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Radiometric and electromagnetic investigations of the Olushosun dumpsite Lagos, Southwest, Nigeria

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ABSTRACT

The Olushosun dumpsite is one of the largest dumpsites in Nigeria, and variety of waste materials are often deposited on the dumpsite. Therefore, radiometric and electromagnetic (EM) investigation of the dumpsite was embarked upon to assess the radioactive status and the extent of leachate contamination. A well calibrated portable radiometric spectrometer nuclear radiation monitoring metre (Model BG0-Super-SPEC RS 230) and the Geonics EM 34 measuring instruments were used to achieve this objective. The mean activity concentration of ^{40}K measured along all the profile lines ranged from 0.22% to 1.19% (68.86–372.47 Bq/kg), while that of ^{238}U and ^{232}Th ranged from 0.88 ppm to 2.02 ppm (10.87–24.95 Bq/kg) and from 4.87 ppm to 15.61 ppm (19.65–63.38 Bq/kg) respectively. The results of the radiation dose rate measurement showed that the overall mean absorbed dose rate measured in the study area were comparable to those reported around some cities in Nigeria. The radiation level along some points on the profile lines, even though high, did not exceed the safe limit of 70 μSvyr^{-1} as recommended by UNESCO on effect of Atomic Radiation. This implies that the inhabitants around this area are not exposed to radiological risk, and the dumpsite when reclaimed in future, could be used for the construction of buildings without any form of restrictions. However, continuous exposure to these radiations may have long term consequences on human health. Results from the EM data set along traverses on the dumpsite show that the subsurface is characterised by high conductivity (60–680 mS/m) up to a depth of 60 m. The high terrain conductivity signature here may be attributed to leached contaminats migrating into the subsurface and contaminating shallow aquifers. The descriptive statistical analysis of the measured EM data sets showed higher level of correlation among parameters measured along control lines outside of the dumpsite. Generally, correlation between the entire EM data on the dumpsite was poor, but reasonably better for the control data. This could be attributed to the heterogeneous properties of waste materials deposited on the dumpsite.

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Introduction

All manner of waste materials are often deposited on the Olushosun dumpsite, one of the largest dumpsites in Nigeria. Waste products dumped on the dumpsite range from domestic, institutional, food products, industrial and electronic wastes. The environment is naturally characterised with ionizing radiation and humans are therefore constantly being exposed to it. Due to advancement in science and technology and activities of human beings, the radionuclide in our environment has increased. Increase in waste generation as a result of increase in population has also led to the increased rate of human exposure to ionizing radiation. Also, waste of industrial origin that may contain some levels of radionuclides are equally deposited indiscriminately on the environment. As a result, the radionuclide component of the waste materials tend to emit radiation if not properly taken care of. In the dumpsite, the probability of emission of radiation from radioactive materials and the natural ionizing radiation from soil is high. Various radioactivity measurements have shown the existence of traces of radionuclide in the staple food consumed in Nigeria [4,7]. Results from past studies have shown that vegetation and environmental fields in Nigeria contain traces of radionuclides [2]. These are associated with waste from homes which more often than not are deposited indiscriminately on bare or excavated lands, water bodies and even along the road sides. At dumpsites, there are possibilities for radiation to be emitted due to the presence of radioactive waste in the landfills as well as naturally occurring radionuclides in the soil. The radioactive contamination of soil, water and air can be transferred to human through the soil via plants (^{40}K) or through inhalation (^{222}Rn and ^{220}Rn). These radionuclides even at low concentrations can have potential impacts on the environmental quality and human health and may pose a long term risk [3]. The most common terrestrial radionuclides that produce gamma-rays are member of the ^{238}U and ^{232}Th series and ^{40}K, and their concentrations vary considerably depending on the soil type and local geology [3]. Induction terrain-conductivity is an electromagnetic method that measures the bulk apparent subsurface electrical conductivity [13]. Subsurface conductivity is the reciprocal of resistivity and is affected by the same factors as resistivity. Surface inductive terrain-conductivity surveys are used to detect conductive features such as buried metal objects, ore bodies, and fluid-filled features and to map conductive plumes, such as landfill leachate or salt water intrusion [5,6,12,17]. The electromagnetic induction method provides fast and low-cost detection of many subsurface waste materials which change the electrical conductivity where they are deposited. This is possible because, unlike the direct current resistivity method that requires contact with the ground, the electromagnetic technique can be used without any contact with coils and the ground. The application of electromagnetic techniques to the measurement of terrain conductivity has been described by Keller and Frischnecht [8]. Ground conductivity electromagnetic instrumentations are frequency domain EM systems that requires the use of two loops or coils.

This research was designed to integrate the radiation and EM surveying techniques to effectively probe and to assess the radioactive status and the evaluation of contamination on the study area. The outcome of this study will be useful in creating a standard data base on the radionuclide activity and terrain conductivity around the study area.

