3) and (4) established the relationship existing between the Dar-Zarrouk parameters and layer parameters. The values of S were used in classifying the aquifers based on its protective capacity (Henriet 1976; Oladapo *et al.* 2004). Areas with poor and weak longitudinal conductance values are vulnerable to contamination from infiltration from contaminants such as dumpsite leachate and/or leakage from buried underground storage facilities. The aquifer conductivity was calculated using the following equation:

$$\sigma = \frac{1}{\rho} \quad (5)$$

The water suitability for irrigation was tested using the sodium adsorption ratio (SAR) given by

$$SAR = \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \quad (6)$$

where Na^+ is the sodium ion, Ca^{2+} is the calcium ion, and Mg^{2+} is the magnesium ion.

Table 1 | Summary of results of resistivity survey from computer modeling

				Resistivity (Ωm)					Thickness (m)				Depth (m)				
VES stations	**Elevation (m)**	**Longitude (°E)**	**Latitude (°N)**	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h_1	h_2	h_3	h_4	d_1	d_2	d_3	d_4	**Curve types**
VES 1	55.3	7.9305	4.6141	1,194.4	1,265.0	172.9	603.8	–	2.5	4.5	46.2	–	2.5	7.0	53.2	–	KH
VES 2	13.4	7.9273	4.6150	309.5	630.8	160.8	–	–	1.0	11.8	–	–	1.0	12.8	–	–	K
VES 3	38.0	7.9360	4.6183	649.1	1,686.5	346.4	128.1	–	0.6	8.1	28.9	–	0.6	8.7	37.6	–	KQ
VES 4	47.2	7.9312	4.6130	985.1	1,664.7	490.7	232.3	–	1.3	7.9	35.2	–	1.3	9.2	44.4	–	KQ
VES 5	93.1	7.9354	4.6155	704.3	945.2	183.5	166.9	–	0.9	11.5	78.1	–	0.9	12.4	90.5	–	KQ
VES 6	37.6	7.9344	4.6146	1,252.0	1,651.4	374.3	78.4	219.0	1.4	4.8	30.2	85.4	1.4	6.2	36.4	121.9	KQH
VES 7	15.8	7.9297	4.6137	588.3	1,669.8	111.9	–	–	3.1	9.2	–	–	3.1	12.3	–	–	K
VES 8	163.5	7.9362	4.6203	368.5	711.9	225.3	282.8	–	1.5	12.0	155.0	–	1.5	13.5	169.4	–	KH
VES 9	81.3	7.9269	4.6163	496.0	945.5	156.3	131.0	–	4.3	25.3	49.6	–	4.3	29.6	78.2	–	KH
VES 10	50.9	7.9311	4.6187	76.3	385.0	235.3	186.3	–	1.5	11.2	35.7	–	1.5	12.7	48.4	–	KQ

Table 2 | (Control) Summary of some results of geoelectric survey from George *et al.* (2015a)

VES stations	Elevation (m)	Longitude (°E)	Latitude (°N)	Resistivity (Ωm)					Thickness (m)				Depth (m)				Curve types
				ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h_1	h_2	h_3	h_4	d_1	d_2	d_3	d_4	
Mbak Itam	96.4	7.8842	5.0649	1,474	3,355	1,151	4,220	1,454	1.4	4.5	9.2	78.1	1.4	5.9	15.1	93.2	KHK
Ekit Itam	86.1	7.8961	5.0652	856	1,154	1,267	5,612	988	2.0	2.9	6.5	75.8	2.0	4.9	11.4	87.2	AAK
Afaha Itam	48.3	7.8988	5.0595	2,101	956	5,410	863	–	2.2	2.1	48.6	–	2.2	4.3	52.9	–	HK
Ikot Ekang	39.7	7.9121	5.0570	1,484	3,703	861	2,993	1,579	0.8	1.6	1.5	38.1	0.8	2.3	3.9	42.0	KHK
Akon Itam	94.6	7.9331	5.1058	692	1,056	5,442	1,006	4,747	0.6	4.1	14.1	33.7	0.6	4.7	18.8	91.2	AKH

The sodium percentage (Na%) in the water sample was determined using

$$Na\% = \frac{(Na^+ + K^+)}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100\% \quad (7)$$

where K^+ is the potassium ion.

