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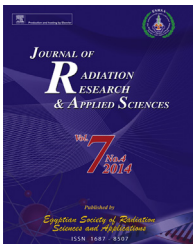

Assessment of radiation exposure levels at Alaba e-waste dumpsite in comparison with municipal waste dumpsites in southwest Nigeria

N.N. Jibiri [a], M.O. Isinkaye [b,*], H.A. Momoh [a]

[a] Department of Physics, University of Ibadan, Ibadan, Nigeria
[b] Department of Physics, Ekiti State University, Ado Ekiti, Nigeria

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ABSTRACT

Radiation exposures at the e-waste dumpsite around Alaba International Market, Lagos and three municipal waste dumpsites located in Ibadan and Ado Ekiti, southwest Nigeria were assessed by gamma ray spectroscopy using a highly shielded Canberra NaI (Tl) detector. Soil samples were collected for analysis at the municipal waste dumpsites for comparison with e-waste dumpsite. Samples were also collected at a location free from waste dumps to serve as control. The mean concentrations of ^{40}K, ^{226}Ra, and ^{232}Th obtained at the e-waste dumpsite were lower than those obtained at the municipal waste dumpsites and the controls site. The values obtained at the e-waste dumpsite were also lower than the world average values of 412 Bq/kg, 35 Bq/kg and 30 Bq/kg for ^{40}K, ^{226}Ra, and ^{232}Th, respectively as reported by UNSCEAR. The mean annual effective dose rate obtained for the soil samples from e-waste dumpsite, Oritaperin, Ring-road and Ilokun dumpsites were respectively 0.026 mSv, 0.074 mSv, 0.080 mSv and 0.093 mSv/yr. The mean absorbed dose rate at the e-waste dumpsite was 21.12nGy/h which is lower than the world average of 60nGy/h. Values for other hazard indices were below the world average and lower than their respective minimum permissible limits. Hence, e-waste and municipal waste does not pose any immediate radiological risk to the people working/living in the vicinity of the dumpsites.

1. Introduction

The use of electronic devices has become so popular especially in this era of information technology (IT) globally. The dependence on, and the vital role that information and communication technology (ICT) is playing in the world economy has brought about an increase in the use of electronic equipment (Odeyingbo, 2011). The rapid growth in IT has led to a continuing improvement in the capacity of electronic products but at the same time, a decrease in the product's lifetime (Nnorom, Osibanjo, & Nnorom, 2007). Old and

* *Corresponding author*. Tel.: +234 803 0516026.
E-mail addresses: matthewisinkaye@eksu.edu.ng, niyikaye2002@yahoo.com (M.O. Isinkaye).
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abandoned phones, computers and other electronic products usually end up as waste in dumpsites. They are called electronic waste (e-waste). The United Nation Environment Program estimates that 20–50 million tons of e-wastes are produced globally every year (Puckett, Westervelt, Gutierrez, & Takamiya, 2005; Robinson, 2009) and the world is faced with new environmental challenges due to poor management of e-waste generated/imported by developing countries. Nigeria's e-waste generation is by far the highest in all of West African Countries (Andreas, Oladele, Adeyinka, & Siddharth, 2011). Health and safety concerns associated with e-waste generation include: inhalation of toxic fumes (from Pb, Cd, Hg etc.), contamination of soil and ground water and potential exposure to radiation from ashes, smoke and dust from the dumpsites. Since Nigeria has no data on the radiological status of these dumpsites, no routine monitoring mechanism to check radiation levels in e-waste sites and no effective regulation on the importation of e-waste, it is necessary to carry out this research study to forestall the possibility of radiation accident as experienced in Mayapuri- India.

Human beings are continuously exposed to ionizing radiations which are naturally present in the environment. In the last few decades, the natural inventory of radionuclides has been increased due to human activities. Waste generation and disposals have also contributed in no small measure to the increased levels of human radiation exposures. Human radiation exposure could either be external due to the concentrations of ^{40}K, ^{226}Ra and ^{232}Th in soil or internal due to inhalation of radon and its progenies in dust and fumes from waste disposal sites. The world-wide average specific activity of ^{40}K, ^{226}Ra and ^{232}Th in the earth's crust is estimated to be 412, 35 and 45 Bqkg^{-1}, respectively (UNSCEAR, 2008). These values give an average outdoor dose of 60 nGy h^{-1} at a height of 1 m to the ground. Knowledge of radiation exposure levels at waste dump-sites enables one to assess any possible radiological risk to human health and environment due to waste generation and disposal.

