Archives of Current Research International

5(4): 1-11, 2016, Article no.ACRI.29577

ISSN: 2454-7077

SCIENCEDOMAIN *international*

www.sciencedomain.org

Resistivity Contouring and Plume Mapping of Municipal Solid Waste Landfills Leachate in Warri Metropolis Using Electrical Resistivity Method

Mamuyovwi Odia[1], Ify L. Nwaogazie[1*], Gregory O. Avwiri[2] and Eunice O. Nwachukwu[3]

[1]Centre for Occupational Health, Safety and Environment, University of Port Harcourt, Nigeria.
[2]Department of Physics, University of Port Harcourt, Nigeria.
[3]Department of Plant Science and Biotechnology, University of Port Harcourt, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. Authors ILN, GOA and EON supervised the PhD project. Author ILN contributed to the design of the project on data analysis approach. Authors GOA and EON guided the literature survey. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/ACRI/2016/29577

Editor(s):
(1) Amal Hegazi Ahmed Elrefaei, Division of Radioisotope Production, Hot Lab and Waste Management Center, Atomic Energy Authority, Egypt.

Reviewers:
(1) Bakkali Saad, University Abdelmalek Essaadi, Morocco.
(2) Nordiana Mohd Muztaza, Universiti Sains Malaysia (USM), Penang, Malaysia.

Complete Peer review History: http://www.sciencedomain.org/review-history/16546

Original Research Article

Received 18th September 2016
Accepted 4th October 2016
Published 14th October 2016

ABSTRACT

Electrical resistivity method was used to study the movement of municipal solid waste landfills leachate of Niger-Cat, Donparkar and Orhuwhorun dump sites in Warri Metropolis, Southern Nigeria. Both Electrical Resistivity Profiling and Vertical Electrical Sounding (VES) were carried out using Schlumberger array configuration. Surfer 10 and ArcGIS 10.3 software packages were used to interpret resistivity profiling data to produce apparent resistivity contour maps of study sites while IPI2Win software package was used to interpret VES data. This computer program automatically generated model curves using initial layer parameters (resistivity and thickness) derived from partial curve matching of the field curves with standard curves, and calculated the true layer parameters of the geo-electric section. The results revealed that at Niger-Cat dump site, leachate had migrated from dump into surrounding soil and contamination had advanced up to a depth of 19.12m which is within the local groundwater system of the area. At Don-Parkar dump site, results

**Corresponding author: Email: ifynwaogazie@yahoo.com;*

showed leachate migration from around the edges of dump site into surrounding soil and contamination had advanced to a depth exceeding 20.7m. At Orhuwhorun dump site, result of resistivity contour map showed leachate migration on the south of the dump; however VES results showed no contamination; thus groundwater in the vicinity is currently safe.

Keywords: Resistivity; vertical electrical sounding (VES); mapping; landfill leachate; groundwater contamination.

1. INTRODUCTION

The disposal of solid waste in landfills has always resulted in serious environmental problems. Landfilling remains the cheapest and one of the most widely practiced method for the disposal of Municipal Solid Waste (MSW) in both developed and developing nations [1,2]. This method of waste disposal has been identified as a major threat to soil, surface water and groundwater resources not only in developing nations [3] but throughout the world [4]. A large volume of MSW generated in Nigeria is directly discarded on land and non-sanitary landfills in an unengineered manner at the detriment of the environment.

The contamination of drinking water by dump site related activities in developing countries has been reported in literature [5-9]. Out of the global available freshwater, more than 98% is groundwater stored in pores and fractures of rock strata [10,11]. The safety of groundwater is being threatened by the indiscriminate dumping of unsorted and untreated waste materials into landfills and open spaces in the ground.

Warri is a major commercial city in Delta State and an oil rich town, home to various multinational oil and gas industries and which has resulted in the generation of both industrial and domestic wastes which are poorly managed at present. Existing landfills in Warri are simply dump sites which also include the study sites. The dump sites lack any form of bottom liners, leachate collection or leachate treatment system. Areas of close proximity to these landfills are more vulnerable to groundwater contamination because of the pollution potential of leachate emanating from these dump sites. The impact of landfill leachate on soil, surface and groundwater has given rise to a number of studies in recent years [12].

Leachate generated during the decomposition of municipal solid waste is generally associated with high ion concentrations and hence very low resistivity [13]. This makes electrical resistivity method adequate for delineating leachate plume around landfills [14]. Electrical resistivity prospecting has been widely discussed in literature [15,16,17]. Various works relating to soil and groundwater contamination have been carried out by various investigators [18-29].

