Available online at www.equijost.com

Equity Journal of Science and Technology, 2023 10(1): 15 - 22

ISSN 2354-1814; E-ISSN 2683-5961

EQUIJOST *An Official Publication of Kebbi State University of Science and Technology, Aliero, Nigeria*

Radiological assessment of the impact of municipal solid waste dumpsite on soil and groundwater using electrical resistivity and gamma ray spectroscopy

*[1]Adenuga, O. Abosede, [1]Ajetunmobi A. Ekundayo, [1]Oladunjoye H. Titi, [1]Adekoya A. Sofiat, [2]Badmus G. Olabode
[1]Department of Physics, Olabisi Onabanjo University, Ago-Iwoye
[2]Department of Mathematical and Physical Sciences, Afe Babalola University, Ekitti
*Corresponding Author's email: adenuga.omolara@oouagoiwoye.edu.ng

Abstract
The radiological assessment of the impact of municipal solid waste dumpsite on soil and groundwater in the vicinity of dumpsite was investigated using electrical resistivity method and gamma ray spectroscopy. The research aims at determining the extent of contamination on the soil, groundwater and evaluation of the radioactivity concentrations in soil and groundwater. Twenty (20) samples of soil were taken on the active and dormant parts of the dumpsite were analyzed. Fourteen (14) Vertical Electrical Soundings were also carried out on and around the dumpsites. Based on the results obtained using the VES, the subsurface information revealed the lithological units of the subsurface and the extent the leachate has migrated through the sand available on the dumpsite vicinity. Leachate has penetrated into depths of about 30m into the groundwater aquifer. The radiological assessment of the radionuclides ^{40}K, ^{226}Ra and ^{228}Ra obtained for the active dumpsite revealed the absorbed dose rates, annual effective dose rates for the active dumpsite ranged from (313.35–1670.29) nGy/h with the mean of 926.33 nGy/h and (0.001–0.31) mSv/y with the mean of 0.15 mSv/y. The mean value for the radium equivalent (211.97) is lower than the permissible limit 370. The absorbed dose rates, annual effective dose rates for the dormant dumpsite ranged from (395.97–1038.38) Bq/kg with the mean of (813.15 nGy/h and 2.43–6.37) µSv/y with the mean of 0.14µSv/y. The mean value for the radium equivalent (185.71) is lower than the permissible limit 370. These results are compared to those reported for other research done on dumpsites, and the dormant part of the dumpsite was found lower than the standard and that of the active dumpsite pose serious threat to the wellbeing of the people near or working there. Results reveals that soil on the active part of the dumpsite have been contaminated by radioactive materials all through the dumpsite area.

Keywords: Vertical Electrical Sounding, Leachate, Gamma-Ray spectrometry, Radionuclides, Mean Absorbed Dose Rate.

1. Introduction

The effect of indiscriminate waste dump on our lands poses a serious threat to the health of the populace across the world. In most developing countries, open dumpsite practice is the common waste disposal method used. In this, citizens or government just picked any available land for waste disposal without putting into consideration the adverse effect of un-engineered dumpsites [1]. The hazard posed by the contamination from leachates produced on dumpsites is not only in terms of the offensive smell and availability of disease-causing micro-organisms, but also from leachate infiltration as a result of non-availability of impermeable materials and radiations arising from the waste disposed [2]. The environment is constantly bombarded with lots of ionizing radiations from man-made and natural sources. The most common radionuclides in soil and groundwater are the three natural decay series, ^{235}U, ^{232}Th and ^{40}K and their concentrations vary considerably depending on the soil type and local geology.

The leachates produced from municipal solid waste find its way to pollute the soil and groundwater. In developing country especially Nigeria, open dumpsites are the most widely used un-engineered waste disposal facility. The wastes are combination of industrial, commercial and agricultural unused products. These wastes contain traces of radiological elements or radionuclides resulting from chemicals, pesticides and fertilizers, chemotherapy, food waste materials, gas and oil production [3]. Most of human exposure to these natural radiations arises from radon present in the rocks and soil. The toxic metals found in the soil and groundwater around the waste dump sites are lead, cadmium, mercury, chromium etc., which is harmful to plants, animals and human beings. Human beings acquire radiations from waste disposal through external irradiations. Local geology, geochemistry and specific solubility of the radionuclide are measures that can be adopted to control the occurrence and distribution in soil and groundwater [4].