Radionuclides contents of soil samples collected from various waste dumpsites have been studied by many researchers in Nigeria (Ademola, Babalola, Alabi, Onuh, & Enyenihi, 2014; Avwiri & Olatubosun, 2014; Emelue, Eke, Oghome, & Ejiogu, 2013; Faweya & Babalola, 2010; Isinkaye & Faweya, 2006; Odunaike, Laoye, Alausa, Ijeoma, & Adelaja, 2008; Oladapo, Oni, Olawoyin, Akerele, & Tijani, 2012). Their results indicated that the activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in dumpsites show no significant radiological health hazards to the population around the dumpsites. But in most cases, moderate increases were observed at the dumpsites in comparison with control sites free from waste disposal. On the national and global scale, little had been done on the radiological health implications of natural radionuclides in e-waste dumpsites. The main objective of the present study is to evaluate the activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in soil samples from e-waste dump-site as compared to municipal waste dump-sites in southwest Nigeria in order to assess the radiological implications on the population around the dumpsites. This study therefore will be useful for establishing a baseline data on natural radionuclides present in Alaba international market e-waste dumpsite.

2. Materials and methods

2.1. Study area

Alaba international market is located in Lagos State, Nigeria. Lagos is the largest city in the whole of Africa with two seaports that serve as a trade portal not only to Nigeria but to the rest of West Africa. It is situated in a flat, coastal, dense forest area with swamps, marches and lagoons. Lagos with a population of about 17.5 million people has a tropical climate with moderate temperature and relative humidity and very importantly, a low water table. This implies that hazardous waste can easily leach and contaminate the ground water.

Alaba international market is the largest electronics market in West Africa. The market was established in 1978 and occupies a land area of approximately 2 km^2 in the southwestern part of Lagos. The market features more than 2500 shops doing refurbishing and offering used electrical and electronic products for sale. Many of these products include end-of-life electronics devices such as mobile phones, television, computers, microwave oven, fridges, air conditioners etc. that are made up of heterogeneous mix of metals, ceramics, glasses and plastics. A major dumpsite (about 100 m^2 in size) is located outside the market where e-waste collectors and recyclers work and indulge in burning and other crude recycling practices without care for their health or environment, in an attempt to recover some useful parts/scrap from e-waste. Due to congestion, makeshift structures are erected on the site to accommodate the teeming population.

The other sampling sites are located entirely in the basement complex geological region of southwest Nigeria. The basement complex of Ibadan and Ado Ekiti comprise of quartzites, banded and augen gneisses, granite gneiss and migmatite. The minor rocks include pegmatite, aplite, quartz veins and doleritic dykes (Oyawoye, 1972; Rahaman, 1976, pp. 41–58). Igneous rocks, which are predominant in these areas generally exhibit higher radioactivity than sedimentary rocks found in most parts of Lagos. Fig. 1 shows the map of southwest Nigeria indicating the sampling locations.

2.2. Sample collection and preparation

In all, 45 soil samples were collected from the waste dumpsites consisting of 20 from e-waste, 10 from Oritaperin, 5 from Ring road and 10 from Ilokun dumpsites (Table 1). The size of the dumpsite dictates the number of samples collected. Two samples were collected from a reference site (free from waste disposal) located close to the e-waste dumpsite to serve as control. All the soil samples were separately packed in black polythene bags, labeled, and safely conveyed to Radiation and Health Physics Laboratory of Physics Department, University of Ibadan. At the laboratory, they were sun dried to attain constant weight, pulverized, and sieved using a 2 mm mesh sieve. Two hundred grams (200 g) of each sample was subsequently measured using an electronic weighing balance and packed in plastic containers of diameter 6.6 cm to sit with good geometry on NaI(Tl) detector used for the measurements. The plastics were hermitically sealed with adhesive

