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Radiological Impact of a Municipal Solid Waste Dumpsite on Soil and Groundwater Using 2-D Resistivity Tomography and Gamma Ray Spectroscopy

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Abstract: *The radiological impact of a municipal solid waste dumpsite on soil and groundwater in Port Harcourt municipality was investigated by integrating 2-D resistivity imaging and gamma-ray spectroscopy. The objectives of the study were to determine the lateral and vertical limits of leachate contamination and to evaluate the radioactivity concentrations in soil and groundwater. Results show that the soil and ground water have been contaminated by dumpsite emissions and radioactive materials throughout the dumpsite area. The distribution of the contaminations is uneven and spotty, both horizontally and vertically, and has penetrated to depths exceeding 31m into the ground water aquifer. The primary contaminants found in the site were leachate, waste gases, and the radionuclides of* ^{40}K, ^{226}Ra, *and* ^{228}Ra. *The mean absorbed dose rates of 31.98nGy/hr, 10.51nGy/hr and 6.98nGy/hr, and mean dose rate equivalents of 0.28mSv/yr, 0.09mSv/yr and 0.06mSv/yr were obtained for the soil, leachate and groundwater samples, respectively. The mean absorbed and equivalent dose rates in the soil and water samples were greater than their controls, suggesting that the dumpsite area is contaminated. These results are comparable to those reported for other waste sites in the area and lower than the maximum permitted limits for the general public of 1mSv/yr and 0.1mSv/yr for soil and water, respectively. These therefore, have no immediate radiological health burden on the inhabitants who depends on the soil and groundwater for their crops and potable water supply. However, with continuous consumption of crop products and intake of groundwater, increase in the activity concentration and dose rates of these radionuclides may occur over time, which will have adverse effects on humans.*

Keywords*: Resistivity Imaging, Leachate, Gamma-Ray Spectrometry, Radionuclides, Absorb Dose Rate and Equivalent Dose Rate.*

I. Introduction

The arbitrary and indiscriminate dumping of wastes in un-engineered landfills has posed serious health challenges to the populace globally. The hazard posed by these point sources of contamination is not only in terms of odour and presence of disease causing micro-organisms, but from radiations emanating from such landfills. Our natural environment is continuously bombarded with ionizing radiations from both natural and man-made sources [1]. The most common radionuclides in soil and groundwater are the radioactive isotopes of the three natural decay series (^{235}U, ^{238}U, and ^{232}Th) and ^{40}K.

Waste disposal by landfill has led to the pollution of soil and groundwater resources ([2], [3], [4]). In Port Harcourt municipality, solid wastes are mostly deposited in un-engineered landfills. The wastes are composed of mainly domestic co-disposed with industrial, agricultural, building and hospital wastes. These wastes contain traces of radiological elements or radionuclides resulting from the use of processing chemicals, fertilizers and pesticides, chemotherapy, food materials, gas and oil production ([5], [6]).

Solid wastes landfills constitute local sites were natural radionuclides are concentrated in the environment. Due to the soil-solute interaction which could lead to the transport of specific contaminants relative to others into groundwater and soil-to-plant transfer processes which results in the accumulation of radionuclides in plants and animals, humans are exposed to high doses of radiation. Humans incur radiations from waste landfills by external irradiations or by incorporation in the body. Their occurrence and distribution in the soil and groundwater are controlled primarily by the local geology, geochemistry, and specific solubilities of the radionuclides.

In view of this, it is important to monitor terrestrial background radiations, especially around municipal solid waste landfills. This is because soils and groundwater resources around landfills may contain naturally occurring radionuclides in significant amounts due to land filling activity [7]. The leaching of radionuclides can result in contaminated soil and groundwater with serious implications on the health of humans over time.

The activity concentration and dose rates of radionuclide in soils and groundwater have been investigated in different parts of the municipality [8], [5]. This reveals increased activity and dose levels of radionuclides in the samples, an observation attributed to industrial and exploratory activities in the area.