Study area

The Olushosun dumpsite is a controlled dumpsite located at Ojota, Lagos, within longitude 03.372E–03.374E and latitude 06.588N–06.595N. It is the largest government-owned dump facility in Nigeria, and it is managed by the Lagos Waste Management Authority (LAWMA). It is about 18 m deep and covers close to 42 hectares of land. Olushosun refuse dump was established in 1991 with a lifespan of 35 years. The dump is surrounded by Oregun industrial layout, Olushosun residential compound, Shangisah residential areas and commercial neighbourhood (Fig. 1). It receives an average of 1.2 million tons of assorted wastes annually and is presently serving as a pilot project for biogas production in Nigeria [9].

Materials and methods

In situ technique of the measurement of background radiation was preferred and implemented in this study to enable radiation values represent the true characteristic of the environment. Readings were taken on and around the dumpsite, at intervals of 10 m along profile lines, to a maximum of 180 m. A well calibrated portable Radiometric Spectrometer nuclear radiation monitoring metre (Model BG0-Super-SPEC RS 230) was used to measure the radiation levels (total dose rate or exposure in a mixed field), while a global positioning system (GPS) was used to measure the precise location of traverses. In all the measurements made across the dumpsites, the detector was placed at about one metre above ground level for effective detection, while three readings were taken at intervals of one minute at each of the selected points and average calculated using the relation [11];

$$1\ \text{radh}^{-1} = 1.0 \times 10^{-2}\text{Gyh}^{-1} \tag{1}$$

The absorbed dose in $rad\ h^{-1}$ was converted to $Gy\ h^{-1}$. The annual dose rate was further determined using the relation.

$$D = \delta \times \mu \times k \times 24 \times 365.25\ \text{Sv year}^{-1} \tag{2}$$

where:

δ = Absorbed dose rate in $Gy\ h^{-1}$.
μ = 0.2, the occupancy factor

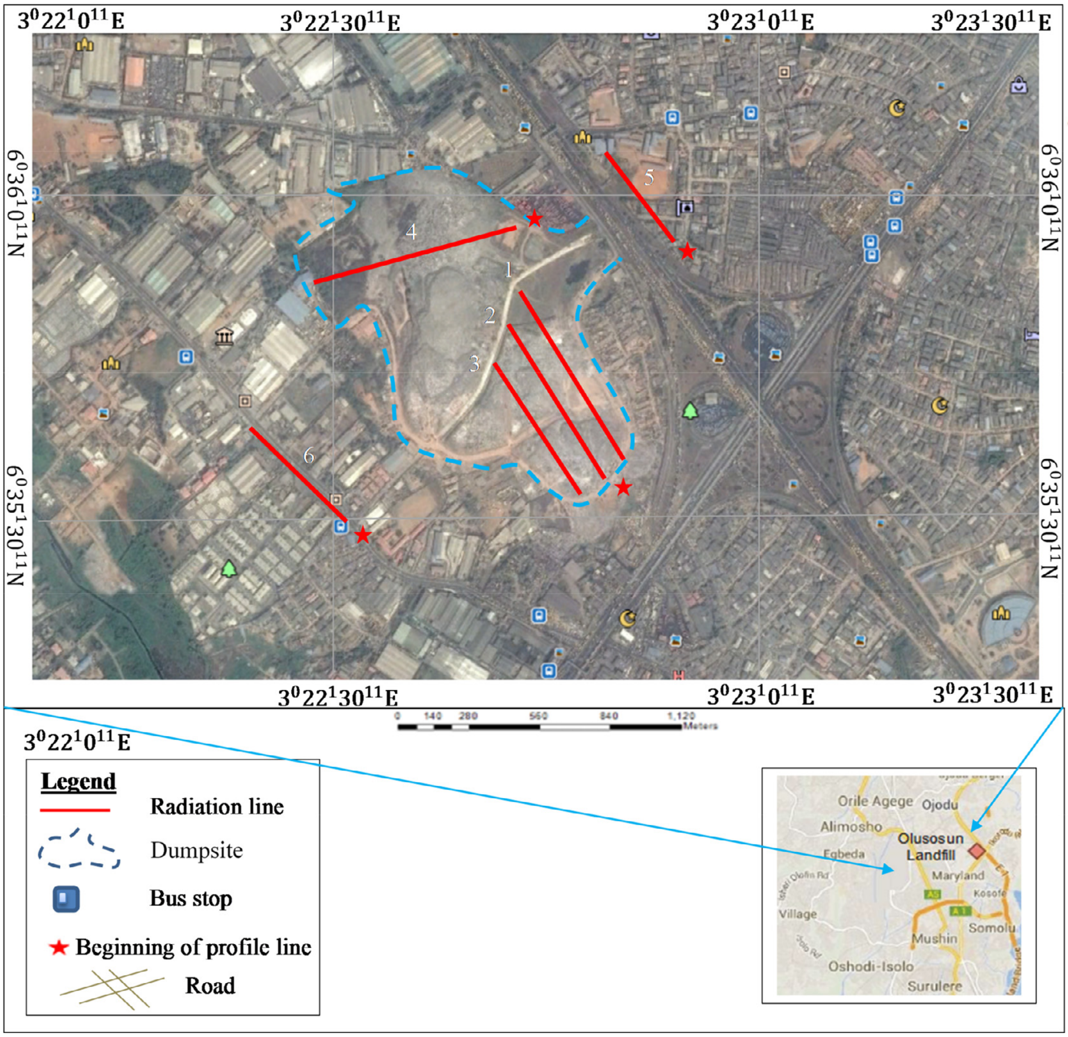

Fig. 1. Data acquisition map of the study area.