The study is aimed at the surface resistivity of the dump sites with respect to leachate contamination and to delineate the depth of leachate plume.

2. METHODOLOGY

The methodology covers the description of the study area, data collection in three dumpsite locations and data analyses. Data collection covers profiling and Vertical Electrical Sounding, while data analyses involved the application of resistivity software packages. The details are as presented in the Sub-sections.

2.1 Study Area

Warri is located within the Niger Delta in the southern portion of Nigeria. It lies within Latitude 5°32'N to 5°40'N and Longitude 5°42'E to 5°50'E covering an area of about 499.81 km^2. Warri is located on northern bank of Warri River about 48 km upstream from the port of Forcados on the Bight of Benin. It comprises of several communities including Warri, Effurun to the North, Ekpan to the West, Aladja to the East and the Bight of Benin to the Southwest.

2.1.1 Geology of the area

Warri metropolis lies between the Quaternary and Tertiary formations of the Niger Delta, consisting mainly of three main geologic formations, which are: the Benin, Agbada and Akata Formation respectively. The geology of the Niger Delta has been described by various authors [30,31,32].

2.1.2 Benin formation

The Benin Formation is the top most layer (Oligocene –Recent), which extends its limit from west to east side across the entire Niger Delta area and Southwards beyond the present coastline. The formation is composed of 90% sandstone with shale intercalations; its thickness is variable but generally exceeds 1800m.

2.1.3 Agbada formation

The Agbada Formation underlies the Benin Formation and consists of sandstone and shale. It consists of an upper predominantly sandy unit with minor shale intercalations and lower shale unit, which is thicker than the upper one. The age range is Oligocene to Recent.

2.1.4 Akata formation

The Akata Formation (Eocene – Recent), a basal unit is over 1200m thick, consisting of discontinuous/undulating clay unit of marine shale. Overlying these three sequences within the Niger Delta are various Quaternary deposits. The Quaternary deposits (40 – 150m thick) generally consist of rapidly alternating sequences of sand and silt/clay, with the latter becoming increasingly more prominent seawards.

Fig. 1 presents the Google map of the study area with the three dump sites located by yellow pins. The first is Niger-Cat waste dump site that lies within 5°34'31.72"N and 5°44'53.41"E along the NPA Expressway, Ekpan, Uvwie LGA of Warri (see Fig. 2). It was constructed in 2005 and still functional to date, with area approximately 36,007.49m^2. The second is Don-Parkar waste dump site that lies within coordinates 5°40'50.24"N and 5°45'17.61"E along Warri-Sapele Expressway, Okuovo, Okpe LGA (see Fig. 3). It was constructed in 2010, with area of an approximately 7,516.98m^2. Thirdly, Orhuwhorun waste dump site located within the coordinates 5°30'59.40"N and longitude 5°50'52.38"E along Warri-Ajaokuta Rail line, Orhuwhorun, Ughelli South LGA (see Fig. 4). It was constructed in 2010.

2.2 Data Collection

The methods employed in investigation of leachate plume contamination of the groundwater and soil around the dump sites is resistivity profiling (Constant Separation Traversing, CST) and Vertical Electrical Sounding (VES). Both resistivity profiling and VES were carried out using the Schlumberger array configuration method. An ABEM Terra meter SAS 1000 was used to measure the variation in the electrical resistivity. The electrical resistivity method involves injecting current into subsurface of the dump site through a pair of current electrode AB and measuring the potential difference through another pair of potential electrode MN. For each resistivity station in which measurement was made a reading of resistance, R of the volume of earth material within the electrical space of the electrode configuration was obtained. The apparent resistivity was obtained from the product of resistance, R and the geometric factor, K for adopted electrode configuration.

Fig. 1. Map of Warri showing locations of the study sites

Fig. 2. Satellite image of Niger-Cat dump site with profile lines and VES locations

Fig. 3. Satellite image of Don-Parkar dump site with profile lines and VES locations

2.2.1 Niger-Cat dump site

Three resistivity profiles (T1-T3) were run with constant electrode spacing AB of 40m and electrode spacing MN of 6m at a constant depth of 20m. Traverse, T1 was located 10m away from the dump site along the eastern section over a distance of 340m. Traverse, T2 was located 10m away from the dump along the western section over a distance of 200m parallel to Traverse, T1. Traverse, T3 was located 50m away from the dump which was within the residential area along the north over a distance of 160m. Traverse, T3 served as control (see Fig. 2).

