Journal of African Earth Sciences 147 (2018) 243–253

Contents lists available at ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

Time dependent electrical resistivity tomography and seasonal variation assessment of groundwater around the Olushosun dumpsite Lagos, South-west, Nigeria

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ARTICLE INFO

Keywords:
Geoelectric layer
Apparent resistivity
Leachate plume
Contaminant
Dumpsite

ABSTRACT

Time-lapse electrical resistivity tomography (ERT) and seasonal variation studies of the physicochemical properties of groundwater were carried out on the Olushosun dumpsite in Lagos South-western Nigeria, to monitor, track the depth of leachate contamination, and to investigate the impact of seasonal variation on groundwater quality around the dumpsite. Six 2-D resistivity imaging lines were investigated. The independent inversion of the dipole–dipole and pole-dipole resistivity data indicated that contaminated zones are characterised by resistivity values ranging from 0.63 to 12.5 Ωm, and a maximum depth of 141 m was investigated. The pole-dipole models show clear evidence of vertical migration of contaminant with time, as depth of contamination increased from 106 m in May 2014 to about 120 m in December 2015 around the investigated portion of the dumpsite. Analysis of the seasonal variation of the examined physicochemical properties of the water samples taken from wells and boreholes within and around the site showed that there is increase in concentration of TDS and EC in the dry season study and a corresponding increase in the mean concentration of pH, Ca, Mg, hardness, Cu, Cr, NO_3, SO_4 and Na from the dry season results. Also, there is reduction in the mean concentration of Fe, Zn, Mn, PO_4, Cl, and Ni in the dry season when compared with the wet season analysis. Generally, there is a strong correlation between the ERT results and the physicochemical parameters of ground water quality viz-a-viz the contamination status of the Olushosun dumpsite. This increased trend in the dry season period could be attributed to the increase in concentration of the dissolved metals due to evaporation, and on the other hand, dilution effect of the rainfall during the wet season. South East direction of contaminant flow was established from the water table contour lines produced for the area. The research has clearly shown that the groundwater within the study area has been impacted by the leachate from the decomposed refuse at the dumpsite and may constitute danger to the life of residents living around the dumpsite.

1. Introduction

The Olushosun dumpsite is one of the largest dumpsites located in Nigeria. Like other dumpsites scattered all over the country, waste materials are dumped on excavated lands without recourse to the subsurface environment. In line with International global best practice, dumpsites are supposed to be designed such that their walls are lined with clayey materials or polyethylene geomembrane liner so as to reduce the vertical and lateral migration of the contaminants generated from the wastes materials deposited on the dumpsites. But all around the world, we have a situation whereby excavated lands are converted to dumpsites with indiscriminate dumping of refuse materials. When this happens, we have a situation whereby the biodegradable component of the waste materials decomposes with time, thereby releasing leachate materials generated within the waste into the subsurface environment and emitting bad odour into the atmosphere. Unfortunately, many communities located around these dumpsites get their water resources from these contaminated aquifers.

Time-lapse ERT study and physicochemical measurement of groundwater parameters were conducted at the dumpsite with the aim of tracking, monitoring and investigating the lateral and vertical extent of leachate contamination within the area, and to also examine the impact of seasonal variation on the physicochemical properties of

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https://doi.org/10.1016/j.jafrearsci.2018.06.024
Received 30 January 2018; Received in revised form 6 April 2018; Accepted 19 June 2018
Available online 21 June 2018
1464-343X/

groundwater around the dumpsite. The electrical resistivity methods are increasingly being deployed in contamination study due their ability to discriminate between the contaminated zones and the areas free of contamination. Usually the methods are not used to detect contamination directly, but rather, they reveal contamination through sharp variation in subsurface resistivities as a results of the presence of these contaminants. Many chemical pollutants are associated with dumpsites depending on the sources of contamination (Ayolabi et al., 2014). These produce vertical and laterally migrating leachates, commonly reducing resistivity, and the decrease in resistivity can be distinguished from natural, non-saline groundwater using electrical resistivity (Ross et al., 1990). Areas near landfills have a greater possibility of groundwater contamination because of the potential pollution source of leachates originating from the nearby site (Aldecy de Almeida and Shozo, 2008; Nixon et al., 1997). Such contamination of groundwater resource poses a substantial risk to local resource user and to the natural environment (Mor and Ravindra, 2006).

Municipal landfill leachates are highly concentrated complex effluents which contain dissolved organic matters; inorganic compounds, such as ammonium, calcium, magnesium, sodium, potassium, iron, sulphates, chlorides and heavy metals such as cadmium, chromium, copper, lead, nickel, zinc among others (Christensen et al., 1998; Lee et al., 1986; Ogundiran and Afolabi, 2008). The greatest contamination threat to groundwater comes from the leachate generated from the materials which most often contain toxic substances especially when wastes of industrial origins are land filled (Longe and Enekwechi, 2007). This research work therefore seeks to deploy time-lapse ERT method with physicochemical parameters analysis of water from existing boreholes and wells to assess contamination and depth of migration viz-a-viz seasonal variation in groundwater quality around the landfill site.

2. Field description

The Olushosun sanitary landfill site is located towards the northern part of the Lagos metropolis in Ikeja Local Government Area of Lagos State (Fig. 1). It is owned and maintained by the Lagos State Waste Management Authority (LAWMA). The landfill was opened in 1989, and it covers an area extent of about 42 ha. (Ayolabi et al., 2014). The landfill site has witnessed rehabilitation which consisted of reclamation of land and construction of accessible road for ease of tipping, spreading, and compaction of waste since inception (Ayolabi et al., 2014). The site receives waste from entire Lagos metropolis and is accessible by tarred road through the Lagos-Ibadan expressway. It is surrounded by residential, commercial, and industrial setups, and the waste stream is made up of domestic, market, commercial, industrial, and institutional origins (Ayolabi et al., 2014).

Basically, there are three major aquiferous units that are being tapped for the purpose of water supply in the Lagos metropolis; these are categorized to first aquifer horizon thought to belong to the recent littoral/alluvial deposit of the Benin formation (Longe et al., 1987). This upper aquifer unit is mostly exploited through hand-dug wells, and it is prone to contamination because of its limited depth. The second aquifer horizon is made up of sands and clay thought to be the coarse sandy estuarine deltaic and continental beds of Ilaro formation (Jones and Hockey, 1964; Longe et al., 1987), while the third aquifer layer consists of alternating sequences of clayey and sandy strata. Only few boreholes tap water from this aquifer (Jones and Hockey, 1964).