$K = 0.7$ Sv year^{-1}, which is the conversion factor from *Gy to Sv*

The mean absorbed dose rate was determined using;

$$\bar{\times} = \frac{\sum \times}{n} \tag{3}$$

where

$\bar{\times} =$ Mean annual absorbed dose rate in micro sievert per year
$\times =$ Annual absorbed dose rate in micro sievert per year
$n =$ Number of data point

Values of ^{238}U, ^{232}Th in ppm, and ^{40}K, in %, were obtained and converted to activity concentration, Bq kg^{-1}, using the conversion factors given by Polish Central Laboratory for Radiological Protection [10]. The specific parent activity of a sample containing 1 ppm, by weight, of ^{238}U is 12.35 Bq kg^{-1}, 1 ppm of ^{232}Th is 4.06 Bq kg^{-1} and 1% of ^{40}K is 313 Bq kg^{-1} [18]. The EM data was recorded using the Geonics EM34 instrument. Three EM terrain conductivity survey (traverses) data were collected on the dumpsite, while two other traverses recorded at various distances from the dumpsite constitute the control (Fig. 1). The distances of traverses 5 and 6, whose apparent conductivity values were used as background from the dumpsite were about 300 m from the dumpsite. Measurements were collected at 10 m interval along the traverse in the Horizontal-dipole (HD) and Vertical-dipole (VD) configurations using the 10, 20 and 40 m coil spacing. These spacing have the capacity of investigating respectively, penetration depths of 7.5, 15 and 30 m for the HD and 15, 30 and 60 m for the VD.

Table 1
Mean radionuclide concentrations along the six profile lines.

S/No.	Profile line	Radionuclide concentration (ppm)			Specific Activity concentration (Bq/kg)			Dose rate (nGyh^{-1})
		K (%)	U (ppm)	Th (ppm)	K (Bq/kg)	U (Bq/kg)	Th (Bq/kg)	
1	Profile line 1	0.22	1.08	6.68	68.86	13.34	27.12	26.59
2	Profile line 2	0.26	1.01	7.41	81.38	12.47	30.08	29.17
3	Profile line 3	0.23	0.90	6.05	71.99	11.12	10.11	25.90
4	Profile line 4	0.26	0.88	4.87	81.38	10.87	19.65	21.19
5	Profile line 5	0.99	2.02	7.86	309.87	24.95	31.91	45.22
6	Profile line 6	1.19	1.90	15.61	372.47	23.47	63.38	52.42

Table 2
Comparison of measured radiation dose rates from selected dumpsites in Abeokuta and Olushosun dumpsite in Lagos.

S/No	Measurements at dumpsites in Abeokuta [16]			Mean Annual dose rate (µSvyr^{-1}) on Olushosun dumpsite
	Locations	Dose rate (nGy h^{-1})	Annual dose rate (µSvyr^{-1})	
1	Panseke A	30.0	36.8	32.64
2	Omida	27.0	33.2	35.79
3	Itoku B	28.0	34.4	31.79
4	Sodeke	30.0	36.8	26.01
5	Abiola way	35.0	43.0	55.49
6	Onikolobo A	33.0	40.5	64.31
	Mean Annual dose rate (µSvyr-1)		37.5	

Result and discussion

Analysis of radiometric parameters

The concentration of the radionuclides measured along the predetermined profile lines varied from location to location. The Mean radionuclide concentrations along the six profile lines are presented in Table 1. The activity concentration of ^{40}K measured along all the profile lines ranged from 0.22% to 1.19% (68.86–Bq/kg), while that of ^{238}U and ^{232}Th ranged from 0.88 ppm to 2.02 ppm (10.87–24.95 Bq/kg) and from 4.87 ppm to 15.61 ppm (19.65–63.38 Bq/kg) respectively. The obtained results are comparable to the worldwide average concentration of these radionuclide in soil reports by the UNSCEAR, [20], which are 40 Bq kg^{-1} for ^{238}U and ^{232}Th and 370 Bq kg^{-1} for ^{40}K. The results of the mean radionuclide activity concentration along profiles 5 and 6 (obtained on the control lines) were generally higher when compared with those recorded on the dumpsite.