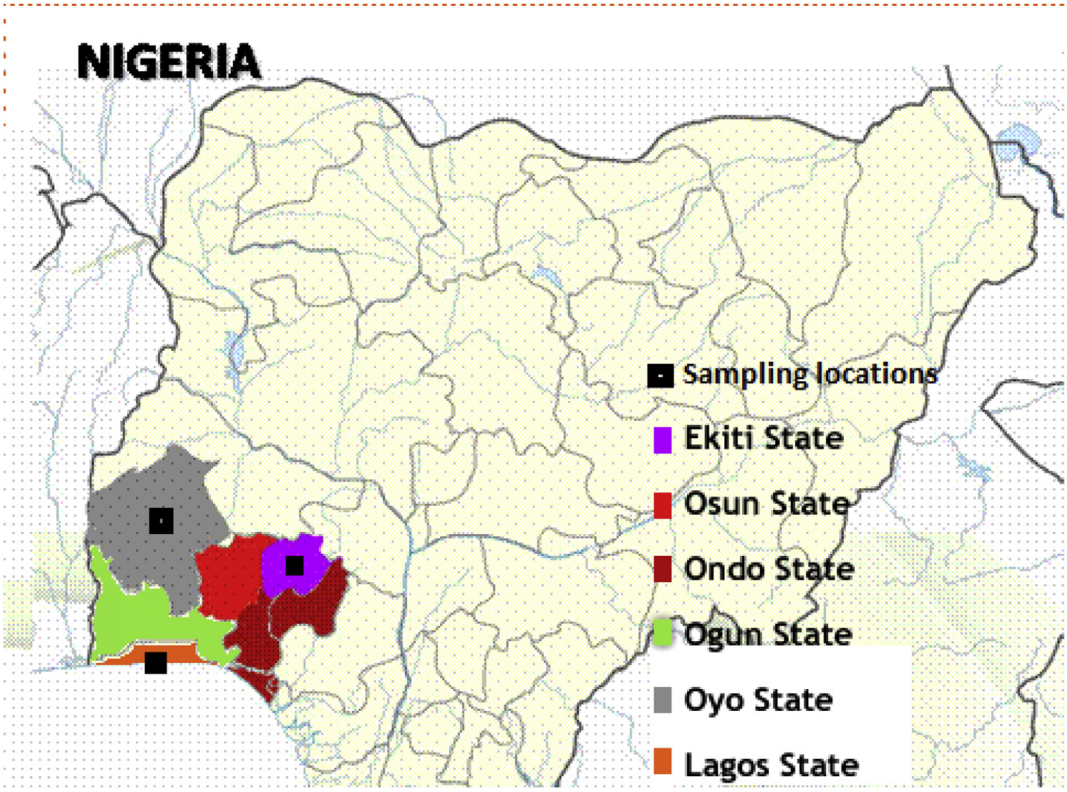

Fig. 1 – Map of Nigeria showing the sampling locations in southwest Nigeria.

tape and kept for 30 d in order to attain secular equilibrium between radium and its gaseous decay progenies.

2.3. *Sample measurements*

Evaluation of radionuclide concentrations was performed by gamma-ray spectrometry using sodium iodide detector. The counting assembly consists of a scintillation detector couple to a Canberra multi-channel analyser. The detector is a 7.6 mm × 7.6 mm NaI(Tl) manufactured by Bicron. A cylindrical lead shield of ~5 cm with a fixed bottom and a moveable lid shielded the detector from the environment. The spectrometer was tested for its linearity and calibrated for energy using gamma sources obtained from IAEA, Vienna, Austria (Ademola, Hammed, & Adejumobi, 2008). The detection efficiency calibration of the system was done using a reference soil sample prepared by Rocketdyne Laboratories, Canoga Park, CA, USA. This reference sample is traceable to a mixed gamma source (No. 48722-356) by Analytics Inc., Atlanta, Georgia (Joshua, Ademola, Akpanowo, Oyebanjo, & Olorode, 2009). The resolution of the detector is about 8% at 0.662 MeV of ^{137}Cs. This resolution is capable of distinguishing the gamma ray energies of interest in this study. Each sample was measured for 10 h to obtain good statistics. Measurements with an empty plastic container having similar geometry with samples container were carried out to determine the ambient background in the laboratory. The background spectrum was subtracted from the measured spectra to obtain the net radionuclide activities. The background, reference sample and the soil samples were measured under the same conditions. Also measurements were repeated at intervals for quality assurance purposes as well as to ascertain the stability of the measuring system.