Physicochemical method

Three water samples were collected from three boreholes (BH A, B, and C) located around the dumpsite at distances of 50 to 200 m away from the dumpsite. The depths for boreholes A, B and C were 210 ft (64 m), 223 ft (70 m) and 180 ft (55 m) respectively. The physical and chemical parameters of water samples were measured to determine the degree of contamination from the contaminant accumulation. This was done to constrain the interpretation of the results of the geophysical data. Physical parameters measured include temperature, pH and electrical conductivity. The temperature, water conductivity and pH were measured using thermometer, water conductivity and 09 Kion pH meters. The laboratory analysis was carried out to determine the cations (Na^+, K^+, Ca^+, Mg^{2+}, Fe^{2+} and Mn^{2+}) using an Atomic Absorption Spectrophotometer (UNICAM 969AAS), while a DR 2000 Spectrophotometer was used to analyse the anions (Cl^- and SO_4^{2-}). Using phenolphthalein and methyl orange indicator, the carbonates and bicarbonates (CO_3^{2-} and HCO_3^-) were determined titrimetrically. To prevent the metallic ions adhering to the walls of the container and to homogenize the water sample, the water for anion determination was acidified with nitric acid (HNO_3). The values of the physicochemical data are compared with the World Health Organisation (WHO) standard (WHO 2010), in order to assess the health risks to human settlement.

RESULTS AND DISCUSSION

Vertical electrical sounding

The quantitative interpretation of the VES data (Figure 2) gives detailed results of true resistivity, thickness and depths (Tables 1 and 2), with a resolution of three to five geoelectric layers observed within the maximum current electrode separation. Based on the interpreted results, the

Table 3 | Results of aquifer parameters from measured resistivity and thickness of the aquifer layers

VES stations	Aquifer resistivity ρ_a (Ωm)	Aquifer thickness h_a (m)	Longitudinal conductance S (Ω^{-1})	Transverse resistance T (Ωm^2)	Aquifer conductivity σ ($\Omega^{-1} m^{-1}$)	Protective capacity
VES 1	172.9	46.2	0.2672	7,987.98	0.0058	Moderate
VES 2	630.8	11.8	0.0187	7,443.44	0.0016	Poor
VES 3	346.4	28.9	0.0834	10,010.96	0.0029	Poor
VES 4	490.7	35.2	0.0717	17,272.64	0.0020	Poor
VES 5	183.5	78.1	0.4256	14,331.35	0.0055	Moderate
VES 6	78.4	85.4	1.0893	6,695.36	0.0128	Good
VES 7	1,669.8	9.2	0.0055	15,362.16	0.0006	Poor
VES 8	225.3	155.0	0.6880	34,921.50	0.0044	Moderate
VES 9	156.3	49.6	0.3173	7,752.48	0.0064	Moderate
VES 10	235.3	35.7	0.1517	8,400.21	0.0043	Weak
Mean	418.94	53.51	0.3119	13,017.81	0.0046	