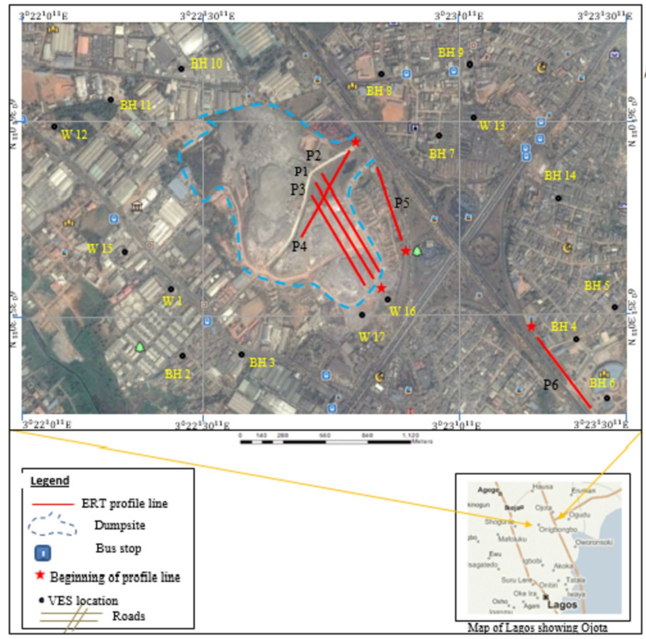

Fig. 1. Map showing the site locations, boreholes, wells and 2D ERT profile lines.

3. Materials and methods

3.1. 2-D resistivity imaging

The ERT surveys were carried out with the aid of a digital readout Super Sting R8 Earth Resistivity/IP metre along six (6) traverse lines (Fig. 1), using a multi-electrode system (84 electrodes). In order to achieve the objective of this research work, a one year and seven months time-lapse ERT experiments were carried out on and around the site in May 2014 (wet season) and a repeat survey in December 2015 (dry season).

The 2D resistivity data were collected along all the traverses using Dipole-Dipole and Pole-Dipole arrays with length of profile line depending on available space on and around the dumpsite. The choice of the electrode arrays was to enable maximum depth of investigation, good horizontal resolution and data coverage (Loke and Barker, 1996). The 2D data were processed and inverted using the Earth Imager inversion algorithm. The algorithm calculates the apparent resistivity values using forward modelling subroutine (AGI, 2003). It generates the inverted resistivity-depth image for each profile line based on an iterative smoothness constrained least-squares inversion algorithm (Loke and Barker, 1996). Generally, the programme automatically creates a 2D model by dividing the subsurface into rectangular blocks and the resistivity of the model blocks was iteratively adjusted to reduce the difference between the measured and the calculated apparent resistivity values (Loke and Barker, 1996).

3.2. Physicochemical analysis of water samples

To establish the level of impact of the leachate on groundwater and to examine the seasonal variation in physicochemical parameters of the groundwater quality around the dumpsite, water samples were obtained from seventeen (17) boreholes and hand dug wells using

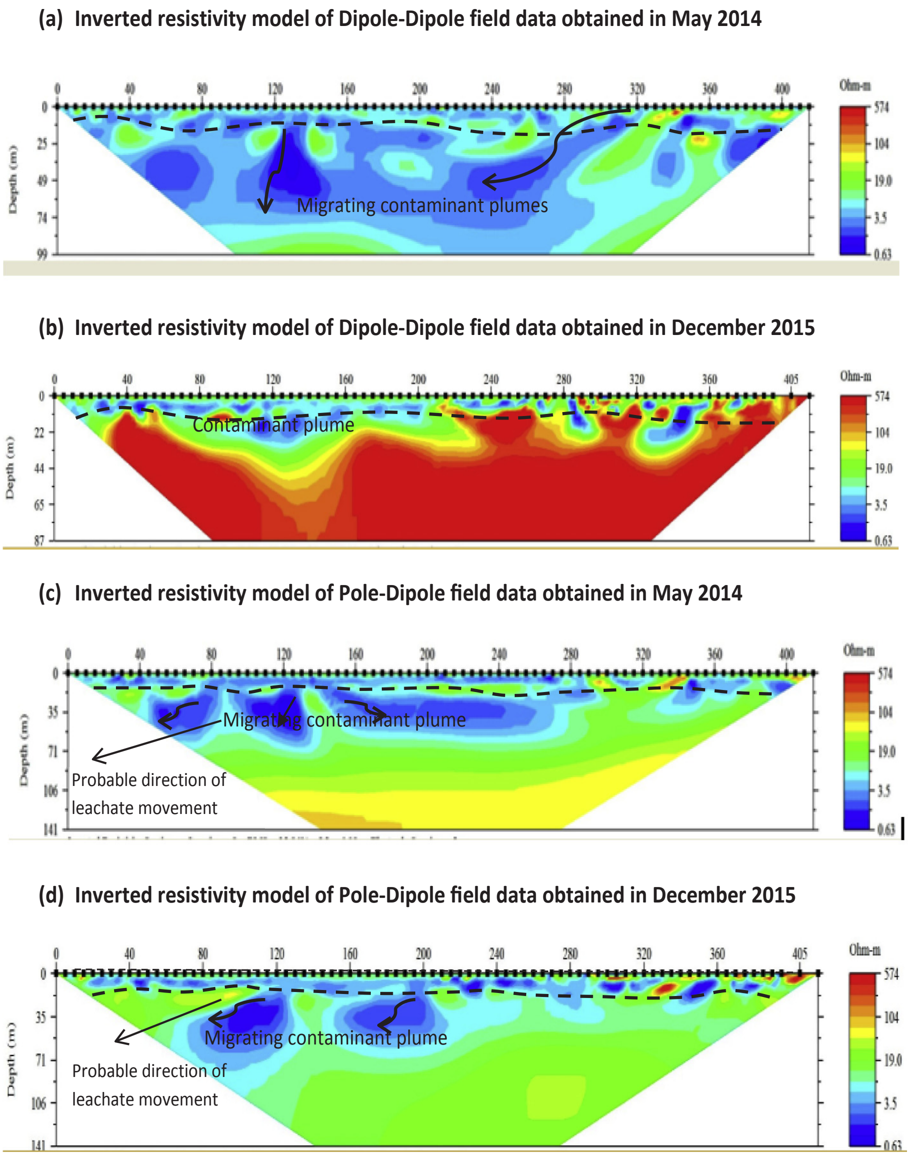

Fig. 2. Resistivity model obtained in May 2014 and December 2015 along traverse 1.
Note: - - - - - represents bottom of dumpsite.

random sampling technique. The distances of the sampled points varied from about 30 to 600 m radius from the dumpsite (Fig. 1). The water sample analysis was conducted in August 2014 (wet season), and a time-lapse study followed in December 2015 (dry season). Some of the sampling points were taken far away from the dumpsite to serve as control.

The physical properties tested for are their total dissolved solid (TDS), pH values, temperatures, hardness and electrical conductivity (EC). The samples were collected in a bowl and these properties were measured in situ with the aid of a portable EC/TDS meter. In addition to determining the physical properties of the water samples, they were also analysed for heavy metals including Iron, Lead, Manganese, Copper, Chromium, Cadmium, and Zinc among others after standard methods for the examination of water and wastewater quality (APHA, 1998). Global Positioning System (Garmin GPS Channel 76 model) was used to take the coordinates of the sampling locations.