Two VES (1 and 2) were also carried out on the dump site with a maximum of 50% AB distance (50m) and MN distance (3m). VES 1 was located 10m away on the mid-eastern section of the dump. VES 2 was located 50m away within residential area on the north of the dump. VES 2 also served as control (see Fig. 2).

Fig. 4. Satellite Image of Orhuwhorun dump site with profile lines and VES locations

2.2.2 Don-Parkar dump site

Four resistivity profiles (T1-T4) were run with constant electrode spacing AB of 40m and electrode spacing MN of 6m at a constant depth of 20m. Traverse, T1 was located 10m away from dump site along the north over a distance of 180m. Traverse, T2 was located 10m away from dump site along the western section perpendicular to Traverse, T1 along Benin-Sapele-Warri Expressway over a distance of 140m. Traverse, T3 was located 20m away from dump site along the south over a distance of 140m. Traverse, T4 which served as control was located in close proximity with residential area about 254m from the dump in south-west direction over a distance of 100m (see Fig. 3).

Three VES (1 – 3) were also carried out on the dump site with a maximum of 50% AB distance (50m) and MN distance (3m). VES 1 was located 10m away on the north of dump site. VES 2 was located 10m away on the mid-western section of the dump. VES 3 which was located along the same Traverse 4 served as control (see Fig. 3).

2.2.3 Orhuwhorun dump site

Four resistivity profiles (T1 – T4) were run with constant electrode spacing AB of 40m and electrode spacing MN of 6m at a constant depth of 20m. Traverse, T1 was located 5m away from the dump site along the south over a distance of 40m. Traverse, T2 was located 5m away from dump site along the eastern section perpendicular to Traverse, T1 over a distance of 280m. Traverse, T3 was located 20m away from dump site on north-west over a distance of 60m. Traverse, T4 was located about 15m away from Traverse, T3 over a distance of 80m. Traverse, T4 served as control (see Fig. 4).

Two VES (1 – 2) were also carried out on the dump site with a maximum of 50% AB distance (50m) and MN distance (3m).VES 1 was located 5m away from dump site on the mid-eastern section. VES 2 which served as control was located 35m away from dump, mid-point of Traverse, T4 (see Fig. 4).

2.3 Data Analysis

The procedure adopted in processing profiling data was computer based using SURFER 10 resistivity software and ArcGIS 10.3 software packages. The VES data analysis was computer based using IPI2Win resistivity software package.

3. RESULTS AND DISCUSSION

3.1 Results

The profiling data were processed using SURFER 10 resistivity software to produce the apparent resistivity contour maps using the Kriging method. ArcGIS 10.3 was also employed to interpret and plot various surfaces and profiles. The profile data are presented as resistivity contour map (Figs. 5 - 7). The VES data were analysed using IPI2Win resistivity software. The apparent resistivity values obtained were plotted against the spacing (AB/2) on a log-log paper on the IPI2Win software. This computer program automatically generates model curves using initial layer parameters (resistivity and thickness) derived from curve matching of the field curves with standard curves, and calculates the true layer parameters of the geo-electric section. The results are presented in terms of the resistivity, thicknesses and depths of the geo-electric section (Tables 1-3). From the analysis of the field data, Figs. 5-7 present results of Apparent Resistivity Contour map of study area while Tables 1-3 show results of Layer Parameters of the Geo-Electric Sections of the study area. Fig. 5 presents apparent resistivity contour map results from the resistivity profiling investigation of Niger-Cat dump site.

The layer parameters of the geo-electric section results from VES investigation of Niger-Cat dump site are as presented in Table 1.

Fig. 6 presents apparent resistivity contour map results from the Resistivity profiling investigation of Don-Parkar dump site.

The layer parameters of the geo-electric section results from VES investigation of Don-Parkar dump site are as presented in Table 2.