In view of this, it is necessary to monitor terrestrial background radiations, most importantly from municipal solid waste sites. It is required simply because the underlain soils and groundwater around dumpsites may possibly contain natural occurring radionuclides in substantial amounts due to waste dump activities [5]. The percolation of radionuclides may result in contamination of the soil and groundwater with severe consequences on human health over time.

Waste disposal sites studies have been done by several researchers, both the study of radioactivity concentration and geophysical investigations, to determine the effects of radionuclides and subsurface characterization of the geological underlain materials. The electrical resistivity technique especially helps to detect the vertical and lateral resistivity changes associated with variations in fluid saturation and composition. The extent of contamination by leachates can also be determined by the electrical resistivity method [7, 8, 9]. The activity concentration and dose rates of radionuclides as well as the extent of pollution by geophysical method have been done at Ijagun dumpsite in Ijebu Ode environs.

2. STUDY AREA

Th**e** study area is located at Ijagun Ijebu Ode in Ogun State, southwestern Nigeria. Ijagun dumpsite is densely populated and its accessible. It is situated outside the major city of Ijebu Ode but along the major road that links Ogun to Benin City. The dumpsite is the largest dumpsite in Ijebu Ode as approved by the state government over 20 years ago. Geologically, the study area lies in the sedimentary part of Nigeria under the cretaceous sediments of Abeokuta group [10] and located between longitudes E $3^0 47' 377''$ - $3^0 47' 483''$ and latitude $6^0 56' 393''$- $6^0 56' 564''$ at Ijagun community. The map showing several communities in Ijebu Ode and its environs with the geological features is presented in Figure 2.1.

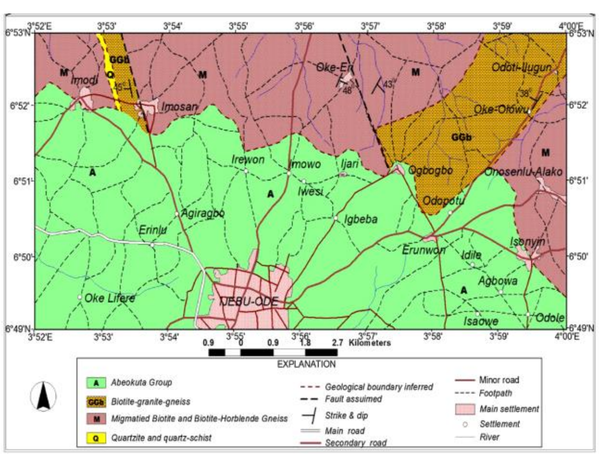

Figure 2.1: Geological map of Ijebu Ode and its environs [18]

3. Methodology

Two methods were adopted for this research. Vertical Electrical Soundings (VES) and radiological assessment methods. Firstly, samples were taken at the northwestern and northeastern part of the dumpsite for the radiological assessment. The northwestern part of the dumpsite is the active part of the dumpsites where there are heaps of waste while the northeastern part of the dumpsite serves as control which is about 200 meters away from the waste site. Twenty (20) samples of soil were taken at both locations (10 each at northwest and northeast) at the dumpsite. The samples were set following the standard methods [7]. The collected soil samples were taken to the laboratory, air dried to remove moistures, pulverized into fine powder for greater surface area using a mini mortar and pestle before homogenized by sieving with a 2mm sieve. The dried samples weighted 0.5kg were measured, packed into a white cylindrical plastic (PVC) container, labeled appropriately, sealed and airtight with a paper tape.

The weight of the empty container was recorded (w1kg), the pulverized sample packaged into the container was weighted (w2kg) and the final weight (W_3 in kg) was calculated by subtracting the weight of the empty plastic container (W_1 in kg) from the weight of the sample plus the container (W_2 in kg).

$$W_3 = (W_2 - W_1)kg \qquad (1)$$

The container was sealed and airtight to prevent the escape of gaseous 220Rn and 222Rn, incubated for twenty-eight (28) days which is about a month to bring the daughter radionuclide into secular radioactive equilibrium with their respective long-lived parents.