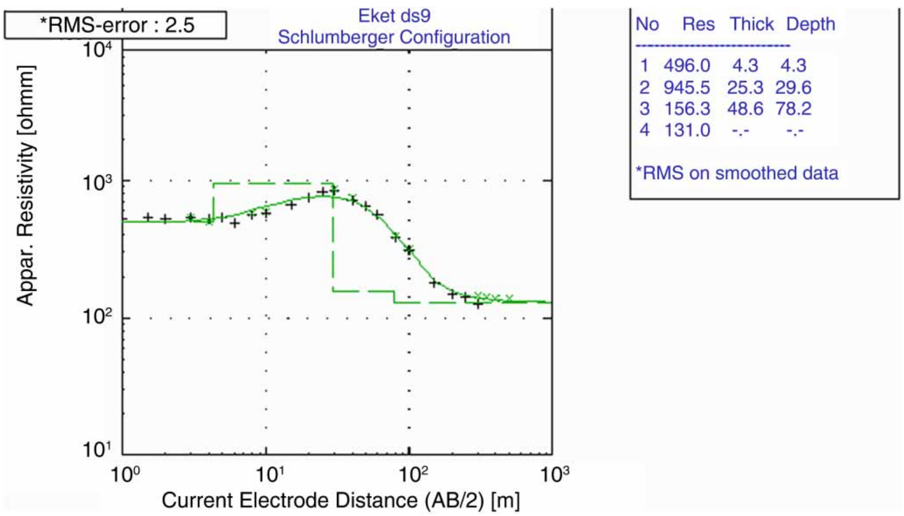

Figure 2 | Ek ds9 geoelectric curve and its parameters.

four curve types observed are: K, KH, KQ and KQH, and the locations with K curve types predominate the study area. The VES result was correlated with the borehole lithologic log of the study area (Figure 3) with a water table of about 16 m. The resistivity of the top soil is observed to range from 76.3 to 1,252.0 Ωm, with both thickness and depth varying from 0.6 to 4.3 m. The top soil is underlain by a layer with resistivity varying in the range 385.0–1,686.5 Ωm with the relative thickness and depth range of 4.5–25.3 m and 6.2–29.6 m respectively. This layer is observed to be more resistive than the first layer. The resistivity of the third layer varies in the range 111.9–490.7 Ωm, while 28.9–155.0 m and 36.4–169.4 m are the ranges of thickness and depth respectively. This layer seems relatively more conductive than the overlying layer with sizeable thickness for groundwater storage which suggests that it is saturated and thus more prolific than the overlying layers.

The fourth layer ranges from 78.4 to 603.8 Ωm with thickness and depth that are undefined within the maximum current separations except at VES 6, which has the fifth layer with a resistivity of 219.0 Ωm. The relatively low resistivity of the third and fourth layers may be due to conductive argillites due to leachate contaminants emanating from the dumpsite. Comparing values of resistivity in the dumpsite with resistivity

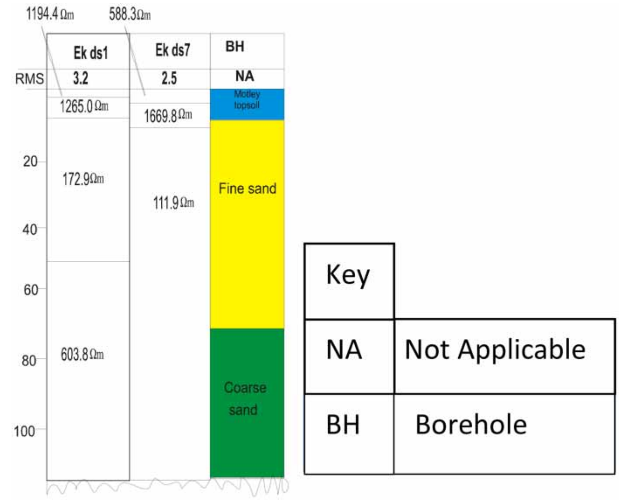

Figure 3 | Correlation of VES lithology with nearby borehole log.

values from VES points located more than 1 km away from the dumpsite in an unpolluted environment as shown in Table 2, high resistivity values were observed in the aquifer layers. Zones of high and low resistivity can be delineated. The zone of lower resistivity may be delineated as the zone where the leachate accumulates and these zones are more conductive compared with the overlying layers.