Table 2 shows the measured radiation dose rates from selected dumpsites in Abeokuta in Ogun State as obtained from the research work of Odunaike et al. [16]. The values of the radiation dose rate ranged from 33.2 µSvyr^{-1} to 43.0 µSvyr^{-1} with a mean value of 37.5 µSvyr^{-1}.Comparing the results with the measured radiation parameters from this work showed that the mean radiation dose rate ranged from 26.01 µSvyr^{-1} to 64.31 µSvyr^{-1}. Apart from the elevated values along the control lines, the results generally is comparable with previous radiometric study carried out around dumpsites in Southwest Nigeria. Fig. 2a–f are histograms showing the comparison of measured radiation levels of the dumpsite and surrounding with the normal background radiation of 70 µSvyr^{-1}. The terrestrial background radiation annual absorbed dose rate was measured along the four traverse lines occupied on the dumpsite (Fig. 2a–d) and the two control profile lines located outside of the dumpsite (Fig. 2e and f). The mean annual absorbed dose rate for all the traverses on the dumpsite ranged from 26.01 µSvyr^{-1} to 35.79 µSvyr^{-1} while values obtained along control lines ranged from 55.49 µSvyr^{-1} to 64.31 µSvyr^{-1}. The values recorded on the dumpsite even though elevated, is comparable with both the results obtained from Obed et al. [14], with an average value of 24.5 µSvyr^{-1}, and that obtained from the investigation of radiation level in waste dumpsites across Lagos metropolis, Nigeria with a mean annual absorbed dose rate of 21.8 µSvyr^{-1} reported by Odunaike et al. [15]. According to Ademola [1], world's average is 0.06 µGy h^{-1} (≈70 µSvyr^{-1} recommended by UNESCO on effect of Atomic Radiation). The mean absorbed dose rate value in the soils of Bangalore region India from the work of Shiva Prasad et al. [19] was reported as 73.9 nGy h^{-1} (90.7 µSvyr^{-1}), while Odunaike et al. [16] mentioned 98.0 µSvyr^{-1} as the Nigerian average annual dose rate. The UNESCO standard value therefore is higher than the results obtained from this study. The values obtained outside of the dumpsite though higher than the values on the dumpsite did not exceed the World's average of 70 µSvyr^{-1}. The higher values recorded along the control traverses could be ascribed to the influence of the local geology (i.e. the radioactive content of the soil around the study area).

When compared with the world's average, the obtained radiometric signatures on and outside of the dumpsite were below the permissible limit of 70 µSvyr-1 recommended by UNESCO and, therefore did not pose a major challenge to the inhabitants of the area. However, continuous exposure to these radiations may have long term consequences on human health. Also, the dumpsite when reclaimed in future could be used for the construction of buildings without any form of restrictions.