Landfill related studies have been carried out using the 2-D resistivity imaging technique by various authors ([9], [10], [11], [12]). This is because of its inherent ability to detect vertical as well as lateral resistivity changes related to variations in fluid saturation and composition. In this study, 2-D resistivity imaging technique and gamma ray spectroscopy were integrated to investigate the lateral and vertical limits of leachate contamination, and to determine the activity concentrations and dose rates of radionuclides in soil and groundwater due to a municipal solid waste dump.

II. Location and accessibility of the study area

The study area is located along Eliozu-Rukpoku road in Port Harcourt municipality. It lies between latitudes $7^0 05'$ to $7^0 10'$N and longitudes $4^0 50'$ to $4^0 53'$E (Fig.1.0). The area is accessible through networks of tarred and untarred motorable roads and tracks which were used for the geophysical survey.

The study area is moderately vegetated with almost flat topography. It is characterized by alternate wet and dry seasons, with a total annual rainfall of about 240cm, relative humidity of over 90% and mean annual temperature of 27^0C [13].

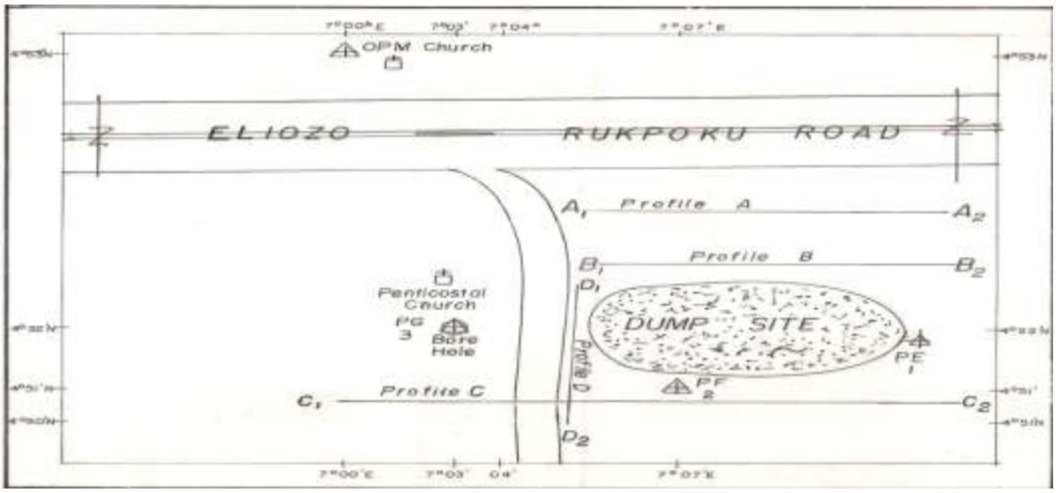

Fig. 1.0: Map of the Study Area showing the dumpsite and the 2D profile lines.

III. Geology of the study area

The study area is located in the Niger Delta sedimentary basin SE of Nigeria. Generally, three statigraphic units namely; Akata, Agbada and Benin formations from earliest to recent, are identifiable in the modern Niger Delta. The study area is underlain by the Benin formation, which is predominantly sandy with intercalations of thin shale beds (Fig. 2.0). The formation has a maximum thickness of about 2130m [14], moderately porous and permeable.

Fig. 2.0: Geologic and Stratigraphic map of the area

The sands are fine to coarse grained, granular in texture and hardly consolidated ([15], [16]). The shale intercalations in the formation has resulted in a multi-aquifer system, and both confined and unconfined aquifers are encountered at varying depths and horizons, which serves as the major source of potable water supply in the area. The depth to the water table varies from 3m during the peak of the rainy season to 15m during the dry season. The dept to the usable aquifer in the area is approximately 30-45m, which is penetrated by most boreholes in the vicinity of the dump. These aquifers are recharged predominantly by infiltrations from surface precipitation.