The distribution of aquifer resistivity and thickness used in calculating the Dar-Zarrouk parameters and conductivity is shown in Table 3. The aquifer layers were determined from the thickness values obtained as these layers were observed to have high thickness values compared with other layers. The aquifer resistivity and thickness vary from 78.4 to 1,669.8 Ωm and 9.2 to 155.0 m respectively. Their mean values were estimated as 418.94 Ωm and 53.51 m. The aquifer may be inferred as a zone with sandy soil intercalated with clay and the electrical resistivity values of 100–1,000 Ωm show that this layer is dominated by medium resistive materials and the sediments can be described as consolidated. Longitudinal conductance varies from 0.0055 to 1.0893 Ω^{-1} with a mean value of 0.3119 Ω^{-1}. This reflects the sensitivity of groundwater quality to the imposed contaminant load. The transverse resistance has relatively high values in the range 6,695.36–34,921.50 Ωm^2 and the mean value of 13,017.81 Ωm^2. The aquifer conductivity varies in the range 0.0006–0.0128 Ω^{-1} m^{-1} with a mean value of 0.0046 Ω^{-1} m^{-1}. The results of the aquifer parameters were interpreted qualitatively by preparing the contour maps for each of the parameters. These maps further provide information on the subsurface geological structure and changes in the geological section of the geolayers.

Figure 4 is a contour map showing the distribution of aquifer resistivity as it decreases from the southwest towards the north. The map indicates that the zone with low resistivity (0–300 Ωm) dominates the layers, thus marked as the zone of high conductivity, reflecting a zone of high impact of leachate. The thickness of the aquifer layer varies across the study area (Figure 5). The zone with high thickness is observed in the northeast and southeast while the zone with low thickness is observed in the southwest.

The protective capacity is assessed using the longitudinal conductance, which determines the capacity to prevent leachate infiltration into the groundwater repository. It

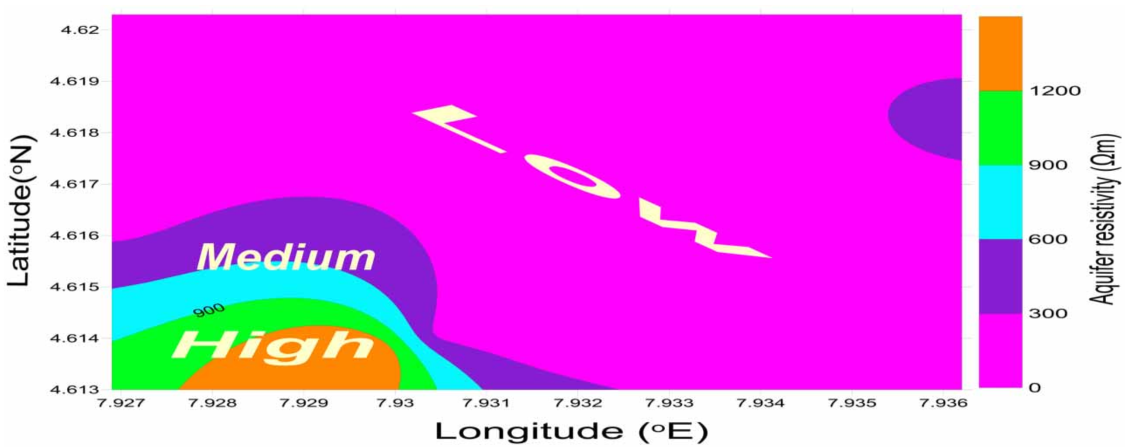

Figure 4 | Contour map showing the distribution of aquifer resistivity.