4. Results and discussion

4.1. Electrical tomography results and analysis

The location of all the traverse lines on the dumpsite was a function of groundwater flow direction around the area and access on the dumpsite. This was so because portions of the dumpsite were not accessible because of thoroughfare by the scavengers and tipping activities going on at the time. Figs. 2, 3 and 5 to 8 shows the resistivity sections from the independent inversion of the dipole–dipole and pole-dipole resistivity data sets acquired in May 2014 and December 2015. With all inversion parameters kept the same, the time-lapse inversion of data set acquired in December 2015 was done with the independent inversion result for the data set acquired in May 2014 used as a reference model. From the inversion result, each section provides useful information on the vertical and lateral spread of the leachate beneath

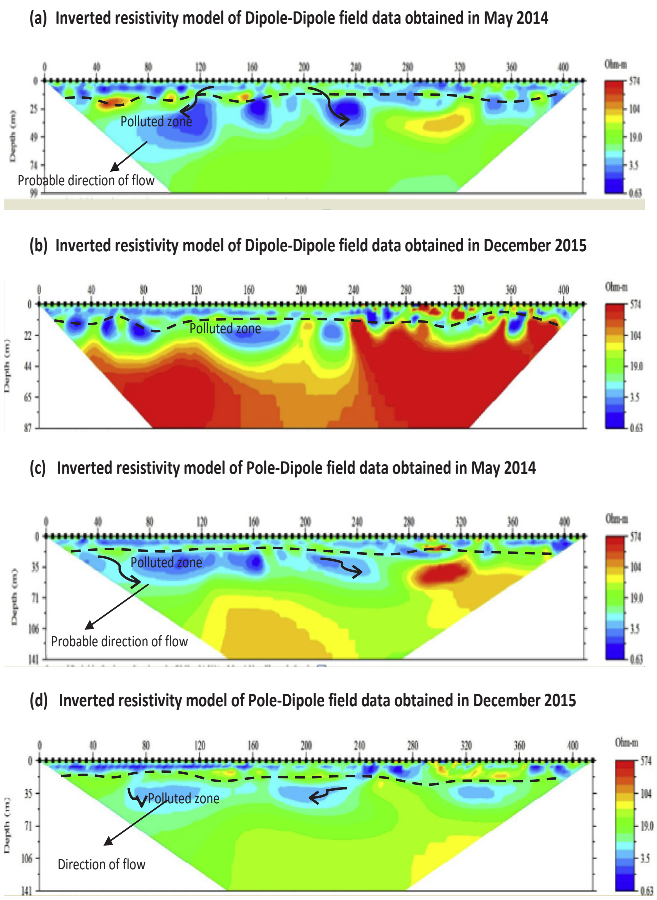

Fig. 3. Resistivity model obtained in May 2014 and December 2015 along traverse 2.

the surface and possible leachate flow direction. Observation of traverses 1 to 4 acquired on the dumpsite for instance indicates high impact and infiltration of leachate into the subsurface environment under the profiles, with a probable southward direction of flow. Subsurface under these profiles are characterized by mostly resistivity values between 0.63 and 12.5 Ωm from the surface to a depth of about 120 m.

The distances from the surface to the dashed lines on the profiles represent the buried refuse material (depth to the base of the dumpsite). The predominantly high resistivity values associated with the dipole-dipole models of traverses 1, 2, 3 and 4 (Figs. 2b, 3b and 5b and 6a) are attributed to the noise in the data acquired along the profiles during the dry season period. This could be due to high electrode contact resistance during the period. However, the relatively higher resistivity region within the contaminated regions, at shallower depths on traverses 1 to 4 may be associated with the presence of non-conductive, non-biodegradable waste materials (such as polythene and rubber) or possibly trapped methane gas from the decomposed refuse materials (Ayolabi et al., 2014). The medium resistivity region (12.5–104 Ωm) correspond to the aquifer units below the dumpsite that are prone to being impacted by the contaminants through constant vertical migration. Available borehole data (Fig. 4) and information from LAWMA indicates that the first geoelectric layers of topsoil and lateritic materials were excavated from the surface to depth of between 15 and 18 m before the commencement of dumping on the site. This actually exposed the underlying aquifer units to the direct impact of the leachate generated within the waste mass, and may be responsible for the high conductivity observed below the profile lines.

The variation in noise levels in the data sets could be responsible for the differences in image resolution for the wet and dry season models. The pole-dipole models show clear evidence of vertical migration of contaminant with time, as depth of contamination increased from about 106 m in May 2014 and about 120 m in December 2015. This trend if not checked could get the different levels of aquifer around the area contaminated. Seasonal resistivity variation of the subsurface mainly relates to the moisture content of the surveyed subsurface rock materials, changes in fluid conductivity and to the varying temperature of the subsoil (Xavier et al., 2012). The moisture content can be influenced by seasonal fluctuations of the water-table, by the volume of rainfall permeating into the subsurface below the root zone (i.e. effective recharge) or both. Air temperature and the bedrock geology control the subsoil temperature (Xavier et al., 2012).

A look at the reference and the time-lapse models reveal a similar pattern of resistivity distribution on all the profiles. Increase in the resistivity of the polluted regions was generally associated with the dry

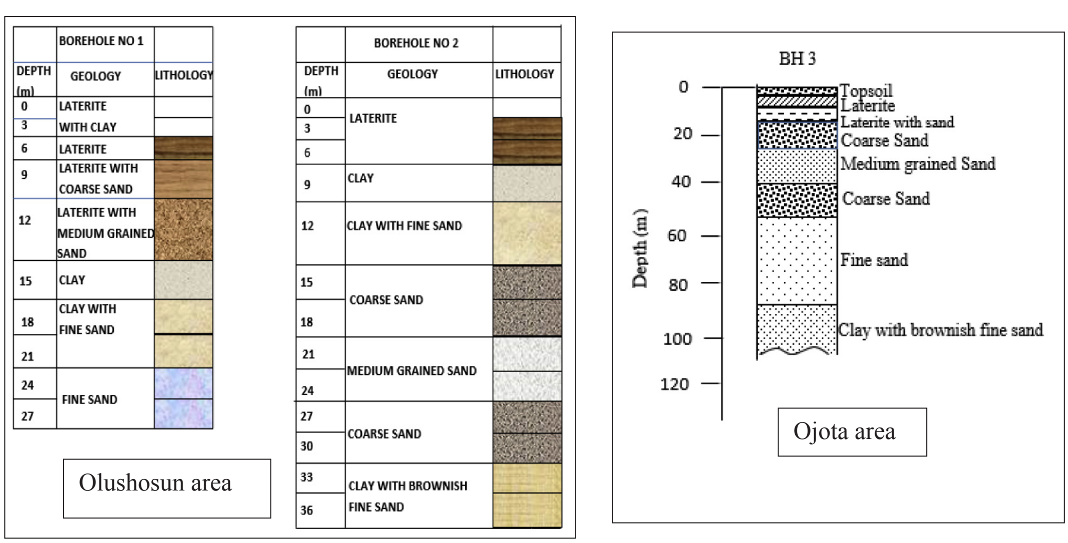

Fig. 4. Hydrogeological profile of boreholes at Olushosun (Modified after LMDGP, 2009) and Ojota areas.