The activity concentrations of ^{232}Th, ^{226}Ra and ^{40}K were calculated using the detected photopeaks in the spectra. Since secular equilibrium was attained between ^{226}Ra and ^{232}Th and

Table 1 – Activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in soil of Alaba International Market e-waste dumpsite in comparison with other dumpsites in southwest Nigeria.

Dumpsite	Location	No of sample	Activity concentration (Bq/kg)		
			^{40}K range (Mean±σ)	^{226}Ra range (Mean±σ)	^{232}Th range (Mean±σ)
E-waste	Alaba (Lagos State)	20	27.36–139.71 (84.26 ± 28.08)	6.43–42.94 (20.70 ± 9.40)	2.15–34.52 (13.32 ± 12.86)
Oritaperin	Ibadan (Oyo State)	10	297.91–1026.17 (488.91 ± 217.24)	6.91–39.61 (27.93 ± 10.52)	28.60–54.02 (44.93 ± 7.24)
Ring-road	Ibadan (Oyo State)	5	297.91–494.49 (405.89 ± 75.79)	25.61–53.25 (35.10 ± 10.97)	45.58–64.02 (52.46 ± 7.29)
Ilokun	Ado-Ekiti (Ekiti State)	10	353.72–912.23 (542.28 ± 155.07)	15.39–49.00 (33.48 ± 11.00)	36.98–81.37 (62.06 ± 15.46)
Control	Lagos	2	157.64–177.81 (167.73 ± 14.26)	19.77–27.64 (23.70 ± 5.60)	27.46–28.85 (28.15 ± 0.99)

Table 2 – Comparison of activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in e-waste dumpsite with other locations in Nigeria.

Location	Activity concentration (Bq/kg)			Reference
	^{40}K	^{226}Ra	^{232}Th	
Ado Ekiti	758.51 ± 132.93	36.57 ± 2.70	25.73 ± 5.60	Isinkaye & Faweya, 2006
Akure	180 ± 6	51 ± 6	34 ± 4	Faweya & Babalola, 2010
Lagos	409.44 ± 86.08	69.19 ± 19.10	14.49 ± 3.22	Oladapo et al., 2012
Oshogbo	186 ± 6	52 ± 6	22 ± 2	Faweya & Babalola, 2010
Owerri	BDL-686.17	BDL-103.51	BDL-65.28	Emelue et al., 2013
Sango Ota	122.1 ± 20.6	3.0 ± 1.2	33.3 ± 9.8	Ademola et al., 2014
Port Harcourt	643.10 ± 5.94	41.96 ± 5.53	62.61 ± 18.97	Avwiri & Olatubosun, 2014
Crustal average	412	32	45	UNSCEAR, 2008
Lagos (e-waste)	84.26 ± 28.08	20.70 ± 9.40	13.32 ± 12.86	Present study

their decay products, radium content of the samples was estimated from the gamma-ray energy of 1.760 MeV from ^{214}Bi, while the gamma-ray energy of 2.614 MeV from ^{208}Tl was use to determine the thorium content and the gamma-ray energy of 1.460 MeV was used for the concentration of ^{40}K in the samples. The activity concentrations (A_C) of ^{232}Th, ^{226}Ra and ^{40}K in Bqkg^{-1} were obtained using the following equation:

$$A_c = \frac{C_{net}}{\gamma_d \times E_{ff}(E_\gamma) \times T \times M} \quad (1)$$

Where C_{net} is the net peak counts, γ_d is absolute gamma decay intensity for the specific energy photopeak (including the decay branching ratio information), E_{ff} (E_γ) is the absolute efficiency of the detector at energy E, T is the counting time in sec and M is the mass of the sample in kg.