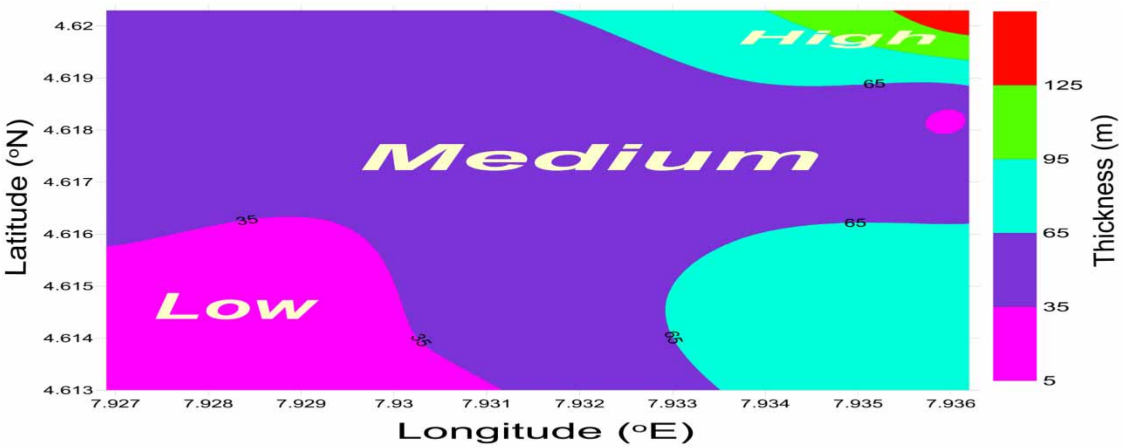

Figure 5 | Contour map showing the distribution of aquifer thickness.

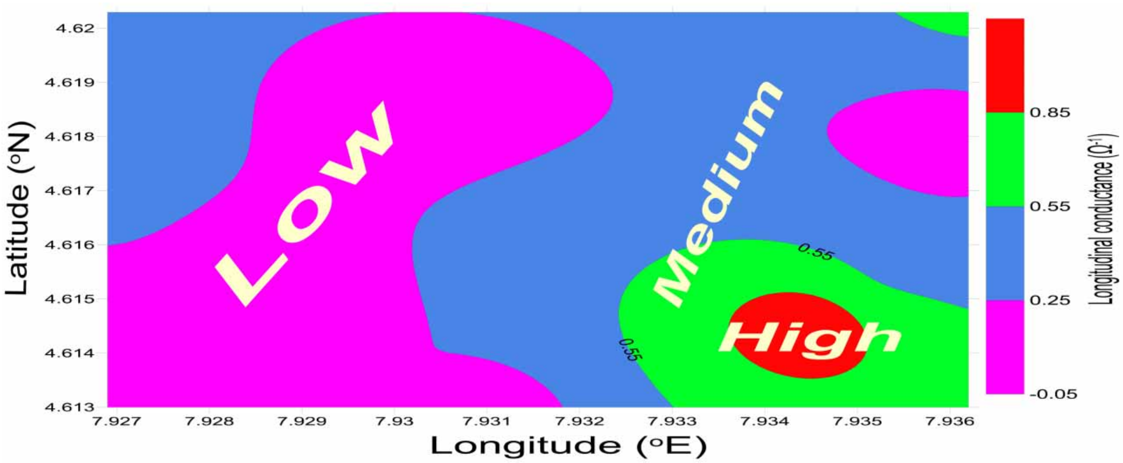

Figure 6 | Contour map showing the variation of longitudinal conductance.

indicates the ability of the characteristics of the subsurface to prevent or favour leachate percolation. Figure 6 is a contour map showing the variation of the longitudinal conductance in the study area (protective capacity). The zone with good protective capacity can be observed in the southeast, while the greater parts of the study area can be classified as zones with poorly, weakly and moderately protective capacity. This makes the zones vulnerable to plumes from leachate contaminants. Figure 7 shows the variation of transverse resistance in the study area. The northeast reflects a zone with high transverse resistance, which is an indication of high aquifer thickness, as shown in Figure 7.