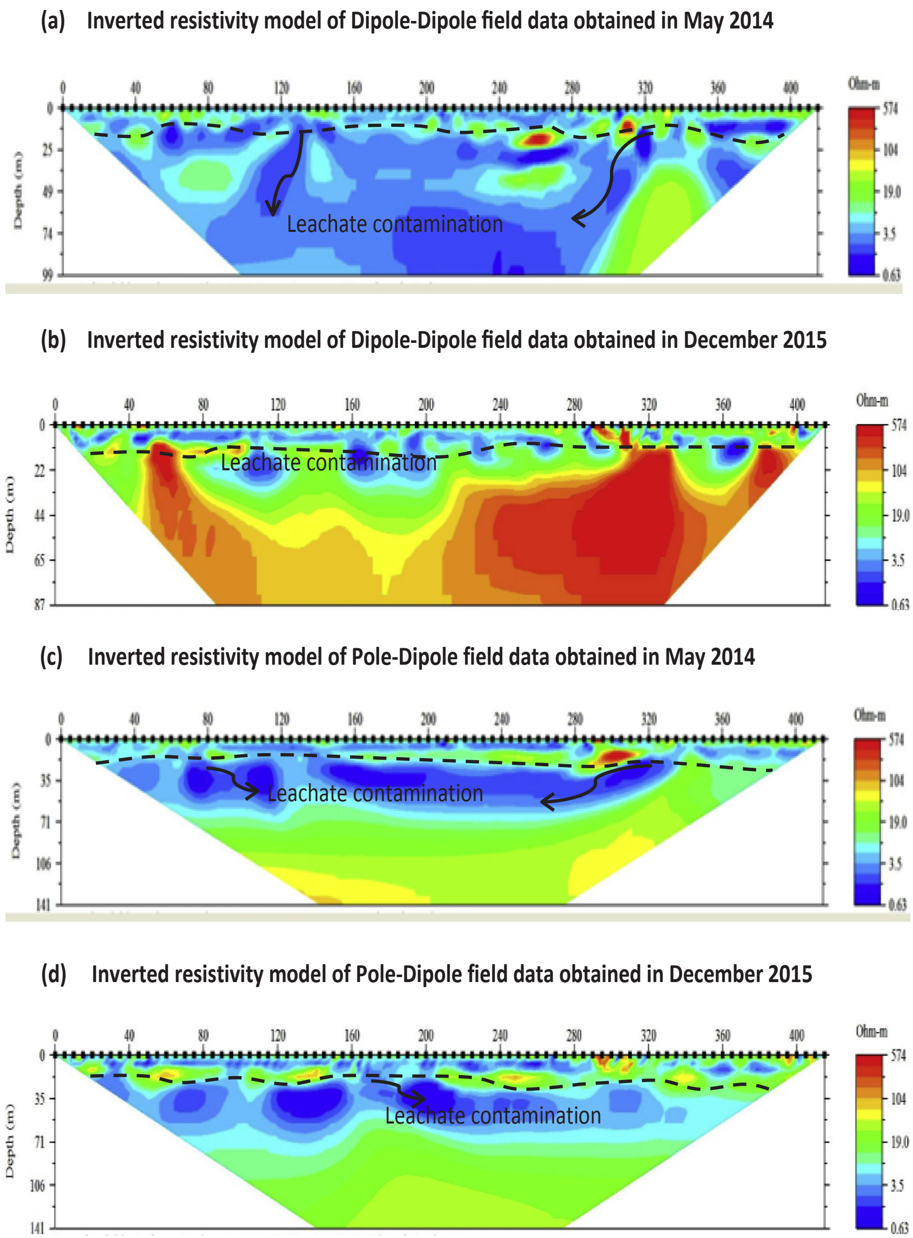

Fig. 5. Resistivity model obtained in May 2014 and December 2015 along traverse 3.

season inverted sections. For instance, comparing the wet and dry season inverted resistivity models of profile 1 (Fig. 2c and d), it is observed that there is slight increase in resistivity in the contaminated regions from the origin of the profile (dry season) to the end, and depth range of 0–71 m compared to the wet season model. Also for profile 2, the May 2014 pole-diploe profile shows more concentration of leachate around the contaminated portions at locations 80–130 m, 150–170 m and 215–240 m and a depth range 12–62 m compared to what was obtained along the same location on the December 2015 pole-dipole profile (Fig. 3c and d).

This increase in the resistivity of the contaminated zone during the drier season could be the result of lower moisture content of the surveyed subsurface rock materials, due to varying temperature of the subsoil, and therefore changes in fluid conductivity of the subsurface rock materials within the time lapse. Meanwhile the areas below the contaminated zones show a general resistivity decrease on the pole-dipole sections.

The pole-dipole profiles of traverse 3 (Fig. 5c and d) show higher level of concentration of leachate from the surface to a maximum depth of 71 m on the wet season model compared to the dry season model, while the resistivity images of the pole-dipole model for profile 4 (Fig. 6b and c) show strong correlation with each other except that the low resistivity zones from the centre of the reference model to the end and at depth range between 10 and 106 m is lower when compared with the time-lapse model. The dipole-dipole data acquired on this traverse in May 2014 could not be inverted due to challenges associated

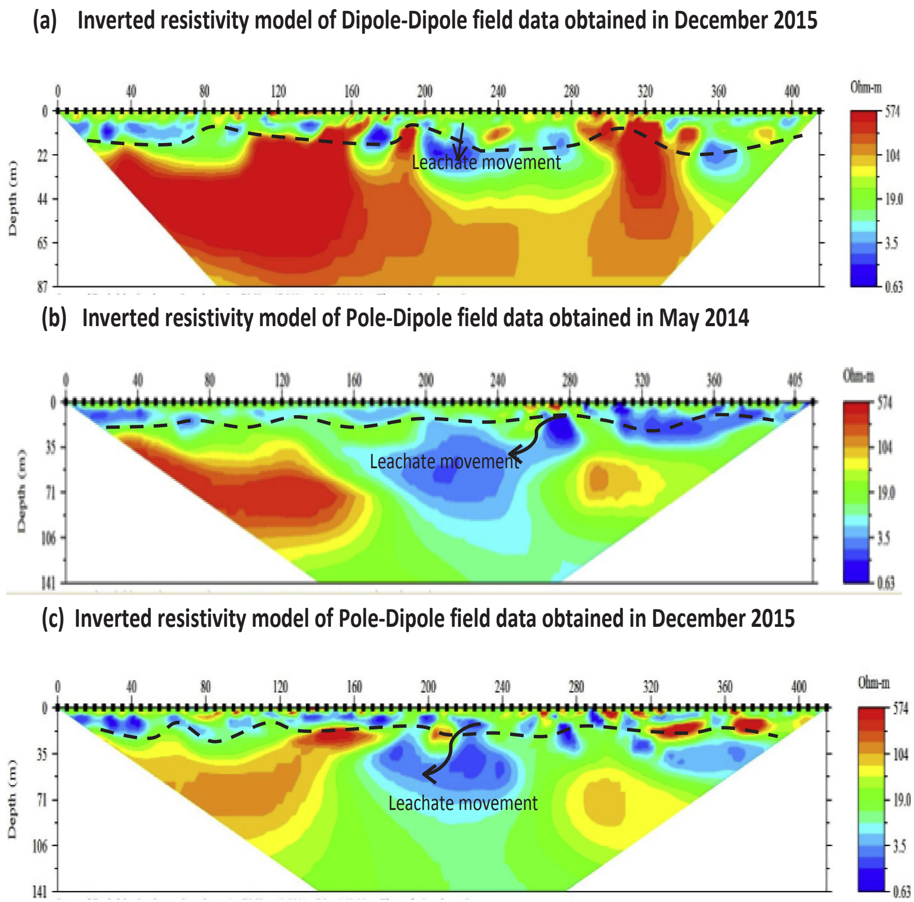

Fig. 6. Resistivity model obtained in May 2014 and December 2015 along traverse 4.
Note: Bottom of dump.

with the data, while that of 2015 was characterised with some degree of noise. Traverses 5 and 6 were located outside of the dumpsite to serve as controls (Fig. 1). While profile 5 was located at about 100 m away from the dumpsite, profile 6 was located at about 600 m away. From the inverted resistivity models for profile 5, the region with the low resistivity anomaly (0.63–12.5 Ωm) under the sections appears to be bounded by relatively higher resistivity materials (104–574 Ωm). This is interpreted as lateritic materials that lie beneath the area and those that were used to construct the roads around this area. The prevalent medium to high resistivity anomalies on this profile validate the interpretation carried out on the dumpsite. The low resistivity anomalies at the centre and towards the origin are interpreted as leachates that might have moved into the sand bearing units around the area.