3. Results and discussion

3.1. Activity concentration

The measured activity concentration of ^{40}K, ^{226}Ra and ^{232}Th, in the soil samples collected from the e-waste dumpsite ranged from 27.36 to 139.71 Bqkg^{-1}, 6.43–42.94 Bqkg^{-1}, and 2.15–34.52 Bqkg^{-1} with an average value of 84.26 ± 28.08 Bqkg^{-1}, 20.70 ± 0.21 Bqkg^{-1}, and 13.32 ± 12.86 Bqkg^{-1}, respectively. For the control site, the concentrations of the radionuclides ranged from 157.64 to 177.81 Bqkg^{-1}, 19.77–27.64 Bqkg^{-1}; and 27.46–28.85 Bqkg^{-1} with average values of 167.73 ± 14.26 Bqkg^{-1}, 23.70 ± 5.60 Bqkg^{-1}, and 28.15 ± 0.99 Bqkg^{-1}, respectively for ^{40}K, ^{226}Ra and ^{232}Th. For the Oritaperin dumpsite, the activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th ranged from 297.91 to 1026.17 Bqkg^{-1}, 6.91–39.61 Bqkg^{-1}and 28.60–54.02 Bqkg^{-1}with mean values of 488.91 ± 217.24 Bqkg^{-1}, 27.93 ± 10.52 Bqkg^{-1}, and 44.93 ± 7.24 Bqkg^{-1}, respectively. The activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th, in the soil samples collected from the Ring Road dumpsite ranged from 297.91 to 494.49 Bqkg^{-1}, 25.61–53.25 Bqkg^{-1} and 45.58–64.02 Bqkg^{-1} with mean values of 405.89 ± 75.79 Bqkg^{-1}, 35.10 ± 10.97 Bqkg^{-1}, and 52.46 ± 7.29 Bqkg^{-1}, respectively. The highest mean concentrations of ^{40}K and ^{232}Th are obtained at Ilokun waste dumpsite, while the highest mean concentration of ^{226}Ra is obtained at Ring-road dumpsite. The mean activity concentrations of three radionuclides obtained in this study is lower at e-waste dumpsite in comparison to the other dumpsites as well as lower than the control site. The specific activity of the radionuclides obtained in this study is a function of the rock compositions of the sampling environments. Sedimentary rock which is predominant in Lagos is known to consist of low concentrations of ^{40}K, ^{226}Ra and ^{232}Th, while granitic rock types prevalent in Ibadan and Ado Ekiti are known to consist higher concentrations of these radionuclides. Table 2 shows the comparison of activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in soil of e-waste dumpsite with values obtained by other authors in soil samples collected from industrial and municipal waste dump-sites in Nigeria. The activity concentrations obtained in e-waste dumpsite is lower than values obtained for different dumpsites located within Nigeria as well as lower than the average crustal values of the radionuclides considered in this study.

3.2. Radiological hazard assessment

In order to estimate the radiation hazards incurred by the population due to the activity levels of the observed radionuclides in soil of the surveyed e-waste and other dumpsites, some radiation hazard indices were evaluated in this study. The distribution of ^{40}K, ^{226}Ra and ^{232}Th in soil is not uniform. Therefore, radium equivalent activity (Ra_{eq}) estimated in Bqkg^{-1} was introduced to define uniformity in respect to radiation exposures due to these radionuclides (Berekta & Matthew, 1985; UNSCEAR, 2000). Radium equivalent activity is the weighted sum of ^{40}K, ^{226}Ra and ^{232}Th activity concentrations based on the assumption that 370 Bqkg^{-1} of ^{226}Ra, 259 Bqkg^{-1} of ^{232}Th and 4810 Bqkg^{-1} of ^{40}K produce the same gamma-ray dose rate (Stranden, 1979). It is calculated as follows:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.77A_K \quad (2)$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively. The radium equivalent activities obtained for the dumpsites and control site are presented in Table 3. The mean radium equivalent activity obtained for e-waste, Oritaperin, Ring road, Ilokun and control site is 39.82 ± 19.55 Bqkg^{-1}, 92.26 ± 5.60 Bqkg^{-1}, 110.19 ± 23.84 Bqkg^{-1}, 122.30 ± 29.83 Bqkg^{-1} and 64.03 ± 5.25 Bqkg^{-1}. The mean value calculated for the e-waste dumpsite is about 9.5% of the maximum permissible limit of 370 Bqkg^{-1}, which also serves as the worldwide average value for soil. All the values obtained in this study are low, which

Table 3 – Mean radiation hazard indices for the dumpsites.