IV. Methodology

The 2-D resistivity imaging is a multi-electrode geophysical data acquisition system with equal minimum spacing “a” between successive electrodes. A total of four (4) 2-D resistivity traverses were occupied with length varying from 100m (B, C and D) to 200m (A) in the study area (Fig. 1.0). The ABEM terrameter SAS 1000C with the Wenner-α electrode configuration were used for the field study.

Four electrodes were chosen at any one time for resistance measurement. Current were injected into the ground via two current electrodes (C1 and C2) located at the exterior of the potential electrodes (P1 and P2). Current and potential electrodes were moved from one end of the traverse to the other in a leap frog manner until spacing’s of 1a, 2a, to a maximum of 6a was acquired to build a pseudo section of the lateral and vertical variation in subsurface resistivity for the entire traverses (Fig. 3.0).

The potential difference between the potential electrodes was measured and the resistance of the ground was calculated automatically and displayed by the meter.

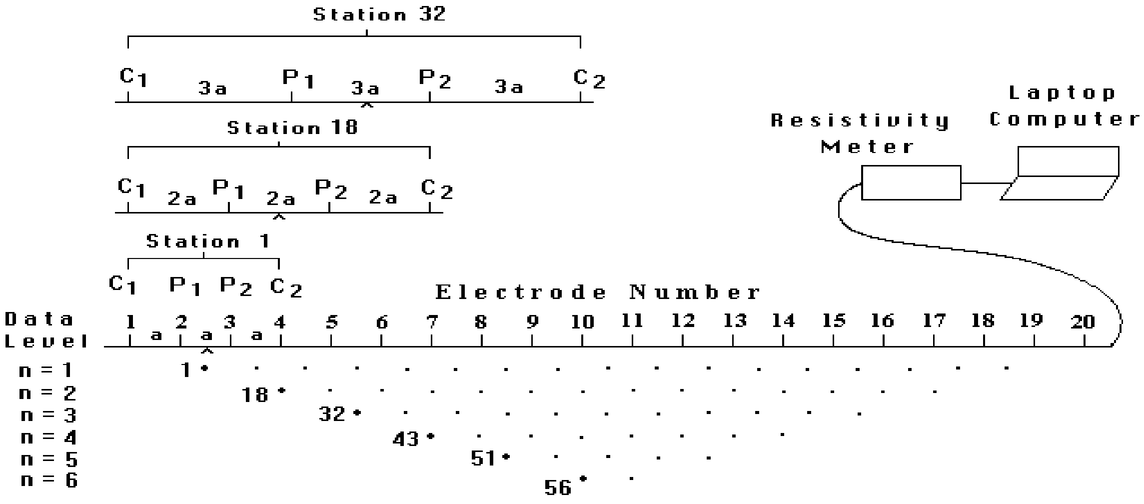

Fig. 3.0: The arrangement of electrodes for a 2-D electrical survey [17]

The resistance values obtained from the field were converted into apparent resistivity values using the equation:

$$\rho_a = 2\pi aR \qquad (1)$$

where a = electrode spacing

R = Resistance of the ground recorded by the resistivity meter.

The resulting apparent resistivity data were recorded in a recording data sheet for subsequent analysis.

Soil, leachate and water samples and their controls were collected around the dump site with black air tight polythene bags and well cocked 1.5 litre plastic bottles for Gamma ray Spectroscopy. The soil samples weighing 200g each were collected between depths of 15cm to 20cm using a coring tool on selected points around the dump site. The leachate samples were collected at the edges of the dump, while the water sample was collected from a monitoring borehole SW of the dump.

The soil and groundwater control samples were collected 150m away from the dump. The soil samples were sieved through a 2mm mesh screen and then placed in a Petri dish container for 30 days to enable the samples reach secular equilibrium before analysis. The samples were subsequently analysed for radionuclide activity using a Canberra vertical high purity 3”x3” NGI (TI) detector coupled to a Canberra series 10 plus multichannel analyser (MCA), through a preamplifier base.