Seasonal variation in the models (traverses 5 and 6) was minimal and therefore strong correlation also exists between the two. Of particular interest is the alignment of the initially isolated contaminants on the pole-dipole section of 2014 clearly shown in the time-lapse inversion (Fig. 7c and d). This signifies lateral migration of the leachates around this area with time. In addition, there is a slight increase in resistivity along the 70–100 m mark and towards the end of the profile, along 300–380 m mark and depth range of 17–66 m in the dry season data. Traverse 6 shows no impact of the migrating contaminants on the area (Fig. 8). The low resistivity zone on the wet and dry season sections around the end of the profile and centre (Fig. 8a and b) may be the result of flowing waste water body around the end of the profile, which may be percolating constantly into the sandy hydrogeologic unit. Seasonal variation along traverse 6 are moderate except for slight reduction in resistivity of underlying sandy rock units across the centre of the profiles with time, unlike the increasing resistivity distribution pattern observed on the previous profiles. Generally, Profiles collected under dry conditions throughout this study illustrate more distinct conductive and resistive regions, whereas the wet periods display a smoother gradient between the conductive and resistive regions. Consistency of the conductive anomalies in both the wet and dry season traverses indicates that these represent actual subsurface conditions rather than random artefacts.

4.2. Physicochemical analysis

The results of the seasonal analysis carried out on the water samples are presented in Tables 1 and 2 below. Concentration of the examined parameters was arranged in tabular form separately to examine the spatial variation in their concentration. The results of each sample were subsequently compared with WHO (2006) standard limit. The mean concentration of TDS around the study area increased from 308.41 mg/l in 2014 to 469.82 mg/l in 2015, with difference of 161.41 (52.34%). TDS exceeded the prescribed Standard limits of 500 mg/l set by WHO (2006) in about 17.6% and 29.4% in wet and dry seasons respectively (Fig. 9). The high concentration of TDS at these points may be an indication of the presence of inorganic salts such as calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulphates which may have been introduced into the water from the contaminants on the

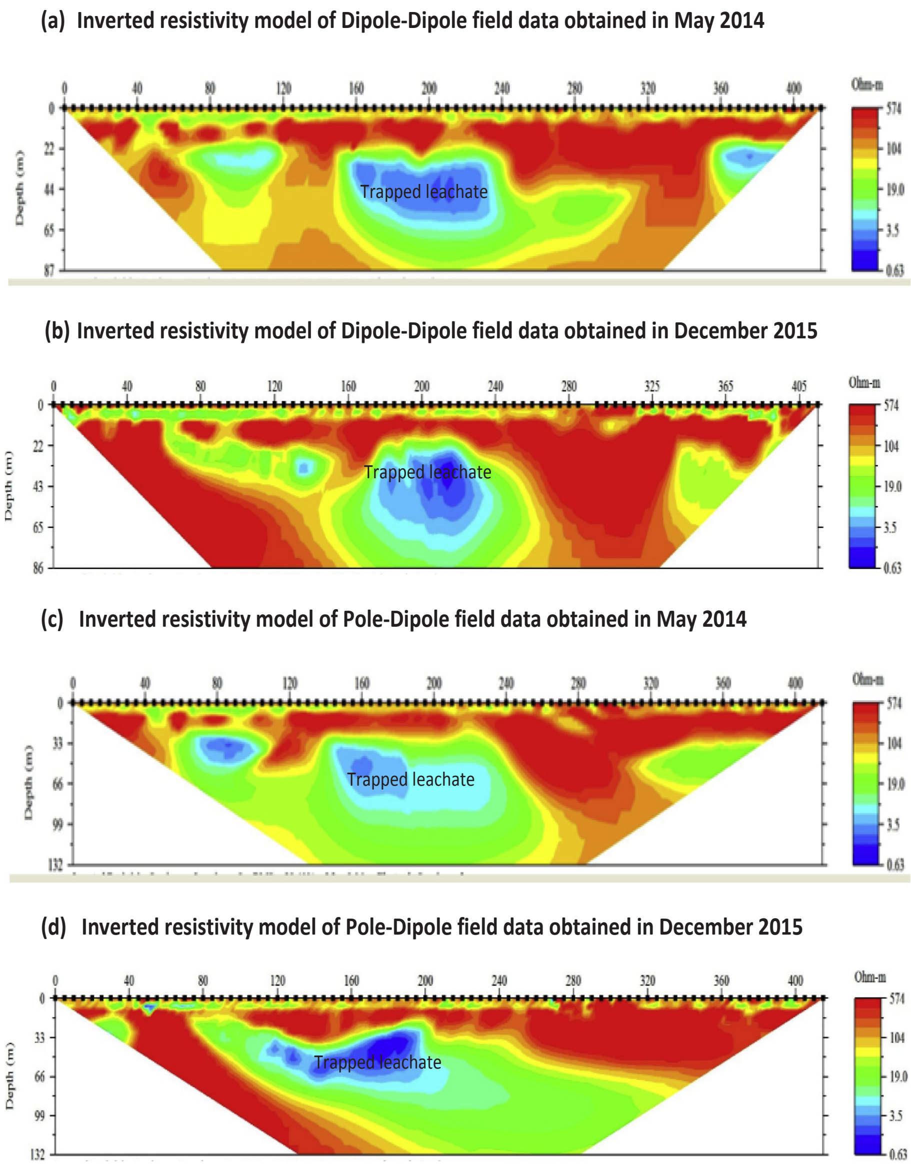

Fig. 7. Resistivity model obtained in May 2014 and December 2015 along traverse 5.

dumpsite. Comparing the wet and dry results, there is generally an increase in concentration of TDS from the dry season study. EC exceeded the standard limit of 1000 μS/cm for drinking water quality in 23.5% of the locations for wet season and about 29.4% in dry season (Fig. 10). The EC concentration shows a strong correlation with the TDS. The results also show a general increase in the EC concentration in the dry season when compared with the wet season results. About 29.4% and 82.4% of the measured pH values were below the minimum requirement in wet and dry seasons respectively. The mean value of pH reduced from 6.01 to 5.36 with interval difference of 0.65 (12.13%), and values ranging from 3.83 to 6.69 in August 2014 and 4.08–7.06 in December 2015. There is 64.7% reduction in pH values obtained around the dumpsite during the dry season study.