At the end of the four weeks in-growth period, the samples were subjected to gamma-ray spectroscopy counting and were transported to the radiation laboratory at Federal University of Abeokuta (FUNAAB) for specific activity concentration measurement. For the VES, fourteen (14) profiles were carried out both on the dumpsites and points that served as control points. The Schlumberger array was adopted. The current and potential electrodes were injected into the ground to build a pseudo section of the vertical variation in subsurface resistivity for the whole traverses. The midpoint of the configuration was kept fixed while the distance between the current electrodes progressively increased. The potential differences between the potential electrodes were measured and the resistance was obtained. It was conducted along the traverse with electrode spacing AB/2 of 100m, which was analyzed using computer WinResist software which reduced the error to an acceptable value [11]. This was done to determine the variation in resistivity values with respect to depth.

4. Results and discussions

The soil samples were analyzed in the laboratory using gamma spectroscopy. The process was done to isolate radionuclide species present in the samples and also to obtain the specific activities and dose rates. The major three radioactive elements ^{234}U (Ra-226), ^{232}Th (Ra-228) and ^{40}K were analyzed and reported in the Tables 4.1 – 4.4.

Table 4.1: Activity concentrations of soil samples at the dormant part of dumpsite at Ijebu-Ode

Sample ID	^{226}Ra	^{232}Th	^{40}K
DI	42.71 ± 2.67	60.90 ±3.62	85.99 ±3.94
D2	58.79 ±7.67	111.48 ±11.23	224.06 ±24.89
D3	64.78 ±7.16	80.43 ±2.37	95.93 ±6.10
D4	67.03 ±3.77	67.11 ±4.81	189.98 ±10.72
D5	35.79 ±3.97	120.89 ±10.94	93.56 ±8.13
D6	25.84 ±4.61	132.16 ±9.98	169.77 ±7.21
D7	61.85 ±2.50	84.82 ±7.42	85.55 ±2.18
D8	34.67 ±2.67	139.79 ±10.51	79.29 ±3.47
D9	22.94 ±1.63	45.32 ±2.46	38.99 ±3.03
D10	36.62 ±4.54	76.59 ±8.88	121.79 ±11.65
Mean	45.10 ±	91.94 ±	118.49 ±

The Northeastern part of the dumpsite in the study is taken as the dormant part of the dumpsite where users of the site generally hardly dispose their wastes. It can also serve as control for the study. The activity concentrations of the ^{226}Ra, ^{232}Th and ^{40}K ranged from 22.94–to 67.03 Bq/kg, with the mean of 45.10 Bq/kg, 45.32–to132.16 Bq/kg with the mean of 91.94 Bq/kg and 38.99 to 189.98 Bq/kg with the mean of 118.49 Bq/kg respectively. Comparing the results to that of the dormant values of [12,13] where the activity concentrations of of ^{238}U, ^{232}Th and ^{40}K were reported to have the mean values of 61.25 Bq/kg ,12.08 Bq/kg and 345.9 Bq/kg respectively. The mean value for the activity concentrations of ^{238}U is higher than the value reported for their study while the activity concentrations of ^{40}K reported in their study is greater than the present study as indicated in Table 4.2. However, the mean value of the activity concentrations of ^{232}Th reported in the present study is greater than that reported in their study

Table 4.2: Activity concentrations of soil samples at the active part of dumpsite at Ijebu-Ode

Sample ID	^{226}Ra	^{232}Th	^{40}K
AI	36.54 ± 3.84	16.36±1.15	109.65 ±5.21
A2	57.24 ±3.61	99.16 ±2.09	88.43±7.92
A3	9.83 ±1.39	152.22±12.12	114.79 ±8.51
A4	154.81 ±26.42	150.74 ±9.32	106.94±5.69
A5	22.43±1.33	26.20±1.10	108.97 ±9.04
A6	14.98 ±1.58	105.09 ±4.66	100.54±6.42
A7	74.29±5.52	197.37±9.84	221.99 ±7.49
A8	BDL	94.33 ±3.98	46.06 ±2.05
A9	58.76±5.16	78.27±3.96	84.16 ±4.98
A10	80.20 ±2.31	143.08 ±10.79	198.18±7.59
Mean	50.91 ±	106.31 ±	117.97 ±