It can be inferred that this zone may have high transmissivity and high aquifer yield. Aquifer conductivity (Figure 8) is observed to be high in the southeast of the study area, in a reverse of aquifer resistivity. It can be inferred that the southwest is low in conductivity, an indication that the zone is highly resistive. The low resistivity zones can be interpreted to be soil or sand saturated with leachate, which reflects the infiltration. Thus, there is a chance for downward migration of leachate to the groundwater in the weak zone (Iyoha *et al.* 2013; Ganiyu *et al.* 2015), in the zone where the overlying layers have high resistivity values compared to the underlying layers. The lateral and vertical flow of leachate in the subsurface of the study area is specifically taking the path of the topographic elevation, which shows a direct flow from a topographically high region to a topographically low region in Figure 9. The flow direction due to elevation

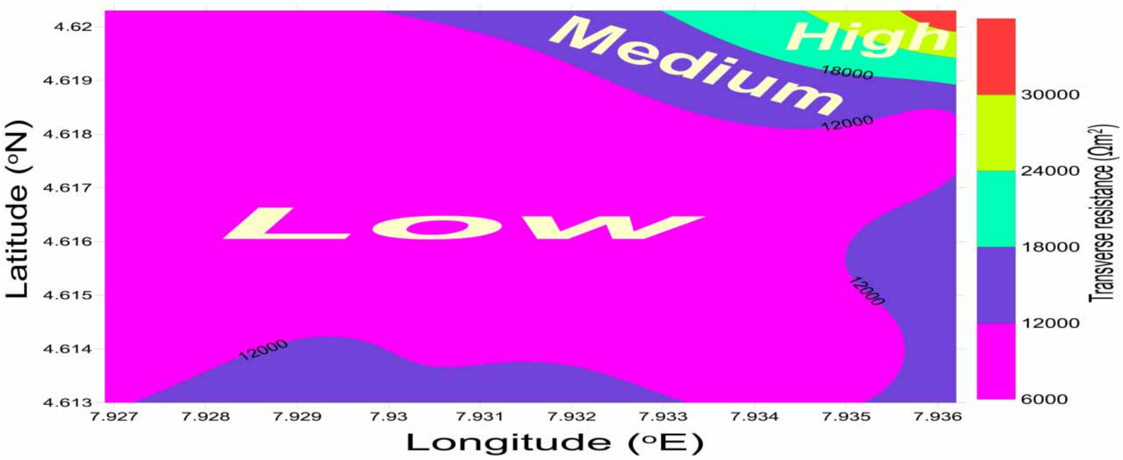

Figure 7 | Contour map showing the variation of transverse resistance.

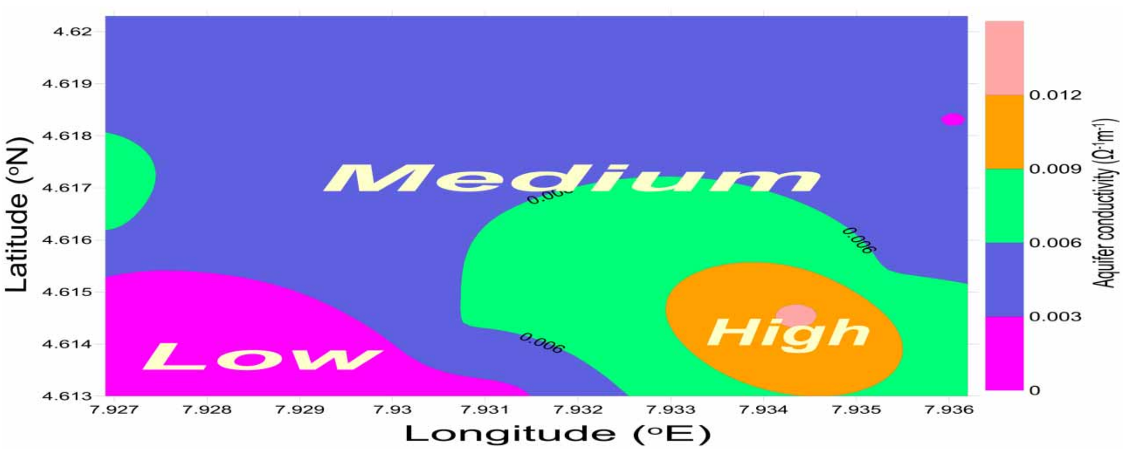

Figure 8 | Contour map showing the distribution of aquifer conductivity.