Hardness is normally expressed as the total concentration of Ca^{2+} and Mg^{2+} in mg/l, equivalent $CaCO_3$. Hardness ranged from 45 to 167 mg/l in the wet season and 75–367 mg/l in December 2015. Strong linear relationship exists between the observed hardness of water and the TDS and EC concentration from all the locations. About 88.2% and 70.6% of the measured hardness values are below the minimum requirement (150 mg/l) for drinking water in wet and dry seasons respectively. Comparing the wet and dry season results, there is generally an increase in concentration of TDS, EC and hardness values in the dry season study for all the sampled locations. This could be attributed to the dilution effect of rainfall during the wet season. The implication is that the water around the study area has lower quality in the drier season and may be unsafe for human consumption.

Table 2 presents the Seasonal Paired Samples Statistics of Heavy metal contents of water sample obtained around the dumpsite. The WHO permissible level of Chromium (0.05 mg/l) is not exceeded in all the sampled wells in the study area except at BH 8 in 2015, which represents 5.88%. Heavy doses of Chromium salts even though are rapidly eliminated from human body, could corrode the intestinal tract

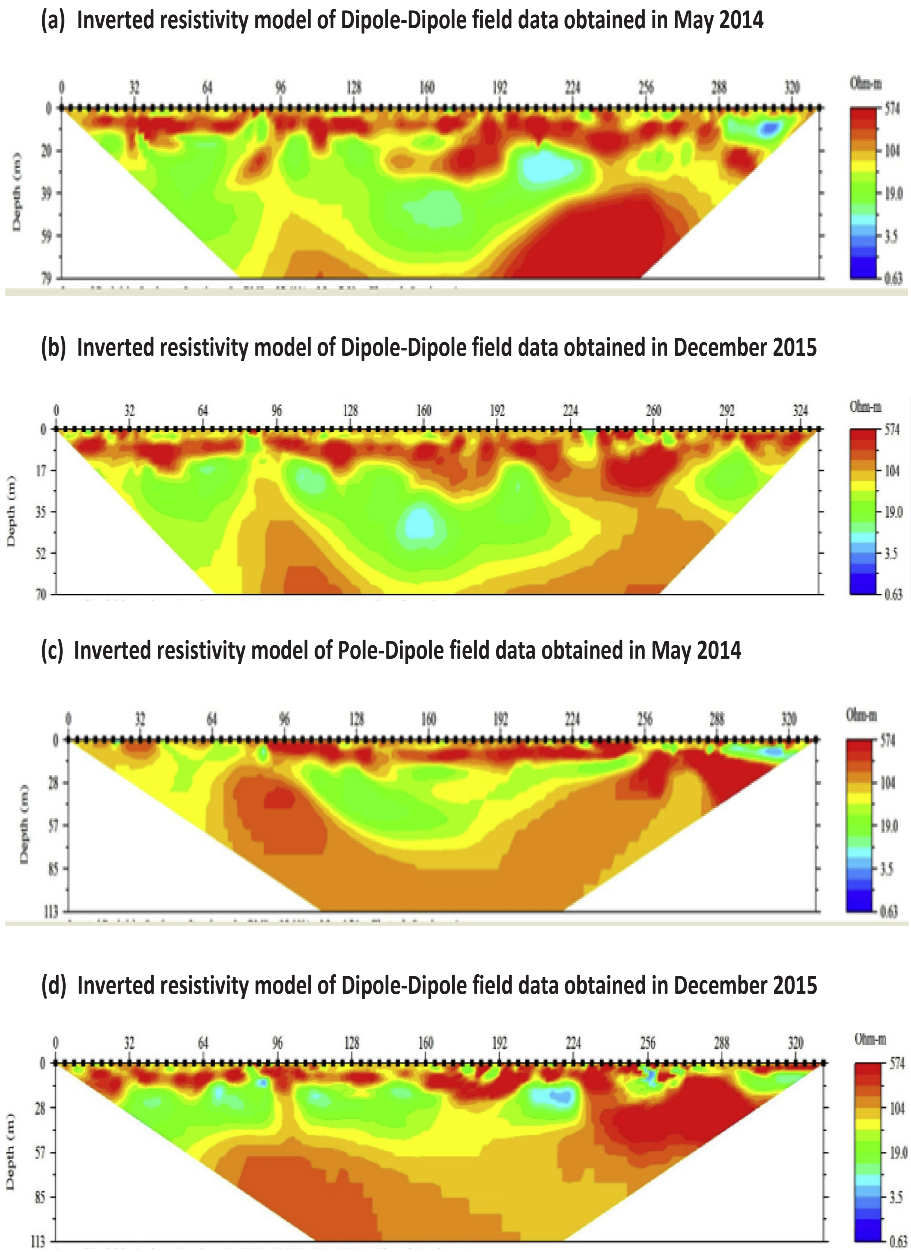

Fig. 8. Resistivity model obtained in May 2014 and December 2015 along traverse 6.

(WHO, 2004). There is 64.7% increase in Cr concentration from the dry season results when compared with the wet season. The concentration of Lead did not exceed the WHO permissible limit (0.01 mg/l) in all the sampled wells except at locations W 1, BH 2, W 13, W 14, W 15 and W17 in 2014 (35.3%) and also minimal at BH 6, BH 7, BH9 and W 10 in 2015 (23.5%). The high concentration of lead detected in the groundwater samples (catchment area) may have originated from used batteries and other lead bearing wastes deposited on the dumpsite. The WHO permissible level of Copper (0.5 mg/l) was not exceeded for all samples at the dumpsite except at BH 9 in 2014 (about 5.88%) but was exceeded at locations BH 2, BH4, BH 8, BH 9, and BH 11 in 2015 which is about 29.4% of the sampled locations. The WHO permissible level of Iron (0.3 mg/l) was exceeded in all the sampled borehole water around the study area in the wet season while in the dry season, the permissible limit was not exceeded at locations BH 4, BH 5, W 10, BH 11 and W 12 i.e. about 29.4% of the locations (Fig. 11). Presence of Fe in water can lead to change of colour of groundwater (Rowe et al., 1995). The study further supports the report of high Fe concentrations in groundwater in Nigeria (WHO; UNICEF, 2006). The Fe concentration generally decreased in the dry season. The WHO permissible limit for Manganese (0.5 mg/l) is exceeded in all the borehole samples in the study area except at locations BH 5, BH 8, BH 9, and BH 11 from the wet season

Table 1
Seasonal variation of groundwater hydrophysical parameters around Olushosun landfill ——— August 2014 results (Wet Season) ——— December 2015 results (Dry Season).