The Northwestern part of the dumpsite in the study is taken as the active part of the dumpsite where users of the site generally dispose their wastes. The activity concentrations of the ^{226}Ra, ^{232}Th and ^{40}K ranged from (9.83 - 154.81) Bq/kg, with the mean of 50.91 Bq/kg, (16.36 - 197.37) Bq/kg with the mean of 106.31 Bq/kg and (46.06 - 221.99) Bq/kg with the mean of 117.97 Bq/kg respectively. Comparing the result with that of the active values of activity concentrations of the radionuclides in the soil samples at the dumpsite reported by [13], with the mean activity concentrations of ^{238}U, ^{232}Th and ^{40}K being 69.69 Bq/kg , 14.49 Bq/kg and 409.44 Bq/kg respectively. The mean values for the activity concentrations of ^{238}U and ^{40}K are higher than the value reported for the present study. Oriyomi *et al.* [14] worked on soils of a dumpsite at Agbara in Lagos and reported that the activity concentrations of ^{238}U, ^{232}Th and ^{40}K were $(11.50\ ,166.0\ and\ 15.6\ )$ Bq/kg respectively. The values of the activity concentrations of ^{238}U and ^{40}K are lower than that reported in the present study. Similarly, [15], reported that the mean activity concentrations of ^{238}U, ^{232}Th and ^{40}K to be (24.06 , $30.45\ and$ 368.25) Bq/kg respectively. These values are all lower than the values reported in the present study. Ulakpa *et al.* [16] Collected the samples at the dumpsites 2018 - 2019 but reported the work in 2021 and this necessitates the re-assessment of the activity concentrations of the radionuclides at the dumpsite at Ijebu Ode. This is necessary because of accumulated domestic and industrial waste over the years. The study is to check the level of safety of the activity concentrations of the radionuclides in the soil samples from the dumpsite since there are possible links (such as erosion and storms carrying soils and wastes) between the dweller in the area and the dumpsite location. The present study shows that the activity concentrations of ^{232}Th seems to be depleted compared to the values reported by Ulakpa *et al.* [16] (BDL–87.54) Bq/kg. This may be due to the solubility of ^{232}Th in water. [1] reported that the activity concentrations of 238U and 40K ranged from (49.71−314.15) Bq/kg and (BDL−3721.3) Bq/kg. This is quite higher than the values reported in the present study. This may be due the non- uniform distribution of the radionuclides in the soil samples collected in the studies.

The estimated radiological parameters for the dormant part of the dumpsites are lower than that of the values estimated for the active dumpsite in the present study. The absorbed dose rates, annual effective dose rates for the dormant dumpsite ranged from 395.97 to 1038.38 Bq/kg with the mean of 813.15 nGy/h and 2.43 to 6.37) μSv/y with the mean of 0.14μSv/y. The mean value for the radium equivalent (185.71) is lower than the permissible limit (370) [17] as indicated in Table 4.3. The external, internal and gamma indices values lie between 0.20-0.9 and are all lower than the permissible limits of 1, 1 and 1 respectively. The mean of the annual gonadal dose (561.1) μSv/y is also lower than the permissible limit (1000). The estimated excess lifetime cancer risk falls between (2.60–7.00) $\times 10^{-4}$ and is higher than the permissible limit of 2.9$\times 10^{-4}$.

Comparing the result of the present study with the work of Oladapo and Akerele [13] where they reported the values for Absorbed dose rates (nGy/h), annual effective dose rates (μSv/y), radium equivalent and excess lifetime cancer risks to range between 50.87− 67.31, with the mean of 56.40 nGy/h, 240.0–310.0 μSv/y with the mean of 280 μSv/y and 107.54–135.13 with the mean of 121.31 respectively.