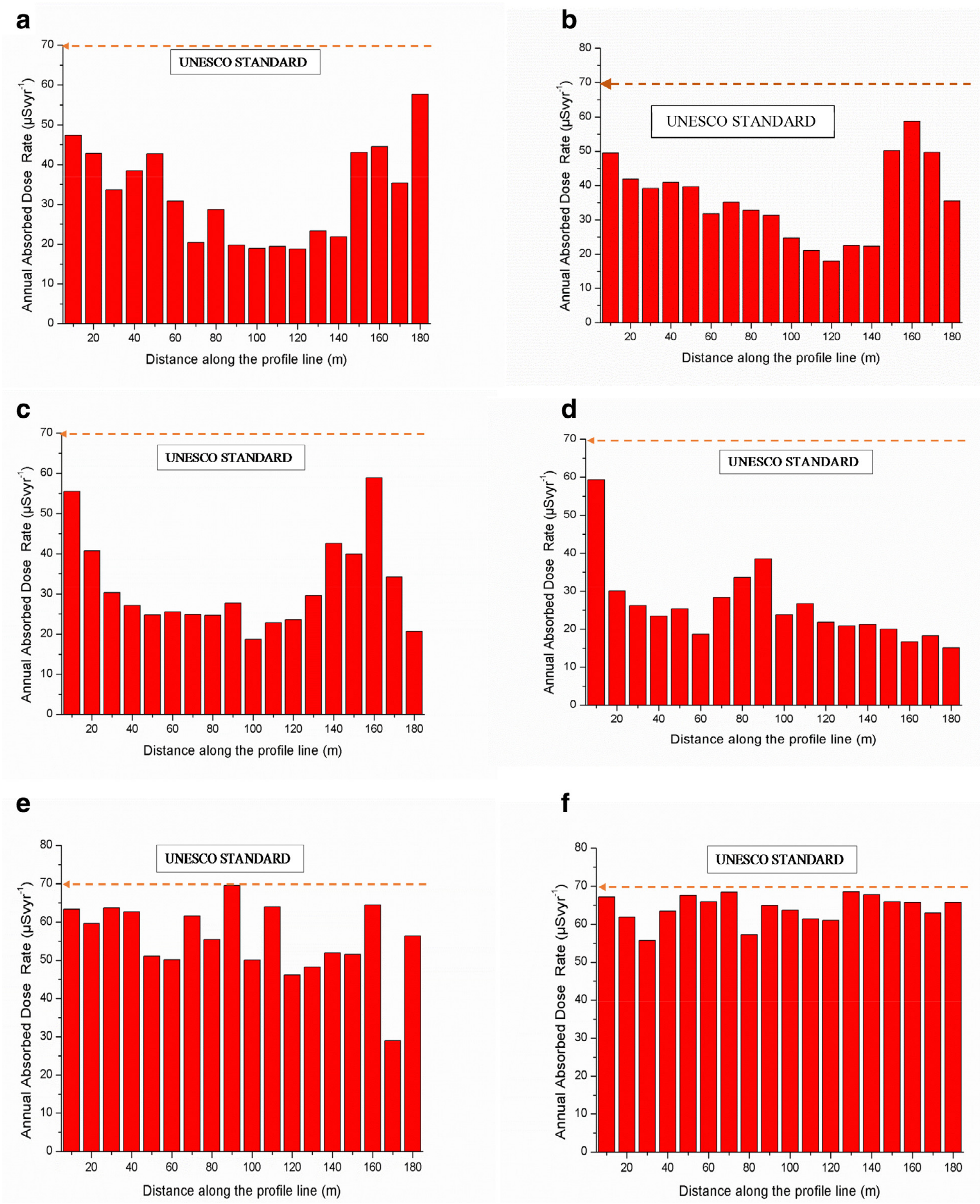

Fig. 2. Comparison of measured radiation level with UNESCO standard along profile lines on the dumpsite (a–d) and lines along control profiles (e–f).

Table 3
Summary statistics of EM parameters obtained on Traverse 1.

Apparent conductivity (mS/m)	HD 10	HD 20	HD 40	VD 10	VD 20	VD 40
Max.	228	274	270	100	118	145
Median	139	186	189	67	68	23
Min.	116	136	113	15	−84	−65
Mean	150.29	195.29	195.94	61.94	49.70	28
St. dev.	34.42	31.13	42.23	27.24	51.81	58.53
Skewness	1.26	0.81	0.24	−0.38	1.40	0.16
Kurtosis	1.01	1.72	−0.025	−0.98	1.78	−0.21

Table 4
Correlation coefficients of EM parameters obtained on Traverse 1.

	HD 10	HD 20	HD 40	VD 10	VD 20	VD 40
HD 10	1	0.69	0.51	−0.75	−0.85	−0.36
HD 20		1	0.56	−0.38	−0.56	−0.02
HD 40			1	−0.49	−0.43	0.13
VD 10				1	0.53	0.47
VD 20					1	0.24
VD 40						1

Analysis of EM data

The terrain conductivity measurement from the four EM traverses on the dumpsite and the two control lines are presented as plots of apparent conductivity against location for both vertical and horizontal dipole modes (Figs. 3 and 4). Apparent conductivity value of 001–058 mS/m was used as the background value for non-contaminated region (Traverses 5 and 6), and the EM profiles were interpreted relative to these values. Results from the EM profiles along traverses 1–4 (Fig. 3) showed that the subsurface is characterised by high conductivity (ranging from 60 to 900 mS/m) up to a depth of 60 m (which represents the maximum depth that can be achieved in the vertical dipole mode), as reflected by very high conductivity values at the 10, 20, and 40 m coil separations. EM plot (VD 10) represents the conductivity of the buried waste materials and leachates at 15 m of depth because information from Lagos waste management Agency showed that the dumpsite was excavated to a depth of between 15 m to 18 m before commencement of dumping activities. The deeper EM plots (VD 20 and VD 40) were interpreted as the conductivity values for the contaminants migrating from the dumpsite into the underlying rock units at 30 m and 60 m of depth respectively. The HD 10, HD 20 and HD 40 parameters represent conductivity at depths of 7.5 m, 15 m and 40 m respectively. Comparing this with the threshold value of 001–058 mS/m, suggests that the shallow aquifer units below the dumpsite may have been contaminated by the percolating leachate from the decomposed refuse materials. A critical look at the VD parameters indicates wide variation in values. This is attributed to the heterogeneous properties of waste materials deposited on the dumpsite. The high level of contamination may have been accelerated by the excavation of the lateritic materials within the study area before the commencement of dumping activities. This means that a fairly continuous leachate leak from the dumpsites are diluted and mobilized by groundwater and being dispersed at distinct depths along these preferential directions.

Descriptive statistics of the EM data

Statistical analysis of the EM data was done to observe and compare the distribution of data obtained on the dumpsite and the controls. Table 3 shows the summary statistics of EM apparent conductivity collected along traverse 1 on the dumpsite during the survey. In the horizontal dipole mode, the EM apparent conductivity (HD 40) exhibited the largest standard deviation (42.23), whereas HD 20 had the maximum value (274 mS/m). The largest average was recorded using the HD 40 (195.94 mS/m). The HD 40 (0.24) values can be said to be normally distributed, with the HD 20 skewed slightly positive (0.81). The HD 20 apparent conductivity exhibited the largest kurtosis (1.72). In the vertical dipole, the VD 40 had the maximum value (145 mS/m) as well as the greatest standard deviation (58.53).