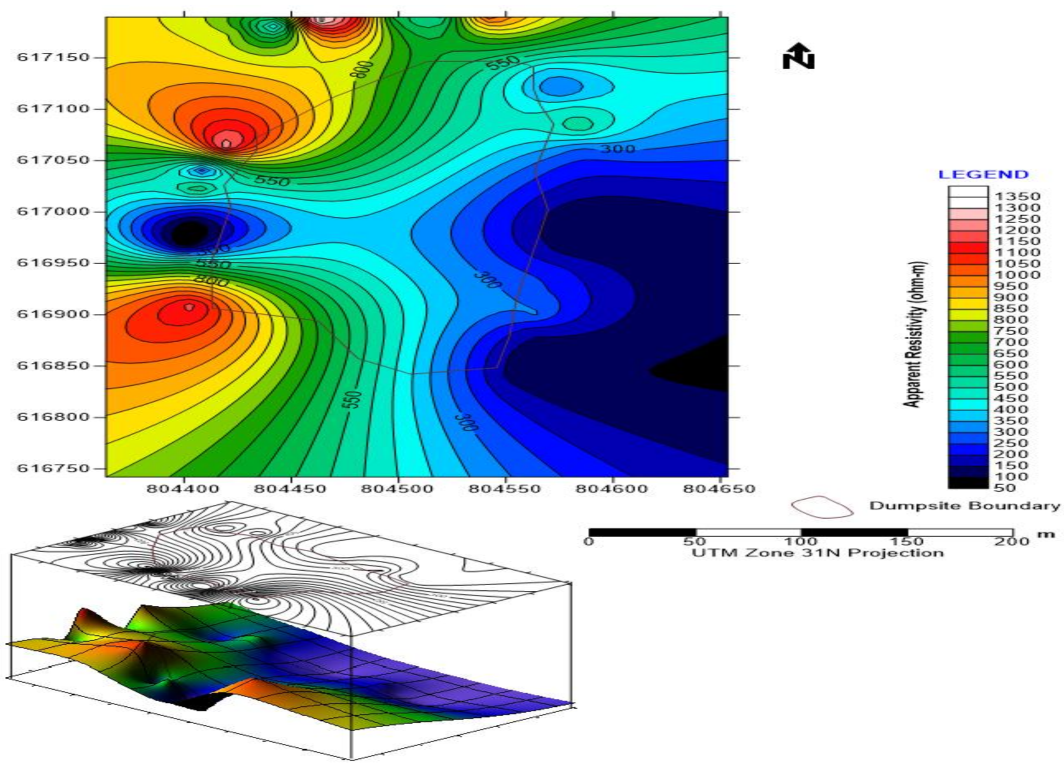

Fig. 5. Apparent resistivity of 2-D and 3-D contour map of Niger-Cat dump site

Table 1. Layer parameters of the geo-electric section for Niger-Cat dump site (VES 1 and 2)

Niger-Cat	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Interpretation
VES 1	1	42.4	2.22	2.22	Topsoil
	2	109.7	12.1	14.32	Contaminant leachate sand
	3	138.6	4.80	19.12	Contaminant leachate sand
	4	197.1	-	-	Contaminant leachate sand
VES 2	1	1604.0	1.98	1.98	Topsoil
	2	659.9	11.09	13.07	Leachate-free sand
	3	567.2	9.55	22.62	Leachate-free sand
	4	1129.0	-	-	Leachate-free sand