distribution is a southwest–northeast (SW–NE) trend. The radial and vertical spread of the leachate and groundwater in the dumpsite based on topographic display and gravitational pull is in the SW–NE direction. The flow pattern in the subsurface could be said to be partially controlled by depth (Wijesekara *et al.* 2014), porosity, permeability and concentration of the fluid.

Physicochemical result

Table 4 gives the results of the physicochemical analysis of water samples from boreholes located close to the vicinity of the dumpsite. The range of pH from 6.71 to 7.86 was obtained. These values were observed to be within the WHO acceptable range for drinking water, though slightly acidic and may be due to the dissolution, draining and decomposition of vegetative materials (WHO 2010). The ranges of the measured species are temperature: 27.4–29.3 °C, electrical conductivity: 96.0–572.0 μS/cm, CO_3^{2-}: 14.0–53.2 mg/L, SO_4^{2-}: 3.9–7.2 mg/L, Cl^-: 20.4–69.5 mg/L, F^-: 0.2–0.6 mg/L, K^+: 0.8–2.6 mg/L, Na^{2+}: 5.9–10.7 mg/L, Ca^{2+}: 9.4–26.8 mg/L, Mg^{2+}: 1.4–6.3 mg/L, Cu^{2+}: 0.06–1.13 mg/L, Fe^{2+}: 0.04–1.75 mg/L and Mn^{2+}: 0.612–1.063 mg/L. The results show that the ions tested have their values below the WHO acceptable standard for drinking water except F^- whose value exceeds the WHO acceptable standard in all the boreholes assessed and may likely lead to the health effect called fluorosis. The K^+,

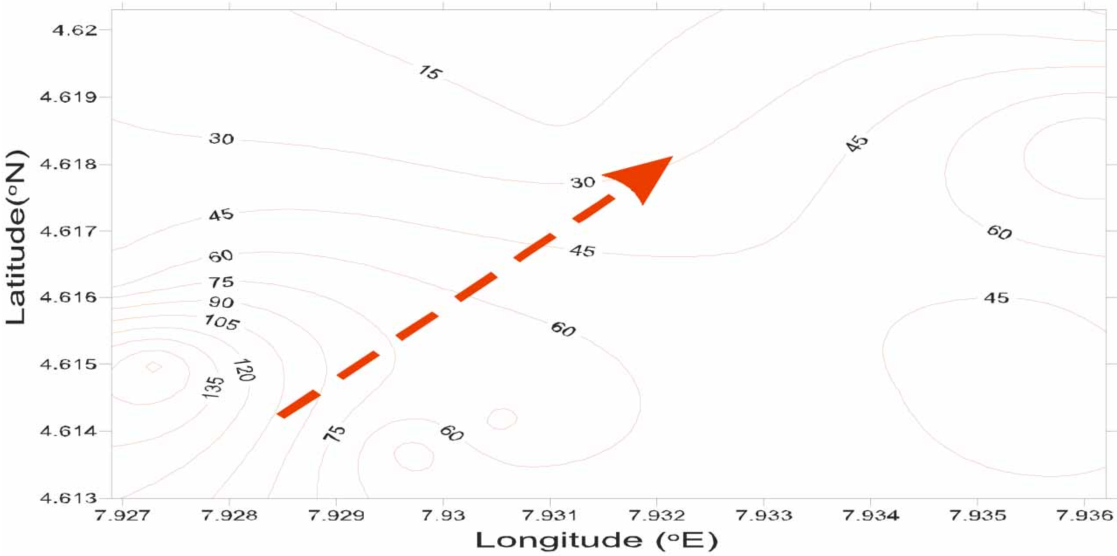

Figure 9 | Elevation contour map showing the direction of groundwater flow.