V. Presentation Of Results

The calculated apparent resistivity (ρa) values, the X-location of the electrodes, and the electrode spacing's were keyed into text files for subsequent inversion using the RES2DINV imaging interpretation software [17]. The finite element approach to the forward model and least square inversion scheme were implemented in the inversion process. This generated inverse model sections of the true resistivity (ρ) variations with depth in the subsurface for the traverses (A-D).

The inverse model sections show a gradational variation in resistivity with depth related to contaminant impact due to the solid waste landfill in the area (Figs. 4.0 – 7.0).

5.1 Traverse A

This is situated along the NE-SW and 20m away from the edge of the dump to the north (Fig. 4.0). The inverse model section delineated two dinstintive anomalous zones. These are the high resistivity zones (purple to pink) to the SW with resistivity ranging from 630Ωm to >1361Ωm at surface points between 12.5m to 80m, and depth ranging from 1.25m to 6.30m. This is interprted as waste gas contaminated soil. Underlying this high resistivity zone is the low resistivivty anomaly (deep blue) extending from the NE to SW of the section. This has resistivity ranging from < 6.39Ωm to > 30Ωm and depth ranging from 9.94m to 26.2m. This is interpreted as leachate contaminated soil. These suspected waste gases and leachate seems to be migrating to the NW-SE in line with the trend of the Niger delta complex and regional groundwater flow in the area.

5.2 TRAVERSE B

This is situated along the NE-SW and 10m away from the edge of the dump to the north (Fig. 5.0). It exhibits two dominant anomalous zones in the inverse model section. The low resistivity anomaly (deep blue) occur to the SW of the section with resistivity ranging from < 0.406Ωm to 3.52Ωm at surface points between 12.5m t0 35m and depth ranging from 0.62 to 10.0m.This is interpreted as leachate contaminated soil. To the central and NE of the section is a semi-oval high resistivity anomaly (pink to purple) with resistivity varying from 146Ωm to > 779Ωm at surface points btween 50m to 80m and depth ranging from 8.64m to 15.6m. This is interpreted as waste gas contamination of soil at the investigated depth.

5.3 Traverse C

Traverse C is situated along the NE-SW and 10m away from the edge of the dump to the south (Fig. 6.0). This traverse delineated two dominant low and high resistivity anomalies. Two high resistivity anomalous regions (pink to purple) were mapped to the NE and SW of the section with resistivity varying from 715Ωm to >1194Ωm at surface points between 25m to 45m and 60m to 105m, respectively, and depths varying from 0.625m to 11.5m. This is interpreted as waste gas contaminated soil. Sandwiched between these high resistivity anomalies is a low resistivity anomaly (deep blue) of resistivity varying from < 33.2Ωm to 92.3Ωm at surface points between 55m to 70m , and depth varying from 0.625m to 3.38m.This is interpreted as soil contaminated by downward migrating leachate plume.

5.4 Traverse D

This traverse is situated along the NW-SE and 10m from the edge of the dump (Fig.7.0). It lies at right angle to the other profiles (A, B and C) to the west. Two dominant low and high anomalous zones were delineated. The low resistivity anomaly (deep blue) was mapped on the surface of the section stretching throughout the entire length of the traverse. It has a resistivity varying from < 2.09Ωm to 5.05Ωm and depth varying between 0.625m to >3.38m. This is interpreted as leachate contaminated soil. Underlying this low resistivity anomaly, is the high resistivity anomaly (pink to purple) with resistivity varying between 2316Ωm to >3459Ωm and depth varying between 6.72m to 15.6m. This also stretches throughout the entire section of the profile and is interpreted as waste gas contaminated soil.