Dumpsite	Mean radiological indices				
	Ra_{eq} (Bq/kg)	H_{ex}	I_γ	D_{out} (nGy h^{-1})	E_{out} (mSv y^{-1})
E-waste	39.82 ± 19.55	0.12 ± 0,05	0.33 ± 0.01	21.12 ± 8.51	0.026
Oritaperin	92.26 ± 5.60	0.35 ± 0.04	0.96 ± 0.12	60.43 ± 7.41	0.074
Ring road	110.19 ± 23.84	0.38 ± 0.06	1.03 ± 0.17	64.83 ± 11.02	0.080
Ilokun	122.30 ± 29.83	0.44 ± 0.10	1.21 ± 0.26	75.56 ± 16.54	0.093
Control	64.03 ± 5.25	0.21 ± 0.01	0.55 ± 0.04	34.95 ± 2.57	0.043

suggest that the soil of these dumpsites could be used without any restriction if the dumpsites are reclaimed for building construction purposes in the nearest future.

Another criterion used for the estimation of gamma-ray radiation exposure levels associated with natural radionuclides in soil is defined by the term external hazard index (H_{ex}) as shown in Eq. (3) (Higgy, El-Tahawy, Abdel-Fattah, & Al-Akahawy, 2000; Tufail, Nasim-Akhtar, & Hamid, 2007; Faanu et al., 2013).

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (3)$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively. The value of the external hazard index must be less than unity for the external gamma dose rate to be less than 1.5 $mSvy^{-1}$, which is the upper limit of gamma dose rates for building construction materials. The mean external hazard indexes obtained for all the dumpsites are presented in Table 3 with values ranging from 0.12 to 0.44 for the dumpsites, while the control site gives mean value of 0.21. E-waste dumpsite gives the lowest external hazard index. All these values are significantly lower than the upper limit of unity recommended for material to be used as building construction materials. The mean value obtained for the control site is comparable to values from the dumpsites indicating that the values from the dumpsites are predominantly due to background concentrations of the considered radionuclides.

To further assess the radiation hazards associated with the dumpsites, another radiation hazard index known as gamma activity concentration index (I_γ) simply called gamma index was evaluated. According to European Union Commission (EC), gamma index is defined for identifying whether a dose standard is met (EC, 1999). It is defined as:

$$I_\gamma = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \quad (4)$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively. The gamma index is correlated with the annual dose due to the excess external gamma radiation caused by building construction materials. The value of gamma index $I_\gamma \leq 0.5$ corresponds to 0.3 mSv y^{-1} and $I_\gamma \geq 1.0$ corresponds to 1 mSv y^{-1}. According to the European Commission guidelines, building materials that increase the annual outdoor effective dose received by individual an amount of 0.3 mSv should not be considered hazardous. Thus, the gamma index criterion should be use only as a screening tool for identifying materials which might be of concern to be used as building materials. The mean gamma index obtained for the e-waste dumpsite is 0.33 ± 0.01, while those obtained for Oritaperin, Ring road, Ilokun and control site are 0.96 ± 0.12, 1.03 ± 0.17, 1.21 ± 0.26, and 0.55 ± 0.04, respectively. The gamma index obtained for the e-waste dumpsite is < 0.5, which shows that the gamma dose due to the evaluated radionuclides at the dumpsite is < 0.3 mSv. It is suffice to say that the soil of the e-waste dumpsite does not pose any radiological hazard to the populace if the land is reclaimed for construction purposes. For the soil of Oritaperin and Ilokun dumpsites, caution should taken in utilizing them as bulk building materials because their gamma index values are slightly higher than the upper limit of unity.