Table 4.3: Estimated radiological parameters for dormant part of the dump site at Ijebu Ode

Sample ID	^{226}Ra (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	Absorbed Dose rate (nGy/h)	Annual Effective Dose (mSv/y)	Radium Equivalent	External Index	Internal Index	Annual Gonadal Dose (μSv/y) (AGD)	Gamma Index	Excess Lifetime Cancer risk ELCR (10^{-4})
D_1	42.71	60.90	85.99	601.01	0.11	136.42	0.37	0.48	414.0	0.48	3.87
D_2	58.79	111.48	224.06	1038.38	0.19	235.46	0.64	0.79	718.0	0.83	6.69
D_3	64.78	80.43	95.93	825.08	0.15	187.18	0.51	0.68	567.0	0.65	5.32
D_4	67.03	67.11	189.98	794.25	0.14	177.63	0.48	0.66	547	0.62	5.12
D_5	35.79	120.89	93.56	934.54	0.17	215.87	0.58	0.68	645	0.75	6.02
D_6	25.84	132.16	169.77	988.42	0.18	227.90	0.62	0.69	686	0.80	6.37
D_7	61.85	84.82	85.55	833.73	0.15	189.73	0.51	0.68	573	0.66	5.37
D_8	34.67	139.79	79.29	1037.57	0.19	240.68	0.65	0.74	716	0.84	6.69
D_9	22.94	45.32	38.99	395.97	0.01	90.75	0.25	0.31	273	0.32	2.55
D_{10}	36.62	76.59	121.79	682.57	0.12	155.52	0.42	0.52	472	0.55	4.40
Mean	**45.10**	**91.95**	**118.49**	**813.15**	**0.14**	**185.71**	**0.50**	**0.62**	**561.1**	**0.65**	**5.24**
W. A				**60nGy/h**	**1mSv/y**	**370**	**1**	**1**	**1000**	**1**	**2.9$\times 10^{-4}$**

Table 4.4: Estimated radiological parameters for active part of the dump site at Ijebu Ode

Sample ID	^{226}Ra (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	Absorbed Dose rate (nGy/h)	Annual Effective Dose (mSv/y)	Radium Equivalent	External Index	Internal Index	Annual Gonadal Dose (μSv/y) (AGD)	Gamma Index	Excess Lifetime Cancer risk ELCR (10^{-3})
A_1	36.54	16.36	109.65	313.35	0.060	68.38	0.18	0.28	216	0.24	0.20
A_2	57.24	99.16	88.43	900.25	0.170	205.85	0.56	0.71	619	0.72	0.58
A_3	9.83	152.52	114.79	1012.69	0.190	236.34	0.64	0.66	703	0.83	0.65
A_4	154.81	150.74	106.94	1670.29	0.310	378.60	1.02	1.44	1142	1.31	1.08
A_5	22.43	26.20	108.97	307.32	0.060	68.29	0.18	0.25	213	0.24	0.19
A_6	14.98	105.09	100.54	745.88	0.140	173.00	0.47	1.51	517	0.61	0.48
A_7	74.29	197.37	221.99	1627.90	0.290	373.62	1.01	1.21	1124	1.31	1.05
A_8	BDL	94.33	46.06	588.96	0.100	138.44	0.37	0.37	409	0.49	0.38
A_9	58.76	78.27	84.16	779.32	0.140	177.17	0.49	0.48	535	0.62	0.50
A_{10}	80.20	143.08	198.18	1317.37	0.0010	300.06	0.81	0.81	908	1.05	0.0002
Mean	**50.90**	**106.31**	**117.97**	**926.33**	**0.15**	**211.97**	**0.57**	**0.77**	**638.6**	**0.74**	**0.51**
W.A				**60nGy/h**	**1 mSv/y**	**370**	**1**	**1**	**1000**	**1**	**2.9$\times 10^{-4}$**

Again, the absorbed dose rates, annual effective dose rates for the active dumpsite ranged from 313.35–1670.29 nGy/h with the mean of 926.33 nGy/h and 0.001–0.31) mSv/y with the mean of 0.15 mSv/y. The mean value for the radium equivalent (211.97) is lower than the permissible limit (370**)** according to UNSCEAR [17] standard and as indicated in Table 4.4. The external, internal and gamma indices values lie between 0.19 - 1.52 and are all lower than the permissible limits of 1, 1 and 1 respectively. The mean of the annual gonadal dose (638.6) μSv/y is also lower than the permissible limit (1000). The estimated excess lifetime cancer risk falls between (0.0001−1.09) $\times 10^{-3}$ and is again higher than the permissible limit of 2.9×10^{-4}.