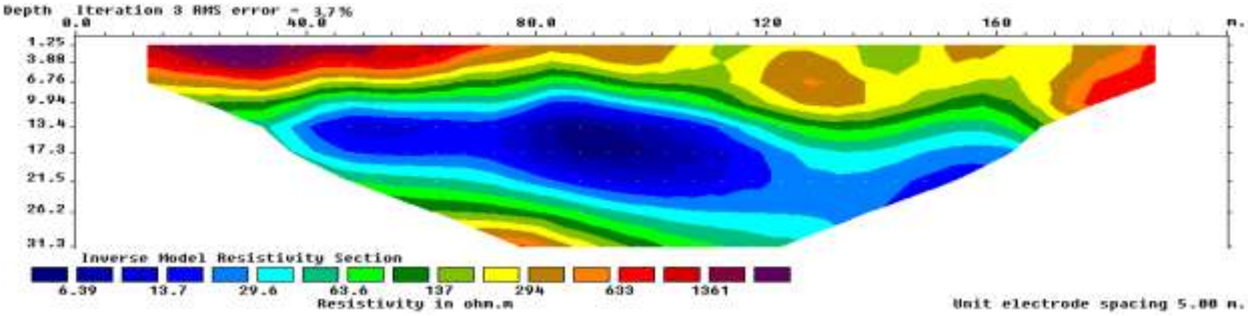

Fig. 4.0: Inverse model resistivity section along traverse A

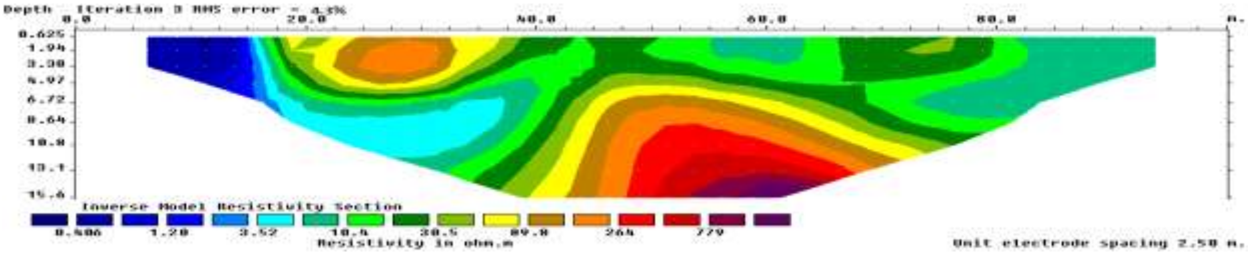

Fig. 5.0: Inverse model resistivity section along traverse B

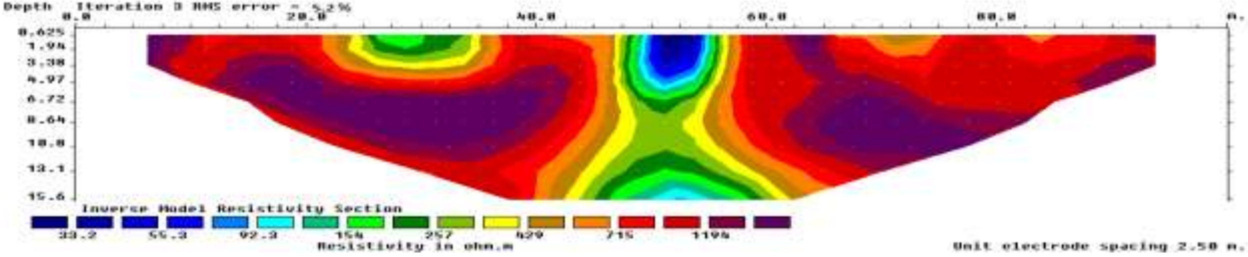

Fig. 6.0: Inverse model resistivity section along traverse C

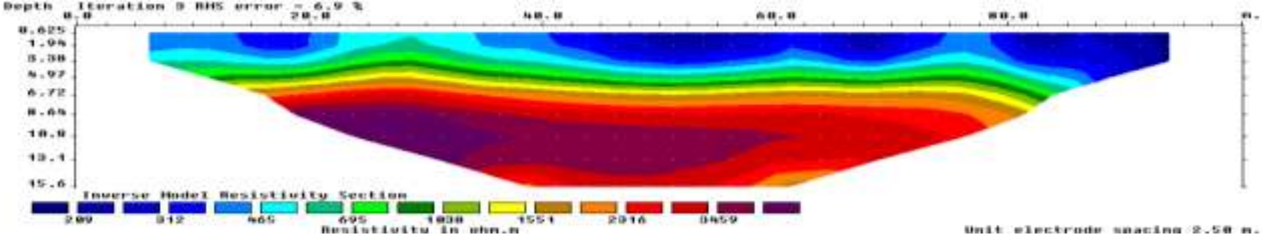

Fig. 7.0: Inverse model resistivity section along traverse D

VI. Gamma Ray Spectrometry Analysis

The soil, water, and leachate samples were analysed in the laboratory using the gamma ray spectroscopy. This was done to isolate radionuclide species present in the samples and to determine their specific activities and dose rates. Three dominant radionuclides were isolated from the spectrometry analysis. These belongs to the decay daughter products of naturally occurring radioactive elements of ^{238}U (Ra-226), ^{232}Th (Ra-228) and ^{40} K. The result show that the mean specific activity concentration of the radionuclides is highest in the soil samples and least in the water samples (Tables 1- 3). This is expected due to the low specific activity of radionuclides in water. However, the mean activity of leachate is greater than that of the water samples. This could be attributed to enhance concentration of radionuclides in the leachate due to the municipal dump.

The ^{40}K radionuclide has the highest mean activity concentration followed by the ^{238} U (Ra-226), and ^{232}Th (Ra-228) the least in the three samples. ^{40}K radionuclide has mean activity concentration of 326.47± 28.44 (Bqkg^{-1}), 186.39±20.17 (BqL^{-1}) and 120.50±37.43(BqL^{-1}), while ^{238}U (Ra-226) has 25.58±7.34(Bqkg^{-1}), 2.87± 2.70 (BqL^{-1}) and 1.95±0.84 (BqL^{-1}), and ^{232}Th (Ra-228) has 10.97±3.79 (Bqkg^{-1}), 2.18±0.99 (BqL^{-1}) and 2.01 ±0.09 (BqL^{-1}) for the soil, leachate and water samples, respectively.

Table 1: Radionuclide Concentrations of Soil Samples (Bqkg^{-1})

Samples	^{40}K	^{238}U (Ra-226)	^{232}Th (Ra-228)
Soil A1	484.70±34.92	34.26 ± 9.25	15.27 ± 6.07
Soil B1	296.81 ± 24.82	19.08 ± 8.22	8.27 ± 3.02
Soil C1	223.02 ± 21.92	25.82 ± 3.98	9.24 ± 2.11
Soil D1(Control)	301.35 ± 32.09	23.16 ± 7.92	11.09 ± 3.97
Mean Values	326.47±28.44	25.58±7.34	10.97±3.79

Table 2: Radionuclide Concentrations of Leachate Samples (BqL^{-1})

Samples	^{40}K	^{238}U (Ra-226)	^{232}Th (Ra-228)
Leachate A2	274.12 ± 24.91	2.73 ± 1.09	2.22 ± 0.97
Leachate B2	98.65 ± 15.44	3.01 ±1.08	2.13 ± 1.02
Mean Values	186.39±20.17	2.87±2.70	2.18±0.99

Table 3: Radionuclide Concentration of Water Samples (BqL^{-1})

Samples	^{40}K	^{238}U (Ra-226)	^{232}Th (Ra-228)
Water C2	132.31 ± 14.53	2.45 ± 0.99	1.99 ± 0.98
WaterD2 (Control)	109.66 ± 22.90	1.44 ± 0.77	2.03 ± 1.00
Mean Values	120.50±37.43	1.95±0.84	2.01±0.09

The absorbed dose rate (nGy/hr) and equivalent dose rate (mSv/yr) of these samples were calculated from the specific activities of these radionuclides (Tables 4-6). The result shows that the soil samples exhibit the highest absorbed and equivalent dose rates, while the water samples the least. The mean absorbed and equivalent dose rates for the soil, leachate and water samples are 31.98nGy/hr and 0.2mSv/yr, 10.51nGy/hr and 0.09mSv/yr, and 6.98nGy/hr and 0.06mSv/yr, respectively.