The absorbed dose rate in air at a height of 1 m above the ground was calculated from (UNSCEAR, 2008):

$$D_{out} = 0.446A_U + 0.662A_{Th} + 0.048A_K \quad (5)$$

Where D_{out} is the dose rate (nGy h^{-1}) at a height of 1 m above the ground due to the concentrations of ^{238}U, ^{232}Th and ^{40}K in soil. About 98% of radiation exposures from the uranium series come from radium and its progenies, therefore, ^{226}Ra is used for the evaluation of dose rate rather than ^{238}U. The mean dose rates evaluated for the dumpsites are presented in Table 3. All the municipal dumpsites have their mean dose rates higher than the world average value of 60 nGy h^{-1}. For the e-waste, the calculated mean dose rate is about 35% of the world average value. This result shows that e-wastes have not contributed significantly to the activity load of the soil analyzed in this site. The difference in the calculated dose rates for all the dumpsites could be attributed to difference in geology and geochemical states of the sampling sites.

The mean annual effective dose equivalent for the e-waste and other dumpsites were calculated from the absorbed dose rates (D) by applying the dose conversion factor of 0.7 $SvGy^{-1}$ and an outdoor occupancy factor of 0.2 (UNSCEAR, 2000) based on the fact that individuals in the study areas spend 20% of their time outdoor. It is given as:

$$E_{out} = D(nGyh^{-1}) * 0.7(SvGy^{-1}) * 0.2 * 8760(hy^{-1}) \quad (6)$$

The calculated annual effective dose for the e-waste dumpsite ranged from 0.003 mSv to 0.042 mSv with a mean of 0.026 ± 0.001 mSv. This value is about 3 orders of magnitude lower than the world average value of 0.07 mSv and also lower than those obtained for control site, located close to Alaba market, and municipal waste dumpsites located several kilometers to the market.

4. Conclusion

In view of the environmental threats posed by e-waste around the globe and in Nigeria in particular, the activity

concentrations of ^{40}K, ^{226}Ra and ^{232}Th in soil samples from Alaba e-waste dumpsite was carried out using gamma ray spectrometer NaI(Tl) detector. Samples were also analyzed for three other municipal waste dumpsites for comparison. The mean activity concentration of ^{40}K, ^{226}Ra and ^{232}Th across Alaba international market e-waste dumpsite are 84.26 ± 28.08 $Bqkg^{-1}$, 20.70 ± 0.21 $Bqkg^{-1}$, and 13.32 ± 12.86 $Bqkg^{-1}$ respectively. These values are below those obtained for the control site as well as lower than values obtained for the municipal waste dumpsites. Both the activity concentrations and the radiation hazard indices obtained for the e-waste dumpsite were all below their world average values. These results may imply that dumping, processing and burning of e-waste on the soil have not affected the natural radioactivity of the soil in the area. Hence, e-waste does not pose any immediate radiological risk to the people working/living on the dumpsite and its environs but care should be taken against long term cumulative effects.

REFERENCES

Ademola, A. K., Babalola, A. I., Alabi, F. O., Onuh, O. D., & Enyenihi, E. E. (2014). Assessments of natural radioactivity and determination of heavy metals in soil around industrial dumpsites in Sango-Ota, Ogun state, Nigeria. *Journal of Medical Physics, 39*, 106–111.

Ademola, A. K., Hammed, O. S., & Adejumobi, C. A. (2008). Radioactivity and dose assessment of marble samples from Igbeti Mines, Nigeria. *Radiation Proection Dosimetry, 132*, 94–97.

Andreas, M., Oladele, O., Adeyinka, A., & Siddharth, P. (2011). *Informal e-waste management in Lagos, Nigeria – Socio-economic impacts and feasibility of international recycling co-operations*. Germany: Oko-Institute e.V.

Avwiri, G. O., & Olatubosun, S. A. (2014). Assessment of environmental radioactivity in selected dumpsites in PortHarcourt, Rivers State, Nigeria. *International Journal of Scientific & Technology Research, 3*, 263–269.

Berekta, J., & Matthew, P. J. (1985). Natural radioactivity of Australian building materials, waste and by-products. *Health Physics, 48*, 87–95.