Table 4 shows the correlation coefficients between EM signal data. The three horizontal readings were better correlated than the vertical readings. The largest was obtained between the HD 10 and HD 20 ($r^2 = 0.69$), followed by HD 20 and HD 40 ($r^2 = 0.56$), with a correlation between HD 10 and HD 40 ($r^2 = 0.51$). Correlation between the vertical readings was small. The largest was between VD 10 and VD 20 ($r^2 = 0.53$). The cross-correlation between vertical and horizontal apparent conductivity was poor, with the largest achieved between HD 40 and VD 40 ($r^2 = 0.13$). This was because, in these modes of operation, the EM34 measures equivalent depths [21].

Table 5 shows the summary statistics of apparent conductivity collected along traverse 2. In the horizontal dipole mode, the HD 10 apparent conductivity exhibited the largest standard deviation (35.61), whereas HD 20 had the maximum value (296 mS/m). The largest average was recorded using the HD 20 (203.41 mS/m). The HD 40 (0.12) was normally distributed,

Fig. 3. Terrain conductivity plot along traverses 1–4 on dumpsite (HD and VD).

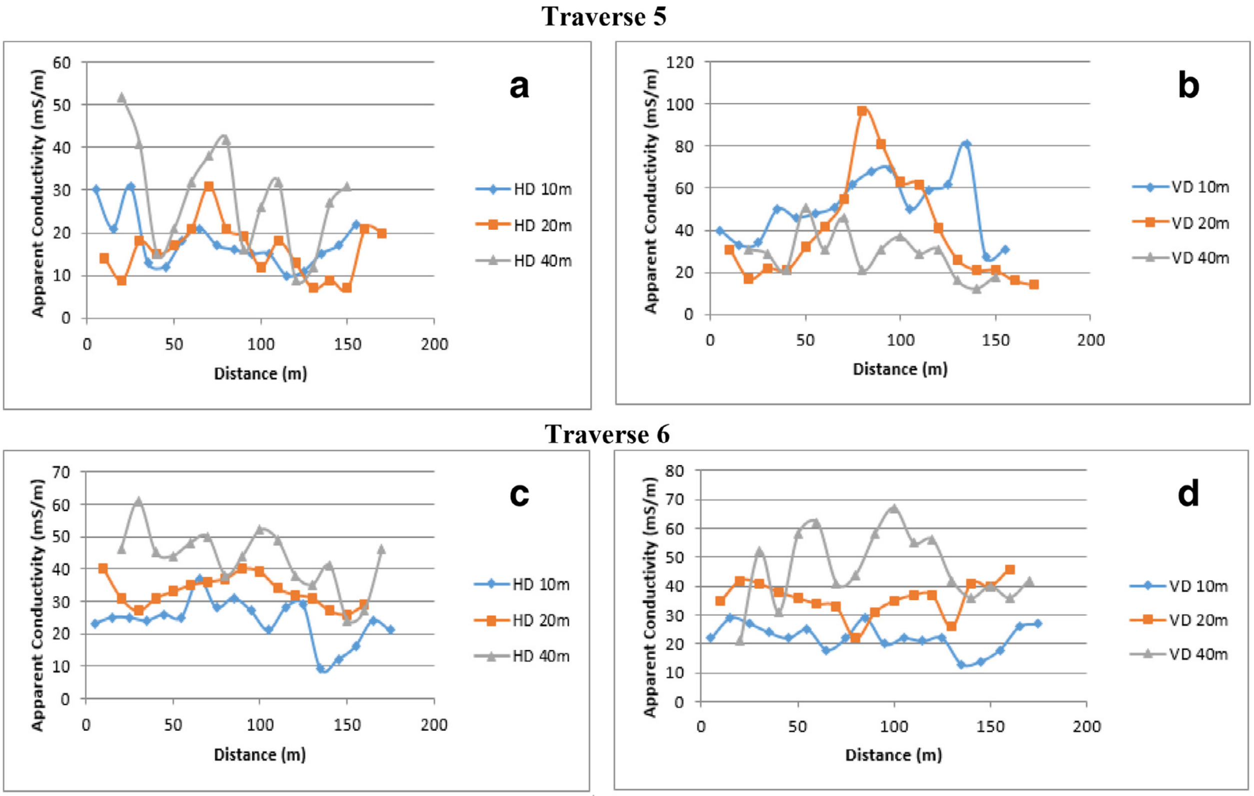

Fig. 4. Terrain conductivity plot along control traverses 5–6 outside the dumpsite (HD and VD).

Table 5
Summary statistics of EM parameters obtained on Traverse 2.