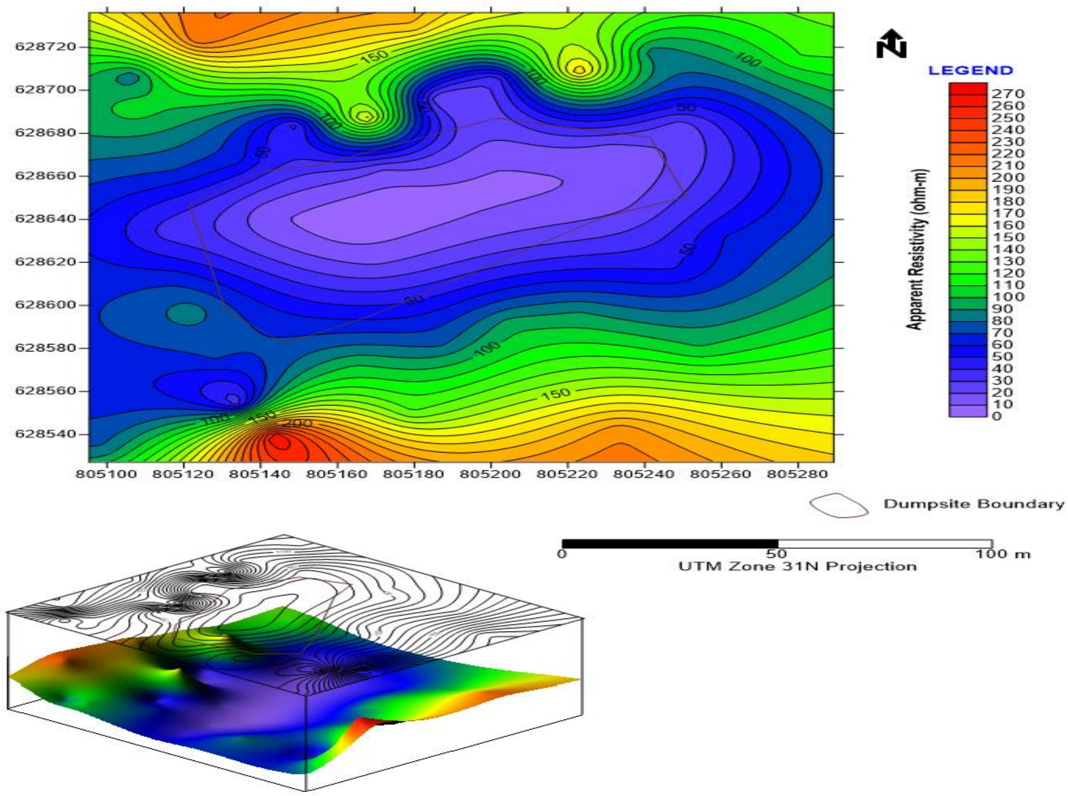

Fig. 6. Apparent resistivity of 2-D and 3-D contour map of Don-Parkar dump site

Fig. 7 presents apparent resistivity contour map results from the Resistivity profiling investigation of Orhuwhorun dump site.

The layer parameters of the geo-electric section results from VES investigation of Orhuwhorun dump site are as presented in Table 3.

3.2 Discussion

3.2.1 Niger-Cat dump site

The resistivity contour map (Fig. 5) of Niger-Cat dump site showed contour interval of 50Ωm. Two distinctive zones were mapped out, these are zones of high resistivity (200Ωm to 1250Ωm) along the north, north-west and south-west and low resistivity (<200Ωm) isolated mid-western section, south-east and along the eastern section (Fig. 5). These high resistivity zones are indicative of absence of leachate while zones of very low resistivity are indicative of presence of high conductivity leachate. These zones are interpreted as zones of high contaminant leachate plume; these zones were further subjected to VES investigation.

The results of VES 1 and 2 (Table 1) show a four layer geo-electric sections each. The first layer is topsoil with thickness ranging from 1.98m to 2.22m and resistivity of 42.4Ωm to 1604.0Ωm at depth varying1.98m to 2.22m for VES 1 and VES 2 respectively. These layers of very low resistivity for VES 1 and very high resistivity for VES 2 at shallow depth were interpreted to be the same low and high delineated in the apparent resistivity contour map (Fig. 4). Underlying the topsoil is the second layer of leachate contaminant sand to leachate-free sand with thickness ranging from 11.09m to 12.1m and resistivity of 109.7Ωm to 659.9Ωm at depths of 13.07m to 14.32m for VES 1 and VES 2, respectively.

The third layer of VES 1 has a thickness of 4.80m and resistivity of 138.6Ωm at depth 19.12m while the fourth layer has a resistivity of 197.1Ωm. The fourth layer cannot be exempted from leachate because it underlies a layer of leachate contaminant sand. The third layer of VES 2 has a thickness of 9.55m with resistivity of 567.2Ωm at depth 22.62m while the fourth layer has a resistivity of 1129.0Ωm. The high resistivity at VES 2 indicates the absence of migrated leachate at a distance of 50m away from dump to the north while the low resistivity at VES 1 implied the presence of high contaminant leachate to a depth exceeding 19.12m which is well within the local groundwater system in the area. The results of the resistivity profiling and VES showed that the surrounding soil and groundwater within Niger-Cat dump site may have been contaminated, and leachate had advanced beyond the edge of the dump site.

3.2.2 Don-Parkar dump site

The resistivity contour map (Fig. 6) of Don-Parkar dump site showed contour interval of 10Ωm. Zones of very low resistivity (<190Ωm) were mapped around the dump. These zones were interpreted as zones of contaminant leachate. Resistivity values increased away from dump site which indicates absence of leachate materials in those zones.

Table 2. Layer parameters of the geo-electric section for Don-Parkar dump site (VES 1, 2 and 3)

Don-Parkar	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Interpretation
VES 1	1	556.0	1.07	1.07	Topsoil
	2	16.0	7.55	8.62	Contaminant leachate sand
	3	84.3	12.10	20.70	Contaminant leachate sand
	4	23.0	-	-	Contaminant leachate sand
VES 2	1	87.2	1.22	1.22	Topsoil
	2	70.3	1.32	2.55	Contaminant leachate sand
	3	181.5	5.72	8.27	Contaminant leachate sand
	4	31.92	-	-	Contaminant leachate sand
VES 3	1	2155.0	1.19	1.19	Topsoil
	2	116.6	4.56	5.78	Leachate-free sand
	3	548.4	20.15	25.93	Leachate-free sand
	4	356.4	-	-	Leachate-free sand