4.1 Electrical resistivity result (using VES Technique)

The obtained apparent resistivity values were analyzed using the log-log graph sheet to smoothen the curve before subjecting to WinResist software for iteration to obtain the best fit. This helped to delineate the lithology and thickness of each layer. The result is presented in the geoelectric section giving the subsurface information of the probed study area and also revealing contaminated zones.

4.2 Geoelectric section presentation of the VES on the dumpsite

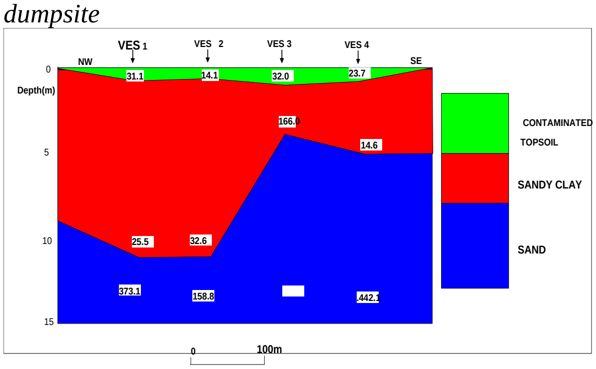

Figure 4.1: Geoelectric section of traverse 1 (VES 1, 2, 3 and 4)

4.2.1 Interpretation of traverse 1

The traverse (Figure 4.1) consists of four VES point which are VES 1,2,3 and 4. The resistivity of the topsoil is 31.1 Ohms, 14.1 Ohms, 32.0 Ohms and 23.7 Ohms, the second Layer is Sandy clay layer with resistivity value of 22.5 Ohms, 32.6 Ohms, 166.0 Ohms and 14.6 Ohms. The last layer which is sand layer with resistivity value of 373.1 Ohms, 158.8 Ohms, 442.1 Ohms respectively. This traverse is showing that leachate has percolated through the sand to the groundwater which will eventually contaminate the water. It is therefore noted that the soil around the dumpsite has also been polluted.

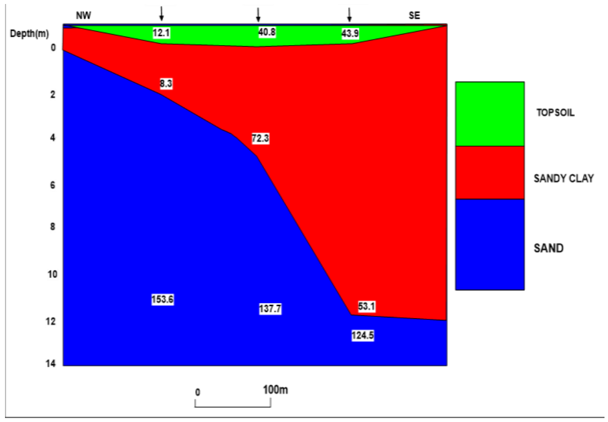

Figure 4.2: Geoelectric section of traverse 2 (VES 5, 6 and 7)

4.2.2 Interpretation of traverse 2

The traverses (Figure 4.2) consist of three VES point which are VES 5, 6 and 7. The resistivity of the topsoil is 12.1 Ohms, 40.8 Ohms, and 43.9 Ohms. The second Layer is Sandy clay layer with resistivity values of 8.3 Ohms, 72.3 Ohms and 53.1 Ohms. The last layer which is sand layer with resistivity value of 153.6 Ohms, 137.7 Ohms and 124.5 Ohms respectively. This traverse is showing that leachate has percolated through the sand to the groundwater which will eventually contaminate the water and the soil for agricultural purposes. It is therefore noted that the soil around the dumpsite has also been polluted.

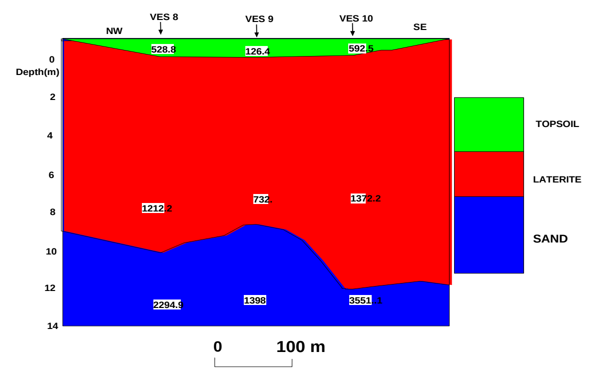

Figure 4.3: Geoelectric section of traverse 3 (VES 8, 9 and 10)