The mean values of the specific activities, absorbed dose and equivalent dose rates for the soil and water samples are greater than their controls. This suggests elevated concentrations of radionuclides due to land filling activity. The mean specific activity of ^{232}Th in soil and water samples are less than their controls, attributed to effects of local geology and varying solubilities ^{232}Th (Ra-228) in the samples.

Table 4: Absorbed dose rate and Equivalent dose rate of Soil Samples

Samples	Absorbed Dose Rate (nGy/hr)	Equivalent Dose Rate (mSv/yr)
Soil A1	45.22	0.40
Soil B1	26.16	0.23
Soil C1	26.60	0.23
Soil D1(Control)	29.98	0.26
Mean Values	31.98	0.28

Table 5: Absorbed dose rate and Equivalent dose rate of Leachate Samples

Samples	Absorbed Dose Rate (nGy/hr)	Equivalent Dose Rate (mSv/yr)
Leachate A2	14.16	0.12
Leachate B2	6.85	0.06
Mean Values	10.51	0.09

Table 6: Absorbed dose rate and Equivalent dose rate of Water Samples

Samples	Absorbed Dose Rate (nGy/hr)	Equivalent Dose Rate (mSv/yr)
Water C2	7.93	0.07
Water D2 (Control)	6.03	0.05
Mean Values	6.98	0.06

VII. Discussion Of Results

The radiological impact of a municipal solid waste landfill on soil and groundwater was investigated by integrating 2-D resistivity imaging and gamma ray spectroscopy. There is strong evidence of soil and ground water contamination from the results of this study due to solid waste land filling activity. The results of the 2-D resistivity imaging along the four (4) traverses revealed that the soil and groundwater in the vicinity of the dump have been contaminated by leachate and waste gases (probably, NH_4, CH_4, CO_2, H_2S, and SO_2), with resistivity varying from < 0.406Ωm to 388.5Ωm, and 264Ωm to >3459Ωm, respectively.

These have penetrated to depths exceeding 31m, which is within the productive aquifer bed in the area. This poses serious health challenges to the inhabitants who depend on the groundwater in the area for their potable water supply due to disease causing micro-organisms and heavy metal poisoning. This revelation is collaborated by the results of the gamma ray spectroscopy which isolated three radionuclide contaminants in the soil, groundwater, and leachate samples. These are ^{226}Ra and ^{228}Ra, which belongs to the decay series of ^{238}U and ^{232}Th, respectively, as well as the non series ^{40}K radionuclide.

The activity concentration of K-40 in the soil samples ranges from 223.02-484.7$Bqkg^{-1}$, with a mean value of 326.47± 28.44$Bqkg^{-1}$. This result is greater than the mean value of 131.8$Bqkg^{-1}$ for soil samples reported by [18], around a nuclear research establishment in Nigeria and lower than 375.66±20.5$Bqkg^{-1}$reported [19] in some selected dumpsites in southwest Nigeria. The activity concentration of ^{238}U (Ra-226) ranges from 19.08 to 34.26$Bqkg^{-1}$ with a mean value of 25.58±7.34$Bqkg^{-1}$. This is lower than the mean value of

53.83±17.5Bqkg^{-1} reported by [19]. The activity concentration of ^{232}Th (Ra-228) ranges from 8.27 to 15.27 Bqkg^{-1}, with a mean value of 10.97±3.79Bqkg^{-1}. This is lower than the mean value of 64±17 Bqkg^{-1} reported by [19]. The ^{40}K is the largest contributor of radionuclide activity concentration in soil samples in the area.