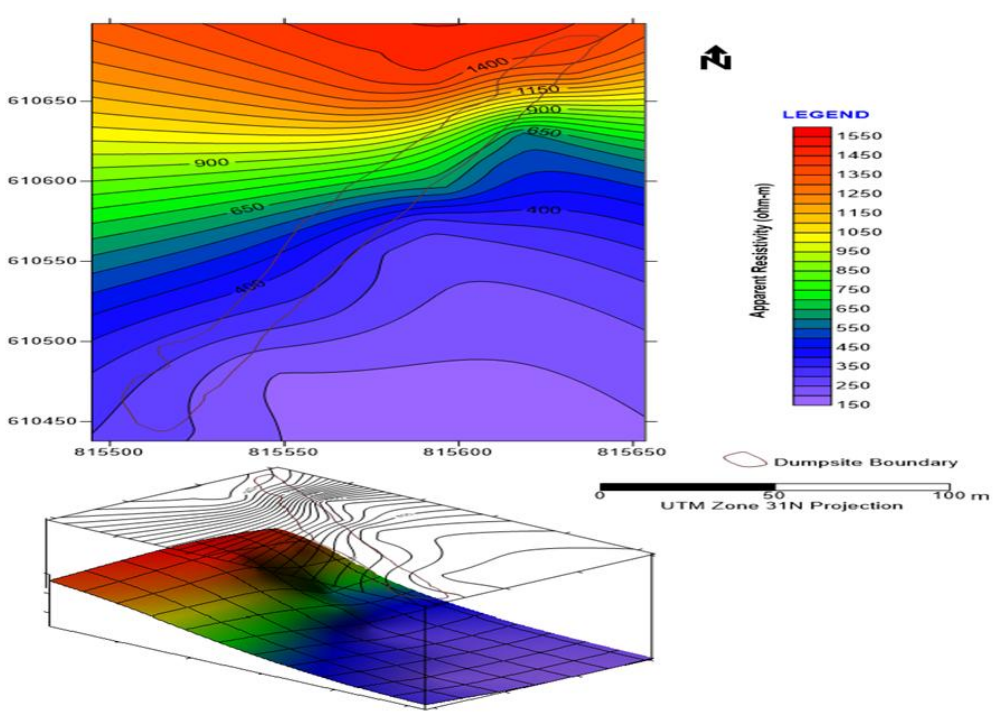

Fig. 7. Apparent resistivity of 2-D and 3-D contour map of Orhuwhorun dump site

Table 3. Layer parameters of the geo-electric section for Orhuwhorun dump site (VES 1 and 2)

Orhuwhorun	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Interpretation
VES 1	1	1084.0	1.01	1.01	Topsoil
	2	1281.0	1.00	2.01	Leachate-free sand
	3	303.6	18.67	20.68	Leachate-free sand
	4	610.5	-	-	Leachate-free sand
VES 2	1	1498.0	1.58	1.58	Topsoil
	2	868.5	4.55	6.13	Leachate-free sand
	3	1460.0	7.74	13.86	Leachate-free sand
	4	3661.0	-	-	Leachate-free sand

The results of VES 1 and 2 (Table 2) showed four layer geo-electric sections each. The first layer revealed topsoil, having thickness ranging from 1.07m to 1.22m and resistivity of 87.2Ωm to 556.0Ωm at depths of 1.07m to 1.22m for VES 1 and VES 2, respectively. The high resistivity of 556Ωm at VES 1 is explained by the presence of lateritic topsoil. The second layer revealed leachate contaminated sand with thickness ranging from 1.32m to 7.55m and resistivity of 16.0Ωm and 70Ωm at depth of 8.62m and 2.55m for VES 1 and VES 2, respectively. The third layer of VES 1 showed low resistivity of 84.3 at depths of 20.70m and the fourth layer has a low resistivity of 23.0Ωm; this indicates presence of leachate. The third layer, VES 2 has a resistivity of 181.5Ωm at depth 8.27m. This zone cannot be exempted from leachate presence because it is underlying a zone of low resistivity and below this layer is the fourth layer with low resistivity of 31.92Ωm. VES 3 shows four layer geo-electric sections. The first layer showed topsoil-lateritic with very high resistivity of 2155Ωm and thickness of 1.19m at depth of 1.19m. The second layer showed resistivity of 116.6Ωm with a thickness of 4.585 at depth 5.776m. The third showed high resistivity of 548.4Ωm with a thickness of 20.15m at depth 25.93m and the fourth layer showed resistivity of 356.4Ωm, which implies leachate contaminant free zone in stark contrast to VES 1 and 2.