4.2.3 Interpretation of traverse 3

The traverse (Figure 4.3) consists of four VES point which are VES 8, 9 and 10. The traverse falls at the dormant part of the dumpsite which serves as control. The resistivity of the topsoil is 528.8 Ohms, 126.4 Ohms and 592.5 Ohms. The second Layer is inferred as with resistivity value of 1212.2 Ohms, 732.5 Ohms and 1372.2 Ohms. The last layer which is sand layer with resistivity value of 2294.9 Ohms, 1398 Ohms and 3551.1 Ohms respectively. This traverse is showing that leachate had found its way to the subsurface through the sand and might have polluted the groundwater. It is therefore noted that the soil around the dumpsite has also been polluted. It is not safe for plant and human beings in the vicinity.

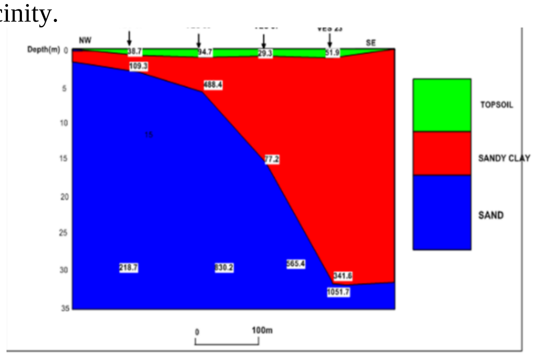

Figure 4.4**:** Geoelectric section of traverse 4 (VES 11, 12, 13 and 14)

4.2.4 Interpretation of traverse 4

This transverse (Figure 4.4) is made up of four (4) VES Point which include VES 11, VES 12, VES 13 and VES 14. Taken meters away from the dumpsites. The resistivity of the topsoil is 38.7 Ohms, 94.7 Ohms, 29.3 Ohms and 51.9 Ohms. The second Layer is a sandy clay layer with resistivity values of 109.3 Ohms, 488.4 Ohms, 77.2 Ohms and 341.6 Ohms. The last layer which is sand layer has resistivity values of 218.7 Ohms-m, 830.2 Ohms, 565.4 Ohms and 1051.7 Ohms respectively. From the inferred lithology, it is possible for leachate to percolate through the available geological materials on this profile, therefore, it can be concluded that the soil around the vicinity of the dumpsite is polluted which will definitely affect the underground water.

5. Conclusions

The Vertical Electrical Sounding (VES) technique of the electrical resistivity method was used to delineate contaminant zones and impact of leachate on soil and groundwater around the dumpsite location. The leachates produced from the decomposed waste have penetrated to depths of about 30m which is within the groundwater aquifer system in the area. This reveals great danger to the resource users, due to disease causing micro-organisms, radiological impacts, and heavy metal poisoning.

The major three radionuclide species were isolated from the gamma ray spectroscopy like, ^{40}K, ^{238}U (Ra-226) and ^{232}Th (Ra-228). Most of the estimated radiological parameters associated to exposure of the public and workers at the active and dumpsites at Ijebu- Ode are below the permissible limit. The estimated values of the dormant dumpsites are all lower than the active dumpsite. This connotes a higher exposure to radionuclides from the active dumpsite when compared to the dormant dumpsite. Conclusively, the workers and the general public are not at risk to health challenges since the estimated radiological parameters are lower than the permissible limit.

6. Acknowledgements

We sincerely appreciate the Ogun state ministry of environment for giving us the permission to carry out surveys on the dumpsite. Also, we acknowledge the radiological unit of Federal University of Agriculture Abeokuta (FUNAAB) for taking their time in the laboratory to assist us in the procedures. This research is self-sponsored.