Emelue, H. U., Eke, B. C., Oghome, P., & Ejiogu, B. C. (2013). Evaluation of radiation emission from refuse dump sites in Owerri, Nigeria. *IOSR Journal of Applied Physics, 4*, 1–5.

European Commission (EC). (1999). *Radiological protection principles concerning the natural radioactivity of building materials*. Radiation Protection 112, Directorate-General, environment, nuclear safety and civil protection. Luxembourg: European Commission.

Faanu, A., Kpeglo, D. O., Sackey, M., Darko, E. O., Emi-Reynolds, G., Lawluvi, H., et al. (2013). Natural and artificial radioactivity distribution in soil and water of the Central Ashanti Gold Mine, Ghana. *Environmental Earth Sciences*. http://dx.doi.org/10.1007/s12665-013-2244-z.

Faweya, E. B., & Babalola, A. I. (2010). Radiological safety assessment and occurrence of heavy metals in soil from designated waste dumpsites used for building and composting in southwestern Nigeria. *Arabian Journal of Science and Technology, 35*, 219–225.

Higgy, R. H., El-Tahawy, M. S., Abdel-Fattah, A. T., & Al-Akahawy, A. U. (2000). Radionuclides content of building materials and associated gamma dose rates in Egyptian dwellings. *Journal of Environmental Radioactivity, 50*, 253–261.

Isinkaye, M. O., & Faweya, E. B. (2006). Occurrence of natural radionuclides in refuse dump sites within the city of Ado-Ekiti, southwestern Nigeria. *Central Europe Journal of Occupational and Environmental Medicine, 12*(1), 9–14.

Joshua, E. O., Ademola, J. A., Akpanowo, M. A., Oyebanjo, O. A., & Olorode, D. O. (2009). Natural radionuclides and hazards of rock samples from Southeastern Nigeria. *Radiation Measurements, 44*, 401–404.

Nnorom, I. C., Osibanjo, O., & Nnorom, S. O. (2007). Achieving resource conservation in electronic waste management: a review of options available to developing countries. *Journal Applied Science, 7*, 2918–2933.

Odeyingbo, O. A. (2011). *Assessment of the flow and driving forces of used electrical and electronic equipment into and within Nigeria*. Germany: Brandenburgische Technische Universitat.

Odunaike, R. K., Laoye, J. A., Alausa, S. K., Ijeoma, G. C., & Adelaja, A. D. (2008). Radiation emission characterization of waste dumpsites in the city of Ibadan in Oyo State of Nigeria. *Research Journal of Environmental Toxicology, 2*, 100–103.

Oladapo, O. O., Oni, E. A., Olawoyin, A. A., Akerele, O. O., & Tijani, S. A. (2012). Assessment of natural radionuclides level in wasteland soils around Olusosun dumpsite Lagos, Nigeria. *IOSR Journal of Applied Physics, 2*, 38–43.

Oyawoye, M. O. (1972). In T. F. J. Dessau Vagie, & A. J. Whiteman (Eds.), *The basement complex of Nigeria in African Geology*. University of Ibadan pp66-102.

Puckett, J., Westervelt, S., Gutierrez, R., & Takamiya, Y. (2005). *The digital dump – exporting re-use and abuse to Africa*. Seattle: Basel Action Network.

Rahaman, M. A. (1976). *Review of the basement geology of south western Nigeria in Geology of Nigeria edited by C.A Kogbe*. Lagos: Elizabeathan.

Robinson, B. (2009). E-waste: an assessment of global production and environmental impacts. *Science of the Total Environment, 408*, 183–191.

Stranden, E. (1979). Radioactivity of building materials and the gamma radiation in dwellings. *Physics in Medicine and Biology, 24*, 921–930.

Tufail, M., Nasim-Akhtar, S. J., & Hamid, T. (2007). Natural radioactivityhazards of building bricks fabricated from saline soil of two districts of Pakistan. *Journal of Radiological Protection, 27*, 481–492.

UNSCEAR. (2000). *Sources and effects of ionizing radiation. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the General Assembly*. New York, USA: United Nations.

UNSCEAR. (2008). *Sources and effects of ionizing radiation. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the General Assembly*. New York, USA: United Nations.