Apparent conductivity (mS/m)	HD 10	HD 20	HD 40	VD 10	VD 20	VD 40
Max.	209	296	282	126	131	136
Median	131	202	202	74	56	27.5
Min.	95	169	95	11	−26	−36
Mean	141.05	203.41	203.72	66.35	58	38.94
St. dev.	35.61	35.43	10.49	31.78	47.03	50.24
Skewness	0.63	1.25	0.12	−0.12	0.14	0.68
Kurtosis	−0.66	1.40	1.32	−0.59	−1.00	−0.28

Table 6
Correlation coefficients of EM parameters obtained on Traverse 2.

	HD 10	HD 20	HD 40	VD 10	VD 20	VD 40
HD 10	1	0.22	0.32	−0.22	−0.43	−0.31
HD 20		1	0.37	−0.25	−0.30	0.17
HD 40			1	−0.46	−0.32	−0.10
VD 10				1	0.47	0.07
VD 20					1	0.33
VD 40						1

with the HD 10 skewed slightly positive (0.63). The HD 20 apparent conductivity exhibited the largest kurtosis (1.40). In the vertical dipole, the VD 40 had the maximum value (136 mS/m) as well as the greatest standard deviation (50.24).

Table 6 shows the correlation coefficients between the EM signal data. Both dipole readings were poorly correlated. The largest was obtained between the HD 40 and HD 20 ($r^2 = 0.37$), followed by HD 10 and HD 40 ($r^2 = 0.32$), with a correlation between HD 10 and HD 20 ($r^2 = 0.22$). Correlation between the vertical readings was also small. The largest was between VD 10 and VD 20 ($r^2 = 0.47$). The cross-correlation between vertical and horizontal apparent conductivity was also poor, with the largest achieved between HD 20 and VD 40 ($r^2 = 0.17$).

Table 7
Summary statistics of EM parameters obtained on Traverse 3.

Apparent conductivity (mS/m)	HD 10	HD 20	HD 40	VD 10	VD 20	VD 40
Max.	218	243	303	112	136	190
Median	134	164	150	65	90	70
Min.	99	143	123	−97	27	−36
Mean	145.76	172.11	182.76	60.82	85.82	73.23
St. dev.	35.83	28.97	59.16	47.26	30.11	57.18
Skewness	0.53	1.28	0.94	−2.43	−0.71	0.18
Kurtosis	−0.57	0.90	−0.65	8.08	−0.24	0.17

Table 8
Correlation coefficients of EM parameters obtained on Traverse 3.

	HD 10	HD 20	HD 40	VD 10	VD 20	VD 40
HD 10	1	0.78	0.04	−0.34	−0.47	−0.42
HD 20		1	0.45	−0.11	−0.37	−0.53
HD 40			1	0.17	−0.05	−0.47
VD 10				1	0.10	−0.38
VD 20					1	0.19
VD 40						1

Table 9
Summary statistics of EM parameters obtained on Traverse 4.

Apparent conductivity (mS/m)	HD 10	HD 20	HD 40	VD 10	VD 20	VD 40
Max.	62	63	60	152	204	221
Median	13	28	26	83	85	73
Min.	1	3	4	2	39	28
Mean	25.09	27.57	29.28	75.76	102.76	90.80
St. dev.	22.70	16.84	17.80	48.18	54.51	58.83
Skewness	0.56	0.58	0.38	−0.10	0.75	1.05
Kurtosis	−1.45	−0.40	−0.94	−1.10	−0.70	0.05

Table 10
Correlation coefficients of EM parameters obtained on Traverse 4.

	HD 10	HD 20	HD 40	VD 10	VD 20	VD 40
HD 10	1	0.21	0.70	0.83	0.47	0.85
HD 20		1	0.39	0.41	0.72	0.50
HD 40			1	0.68	0.66	0.67
VD 10				1	0.67	0.81
VD 20					1	0.71
VD 40						1

Table 7 shows the summary statistics of EM apparent conductivity collected along traverse 3. In the horizontal dipole mode, the HD 40 apparent conductivity exhibited the largest standard deviation (59.16), whereas HD 40 had the maximum value (303 mS/m). The largest average was recorded using the HD 40 (182.76 mS/m). None of the horizontal dipole data along this traverse was normally distributed, as all the data were highly skewed. The HD 20 apparent conductivity exhibited the largest kurtosis (0.90). In the vertical dipole, the VD 40 had the maximum value (190 mS/m) as well as the greatest standard deviation (57.18).

Table 8 shows the correlation coefficients between the EM signal data. Both dipole readings were poorly correlated except for the one obtained between the HD 20 and HD 10 ($r^2 = 0.78$), followed by HD 20 and HD 40 ($r^2 = 0.45$). Correlation between the vertical dipole readings was also small. The largest was between VD 40 and VD 20 ($r^2 = 0.19$). The cross-correlation between vertical and horizontal apparent conductivity was also poor, with the largest achieved between HD 20H and VD 10 ($r^2 = -0.11$).