References

1. United Nations scientific committee on the effects and risks of ionizing radiation, source, effects and risks of ionizing radiation. report to the general assembly, United Nations, New York.1998
2. Christensen JB, Jensen DL, Gron C, Filip Z, Christensen TH. Characteristics of the dissolved organic carbon fraction in landfill leachate polluted groundwater. *Water Research*. 1998; 32(1): 125-135.
3. Ademola JA. Determination of natural radionuclides content in some building materials in Nigeria by gamma ray spectrometry. *Health Physics Society*. 2008; 94 (1): 43-48.
4. Ehirim CN, Itota GO. Radiological impact of a municipal solid waste dumpsite on soil and groundwater using 2D resistivity tomography and gamma ray spectroscopy. *Journal of environmental science, toxic and food technology*. 2013; 2(1): 35-42.
5. Jibiri NN, Adewuyi GO. Radionuclide contents and physiochemical characterization of solid waste and effluent samples of some selected industries in the city of Lagos, Nigeria. *Radioprotection*. 2008; 43(2): 203-212.
6. Avwiri GO. Determination of radionuclides level in soil and water around cement companies in Port Harcourt. *Journal of Applied Science & Environmental Management.* 2005; 9: 27-29.
7. Olayinka AI, Olayiwola MA. Integrated use of Geophysical Imaging and Hydro-chemical Methods in delineating limits of polluted surface and groundwater at a landfill site in Ibadan Area, S.W, Nigeria. *Journal of Mining and Geology*. 1991; 37 (1): 193-198.
8. Ehirim CN, Ebeniro JO, Ogwu DA. A geophysical and Hydro-physiochemical impact of a Solid Waste Landfill in Port Harcourt municipality, Nigeria. *Pacific Journal of Science & Technology*. 2009a; 10: 596-603.
9. 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 Journal of Science & Technology*. 2009; 10: 604-613.

10. Jones HA, Hockey RD. The Geology of Parts of Southwestern Nigeria. *Geological Survey of Nigeria.* 1994; 31:101 - 110.
11. Olatunde IP, Omolara AA. Determination of leachate curtailment capacity of selected dumpsites in Ogun State southern Nigeria using integrated geophysical methods. *Scientific African*. 2019; 6: e00208.
12. Farai IP, Okkwunakwe CE, Makinde OS. Gamma Spectrometric Assay of soil samples from waste dumpsites in Port Harcourt, Nigeria. In: *Proceedings of the 16th International Conference on Radionuclide Metrology 2007.* June – July 2007. Cape Town, South Africa: Elsevier BV; 2007. p. 850-854
13. Oladapo OO, Akerele TS. 2012. Assessment of Natural Radionuclides level in Wasteland Soils around Olusosun Dumpsite Lagos, Nigeria. *Journal of Applied Physics (IOSR-JAP).* 2012; 2(3): 38-43.
14. Oriyomi O, Oluwayemi O, Muideen G, Adejoke O. Chemical speciation of some heavy metals and human health risk assessment in soil around two municipal dumpsites in Sagamu, Ogun state, Nigeria. *Chemical Speciation and Bioavailability*. 2017; 20: 1-4
15. Gbadamosi MR, Abayomi AA, Afolabi TA, Adegboye MA, Bakare HO, Banjoko OO, Ogunneye AL, Ugbomeh IL, Jegede DO, Ajetunmobi AE, Bakare TE. Pollution sources identification, health, and radiological risk assessment of naturally occurring radioisotopes and heavy metals in waste dumpsites in Ijebu-Ode, Ogun State, Southwest Nigeria. *Environmental Forensics.* 2021. Available from: https://doi.org/10.1080/15275922.2021.2006365.
16. Ulakpa W, Eyankware EO, Eyankware M, Eyankware RO. Evaluation of radionuclides in Eliozu Dumpsite, Obio-Akpor L.G.A. South-South Nigeria. *International Journal of Science and Healthcare Research*. 2016; 1(2).
17. UNSCEAR. *Source, effects and risks of ionizing radiation.* United Nations Scientific Committee on the Effects of Atomic Radiation, United Nations, New York. 1998.
18. Bakare K, Aizebeokhai A, Oyeyemi KD. Investigating groundwater pollution at an open dumpsite using 2D Geo-electrical resistivity imaging and vertical electrical sounding. *Journal of Physics: Conference Series.* 2019; 1299(1):012077.
19. Osinowo OO, Akanji AO, Akinmosin A. Integrated geophysical and geotechnical investigation of the failed portion in basement complex terrain, Southwest Nigeria. *RMZ-Materials and Geo environment.* 2011; 58(2): 143-162.