The results of the resistivity profiling and VES implied the surrounding soil and groundwater within Don-Parkar dump site may have been contaminated to a depth of 20.70m and leachate has migrated over 10 metres away from the edge of the dump site within six years.

3.2.3 Orhuwhorun dump site

The resistivity contour map (see Fig. 7) of Orhuwhorun dump site showed contour interval of 50Ωm. Zones of low resistivity (<200Ωm) was mapped around the south. These zones are indicative of presence of leachate contaminant. The north section of the dump site showed high resistivity (>200Ωm), indicative of absence of leachate. The results of VES 1 and 2 (Table 3) at Orhuwhorun dump site showed four layers of geo-electric sections. The first layer showed thickness ranging from 1.01m to 1.58m and resistivity of 1084.0Ωm to 1498.0Ωm at depths of 1.01m to 1.58m for VES 1 and VES 2, respectively. This high resistivity in the first layer of VES 1 and 2 was as a result of the lateritic topsoil. The second layer revealed resistivity of 1281.0Ωm and 868.5Ωm with thicknesses of 1.0m and 4.55m at depths 2.01m and 6.13m for VES 1 and 2, respectively. This was interpreted to be absence of leachate. Underlying this layer is the third layer of 303.6Ωm resistivity and 1460.0Ωm with thicknesses of 7.74m to 18.67m at depths13.86m and 20.68m, respectively. The high resistivity of shallow depth at VES 1 at Orhuwhorun dump site is an indication of absence of leachate contamination and that of the surrounding soil and groundwater.

4. CONCLUSION

The results of the electrical resistivity profiling and VES are quite revealing, viz:

1. At Niger-Cat dump site, results showed leachate migration from edge of the dump site to a depth of 19.12m which is a threat to the local shallow groundwater.
2. At Don-Parkar dump site, results showed leachate migration from around the edges and bottom of dump site into surrounding soil to a depth exceeding 20.7m. Again, this is a threat to local shallow groundwater in the study area.
3. At Orhuwhorun dump site, results of resistivity contour map showed leachate migration on the south of the dump; however VES results showed no

contamination to the surrounding soil and local groundwater resource at the time of the study.

5. RECOMMENDATION

There is need for waste managers to adopt engineered sanitary landfill for solid waste disposal and government policy should address this issue to help safeguard the groundwater resources in the area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENECS

1. Ariyo SO, Omosanya KO, Oshinloye BA. Electrical resistivity imaging of contaminant zone at Sotubo dumpsite along Sagamu-Ikorodu Road, Southwestern Nigeria. African Journal of Environmental Science and Technology. 2013;7(5):312-320.
2. Bovwe O, Nwaogazie IL. Application of ant colony optimisation algorithm on solid waste collection. A case study of University of Port Harcourt. British Journal of Applied Science & Technology. 2015;10(2):1-19.
3. Fatta D, Papadopoulos A, Loizidou M. A study on the landfill leachate and its impact on the groundwater quality of the greater area. Environ Geochem Health. 1999; 21(2):175–190.
4. United States Environmental Protection Agency. Office of drinking water. A Ground Water Protection Strategy for the Environmental Protection Agency. 1984; 11.
5. Feachem RG, Bradley DJ, Garelick H, Mara DD. Sanitation and disease, health aspect of excrete and waste water management. New York. Willey. New York; 1983.
6. Ramteke PW, Bhattacharjee JW, Pathak SP, Kalra N. Evaluation of coliform as indicators of water quality in India. J. Applied Bacteriol. 1992;72:352-356.
7. Edema MO, Omemu AM, Fapetu OM. Microbiological and physico-chemical Analysis of different sources of drinking water in Abeokuta, Nigeria. Niger. J. Microbiol. 2001;15:57-61.
8. Ikem A, Osibanjo O, Sridhar MKC, Sobande A. Evaluation of ground water quality characteristics near two waste sites in Ibadan and Lagos, Nigeria. Water Air Soil Pollution. 2002;140:307-333.
9. Akpomedaye DE, Ejechi BO. Bacteriological analysis of groundwater in Ethiope-East council area of Delta State. Nig. J. Natl. Acad. Adv. Sci. 2003;2:10-16.
10. Nwaogazie IL. Water for all. Who cares? Inaugural Lecture Series. No. 52. University of Port Harcourt. Rivers State, Nigeria; 2006.
11. Kola-Olusanya A. Impact of municipal solid wastes on underground water sources in Nigeria. European Scientific Journal. 2012; 8:11.
ISSN: 1857 – 7881 (Print).
e – ISSN: 1857- 7431.
12. Saarela J. Pilot investigations of surface parts of three closed landfills and factors affecting them. Environ Monit Assess. 2003;84:183–192.
13. Ehirim CN, Ebeniro JO, Olanegan OP. A geophysical investigation of solid waste landfill using 2-D resistivity imaging and vertical electrical sounding methods in Port Harcourt Municipality. Rivers State, Nigeria. Pacific J. Sci. Technol. 2009; 10(2):604-613.
14. Bernstone C, Dahlin T. Assessment of two automated DC resistivity data acquisition system for landfill location surveys: Two case studies. Journal of Environmental and Engineering Geophysics. 1999;4(2):113-121.
15. Zhdanov SM, Keller GV. The geoelectrical methods in geophysical exploration. Elsevier. Amsterdam. The Netherlands. 1994;83.
16. Todd DK. Groundwater hydrology. 2nd edition. John Wiley and Sons Inc., New York. 1980;535.
17. Roy A, Apparao A. Depth of investigation in direct current methods. Geophysics. 1971;36:943-959.
18. Adebayo SA, Ariyibi EA, Awoyemi MO, Onyedim GC. Delineation of Contamination Plumes at Olubonku dumpsite using geophysical and geochemical approach at Ede Town. Southwestern Nigeria. Geosciences. 2015; 5(1):39-45.
19. Aweto KE, Mamah LI. Evaluation of soil corrosivity and aquifer vulnerability in Otor - Jeremi, Western Niger Delta. Research Journal in Engineering and Applied Sciences. 2014;3(2):88-92.
20. Nagarajan R, Thirumalaisamy S, Lakshumanan E. Impact of leachate on