Sample	Location	Coordinate	pH	Temp (°C)	EC (µS/cm)	TDS (ppm/mg/l)	Hardness (mg/l)
W 1	Mashalachi street	06° 35′ 27.69″N 003° 22′ 19.48″E	6.52	27.4	1024	496	125.0
			6.71	30.7	1079	539	200.0
BH 2	Anisere Close	06° 35′ 23.13″N 003° 22′ 21.75″E	6.96	26.4	147	73	65.0
			6.67	30.7	575	257	80.0
BH 3	Kudirat Abiola Way	06° 35′ 23.86″N 003° 22′ 30.67″E	6.21	27.3	1950	992	145.0
			7.06	30.6	4043	2021	246.0
BH 4	Ayinde Street	06° 35′ 26.12″N 003° 23′ 26.79″E	6.79	27.0	139	48	70.0
			6.46	30.7	1158	579	160.0
BH 5	Niyi Ogunleye Street	06° 35′ 19.26″N 003° 23′ 24.76″E	6.83	27.4	137	50	90.0
			6.14	30.4	646	321	95.0
BH 6	By Chinese Village	06° 35′ 17.74″N 003° 23′ 18.73″E	6.81	26.2	325	161	60.0
			6.10	30.8	634	319	95.0
BH 7	By Jehovah Witness	06° 35′ 59.49″N 003° 22′ 54.21″E	6.85	26.7	117	40	60.0
			4.08	30.4	727	361	100.0
BH 8	Ikosi Street	06° 36′ 08.46″N 003° 22′ 56.23″E	3.83	28.1	607	304	75.0
			4.49	30.6	219	110	75.0
BH 9	Ogunmoyo Street	06° 36′ 08.39″N 003° 22′ 47.71″E	6.67	28.0	140	75	80.0
			4.29	30.3	521	257	125.0
W 10	Adeniyi Street	06° 36′ 04.19″N 003° 22′ 04.16″E	4.02	27.1	397	193	45.0
			4.45	30.5	306	154	105.0
BH 11	Bankole Street	06° 36′ 07.44″N 003° 21′ 58.17″E	4.00	26.9	790	325	95.0
			5.76	30.6	107	53	75.0
W 12	Bankole Street	06° 36′ 05.23″N 003° 21′ 53.09″E	4.31	27.8	366	187	70.0
			4.61	30.4	353	176	85.0
W 13	Ikosi High School	06° 35′ 56.92″N	6.21	28	160	83	68
		003° 22′ 47.30″E	4.67	28.5	178	90	75
W 14	Anglican Church	06° 35′ 58.11″N	6.77	27.0	127	56	64
		003° 22′ 45.44″E	5.42	28.0	170	80	80.0
W 15	Supreme Road	06° 35′ 42.03″N	5.84	29.3	482	222	82
		003° 22′ 23.20″E	4.80	30.0	400	220	98
W 16	Ojota Motor Park	06° 35′ 31.47″N	6.79	32.4	2589	1200	167
		003° 22′ 50.05″E	4.21	30.7	3200	1500	367
W 17	Agofure Motors	06° 35′ 27.95″N	6.83	33.6	1437	738	156
		003° 22′ 48.84″E	5.20	31.7	1734	950	256
Mean			6.01		643.18	308.41	89.23
			5.36		944.12	469.82	136.29
Range			3.83–6.69		117–2589	40–1200	45–167
			4.08–7.06		107–4043	53–2021	75–367
St. Dev.			1.17		722.1	350.94	36.53
			1.00		1100.9	542.56	83.57
Coef. Of Variation (%)			19.47		112.3	92.25	40.93
			18.65		116.6	115.5	61.31
	WHO/SON Standard		6.5–8.5	–	1000	500	150

Note: BH = Borehole, W = Well.

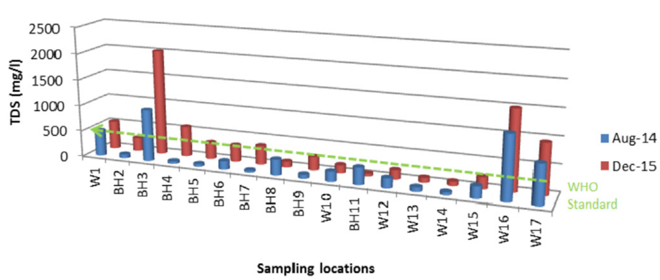

Fig. 9. Seasonal variations in TDS concentration of water sample versus WHO standard around the Olushosun dumpsite.

results while the dry season samples show that Mn concentration was exceeded at W 1, W 15 and W 16 locations i.e. about 17.65% (Fig. 12).

Concentrations of Manganese in excess of 0.2 mg/l make water distasteful to drinking with no specific toxic effects (Longe and Enekwechi, 2007). The measured SO_4 ion exceeded the prescribed standard limits of (200 mg/l) set by WHO (2007) in about 17.65% (BH 3, BH 6, W 12 and W 16) and 11.76% (BH 3 and BH 5) in dry and wet seasons, while NO_3 values in the wet season are all below the minimum requirement (10 mg/l) set by WHO. About 58.8% (BH 6, BH 7, BH 8, BH 9, W 10, W 13, W 15, W 16 and W 17) of NO_3 values in the dry season however exceeded the WHO minimum standard.

Comparing the wet and dry season results, there is generally an increase in concentration of TDS and EC in the dry season study around the dumpsite and a corresponding increase in the mean concentration of pH, Ca, Mg, hardness, Cu, Cr, NO_3, SO_4 and Na from the dry season results. Also, there is reduction in the mean concentration of Fe, Zn, Mn, PO_4, Cl, and Ni in the dry season when compared with the wet season analysis. This is partly because heavy metals have tendency and capability of depleting with time compared to physicochemical parameters. Also, the increased trend in the dry season period could be attributed to the increase in concentration of the dissolved metals due to evaporation, and on the other hand, dilution effect of the rainfall during the wet season.

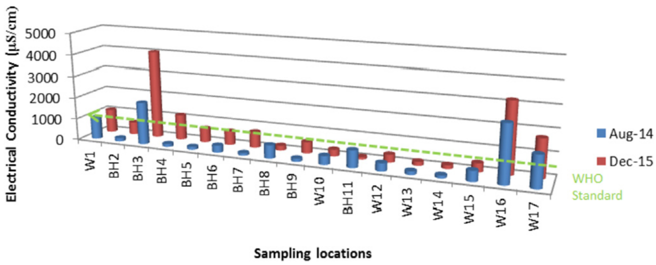

Fig. 10. Seasonal variations in EC concentration of water samples versus WHO standard around the Olushosun dumpsite.

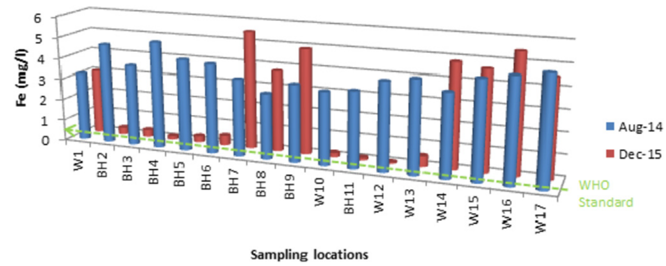

Fig. 11. Seasonal variations in Fe concentration of water sample versus WHO standard around the Olushosun dumpsite.

Data from about eight equally spread hand dug well locations around the dumpsite were selected and used in constructing water table contour lines of equal head in meters above sea level as shown in Fig. 13. The water elevation contour for this area revealed that groundwater and contaminant flow direction is mainly towards the South-eastern part of the region. This was validated from the results of water sample analyses conducted from the zone. Generally, the quality of water obtained from the southern part of the area is unsafe for consumption when compared with other parts of the study area.