The absorbed dose rate of ^{40}K ranges from 26.60 to 45.22nGy/hr, with a mean value of 31.98nGy/hr for the soil samples. This moderately lies within the range of measured values (20.831-44.95) nGy/hr, with a mean value of 33.65nGy/hr in the five Niger delta states [20]. This is higher than the mean value of 29.3 nGy/hr reported by [21] in a dumpsite in Abeokuta, Nigeria, 20.04nGy/hr reported by [5] from a dumpsite in Port Harcourt, 19.96nGy/hr reported by [22] in eighteen cities across Nigeria, but lower than the mean value of 76.83nGy/hr reported by [19], in some selected dumpsites southwest Nigeria. The high values of activity concentration and absorbed dose rates reported by [19] were attributed to the basement rock exposures in the area contributing to the background radiation.

The mean dose equivalent of the soil samples varies between 0.23-0.40 mSv/yr, with a mean of 0.28 mSv/yr. This is greater than the value of 0.24 mSv/yr for a similar study in Port Harcourt [5].

The activity concentration of leachate samples for ^{40}K ranges from 98.65 to 274.12 (BqL^{-1}) with a mean value of 186.39± 20.17 (BqL^{-1}), for ^{238}U (Ra-226), this ranges from 2.73 to 3.01 (BqL^{-1}), with a mean value of 2.87± 2.70 (BqL^{-1}) and 2.13 to 2.22 (BqL^{-1}), with a mean of 2.18±0.99 (BqL^{-1}) for ^{232}Th (Ra-228). The mean absorbed and equivalent dose rates of the leachate samples are 10.51nGy/hr and 0.09mSv/yr, respectively.

The activity concentration of groundwater samples ranges from 109.66 to 132.31 (BqL^{-1}), with a mean of 120.50 ± 37.43 (BqL^{-1}), 1.44 to 2.54 (BqL^{-1}), with a mean value of 1.95±0.84 (BqL^{-1}), and 1.99 to 2.03 (BqL^{-1}), with a mean of 2.01±0.01 (BqL^{-1}) for ^{40}K, ^{238}U (Ra-226) and ^{232}Th (Ra-228), respectively. The mean dose rate and equivalent dose rate of the water samples are 6.98 nGy/hr and 0.06mSv/yr, respectively.

The study revealed elevated concentration of the radionuclides in the soil, groundwater and leachete samples in the vicinity of the dump than their controls. This suggests that the waste dumpsite area has been contaminated by the activities of the dump site. The absorbed dose rate and the equivalent dose rate of the samples are however, within the world average of 55.0nGy/hr [1] and 1.0mSv/yr [23], respectively, for the soil samples, and 0.1 mSv/yr for groundwater [23].

VIII. Conclusion

The 2-D resistivity imaging delineated leachate contaminant plumes and landfill gas in soil and groundwater around the dump site in the entire four traverses. These contaminants have penetrated to depths exceeding 31m which is within the groundwater aquifer system in the area. This portends great danger to the resource users, due to disease causing micro-organisms, radiological impacts and heavy metal poisoning.

Three radionuclide species were isolated from the gamma ray spectroscopy namely; ^{40}K, ^{238}U (Ra-226) and ^{232}Th (Ra-228). The result shows that the mean absorbed and equivalent dose rates due to activity concentration of these radionuclides in soil and water samples are greater than their controls, suggesting that the dumpsite area is contaminated. The mean absorbed and equivalent dose rates are 31.98nGy/hr, 10.51nGy/hr and 6.98nGy/hr and 0.28mSv/yr, 0.09mSv/yr and 0.06mSv/yr, respectively, for the soil, leachate and water samples. This is comparable to those reported for other dumpsites in Nigeria, but lower than the world average of 50.0Gy/hr and 1.0mSv/yr for soil, and 0.1mSv/yr for potable water.

These therefore, do not pose any serious health problem to the inhabitants of the dumpsite area who depends on the soil for their agricultural activities and groundwater as their only source of potable water. However, with continuous consumption of crop products and intake of groundwater, increase in the activity concentration and dose rates of these radionuclides may occur over time with adverse effects on humans.

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