groundwater pollution due to non-engineered municipal solid waste landfill sites of erode city. Tamil Nadu, India. Iranian Journal of Environmental Health Sciences & Engineering. 2012;9:35.
Available:http//www.ijehse.com/content/9/1/35

21. Akudo EO, Ozulu GU, Osogbue LC. Quality assessment of groundwater in selected waste dumpsites area in Warri, Nigeria. Environ. Res. J. 2010;4(4):281–285.
22. Ariyo SO, Enikanoselu EM. Integrated use of geoelectrical imaging and geochemical analysis in the environmental impact assessment of Egbe dumpsite in Ijebu-igbo area, South West Nigeria; 2007.
23. Tesfaye Z. Groundwater pollution and public health risk analysis in the vicinity of Reppisolid waste dumping site. Addis Abeba City. Ethiopia. 2007;2-17.
24. Samsudeen AR, Rahim BEA, Yaacob WZW, Hamzah U. Mapping of contamination plumes at municipal solid waste disposal sites using geoelectrical imaging technique: A case studies in Malaysia. J. Spatial Hydrol. 2006;6(2):13-22.
25. Tałałaj IA, Dzienis L. Influence of leachate on quality of underground waters. Polish J. Environ. Stud. 2006;16(1):139-144.
26. Tijani MN, Jinno K, Horoshiro Y. Environmental impact of heavy metals distribution in water and sediments of Ogunpa River. Ibadan Area. Southwestern Nigeria. J. Mining and Geol. 2004;40(1):73.
27. Olayinka AI, Olayiwola MA. Integrated use of geoelectical imaging and hydrochemical methods in delineating limits of polluted surface and groundwater at a landfill site in Ibadan Area, South West Nigeria; 2001.
28. Christopher LB, Jones SA. Subsurface evaluation of the west parking lot and land filling 3 areas of air force plant 4. Fort Worth, Texas, Using 2-D Direct Current Resistivity Profiling. United States Geological Survey. 1999;1-11.
29. Keller GV, Frischknecht FC. Electrical Methods in geophysical prospecting. Pergamon Press Inc.: New York, NY. 1988;38-39.
30. Short KC, Stauble AJ. Outline of geology of Niger delta. Bull. Amer. Assoc. Petr. Geol. 1967;54(5):761–779.
31. Murat RC. Stratigraphy and palaeogeography of the cretaceous and lower tertiary in Southern Nigeria in African Geology (eds T.F.J Dessauvagie and A.J. Whiteman). Ibadan Univ. Press Nigeria. 1970;251–268.
32. Etu-Efeotor JO, Akpokodje EG. Aquifer systems of the Niger Delta. J. Mining Geol. 1990;26(2):279-285.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/16546