5. Conclusion

The results of the time-lapse ERT imaging was able to delineate contaminants and track their depth of distribution on the dumpsite. The results show clear evidence of lateral and vertical migration of contaminants into the subsurface environment, with contaminated depth increasing from about 106 m in 2014 to about 120 m in 2015. Comparing the wet and dry season results from the water sample analysis, there is generally an increase in concentration of TDS, EC and

Table 2
Seasonal Paired Samples Statistics of Heavy metal contents of water sample obtained around the Olushosun dumpsite ▬▬ August 2014 results (Wet Season) ▬▬ December 2015 results (Dry Season).

Samples	Fe (mg/l)	Zn (mg/l)	Mn (mg/l)	Cu (mg/l)	Pb (mg/l)	Ni (mg/l)	Cr (mg/l)
W 1	3.22	1.30	1.01	0.42	0.08	0.02	0.04
	3.06	2.40	0.89	0.29	0.02	ND	0.12
BH 2	4.71	1.20	0.81	0.42	0.04	0.01	0.02
	0.32	1.90	0.25	0.62	0.03	ND	0.04
BH 3	3.81	1.01	0.70	0.40	0.01	0.02	0.03
	0.34	1.20	0.41	0.34	0.03	ND	0.04
BH 4	5.01	1.10	0.92	0.41	0.01	0.02	0.03
	0.16	1.42	0.43	0.52	0.02	0.002	0.04
BH 5	4.30	1.06	0.31	0.44	0.01	0.02	0.02
	0.30	1.30	0.22	0.28	0.02	0.006	0.04
BH 6	4.20	1.91	0.67	0.40	0.01	0.03	0.02
	0.46	1.67	0.42	0.44	0.007	0.01	0.04
BH 7	3.61	1.20	0.70	0.30	0.01	0.02	0.02
	5.52	2.42	0.09	0.29	0.005	0.008	0.01
BH 8	3.06	1.22	0.21	0.39	0.01	0.03	0.03
	3.80	2.70	0.09	0.53	0.013	0.002	0.07
BH 9	3.60	1.25	0.44	0.51	0.01	0.01	0.03
	4.92	2.04	0.03	0.51	0.007	0.01	0.02
W 10	3.40	1.03	0.57	0.34	ND	0.02	0.02
	0.20	2.13	0.09	0.34	0.01	ND	0.02
BH 11	3.55	1.20	0.50	0.27	ND	0.01	0.02
	0.12	2.67	0.07	0.55	0.03	ND	0.03
W 12	4.10	2.11	0.512	0.26	0.01	0.02	0.03
	0.06	2.55	0.043	0.43	0.02	ND	0.02
W 13	4.31	1.25	0.55	0.34	0.02	0.01	0.03
	0.50	2.02	0.21	0.47	0.03	0.01	0.03
W 14	3.85	2.01	0.63	0.40	0.04	0.02	0.02
	4.85	2.04	0.34	0.44	0.03	ND	0.04
W 15	4.55	1.34	1.05	0.45	0.05	0.02	0.03
	4.65	1.31	1.35	0.25	0.04	0.01	0.04
W 16	4.78	1.30	0.82	0.39	0.01	0.03	0.04
	5.51	2.00	0.98	0.40	0.03	0.02	0.03
W 17	5.00	1.38	0.56	0.38	0.02	0.01	0.02
	4.54	2.05	0.08	0.40	0.03	0.01	0.03
Mean	4.06	1.35	0.64	0.38	0.023	0.02	0.03
	2.31	1.99	0.35	0.42	0.022	0.009	0.038
Range	3.06–5.01	1.01–2.11	0.21–1.05	0.26–0.51	0.01–0.08	0.01–0.03	0.02–0.04
	0.06–5.52	1.2–2.7	0.03–1.35	0.25–0.62	.005–0.04	.002–0.02	0.01–0.12
St. Dev.	0.61	0.34	0.23	0.07	0.021	0.007	0.007
	2.29	0.48	0.38	0.12	0.01	0.005	0.025
Coef. Of Variation (%)	15.02	25.18	35.94	18.42	91.3	35	23.33
	99.13	24.1	108.57	28.57	45.45	55.5	65.78
WHO/SON Standard	0.3	5.0	0.5	0.5	0.01	0.02	0.05

Note: BH = Borehole, W = Well, ND = Not Detected.

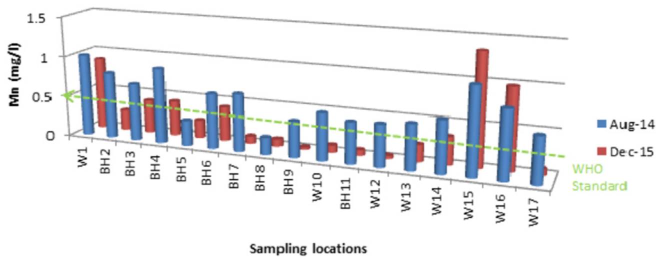

Fig. 12. Seasonal variations in Mn concentration of water sample versus WHO standard around the Olushosun dumpsite.

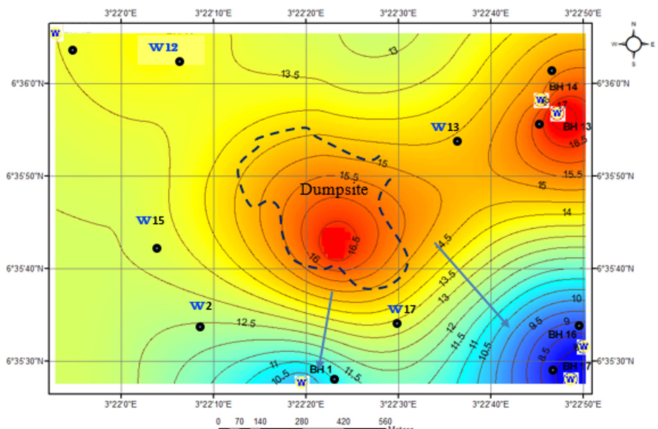

Fig. 13. Contour Map of Olushosun dumpsite showing Groundwater flow direction.

hardness values, and a corresponding increase in the mean concentration of pH, Ca, Mg, hardness, Cu, Cr, NO_3, SO_4 and Na from the dry season results. Also, there is reduction in the mean concentration of Fe, Zn, Mn, PO_4, Cl, and Ni in the dry season when compared with the wet season analysis. This trend could be attributed to the dilution effect of rainfall during the wet season. The implication is that the water around the study area has lower quality in the drier season and may be unsafe for consumption. The results also showed strong correlation between the ERT results and the physicochemical parameters of groundwater quality measured viz-a-viz the contamination status of the Olushosun dumpsite. The constant migration of leachates around the dumpsite calls for worry. Therefore, a well thought out monitoring programs and environmental remediation process should be put in place by the concerned agencies of Government to constantly gather real time information about the movement, behaviour and interactions of the leachate materials with the subsurface environment, particularly the groundwater aquifer where many inhabitants around the dumpsite tap their water from.

Acknowledgment

The authors acknowledge the funding support offered by Covenant University (CUCRID/CSG/16/02/64-FS) for the project and also to Lagos State Waste Management Authority (LAWMA) for the permission to work on their dumpsite.

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