Table 4 | Results of physicochemical analysis of water samples from boreholes in the study area

	Parameters	BH A	BH B	BH C	WHO
1	pH	6.71	7.86	6.95	6.5–8.5
2	Temperature (°C)	27.80	27.40	29.30	NS
3	Electrical conductivity (μS/cm)	96.0	572.0	135.0	1,400
4	CO_3^{2-} (mg/L)	24.00	14.00	53.2	NS
5	SO_4^{2-} (mg/L)	3.9	7.2	5.8	400
6	Cl^- (mg/L)	69.5	43.6	20.4	600
7	F^- (mg/L)	0.3	0.2	0.6	0.01
8	K^+ (mg/L)	1.4	2.6	0.8	2.0
9	Na^{2+} (mg/L)	8.3	10.7	5.9	200
10	Ca^{2+} (mg/L)	12.7	26.8	9.4	250
11	Mg^{2+} (mg/L)	1.4	6.3	5.7	150
12	Cu^{2+} (mg/L)	0.18	0.06	1.13	1.5
13	Fe^{2+} (mg/L)	0.04	1.75	0.06	1.0
14	Mn^{2+} (mg/L)	1.063	0.612	1.004	1.05

Fe^{2+} and Mn^{2+} have values that exceed WHO acceptable standard in some boreholes, an indication that groundwater quality is affected by migrated leachate from the dumpsite (Abd El-Salam & Abu-Zuid 2015). The high concentration of Fe^{2+} in BH B may also be attributed to ferrigenous Benin sands which contain the minerals haematite, limonite and goethite (George *et al.* 2015b). The electrical conductivity falls below the WHO acceptable standard. This may be attributed to dissolution of humus-related leachate into the subsurface aquifer.

For agricultural purposes, sodium plays an important role in irrigation as its concentration affects the hardness and permeability of the soil. It was observed that the calculated values of SAR for the three boreholes (BH A, BH B and BH C) were 3.12 meq/L, 2.63 meq/L and 2.15 meq/L respectively. The SAR, which measures the alkali/sodium hazard to crops, was found to be low. The low values indicate that the sodium content is low compared to the desired upper limit of 10 in the excellent class of water (Raju *et al.* 2009).

From the result, the Na% values for BH A, BH B and BH C were 40.76%, 28.66% and 30.73% respectively. Since the values are below the reference point of 60%, this shows that the water samples will be favourable for irrigation and other agricultural purposes (Raju *et al.* 2009; Bahar & Reza 2010; Akpan *et al.* 2013). This may due to the fact that the calcium which gives the soil its friable, loamy and permeable structure is not affected by the percentage of sodium, thus indicating that the dumpsite water will not affect agricultural production negatively by resulting in impaired drainage and increase in compaction.

CONCLUSION

The results of the geophysical and physicochemical study carried out have been presented in this paper. A total of ten VES and water analysis from three boreholes close to the dumpsite were evaluated. The spatial distribution of aquifer resistivity and thickness were displayed on the contour maps as well as the distribution of longitudinal conductance, transverse resistance and aquifer conductivity. The third and fourth aquiferous layers were observed to be zone-dominated with low resistivity values. This seems to be an aberration considering the kind of geological materials within these layers. These layers occur at depths exceeding 30 m, the zone suspected to be leachate-prone. From the longitudinal conductance map, the southeastern zone is depicted on the average to have good aquifer protective capacity. The groundwater flow pattern shows a SW–NE trend. The pH values were within the WHO standard and show slight acidicity. Some ions like F^{-}, Fe^{2+}, Mn^{2+} have concentrations above the WHO standard, which may contaminate groundwater quality and lead to water-borne diseases. The importance of sodium as regards irrigation was also observed from the SAR and percentage of sodium (Na%). Hence the water in the study area will boost agricultural production as it will not have any adverse effect on plants and soil.

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