Table 9 shows the summary statistics of EM apparent conductivity collected along one of the controls, traverse 5 outside the dumpsite during the survey. In the horizontal dipole mode, the HD 10 apparent conductivity exhibited the largest standard deviation (22.70), as well as the maximum value (62 mS/m). The largest average was recorded using the HD 40 (29.28 mS/m). The EM horizontal values were not normally distributed, with the three dipole modes skewed slightly positive (0.56, 0.58 and 0.38 respectively). The HD 20 apparent conductivity exhibited the largest kurtosis (−0.40). In the vertical dipole mode, the VD 40 had the maximum value (221 mS/m) as well as the greatest standard deviation (58.53).

Table 10 shows the correlation coefficients between EM signal data. For this traverse, the vertical readings were better correlated than the horizontal readings. For the horizontal dipole, the largest was obtained between the HD 10 and HD 40

Table 11
Summary statistics of EM parameters obtained on Traverse 5.

Apparent conductivity (mS/m)	HD 10	HD 20	HD 40	VD 10	VD 20	VD 40
Max.	53	81	41	60	64	51
Median	21	37	18	31	29.5	32
Min.	1	12	4	4	11	12
Mean	22.7	38.77	17.82	28.95	34.33	31.17
St. dev.	17.44	21.86	9.31	17.23	16.33	11.40
Skewness	0.50	0.81	0.83	0.07	0.64	−0.16
Kurtosis	−0.99	−0.26	1.24	−0.99	−0.78	−0.84

Table 12
Correlation coefficients of EM parameters obtained on Traverse 5.

	HD 10	HD 20	HD 40	VD 10	VD 20	VD 40
HD 10	1	0.48	−0.25	0.84	−0.27	−0.51
HD 20		1	0.13	0.33	0.05	0.06
HD 40			1	−0.12	0.15	0.87
VD 10				1	−0.20	−0.34
VD 20					1	0.10
VD 40						1

(r^2 = 0.70), followed by HD 20 and HD 40 (r^2 = 0.39). Correlation between the vertical readings was higher with the largest between VD 10 and VD 40 (r^2 = 0.81). The cross-correlation between vertical and horizontal apparent conductivity was also high with the largest achieved between HD 10 and VD 10 (r^2 = 0.83).

Table 11 shows the summary statistics of EM apparent conductivity collected along traverse 6 (control) outside the dumpsite. In the horizontal dipole mode, the HD 20 apparent conductivity exhibited the largest standard deviation (21.86), as well as the maximum value (81 mS/m). The largest average was recorded using the HD 20 (38.77 mS/m). The EM horizontal values were not normally distributed, with the three dipole modes skewed slightly positive too (0.50, 0.81and 0.83 respectively). The HD 40 apparent conductivity exhibited the largest kurtosis (1.24). In the vertical dipole mode, the VD 20 had the maximum value (64 mS/m) with the VD 10 having the greatest standard deviation (17.23).

Table 12 shows the correlation coefficients between EM signal data. For this traverse, the vertical readings and the horizontal readings were poor with the cross-correlation between the two modes being better. For the horizontal dipole, the largest was obtained between the HD 10 and HD 20 (r^2 = 0.48) while for the vertical readings the highest was recorded between VD 40 and VD 20 (r^2 = 0.10).The cross-correlation between vertical and horizontal apparent conductivity was high with the largest achieved between HD 40 and VD 40 (r^2 = 0.87), followed by that between HD 10 and VD 10 (r^2 = 0.84).

Generally correlation between the entire EM data on the dumpsite was poor, but reasonably better for the control data. This could be attributed to the heterogeneous properties of waste materials deposited on the dumpsite.

Conclusion

Radiometric and electromagnetic assessment of the dumpsite was embarked upon to assess the radioactive status and the extent of contamination on the Olushosun dumpsite. The terrestrial background radiation annual absorbed dose rate was measured along the four traverse lines occupied on the dumpsite and the two control profile lines located outside of the dumpsite. The mean annual absorbed dose rate for all the traverses on the dumpsite ranged from 26.01 μSvyr^{-1} to 35.79 μSvyr^{-1} while values obtained along control lines ranged from 55.49 μSvyr^{-1} to 64.31 μSvyr^{-1}. The results obtained are comparable to the worldwide average concentration of these radionuclide in soil reports by the UNSCEAR [20]. These therefore, may not pose any serious health problem to the inhabitants of the dumpsite area. However, with continuous exposure to the radiation and increase in the activity concentration and dose rates of these radionuclides may occur over time with adverse effects on humans. Therefore, a regular investigation to monitor the level of radiation emission from dumpsites would be a proactive measured put in place to avert any likely impact on human health.

The apparent conductivity distributions within the subsurface indicated that there is obvious leachate contamination of the shallow aquifer, and by extension, on the groundwater around the site. Generally, correlation between the entire EM data on the dumpsite was poor, but reasonably better for the control data sets. This could be attributed to the heterogeneous properties of waste materials deposited on the dumpsite.

Urgent Government interventions and constant monitoring programs for leachate, surface water, groundwater, and landfill gas control are therefore required so as to prevent the site from becoming a potential death traps for the inhabitants around the site.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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